



Conférence Européenne
des Directeurs des Routes

Conference of European
Directors of Roads

Adaptation to climate change



January 2012

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Edited and published by: CEDR's Secretariat General

Approved and amended by: CEDR's EXECUTIVE BOARD on 8 September 2011

Approved by: CEDR's GOVERNING BOARD on 27 October 2011

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This report is: FOR INFORMATION

Preface

The objective of task group 16 is to provide the directors of public roads with information about on-going activities concerning adaptation to climate change and to exchange information about policies, strategies, and measures and their consequences for the work of the national roads administrations (NRAs).

The goal of this report is to outline the main consequences of climate change for road infrastructure and to propose actions for adapting the road network to climate change. Our aim is to submit a concise document presenting the challenges and the tools available or to be created, supplemented with best practice examples.

The focus of this task is not so much on research, but on the implementation of adequate measures.

The report includes:

- a survey of risks related to climate change (Appendix 1);
- a survey of on-going work on adaptation to climate change (Appendix 2); and
- examples of adaptation work and good practice relevant to adaptation to climate change (Appendix 3).

The surveys cover the member states of both task groups 16 and 17, except Greece, which only recently became a member. Task groups 16 and 17 are organised as a single project group and led by Norway.

The leader of the Project Group on Climate Change (covering task groups 16 and 17) is Gyda Grendstad (Norway).

Task group 16 is led by Gordana Petkovic (Norway).

This report has been compiled by the Project Group on Climate Change (task group 16), with contributions from task group 17.

The report has been edited by Gordana Petkovic and Skuli Thordarson (of Vegsýn Consult, Iceland), who was engaged by the Norwegian Public Roads Administration to assist in the production of this document.

Oslo, November 2011

Gyda Grendstad
Leader, Project Group on Climate Change

Executive summary

The climate in Europe will change during the twenty-first century. Model predictions indicate that the mean annual temperature will rise by between 1 and 5.5°C. While annual precipitation is likely to increase in the north and decrease in the south, the intensity of daily precipitation and the probability of extreme precipitation intensities may increase in all regions. Mean annual wind speeds are expected to increase in the northern regions as well, while possibly decreasing in the Mediterranean regions. Extreme wind speeds may increase in western and central Europe and in the North Sea area. As a consequence of climate change, the sea level in some areas is likely to rise by up to 0.9 m by the end of the century.

Climate change will modify actual risk levels and therefore challenge design guidelines and procedures for the operation and maintenance of the road infrastructure. There will be an increase in unusual climatic events, with significant impacts on infrastructure, operations, and the economy as a whole. For road owners, adaptation to climate change should be included in current and future procedures covering all aspects of road planning, design, maintenance, and operation.

The goals of this report are to:¹

- show the consequences of climate change for infrastructure; and
- propose actions for adapting the road network to climate change.

The working group conducted two surveys among its member states: an overview of risks related to climate change for each country (Appendix 1) and an overview of on-going work related to adaptation to climate change at national level and road administration level (Appendix 2). In addition, examples of on-going adaptation work and good practice relevant to adaptation to climate change were collected (Appendix 3).

Climate change, as described by the projections from global and regional models, will bring about a number of challenges for the road network in Europe. In most cases, these will be the same challenges as today, but on a larger scale, occurring more frequently and at other locations than expected. In addition, more unusual weather combinations may be experienced, e.g. winter floods. In some cases, climate change may be beneficial for road owners, e.g. in places where less snow can be expected.

Chapter 1 summarises the main effects of climate change on the road network as follows:

- more flooding and erosion: a challenge for drainage systems and erosion protection and for the design and maintenance of culverts and bridges;
- landslides and avalanches: occurring more frequently, at new locations and with a higher share of 'wet' landslide types, such as slush avalanches and debris flow;

¹ Mandate for CEDR Task 16 working group: Adaptation to Change (this working group).

- droughts and high summer temperatures may pose problems for asphalt surfacing, due to softening, but also for run-off conditions, due to lower permeability. Risk of wildfires may also increase in the southernmost regions;
- deterioration of roads and pavements: as expressed by service life and rutting, mostly in cases where drainage is insufficient;
- effects of sea-level rise on coastal stability and importance of ensuring sufficient elevation for roads, quays, and bridges, as well as entrance levels for sub-sea tunnels;
- heavy snowfall in mountain areas of northern Europe causing trouble for winter maintenance and operation under difficult conditions; and
- the need for better risk management and efficient procedures for initiating remedial actions after a weather-related event occurs, due to the fact that existing protective measures may not be sufficient and that the planning of remedial measures requires time.

All these effects can be recognised in all phases of road management: planning, design, construction, maintenance, and operation.

Chapter 2 indicates some possible routes towards adaptation to climate change. The measures are divided into working procedures from planning to operation.

Adaptation to climate change should begin during the **planning of a road project** by choosing an alignment (including elevation) where the road is not too exposed to risk from landslides, floods, etc. A good overall plan for management of run-off water should be prepared during this phase of work.

Climate change will require the adaptation of **design** guidelines in order to ensure sufficient drainage capacity and erosion protection, define adequate quality requirements for road construction materials, manage landslide risks, and implement measures to ensure protection of the environment. **Construction contracts** that consider climate change are important in order to avoid some of the problems that could occur during maintenance and operation.

Maintenance and operation of the existing road network is where most of the adaptation work needs to be done. This includes risk assessment, by identifying vulnerable assets and potential risks, and risk management related to weather-related events, including both preventive measures and emergency plans. Taking care of maintenance backlogs is an important part of adaptation to climate change and is also beneficial for other reasons. In mountain areas and in northern countries, it is necessary to prepare for harsher winter conditions. Traffic management under difficult weather conditions needs attention, including communication of risks, re-routing, and the use of good monitoring systems for traffic control. Contracts for maintenance and operation need to be revised to ensure that adequate account is taken of climate conditions.

At the same time, it is important to **keep developing the knowledge base for adaptation**. This is achieved by supporting research on climate change and its effects on infrastructure, by improving the monitoring, mapping, and documentation of weather-related events on the road network, by better education on climate change, and by raising awareness about the importance of adaptation.

Chapter 3 describes some principles for making decisions concerning alternative adaptation measures and for prioritising them.

Adaptation to climate change should begin in the planning phase of a road project and should infiltrate all other working procedures. For existing infrastructure, adaptation measures should be considered as part of planned maintenance or repairs. The measures should be chosen to ensure that adequate safety is achieved during the (remaining) service life of the structure. Postponing action is advisable only if it is followed up by monitoring of the condition of the structure and of the development of the relevant climate factors. In some cases, accepting damage and the costs of repairs may be the best solution. Risk analysis and cost-benefit analysis for possible adaptation measures are recommended as a basis for decision-making.

However, defining the *acceptable* risk level is a difficult task. It is also difficult to define the standard or 'normal' climate applicable to the service life of a structure or for the duration of a maintenance contract. This underlines the need for good contact with experts in meteorology and hydrology and for good contracts for maintenance and operation.

This report can be read in several ways:

If you are mostly interested in how climate parameters affect the road network and what can be done, concentrate on the following chapters:

- 1.5, where the current situation as reported by the NRAs is described; and
- 1.6, where an overview of all the most important effects and remedial measures are given.

If you are mostly interested in how climate change affects a certain working operation, from planning to operation and maintenance, concentrate on:

- 1.9, for a short overview of the effects of climate change; and
- 2.3, for a more detailed description of effects and measures.

If you are interested in ideas for the development of the NRAs' top-level strategic approach to adaptation to climate change, focus on:

- 2.2, for ideas on what to include in the adaptation strategy; and
- 3 and 4, for a discussion of uncertainty and decision-making.

For an overview of good examples of on-going adaptation work or good practice relevant to adaptation to climate change, see Appendix 3.

Table of contents

Preface.....	3
Executive summary	4
Table of contents.....	7
1. Definition of the issue.....	8
1.1. Task description	8
1.2. The task group's understanding of the task: surveys conducted.....	8
1.3. Climate change projections and impacts: an overview.....	10
1.4. European framework for adaptation to climate change	12
1.5. Current situation	13
1.6. Main effects and remedial measures	22
1.7. Risk assessment and management.....	29
1.8. Calculating the costs of climate change to the network.....	30
1.9. Main effects of climate change on working procedures.....	31
1.10. Summary of Chapter 1	32
2. Possible ways forward (solutions).....	33
2.1. European level	33
2.2. National level: strategies for adaptation to climate change	33
2.3. National level: working procedures from planning to operation of the road network...	34
2.4. The knowledge base for adaptation to climate change	39
2.5. Topics for research.....	39
2.6. No-regret actions.....	40
3. Comparison of the ways forward.....	41
4. Conclusions	44
Appendix 1 - Risks related to climate change	46
Appendix 2 - Survey of on-going work on adaptation to climate change.....	67
Appendix 3 - Examples of adaptation work and good practice relevant to adaptation to climate change.....	98

1. Definition of the issue

1.1. Task description

'Excerpt from the mandate:

Infrastructures are designed to withstand some variation in the climate and according to specific 'reference' events. References on specific events are currently based on past experience with a stable climate hypothesis

Climate change will modify the actual risk levels and therefore challenge design guidelines and procedures for the operation and maintenance of road infrastructure. There is and will be an increase in unusual climatic events caused by climate change, in addition to foreseen changes in mean values for individual climate parameters. Impacts on infrastructures, operations and the economy at large may be significant, and in some cases more dangerous than many now think. In mountainous and rugged regions it is expected a higher frequency of rock-falls and landslides due to heavier rainfalls, and on seaside areas or along riverbanks, erosion of the road infrastructure may increase due to higher water level.

Goals to be achieved:

- *show the consequences of climate change for infrastructures; and*
- *propose actions for adapting the road network to climate change.'*

Adaptation to climate change should cover existing road infrastructure as well as future infrastructure and also harmonise with other important developments in road management, such as the demand for increased traffic safety. Environmental characteristics, such as topography and soil type, should also be included.

The collaborative research programme, 'Road owners getting to grips with climate change', was initiated by ERA-NET ROAD and managed by a programme executive board on which all the national roads administrations (NRAs) providing financial support for the programme were represented. The programme was launched in order to exploit synergies and minimise duplicated costs in developing common knowledge, adaptation tools, and strategies.

Similarly, the current task should be a platform for the exchange of knowledge and experiences, and be an opportunity to discuss different tools and strategies towards adaptation.

1.2. The task group's understanding of the task: surveys conducted

The working group for task 16 has discussed all the main challenges for the road network: increase in precipitation and precipitation intensity, heavy snowfall, droughts, sea-level rise, extreme temperatures, and temperature fluctuation around 0°C. Aspects relevant to new structures as well as existing roads and assets have been studied. The effects of climate change on the physical infrastructure as well as on operation and traffic safety were included.

An important but difficult question is how to define the level of acceptable or tolerable risk. The acceptable risk level will to a great extent depend on issues such as the financial situation of the NRA, political priorities, and goals. These aspects were therefore not discussed by the group. Instead, the focus was on obtaining an overview of existing know-how, risk management tools, and approaches to maintaining a robust and functional road network in a demanding climate.

The working group conducted two surveys among the member states:

- **Appendix 1** gives an overview of risks related to climate change, as seen and reported by the member states; and
- **Appendix 2** gives an overview of on-going work related to climate change at national level and at road administration level.

The results of these surveys are summarised in Chapter 1.5 and are referred to in several places in the report.

An important part of this report is the **collection of examples** of adaptation work and of good practice relevant to adaptation to climate change. For practical reasons, these examples are compiled in **Appendix 3**. The examples are referred to in the corresponding sections of the thematic overview in Chapter 1.6.

Studies of the effect of climate change on road networks have previously been carried out by other transnational networks. The Nordic Road Association (Nordiskt vägforum, NVF) Technical Committee 41² on road maintenance established a working group on climate change during the period 2004–2008. The main results of the work were presented at the Via Nordica conference in Helsinki in 2008.³ The group produced an overview of climate change from a Nordic perspective and compared the risks considered to be most significant for each of the Nordic countries. A simplified risk analysis showed that increased rain and flooding represent the most common and severe risk in the participating countries (unpublished draft report).

For this reason, a follow-up group was set up to work on the risks of flooding on the road network for the period 2008–2012. The main tasks of this group are to collect information on the strategies and action plans of municipal and national road owners within the Nordic countries, identify and share information about good examples of preventive measures, organise a Nordic workshop, and contribute to the realisation of student projects in each of the Nordic countries.

The World Road Association (PIARC) Technical Committee D.2: Road Pavements,⁴ working group D.2.b.5, produced a report entitled *Best practices to deal with effects of climate change on road pavements*. A survey was conducted among the 14 participating countries in order to map the concerns of road owners relating to the effects of climate change on road pavements. These effects were analysed and divided into direct and secondary impacts. Furthermore, a thematic overview is provided of possible solutions and mitigation techniques. The solutions are divided into short-, medium-, and long-term solutions. Finally, the report discusses the development of adaptation policies and strategies.

² NVF technical committee 41, *Operation and maintenance of roads and streets*, Working group on climate change. (<http://www.nvfnorden.org/pages/773>)

³ Session 7 ‘Climate change’, Via Nordica congress. Helsinki, 9–11 June 2008. (<http://vianordica2008.vegagerdin.is/>)

⁴ PIARC Technical Committee D.2: Road Pavements. (<http://www.piarc.org/en/technical-committees/committee-D.2/>)

1.3. Climate change projections and impacts: an overview

The following summary of projected climate change in Europe towards the end of the twenty-first century is based on the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) of 2007.^{5,6} The changes listed here are based on a range of greenhouse gas (GHG) emission scenarios and are thus only intended to provide an idea of the climate changes to which European road owners will need to adapt.

Temperature

Mean temperatures are predicted to increase throughout Europe and during all seasons. The warming is expected to be greater in the winter than in the summer months in northern and eastern Europe, whereas greater warming is expected in summer in western, southern, and central Europe than in winter. In general, the mean annual temperature may rise by between 1 and 5.5°C, depending on the region, the emission scenarios, and the models.

The annual maximum temperature is expected to increase much more in southern and central Europe than in northern Europe. In summer, the temperature increase is linked more to higher temperatures on warm days than to general warming. Similarly, during winter, the warming is associated with higher temperatures on cold days, leading to less frequent cold extremes. Fig. 1 shows model results of the expected temperature change throughout Europe in the twenty-first century.

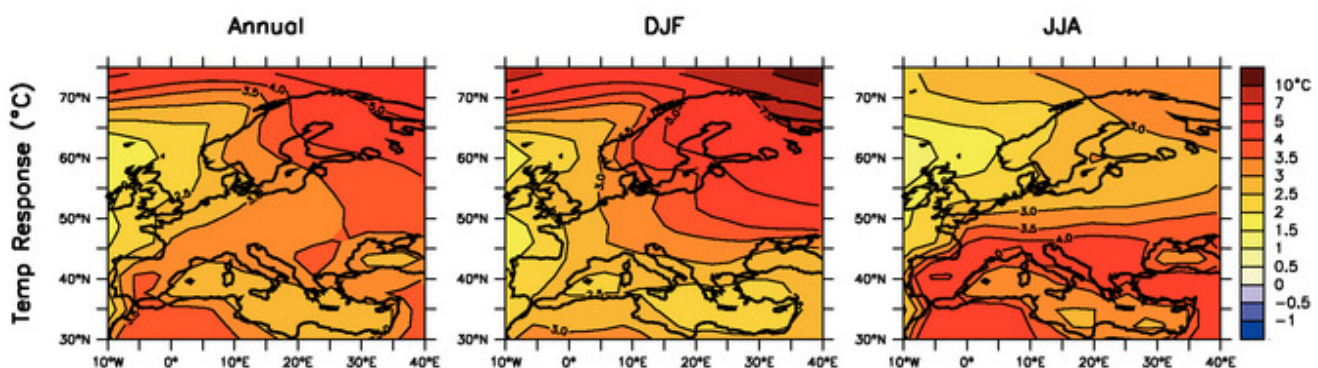


Fig. 1: This is part of Fig. 11-5 from the Physical Science Basis section of the IPCC's 2007 report: annual mean, winter (DJF), and summer (JJA) temperature change between the late twentieth and late twenty-first centuries

⁵ IPCC, 2007: *Climate Change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds.), Cambridge University Press, Cambridge, UK, 976pp.
(http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml)

⁶ IPCC, 2007: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.
(http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml)

Precipitation

Mean annual precipitation increases in northern Europe and decreases in the south for all scenarios, while seasonal precipitation changes can vary across regions. Some models identify an increase in winter precipitation in western, northern, and central Europe, while a decline is predicted in the Mediterranean regions. Summer precipitation decreases substantially in southern and central Europe, but to a lesser degree further north and in Scandinavia.

An increase in the intensity of daily precipitation is likely, even in areas with projected less mean precipitation. The probability of extreme precipitation might be multiplied in some regions in northern Europe.

Prolonged droughts will be more frequent in areas of reduced mean summer precipitation and warmer temperatures. A graphic presentation of expected precipitation changes over Europe is shown in Fig. 2.

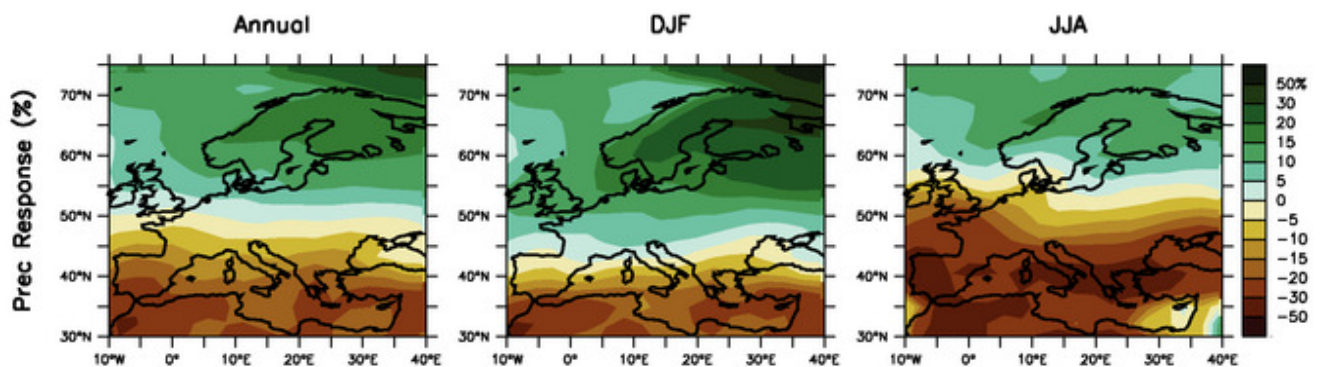


Fig. 2: Annual mean, winter (DJF), and summer (JJA) change in precipitation between the late twentieth and late twenty-first centuries (same source as for the previous figure)

Wind

Change in mean wind speed is subject to less confidence in climate models, due to differences in large-scale circulation between different models. However, some regional models predict an eight-per cent increase in the mean annual wind speed over northern Europe and a reduction in the Mediterranean regions. The increase for northern Europe is greatest in winter and early spring.

Extreme wind speeds are found to increase in western and central Europe and in the North Sea area.

Sea-level

Model projections give a global mean sea-level rise of 0.09 to 0.88 m by 2100, depending on emission scenarios. The rate of sea-level rise could be as great as two to four times faster than today. In Europe, regional influences may result in a sea-level rise up to 50% higher than these global estimates. The impact of the North Atlantic Oscillation on winter sea levels adds an extra uncertainty of 0.1 to 0.2 m to these estimates. Another contribution to the uncertainty comes from inadequate models for the melting of polar ice-caps, including the Greenland glacier.

1.4. European framework for adaptation to climate change

- IPCC 2000 published a set of emission scenarios, the four main ones, denoted A1, A2, B1, and B2, differing in the assumptions on population growth, economic growth, growth distribution, and the extent of remedial measures taken by the international community. These scenarios are the basis for developing downscaled scenarios at national and regional level, which provide the basis for formulating measures for adaptation to climate change.
- The UN Framework Convention on Climate Change (UNFCCC) was negotiated in 1992 and serves as the global framework for the member states' efforts to combat climate change. With regard to adaptation, the UNFCCC formulates commitments from the participating countries to develop integrated national adaptation plans and programmes that prepare for adaptive measures.
- The EU Directive on the assessment and management of flood risks (Directive 2007/60/EC) was published in October 2007.⁷ Although it does not specifically cover climate change, the directive is highly relevant to the NRAs' adaptation work.
- The European Commission's White Paper of 2009,⁸ *Adapting to climate change: Towards a European framework for action*, outlined a two-phase adaptation policy in the EU, the first phase (2009–2012) aiming to:
 - o build a solid knowledge base on the impact and consequences of climate change for the EU;
 - o integrate adaptation into EU key policy areas, 'mainstreaming';
 - o employ a combination of policy instruments (market-based instruments, guidelines, public-private partnerships) to ensure effective delivery of adaptation; and
 - o step up international cooperation on adaptation.

An Impact and Adaptation Steering Group (IASG) was set up and supported by a number of technical groups to help develop the EU strategy and prepare national adaptation strategies by the member states.

- The European Commission's White Paper of 2009,⁹ *A sustainable future for transport*, states that, 'Transport itself will suffer from the effects of climate change and will necessitate adaptation measures. Global warming resulting in a rising sea level will amplify the vulnerability of coastal infrastructure, including ports. Extreme weather would affect the safety of all modes. Droughts and floods will pose problems for inland waterways.'

⁷ EU Directive of October 2007 on the assessment and management of flood risks (Directive 2007/60/EC). http://ec.europa.eu/environment/water/flood_risk/index.htm.

⁸ The European Commission White Paper of 2009 *Adapting to climate change: Towards a European framework for action* (<http://www.eurosite.org/en-UK/content/adapting-climate-change-towards-european-framework-action>)

⁹ The European Commission White Paper of 2009 *A sustainable future for transport*. (http://ec.europa.eu/transport/strategies/2009_future_of_transport_en.htm)

- The Partnership for European Environmental Research (PEER) report of 2009, *Europe adapts to climate change—comparing national adaptation strategies*¹⁰ compares adaptation strategies in nine European countries and shows that very different paths have been chosen, regarding for example, interaction between government and sector policies, prioritising adaptation on the regional or the national level, and conducting research as a basis for adaptation. The importance of sharing knowledge is highlighted.
- The European Commission's White Paper of 2011,¹¹ *Roadmap to a Single European Transport Area—Towards a competitive and resource efficient transport system*, focuses on reducing GHG emissions. However, the need for a climate-resilient infrastructure is recognised and suggested as an integrated part of research work. It should be ensured that EU-funded infrastructure projects consider both energy efficiency and climate resilience.

1.5. Current situation

*The following description of the current situation regarding risks from climate change, on-going research work, and strategy development is based on the surveys in **Appendices 1 and 2**.*

1.5.1. Main risks to the road network related to climate change

As shown in Chapter 1.3, regarding increasing temperatures, Europe can be divided into two main regions: 1) northern and eastern Europe and 2) southern, western, and central Europe. In northern and eastern Europe the expected greater increase in winter temperatures (compared to summer temperatures) could lead to more frequent freeze/thaw changes in areas that currently have stable winter conditions. This may lead to more frequent events of reduced road friction and increased deterioration/frost heave damages and thereby demand more de-icing chemicals and more frequent pavement renewal. This is a concern referred to by Norway, Sweden, and Finland. A further effect could be an increase in the probability of rockfall, although this effect is hard to predict, as stated by Norway. A general increase in temperatures will also lead to a loss of frozen soil or permafrost as an important load-bearing capacity factor, for example in Sweden, and thereby cause problems for heavy goods transport and increase road deterioration.

In southern, western, and central Europe, the main risks are associated with a higher frequency of days with extreme maximum temperatures and a general warming in summer. These changes mainly have a negative effect on pavement conditions and the durability of pavements/surfaces. Even member states such as Spain, which are already confronted with high temperatures and problems with pavement durability, state the necessity for research in this field. Higher winter temperatures in central Europe could diminish the demand for snow clearing but at the same time increase the need for de-icing where rainfall on cold road surfaces reduces friction.

¹⁰ PEER Report no 1, 2009. *Europe adapts to climate change. Comparing national adaptation strategies*. (http://www.peer.eu/publications/europe_adapts_to_climate_change/)

¹¹ The European Commission White Paper of 2011 *Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system* (http://ec.europa.eu/transport/strategies/2009_future_of_transport_en.htm)

A probable increase in winter precipitation in western, northern, and central Europe could generally lead to higher operational costs (snow clearing and salting) and increase the need for the development or adaptation of emergency plans, winter maintenance guidelines, and traffic safety measures. Increased snowfall (in terms of both quantity and intensity) increases the risk of avalanches and may require higher investment in protective installations. Norway and other member states highlight the need to develop landslide and avalanche risk models, better tools for predicting avalanches, and avalanche alert systems.

In southern and central Europe, a substantial reduction in summer precipitation, combined with an increase in temperature, will lead directly to more severe and prolonged drought periods, as stated by Spain. In addition, there will be a risk of more frequent wildfires. While southern Europe is already well acquainted with this problem, this will be a new challenge for central European countries. Water regulation systems, as already used in Spain, for example, and special action plans for alert situations will have to be adopted by countries where this problem will be fairly new, for example Austria.

Across Europe, there is a risk of an increase in the intensity of daily precipitation and the probability of extreme precipitation, especially in some regions in northern Europe, as also stated in the survey by Norway and Sweden.

This may cause more frequent flooding in existing drainage systems of insufficient capacity. It may also cause erosion and landslides, a risk highlighted by all member countries. Adaptation of guidelines for the design of appropriate culverts, drains, bridges, erosion, and landslide protection will be necessary. Problems due to stronger winds or storms are generally not considered as very severe by the member states of this task group. These risks can be managed by means of improved emergency plans. Maintenance costs could rise in any case because of fallen trees or snow drifts.

Roads in coastal areas are at risk from anticipated changes in sea-level. Sweden, Norway, Denmark, and France in particular report concern for existing low-lying road sections, ferry berths, and sub-sea tunnel entrances. Besides the need for a better analysis of probable sea-levels, design guidelines for sea defences against wave erosion will have to be adapted and implemented.

For easier comparison between countries, and for identification of the most common challenges, a summary table was produced. The table is based on the risks survey, provided in full detail in Appendix 1. The estimated probability and severity of risks was given for each country as a number between zero and three. The following scale was applied:

Table 1: Score assigned to assumed probability and severity of individual threats.

Points	Probability, scientific basis	Severity of the risk
3	Verifiable risk	Extremely severe
2	Probable risk	Severe
1	Slight probability	Less severe
0	Improbable	Not relevant

Using this numerical approach, the overall risk can be characterised according to a colour code provided by a typical risk matrix. Here, a risk matrix from the Risk Management for Roads in a Changing Climate (RIMAROCC)¹² project is used:

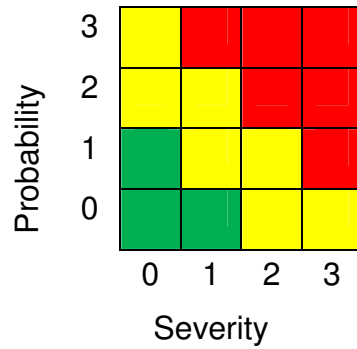













Fig. 3: Risk matrix – colour codes for the combined effect of probability and severity

Table 2 summarises the overall probability and severity of the main challenges.

¹² Bles Thomas, Ennesser Yves, Fadeuilhe Jean-Jacques, Falemo Stefan, Lind Bo, Mens Marjolein, Ray Michel and Sandersen Frode, 2010: *A guidebook to the RIMAROCC Method*, RIMAROCC project, ERA-NET ROAD.

Table 2: Results from individual country surveys on the assessment of the probability of effects and severity of consequences due to changes in climate parameters. P = probability, S = severity.

	High temperatures		±0 temperatures		Wind		Storm		Rain intensity		Increased flow rates in rivers		Flood		Drought		Landslides		Avalanches		Snowfall intensity		Sea-level rise	
	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S
 Norway	3	1	3		1		1		3	3	2	2	3	2	1	1	2	2	2	2	3	2	3	2
 Finland	2	1	3	2	2	2	1	2	2	2	2	2	2	2	1	1	1	3	1	1	3	2	1	0
 Sweden	2	2	3	2	1	2			3	3	2	2	3	2	1	1	3	3	1	1	1	2	2	2
 Denmark	2	2	1	1	2	1	1	1	3	2	2	1	2	2	2	1	0	0	0	0	1	1	2	2
 UK	3	1	1	0	1	1	2	2	3	2	3	1	3	2	2	1	1	0	0	0	1	1	2	1
 Ireland	2	1	1	2	1	1	1	1	3	2	1	1	3	2	1	0	1	2	0	0	0	0	1	1
 France	3	1	2	1	1	1	1	2	2	1	1	2	2	2	3	3	1	2	1	1	2	2	3	2
 Austria	2	2	3	2	1	1	1	1	2	2	1	2	3	2	3	2	2	2	2	1	2	2	0	0
 Hungary	3	2			2	1	3	2	3	2	3	2	3	2	3	1	2	1	0	0	3	2	0	0
 Italy	3	2	2	2	1	1	2	1	2	2			2	2	1	1	2	2			2	2	1	1
 Spain	3	2	2	1	1	1	2	1	2	1	2	1	2	1	3	2	2	1	2	1	2	1	2	1

1.5.2. Beneficial effects

In some areas of work, climate change may have a beneficial effect. France refers to a probable positive effect on the frost index, one of the basic sources of data used for pavement design. Hungary expects a generally shorter winter period, which could lead to a reduction in frost damage and in the number of accidents caused by ice or snow.

Norway and Sweden also expect less snow in the lowlands and in the southern parts of their countries, which would reduce the need for winter maintenance, and consequently reduce costs and enable more road sections to be open during the winter months. In Norway, less snow in the lowlands may also imply a reduction in snow avalanches in some places.

A longer growing season can be unfavourable in terms of vegetation along roads, but on the other hand, higher tree lines can reduce the problem of snow drifts at higher altitudes and have a stabilising effect on avalanches.

The fact that ice-free routes in the Arctic Ocean can already be used this century is highlighted as being beneficial for sectors other than road transport. However, more activity in the far northern areas of Europe will also increase road transportation and place higher demands on a well-functioning road network.

1.5.3. National policies on adaptation to climate change

Finland has a national strategy for adaptation to climate change (2005).¹³ In 2009, the Ministry of Transport and Communications issued a short-term (2009–2020) climate change policy.¹⁴ Climate change adaptation will not increase the need for additional resources for basic infrastructure management during this electoral term, but this may change in the near future. The most important measures to be taken by 2015 are defined in the policy. These include the integration of climate change adaptation into all processes, planning for long-term investment, better warning systems, more research, and international involvement.

In 2010, **France** issued a National climate change adaptation plan,¹⁵ where transport infrastructure is one of the themes. Five main areas of work were identified:

- updating existing procedures and guidelines;
- promoting research on all technical innovations allowing better and less expensive responses to climate change problems;
- communicating and raising awareness among stakeholders;
- developing risk and vulnerability assessment projects; and
- coping with the consequences of sea-level rise

For further description of the French adaptation plan see example 1.5.3 in Appendix 3.

¹³ Finland: *National strategy for climate change*, see Appendix 2.
(<http://www.mmm.fi/en/index/frontpage/ymparisto/ilmastopolitiikka/ilmastomuutos.html>)

¹⁴ Finland: *The climate change policy of the Ministry of Transport and Communications* (2009), see Appendix 2.

¹⁵ France, *Adaptation plan, PNACC 2011-2015*, see Appendix 2 and example 1.5.3 in Appendix 3.
(<http://www.developpement-durable.gouv.fr/Le-Plan-national-d-adaptation,22978.html>,
<http://www.developpement-durable.gouv.fr/The-national-climate-change.html>)

In **Norway**, climate change and adaptation are discussed in the 2008 report *Adaptation to climate change in Norway—the Norwegian government's adaptation efforts*¹⁶ and in the Minister of the Environment and International Development's climate policy report to the Norwegian Parliament of May 2009.

A special committee was set up to carry out a thorough analysis of society's vulnerability and its need to adapt to the consequences of climate change. The committee delivered its report in November 2010.¹⁷ Physical infrastructure, including transport infrastructure, is one of the focus areas of the investigation. The report highlights the importance of considering the effects of climate change in all phases of work, conducting surveys of vulnerability on the existing road network, and adaptation of design guidelines. This investigation will be the basis for the production of a white paper on adaptation to climate change.

Hungary's *National climate change strategy*¹⁸ for 2008–2025 contains a section dealing with adaptation to climate change and includes transport infrastructure. Some of the needs outlined are: nature preservation and new road alignments, revision of construction standards, guidelines and regulations, and conducting complex risk analyses for 'critical infrastructure'.

The **Spanish** *National climate change adaptation plan (PNACC)*,¹⁹ formulated for a time horizon of 2100, includes the transport sector, but does not consider it as a priority sector at this stage (the Spanish marine ecosystem for the optimisation of harbour exploitation and maritime navigation is given priority). However, the possible need to modify infrastructure works, such as bridges and runways, modify climate-related parameters, and remediate the effects of sea-level rise is recognised. Evaluation of risk and vulnerability in terms of infrastructure safety is required.

Denmark's policy, the *Danish strategy for adaptation to a changing climate* was issued in March 2008.²⁰ This strategy is based on the notion that adaptation to climate change is a long-term process, and that it is still uncertain what the consequences of climate change will be and how soon they will take place. The government will therefore initiate an information campaign and organise the topic, with the aim of ensuring that climate change is incorporated into planning and development so that public authorities, businesses, and citizens have the best possible basis for considering whether, how, and when climate change should be taken into account.

¹⁶ *Adaptation to climate change in Norway. The Norwegian government's adaptation efforts*, Ministry of the Environment, 2008, (http://www.regjeringen.no/upload/MD/Vedlegg/Klima/Klimatilpasning/Klimatilpasning_redegjorelse150508.pdf)

¹⁷ Norwegian National Risk Assessment, NOU 2010:10, Green paper from the Ministry of the Environment (in Norwegian). (<http://www.regjeringen.no/en/dep/md/kampanjer/klimatilpasning-norge-2/bibliotek/publikasjoner/nou-rapporten-lagt-fram.html?id=624557>)

¹⁸ Hungary: National Strategy Parliamentary Decree No. 29/2008. (III. 20.) on the National Climate Change Strategy.

¹⁹ Spanish Adaptation plan, PNACC (2006) Ministry of the Environment and Rural and Marine Affairs of Spain, see Appendix 2.

²⁰ *Danish strategy for adaptation to a changing climate*, the Danish Government, March 2008. (http://www.kemin.dk/Documents/Klima-%20og%20Energipolitik/klimatilpasningsstrategi_UK_web.pdf)

1.5.4. NRA strategies for adaptation of the road network to climate change

The Finnish Transport Agency has published a long-term plan, *Transport conditions in 2035 (Liikenneolosuhteet 2035)*,²¹ which is the Finnish Transport Agency's expert opinion on the transport system of the future and associated implementation. It includes guidelines for work on the transport system and road management. It includes four strategic visions, one of which is: 'Our Actions Today Impact Tomorrow'. Mitigation of and adaptation to climate change is the main issue in this chapter, another being safety and environment. In the actual plan, the focus is on mitigation activities. The adaptation section states that the level of service should be sustained even if flooding, wind, more intense rainfall, and zero-temperatures become more frequent.

The Norwegian *National Transport Plan*²² contains recommendations from the Ministry of Transport and Communications for the government's transport policy and a strategic plan for development of the overall state infrastructure for transport by road, rail, air, and sea. It is issued every four years and is based on a number of thematic reports developed by the transport administrations, including the Norwegian Public Roads Administration (Statens vegvesen, NPRA). Although adaptation to climate change has been the subject of thematic reports in two consecutive plans, a separate adaptation strategy has not yet been formulated, neither for the road administration nor for the transport sector as a whole.

In May 2011, the United Kingdom government published *Climate-resilient infrastructure: preparing for a changing climate*²³ which sets out the government's view on adapting infrastructure in the energy, information and communications technology, transport and water sectors to the impacts of climate change. Although these are only part of the national infrastructure system, they are all vital in their own right and form a set of interconnected networks on which other infrastructure sectors and parts of the economy and society rely in order to function. The Highways Agency's response to the challenge of climate change must involve both mitigation (taking action to reduce greenhouse gas emissions) and adaptation (changing behaviour so that it is more appropriate to the expected future climate).

Many of the Highways Agency's activities are directly affected or influenced by the climate. The Highways Agency's commitment is to assess the potential risks posed by climatic changes to the on-going management, maintenance, improvement, and operation of the strategic road network. It will factor anticipated climatic changes into the delivery of its business and develop appropriate management and mitigation solutions to remove or reduce these risks.

²¹ Finnish NRA long-term plan, *Transport conditions 2035 (Liikenneolosuhteet 2035)*.
(http://portal.liikennevirasto.fi/sivu/www/f/liikennevirasto/tapamme_toimia/liikenneolosuhteet_2035)

²² Norwegian National Transport Plan 2010-2019, White Paper from the Ministry of Transport, March 2009, <http://www.ntp.dep.no>.

²³ *Climate-resilient infrastructure: Preparing for a changing climate*, 2011. United Kingdom Government, Secretary of State for Environment, Food and Rural Affairs. ISBN: 978010180652

The Highways Agency needs to ensure it can continue to provide a robust strategic road network in a changing climate and has developed the Highways Agency climate change adaptation strategy and framework (2009).²⁴

1.5.5. On-going research programmes on climate change

Work on adaptation to climate change has started in almost all member states. However, differences are significant concerning the type of work, the approach, and the anchoring of work to political initiatives. Many of the participating NRAs are involved in collaborative national projects driven by other domestic institutions. The following summary reviews just some of the projects dedicated to the transport or road sectors.

European research programme

The EU programme ERA-NET ROAD has combined research funds from 11 road administrations in a common call for research projects in the field of adaptation to climate change: 'Road owners getting to grips with climate change'²⁵. From the CEDR task group 16, the UK, Finland, Sweden, Spain, Norway, Austria, and Denmark are also partners in ERA-NET ROAD. Four projects have been carried out: 'Improved local Winter Index to assess Maintenance Needs and Adaptation Costs in Climate Change Scenarios' (IRWIN), 'Pavement Performance and Remediation Requirements following Climate Change' (P2R2C2), 'Storm Water Prevention - Methods to predict Damage from the Water Stream in and near Road Pavements in lowland Areas' (SWAMP) and 'Risk Management for Roads in a Changing Climate' (RIMAROCC). These projects are included in the examples of research and development (R&D) work under the specific topics.

Examples of R&D work initiated/conducted/driven by the NRAs

Norway

The NPRA is finalising a research and development programme on 'Climate and Transport 2007–2010',²⁶ dedicated to adaptation to climate change. The programme deals with all aspects of road planning, construction, and management, and aims to investigate the effects of climate change and to propose remedial measures. In addition, the NPRA is supporting several larger R&D programmes on climate change initiated by other agencies.

²⁴ *Climate change adaptation strategy and framework*, 2009. Revision B - issued November 2009. Highways.

²⁵ <http://www.eranetroad.org>,
http://www.eranetroad.org/index.php?option=com_content&view=article&id=76&Itemid=79

²⁶ www.vegvesen.no/klimaogtransport

Sweden

The Swedish traffic administration has supported, financed, initiated, and carried out a large number of research projects concerning geotechnical conditions, environmental effects of climate change, and methods for risk analyses. Among these is the programme 'Naturhändelser med negativa konsekvenser för samhället i dagens och morgondagens klimat' (Natural hazards with negative consequences for society in present and future climate)²⁷, under the administration of the Swedish Civil Contingencies Agency (Myndigheten för samhällsskydd och beredskap, MSB). The programme deals with Swedish conditions and the whole process: inventory, prevention, preparedness, management, monitoring, and learning from earlier incidents and their consequences for the society. The funding is for research projects to commence in late autumn 2011 and to be completed at the end of 2015.

Finland

Finnish research activities include:

- The R&D project ILMATIE²⁸, which studies ways of making climate policy more efficient in road management. It suggests that transport system planning should be developed actively and climate change highlighted in procurement of goods and services, future studies, and risk management. The results of the study were used in the development of the *Transport conditions 2035 (Liikenneolosuhteet 2035)* long-term plan, although they have become somewhat outdated since the reorganisation of the transport sector. The project was documented in the report, *Strengthening climate policy in road maintenance*²⁹.
- The R&D project ITARA³⁰ (completed) which studied the effects of climate change on freight transport. The report of the project was published by the Ministry of Transport and Communications (*Climate change and freight transport*). The report draws the following conclusions: competitiveness and different transport modes will change, as will the location pattern of industry and traffic flows. Climate change mitigation measures will be much more significant than changes in average climate. Climate change may also have an impact on traffic safety. The timing of road damage due to thawing as well as the timing of resulting weight limitations will change and the total period of road damage may increase. Flooding caused by rainfall and other flooding may exceed drainage capacity.
- The Finnish Transport Agency's R&D plan 2011–2014³¹ includes four main categories. The first is climate change mitigation, while adaptation to climate change is covered within the category *Efficient traffic lane management and innovative operation models*.

²⁷ Programme 'Naturhändelser med negativa konsekvenser för samhället i dagens och morgondagens klimat' (Natural hazards with negative consequences for society in present and future climate), Swedish Civil Contingencies Agency, www.msb.se.

²⁸ Raisa Valli ja Liisa Nyrölä: Ilmastopolitiikan tehostaminen tienpidossa. Helsinki 2009. Tiehallinto, Keskushallinto. Tiehallinnon selvityksiä 27/2009. 68 s. + liitt. 8 s. ISSN 1457-9871, ISBN 978-952-221-265-8, TIEH 3201141.(Finland: ILMATIE project).

²⁹ <http://www.tiehallinto.fi/pls/wwwedit/docs/25751.PDF>

³⁰ [Climate change and freight transport](#), 2010. Publications from the Ministry of Transport and Communications 15/2010 (Finland ITARA project).

³¹ Finish Transport Agency: R&D plan. (http://portal.liikennevirasto.fi/sivu/www/e/fta/research_development)

1.6. Main effects and remedial measures

In the following overview, the main challenges concerning climate change are described, reasons for their being a challenge are given, and possibilities for dealing with them are proposed.

1.6.1. Flood and erosion

Run-off and necessary drainage capacity

Higher precipitation intensity increases the risk of floods that exceed the capacity of the drainage infrastructure serving the road system. In colder regions, sudden snowmelt will further increase this risk. In addition, unusual combinations of weather could occur more frequently in the future, such as rain on frozen ground. Another concern is that increased precipitation rates will lead to greater risk of aquaplaning. This is an important safety issue that should be considered when discussing the capacity of drainage systems.

Capacity calculation, methods and design criteria

Capacity requirements are usually calculated on the basis of rain intensity, catchment area, and properties of the run-off surface. However, there is a lack of good data for rain intensity. In addition, changes in area use can alter the properties of run-off surfaces in terms of infiltration. Measurements of the actual run-off, as opposed to measurements of precipitation only, are therefore preferable.

Possible ways of temporarily compensating for the lack of measurement data and predicted run-off are the use of more conservative return periods, or increasing the design capacity by an additional climate factor. See Appendix 3 for examples of revised drainage specifications in Nordic countries. Future design criteria should also focus on more robust foundation types, requirements for foundation depth, and erosion control.

Projection of flood values

There is a need for new design and maintenance criteria based on future climate projections. The projection of flood values based on global or regional climate change scenarios is, however, a difficult task, due to the general uncertainty already present in the calculation methods for run-off volumes. The lack of long-term measurement series on precipitation and run-off in important areas makes statistical work and future projections difficult.

Maintenance procedures

The effective capacity of drainage structures, such as ditches and culverts, depends on maintenance procedures. With higher precipitation and run-off peaks, and increased erosion and sediment transport, the failure frequency of existing structures is expected to increase if maintenance procedures remain unchanged. This is especially important for more expensive assets like bridges, when more frequent and larger floods increase scouring and pose higher demands for inspection and maintenance of the structures involved. Proper methods are needed for identifying vulnerable assets with respect to different types of foundation, erosion protection, etc. Risk and susceptibility analyses covering bridges, culverts, and other drainage structures are being conducted in some countries.

Avoiding problems through planning

Many problems caused by flooding or excessive run-off could be avoided with better alignment of the roads. Vertical alignment implies elevating the road to a level with small or no risk of flooding. Horizontal alignment implies placing the road in such a way that it does not constitute a barrier for waterways, especially if sediment transport in flood situations is to be expected. In addition, areas prone to coastal erosion should be avoided.

Pollution/environmental issues

More rain and more intense rain episodes may increase the risk of the uncontrolled transport of pollution. The sources can be run-off water (traffic), pollution accumulated in snow and washed away by heavy rain, erosion and particle transport from surrounding areas, uncontrolled wash-out of sedimentation basins, or other sources, such as abandoned waste depots which become active during heavy, long-lasting rain. Run-off water from roads can cause environmental problems in urban areas if connected to municipal sewage systems with insufficient capacity.

Retention ponds and sedimentation basins are a good protective measure if of adequate dimensions and functionally sited. A holistic approach to drainage design is needed, involving all water management parties as early in the planning process as possible.

EU flood risk directive

Many countries are already working with preliminary flood risk assessment, flood hazard mapping, and flood risk management plans, in accordance with the EU Directive of October 2007 on the assessment and management of flood risks. For proper results, this work must consider the effects of climate change, both regarding sea-level rise and increased run-off in river basins.

Examples of relevant practice or R&D work

1.6.1 a	Joint	ERA-NET ROAD: SWAMP
1.6.1 b	Denmark	Blue Spot Map
1.6.1 c	UK	National Flood Register
1.6.1 d	Denmark, Norway, Sweden	New drainage standards
1.6.1 e	Hungary	Sludge spill 2010

1.6.2 Landslides, rockfall, and avalanches

More precipitation and more *intense* precipitation will increase the risk of weather-related events, such as landslides, mud flows, snow avalanches, and rockfalls. The effects of these events may range from minor damage to the complete destruction of a part of the infrastructure. The extent to which extreme events will become more prevalent is still uncertain. Potentially unsafe areas can be identified by soil and landscape characteristics, taking into account the probable changes in the climate.

Landslides

Increased annual precipitation and the likely rise in local groundwater levels reduce soil stability. Increased daily precipitation and higher intensities will have similar effects. This applies both to natural slopes and man-made structures, such as road embankments and cuttings. Consequently, the frequency of slope failures affecting the road system is believed to increase in regions where more intense rainfall is expected. This means that existing protection may be insufficient and that climate change considerations must be included in the process of making decisions on prioritising protective measures. This also means that new areas with no prior history of landslides need attention.

Rockfall

More rainfall, an increasing number of freeze-thaw fluctuations, following higher mean winter temperatures and the melting of permafrost soils, accelerate rock deterioration. This is a result of rainwater penetrating into pores and cracks in the rock, resulting in chunks of rock coming loose. Exposure to more frequent freezing and thawing will further speed up this process. The melting of permafrost in the mountains leads to increased rock fall, as the existing rock structure may only have sufficient stability under permafrost conditions. These expected changes in climate conditions may thus lead to more soil and rock slides along exposed roads.

Avalanches

Higher winter temperatures in some European regions will, while expecting the same amount of precipitation, thus lead to less snow in lower and coastal areas. More rainfall during winter in those areas can introduce new hazards involving debris flows and slush avalanches. On the other hand, increasing precipitation and storm frequency will result in a higher probability of snow avalanches in higher mountain areas where temperatures still remain cold. These effects could also trigger avalanches with increasing mass/volume giving a longer run-out and more severe effects than recorded in the past.

Potentially unsafe regions or local areas which may be significantly affected by climate change can only be identified by means of an assessment of past recorded avalanches and landscape characteristics, taking into account possible changes in winter precipitation and snow drift.

‘Wet’ slide types

Debris flow and slush avalanches are slide types that are released during intense precipitation periods. The frequency of these slides is therefore expected to increase. Areas with dry avalanche history may be more prone to slush avalanches in the future, and existing protection measures may be insufficient.

Quick clay

In most cases, slides in quick clay are caused by human activity, especially construction work. They may also be induced by natural processes, such as increased erosion in rivers and streams. These natural processes may be locally more severe in a changed climate. Thus better field methods for revealing potentially unsafe regions, calculating stability, and optimising protective measures are needed.

Landslide and avalanche databases

National databases combining landslide and avalanche data from different databases are an important tool for improving prediction and protection from landslides and avalanches. In Norway, a national landslide database is currently being developed. Austria has an operative database on avalanche damage.

Examples of relevant practice or R&D work

1.6.2 a	Norway	Landslide risk evaluation model
1.6.2 b	Norway	Avalanche alert system
1.6.2 c	Austria	Hazard zone planning
1.6.2 d	Austria	Simulation software

1.6.3. Drought and effect of high temperatures

Higher summer temperatures affect the durability of road pavements by softening bitumen mixtures, leading to more rutting. Higher temperatures and less precipitation in southern Europe also increase the frequency of prolonged drought periods, which in turn lead to a greater risk of wildfires. Even in Nordic countries, increased maximum summer temperatures experienced during the past decade have raised questions about the durability of current pavement materials with respect to heat resistance. For this reason, stiffer binders have been recommended in some regions.

Examples of relevant practice or R&D work

1.6.3 a	Spain	Pavements and slopes
1.6.3 b	France	Calculating the cost of heat waves

1.6.4. Effects leading to increased deterioration of roads

Rutting with higher precipitation

Increased precipitation may lead to local elevation of groundwater levels. This, in addition to more infiltration into the road structure from above, will increase water content in the road sub-base. This may lead to more rutting (as is the case for higher temperature extremes) and faster deterioration of materials in the road sub-base. Traditional methods for estimating road service life, which consider these effects, have indicated a shorter service life for roads when increased precipitation is included in the calculation.

Thaw weakening

Higher precipitation, higher groundwater levels and more frequent freeze-thaw cycles affect the bearing capacity of roads. Frozen layers in the sub-base of roads with poor drainage properties or made of frost susceptible materials prevent melt water or precipitation from draining away from the road structure when thaw sets in. This temporarily reduces the bearing capacity of the road. Traffic loads cause water pressure and water movement in the sub-base, wearing down minerals, increasing the content of fine, frost-susceptible material. During thaw, rutting of the pavements is faster and water pressure may even cause the pavement to break up. A higher content of fines due to sub-base wear will increase moisture in the structure and the risk of subsequent frost heave.

In Scandinavia, roads in regions that previously enjoyed stable winter conditions are now subject to several freeze-thaw cycles each winter. This will accelerate road deterioration and consequently increase maintenance costs. Axle load restrictions are applied in some places during the thawing period, causing problems for heavy goods transport.

Low-traffic-volume gravel roads in sparsely populated northern areas are at particular risk. New design methods and material requirements are needed to meet these challenges.

Loss of permafrost

The loss of permafrost and shorter winter periods challenge special transport functions which depend on frozen ground, and even frozen lakes and rivers. This is a concern for the forest industry in the northernmost regions in Scandinavia.

Examples of relevant practice or R&D work

1.6.4 a	Joint	ERA-NET ROAD: P2R2C2
1.6.4 b	Joint	Northern Periphery Programme: ROADEX
1.6.4 c	Finland	Survey of surface frost heave problems

1.6.5. Effect of sea-level rise

Rising sea-levels and storm surges create problems such as coastal erosion, flooding, and wave splash-over, which may result in damage and traffic disruptions. This can also increase the risk of water flowing into low-lying sub-sea tunnels. Road embankments and bridge foundations may be exposed to more strain and erosion. Groundwater levels will rise in low-lying coastal regions, affecting the bearing capacity of roads.

Of the countries taking part in the task group, sea-level rise represents particular challenges for Denmark. About 80 per cent of the Danish population lives in urban areas near the coast. Many of the coastal towns near larger river estuaries or at the ends of fjords may face complex problems. Around 1,800 km of coastline is already protected by dykes or other forms of coastal protection. Building higher dykes is, however, not a long-term solution, as the problem of backwater flooding will just become greater as a result of river water being unable to flow freely into the sea. A long-term solution requires the involvement of river valleys further inland.

In March 2011, the Danish Coastal Authority developed a web-based tool that provides assistance in land-use planning for coastal areas with respect to the projected sea-level rise towards 2050 and 2100.³² For a selected location and a selected climate change scenario (low, medium or high), the map will display the sea level which is probable to occur every 20, 50 or 100 years, in the year 2050 and in 2100. The consequences are presented visually. Information on wave energy, sediment transport, coast type, and existing protection is also provided. The tool is part of the web portal 'Climate change adaptation in Denmark'.

An interesting vulnerability assessment of a road network exposed to coastal hazards was undertaken in France in 2009. See 1.6.5 a in Appendix 3.

Examples of relevant practice or R&D work		
1.6.5 a	France	Vulnerability of transport infrastructure to coastal hazards

³² <http://klimatilpasning.dk/da-DK/Info/kort/kystplanlaeggeren/Sider/Kystplan.aspx>

1.6.6. Effects on winter conditions

Snow removal

More intense precipitation will result in more frequent or intensified snowfall in high-latitude or mountainous regions, with an impact on demand for snow ploughing. More wind in these regions will increase snow drifting and thus necessitate more ploughing. In the lowlands, less snowfall is expected, since a greater proportion of the winter precipitation will be rain.

Friction control

The effects of climate change on winter road services will differ by region. In Scandinavia and Finland, it is expected that the zone where roads are salted will extend further north, due to higher winter temperatures. Roads that have until now been subject to 'white road' policy management may suffer frequent temperature fluctuations around freezing point and salt use is expected to increase, in spite of a shorter winter season. A larger portion of the road network will thus require a 'black road' strategy. In general, it can be expected that climate change will change local demand for winter services, some road sections may need less attention, while others may need more.

The ERA-NET ROAD initiative IRWIN proposed a technique to develop a winter index which can be used to assess the effects of future climate on demand for friction control (see examples of R&D work in Appendix 3).

Adaptation depends, among other factors, on how fast the expected changes within the individual climate parameters appear, and how fast the affected structures or systems can be adapted. In the case of snow removal and friction control, services are already subject to highly fluctuating annual demand. Road operators are therefore quite flexible in most cases and will adapt with time when climate changes are evident.

Traffic management on roads exposed to strong winds

Strong winds affect the transport system in several ways. Strong winds can threaten traffic safety and transport reliability on exposed sections, such as bridges and mountain passes. In combination with sea-level rise, storm surges affecting roads in coastal regions might become a greater problem in future climate conditions. Storms can also cause fallen trees or other obstacles to block road traffic.

Examples of relevant practice or R&D work

1.6.6 a	UK	Winter resilience
1.6.6 b	Joint	ERA-NET ROAD: IRWIN

1.7. Risk assessment and management

Risk assessment and management in the infrastructure sectors, including road transport, has been practised using various approaches in different countries. Risk assessment by the NRAs commonly involves addressing factors such as traffic safety, infrastructure safety in relation to natural hazards, including climatic parameters, and tunnel safety and dangerous goods transport.

Currently, the most interesting work in the field of risk assessment related to climate events, including the effects of climate change, is the development of the Risk Management for Roads in a Changing Climate (RIMAROCC) method.³³ The method has been developed within a common initiative by the ERA-NET ROAD countries and is briefly explained in an example following this chapter. The purpose of the method is to meet the common needs of the NRAs to have an overall framework for adaptation work, which is compatible with existing methods and follows the general standards of risk management.

A survey of existing methods for risk analysis and risk management³⁴, conducted as part of the RIMAROCC project, identified three previous schemes that are applicable to road infrastructure risk assessment with respect to climate change: the French GeRiCi project (Risk Management related to Climate Change for Infrastructures), the UK adaptation strategy, and the 'Deltares' approach from the Netherlands, originally developed for spatial planning and water management systems.

Regardless of the chosen method or tool, the key questions for the NRAs are how to identify vulnerable assets, what the actual threats from changing climate are, and how to define the acceptable risk level. These questions have to be dealt with on a regional basis, since the climatic challenges and local conditions vary from country to country. However, risk management schemes such as RIMAROCC provide a suitable framework for a common approach that enables synergies among the European NRAs.

Examples of relevant practice or R&D work		
1.7 a	Joint	ERA-NET ROAD: RIMAROCC
1.7 b	France	GeRiCi system
1.7 c	Norway	FøreVar web portal
1.7 d	Norway	Risk and susceptibility analyses of assets on the road network
1.7 e	UK	Severe weather plan

³³ RIMAROCC Guidebook on the FEHRL web site:
<http://www.fehrl.org/index.php?m=192&mode=view&id=12340>

³⁴ Hjördis Löfroth, Yves Ennesser, Thomas Bles and Stefan Falemo, 2009: *Existing methods for risk analysis and risk management within the ERA-NET ROAD countries—applicable for roads in relation to climate change*. RIMAROCC project, ERA-NET ROAD.

1.8. Calculating the costs of climate change to the network

Costs are the most concrete way of expressing consequences of climate change. Within the RIMAROCC system, the consequences of a weather-related event are divided into five categories:

- loss of safety on the road (injuries or deaths);
- direct costs; costs of reconstruction;
- financial costs (indirect costs of unavailability of the road);
- loss of confidence/image/prestige/political consequences; and
- impact on the environment.

Consequences and costs can be immediate or progressive. The consequences of the same event may be very different, depending on factors such as season, time of day, holidays, etc. It is important to estimate the costs and benefits of remedial (mitigating) measures. The effect of mitigating measures depends on when in the service life they are undertaken and on the required safety level. Improving the capacity of the road network to withstand the future climate must be seen in relation to planned maintenance or reconstruction work.

Achieving a balance between investing in mitigation measures and accepting a certain level of costs for the repair of damage after a weather-related event is a challenge that will increasingly form part of decision-making for NRAs.

Examples of relevant practice or R&D work

1.8 a	France	Costs concerning sea-level rise and coastal damage
1.8 b	Sweden	Estimating costs related to climate change
1.8 c	Finland	Costs of climate change in maintenance

1.9. Main effects of climate change on working procedures

Chapters 1.6–1.8 describe the effects of particular aspects and parameters of climate change on the road network. In this chapter, these effects will be described in relation to the road owners' working procedures.

In the **planning** phase, climate change will emphasise the importance of good flood maps or maps of landslide risk zones. At the next stage, good planning of water management will reduce the problem of insufficient capacity of drainage structures. In addition, climate change must be taken into consideration in order to avoid exposure to demanding operational conditions, especially in winter.

Standard **design** procedures, especially combined with loads based on historical data only, may prove inadequate and lead to inadequate structural safety, such as landslide or flood protection. Methods of calculating and estimating capacity may prove to be insufficient. In addition, new combinations of weather conditions (for example, high run-off on frozen ground) may require additional capacity for culverts or drainage systems or better preparedness for floods etc.

Good regional (local) projections of climate change and meteorological data (up-to-date, of good quality, and easily accessible), such as precipitation and precipitation intensity, will be a necessary precondition. In addition, road data, including information about drainage structures and good records of weather-related events on the road network are important preconditions for climate adaptation.

Maintenance of drainage structures and culverts must be based to a greater degree on weather forecasts. Surveys of vulnerable assets will be important, taking climate change into consideration. Maintenance will also be affected by the standard of the road—road sections of low standard are difficult to maintain. Contracts that adequately address climate conditions are important for good road management.

Operation: traffic management, risk assessment and risk management during operation, preparedness, emergency plans, and contracts will all depend on a good knowledge of weather conditions. It may become more challenging to define *standards* for day-to-day maintenance and also to define *unexpected* weather conditions for this kind of maintenance. Contracts which ensure safety in a more demanding climate will be of increasing importance. An additional means of maintaining safety is through good communication with road users.

Examples of relevant practice or R&D work

1.9 a	Norway	National Road Database
1.9 b	Norway	Successive preparedness system
1.9 c	Norway	Information technology systems for communicating risks and alerts

1.10. Summary of Chapter 1

Climate change as described by the projections from global and regional models will bring a number of challenges for the road network in Europe.

- In most cases, the same challenges as are faced today will have to be met, but on a larger scale, occurring more frequently, and at other locations than expected.
- In some cases (or in some areas), climate change will bring some benefits for road owners, for instance in areas where less frost and snow are expected.
- Certain new challenges will arise: unusual combinations of weather conditions, such as floods on frozen ground or 'wetter' landslide types.

The most important effects on infrastructure and operations are:

- more flooding and erosion: a challenge for drainage systems and erosion protection and for the design and maintenance of culverts and bridges;
- landslides and avalanches: occurring more frequently, at new locations, and with a higher proportion of 'wet' landslide types such as slush avalanches and debris flow;
- droughts and high summer temperatures may cause problems for the asphalt surfacing (due to softening), but also for run-off conditions (due to lower permeability). Risk of wildfires may also increase in most regions;
- deterioration of roads and pavements, as expressed by the service life and rutting, mostly in cases where drainage is inadequate;
- effects of sea-level rise for coastal stability and sufficient elevation of roads, quays, and bridges as well as levels of sub-sea tunnel portals;
- heavy snowfall in mountain areas of northern Europe causing problems for winter maintenance and operation under difficult conditions; and
- the need for better risk management and efficient procedures for initiating remedial actions after a weather-related event occurs, since existing protection measures may not be adequate and the planning of remedial measures requires time.

All these effects can be recognised in all phases of road management: planning, design, construction, maintenance, and operation.

Examples of on-going work on adaptation to climate change and examples of good practice supporting adaptation show that NRAs are aware of the challenges ahead, and that there is a good basis for action aimed at mitigating damage and costs.

2. Possible ways forward (solutions)

Adaptation to climate change and the choice of actions to implement it depend on a large number of factors, ranging from variations in climate projections to national policies and budgets. The task group will nevertheless suggest some actions for implementation at European and national level. At national level, the group proposes a number of strategic actions and actions within the framework of maintenance and operation. In addition, some 'no-regret actions' are proposed, i.e. actions that are relevant to adaptation but are beneficial regardless of climate change.

2.1. European level

The task group is of the opinion that there is no need for a common European strategy for the adaptation of road networks to climate change. Strategies for adaptation to climate change are mainly carried out at national level. However, when preparing new transport strategy (e.g. European Commission White Papers 2009 and 2011), adaptation to climate change should be highlighted as a future challenge in addition to climate change mitigation measures (see 1.4).

The task group suggests that European collaboration should focus on research strategies and joint research programmes. ERA-NET ROAD (described in 1.5.5) developed a model for co-financing research within common fields of interest. The funding came from 12 NRAs and the programmes were carried out by means of transnational collaboration between research institutes. There are good reasons for further developing research co-financing methods.

Suggestions for future research topics are given in 2.5.

2.2. National level: strategies for adaptation to climate change

As indicated in 2.1, strategies for coping with climate change are a national issue and should be given priority. Delegates from all the member states in task group 16 define adaptation to climate change as an important strategic issue. Several countries have already included adaptation in their transport or road management strategies. Some countries have a climate change strategy that emphasises mitigation but also includes adaptation. In this context, it is important to note that mitigation and adaptation in many cases require different expertise and the involvement of different units within the organisation. For information on the status of strategy work in the member states, see 1.5.3 and Appendix 2.

There follows a list of a few general ideas that could be included in a climate adaptation strategy:

- plan for carrying out a survey of vulnerable assets—assessing the risk arising from climate change;
- adaptation measures on the technical side: adjusting guidelines for planning and design, other technical procedures, adjusting methods for risk assessment;
- strategies for improving the knowledge base: promoting research, adapting results from climate research for practical use, etc.;
- economic aspects: estimating the costs and benefits of actions (compared to the costs of no action) and relating the investments to risk level;

- strategies for improving communication to road users, both before and after weather-related events;
- ensuring a clear and well-communicated *role* for the NRA in securing a functional transport system. This could imply formulating strategy for the NRA on a regional basis; and
- strategies for implementation: formulating action plans, encouraging political effort /legislation.

It is important to put effort into the implementation of the strategy. One way of doing this is to define follow-up indicators to see whether the strategy has been implemented and whether damage or unnecessary costs due to weather and climate could have been prevented or reduced. This requires good knowledge of the effects of weather and climate and good records of maintenance history and disruptive weather-related events.

2.3. National level: working procedures from planning to operation of the road network

In this section, we bring together suggestions on how adaptation to climate change should be taken into consideration in road management and road transport services offered by the NRAs. These suggestions are based on the group's discussion of the challenges described in Chapters 1.6 to 1.9 and results from R&D work on adaptation to climate change.

2.3.1. Planning

Including consideration of climate change in the planning phase of projects can help to avoid difficulties in the later phases. For example:

- vertical alignment: sufficient elevation with respect to water level (sea level, storm surge levels, flooding). Super-elevation should also be considered to ensure sufficient run-off efficiency from the road surface in the event of intense precipitation;
- horizontal alignment: minimising consequences of crossing waterways, avoiding landslide risk zones or coastal erosion;
- holistic approach to water management: retention basins and drainage systems ensuring both efficient run-off and pollution control, sub-surface drainage, extended use of retention ponds and planning flood ways; and
- including consideration of good maintenance and operations in the planning phase.

2.3.2 Design and construction

Drainage and culverts

Ensuring good drainage is one of the most important adaptation measures. Design standards should be adapted to the demands of climate change, see 1.6.1 for examples. Maintenance of existing drainage structures should be carried out with respect to future needs, and if possible as a part of planned regular replacement of old systems.

The knowledge base should be improved by ensuring access to high-quality weather data, including short-term precipitation (rain intensity), as well as flood values (see 2.4) and good predictions of water flow (of particular interest in catchments where intensive precipitation can accumulate quickly).

Bridge design

Bridges need good erosion protection and robust foundations. This influences the choice of foundation type and erosion protection and the choice of design levels for flood.

Guideline revision is necessary to ensure robust structures in the future. Redesigning existing guidelines requires retrofitting of design criteria, preparing the structure for new and higher loads.

Other effects that should be taken into consideration in the revision of design guidelines include free height above the water level and the effect of drifting ice.

Landslide protection

In a changed climate, protection measures that have already been implemented may be insufficient. Landslides may occur in different places. The main issues are: description of risk related to weather parameters, planning, and prioritising protection measures.

Developing better *prediction models and risk assessment methods* is crucial for optimising actions to prevent landslide, see 1.6.2. In addition, design guidelines for landslide protection should be adapted to changed conditions wherever necessary, and the risk of new landslide types (such as debris flow and slush avalanches) assessed. Models for identifying priorities should be developed and adapted to climate change.

Preventive actions (e.g. removing material, soil treatment, subdrainage, soil replacement, benching, counter fills, constraining structures, or relocating the road) need to be reviewed and updated.

In this field, there is also a need to *improve the knowledge base*, by developing functional databases for landslide data on a national basis, and improving registration of landslide and avalanche events in day-to-day operations.

Road structure and pavements

Road pavements may be exposed to higher temperatures or difficult conditions relating to friction during temperatures around 0°C. Some actions that could be developed further in cooperation with construction contractors include (see 1.6.3 and 1.6.4):

- stiffer binders (but environmentally safe ones) to protect against increasing temperatures;
- asphalt design that is resilient to freeze-thaw effect and salting;
- hydrophobic pavements that reduce slipperiness in areas where the temperature is around 0°C, nights are cold, and days warm, e.g. in mountain areas; and
- hydrophobic structure treatment, which can keep the water away from the structure and reduce frost-heave problems (see 1.6.4).

Environment protection

The design and placement of sedimentation basins should be undertaken in such a way that they can also be used for the retention of flood water.

The road should be recognised as a barrier for waterways, but also for wildlife. Ensuring corridors for wildlife in new conditions in a future climate is an important part of the design.

Due to better conditions for vegetation growth, maintenance of vegetation may require more attention. The aim is to ensure good visibility. Maintenance problems can be reduced by adequate planning.

Signs and lighting

In a wilder climate, greater safety and better mobility can be achieved with good signage and lighting along the road network.

Contracts

In cases where maintenance is included in construction contracts, the contract period can be very long. It should therefore be noted that climate change may affect the contract.

The construction work itself may be affected by difficult or changing climate conditions. Risk assessment of possible dangers during construction should be carried out, including landslide, flooding, heavy rainfall, etc. Special care may be necessary in order to secure temporary structures such as temporary bypasses, scaffolding, casting, excavation etc. This is important for safety reasons.

2.3.3. Maintenance and operation

Risk assessment and risk management can be seen as tools in almost every work procedure. Therefore common principles should be established for how to use them, at least at national level. Risk assessment and management tools are required for different purposes and at different levels. In some places, there might be a need to calculate landslide risk in more detail, whereas the risk of flooding in other places may be so obvious that a plan for how to handle the situation is essential.

- Assessing risks—evaluating preventive measures compared to accepting a certain level of damage.
- Mapping vulnerable assets and prioritising risks.

Since funding is generally sparse, there is a need to locate the most vulnerable assets and to provide information that helps assign priorities. Chapter 1.5 shows an estimation of risks in each participating country. This may provide an indication of where to start the mapping of vulnerable assets (although some issues apply to almost the whole national road network, for example high temperatures).

In addition to the usual maintenance procedures and criteria, adapting to climate change requires a critical investigation of the actual capacity of the road network to withstand more severe conditions than it was designed for.

Developing guidelines for a better (climate-adapted) inventory of assets along the road network (including landslide protection) implies developing good risk and susceptibility analyses, which should contain:

- criteria for identifying especially exposed or vulnerable assets (inadequate types of structures, assets in poor condition or documented insufficient capacity);
- procedures for calculating their realistic capacity;
- plans for improved (e.g. more frequent) inspection and better maintenance procedures (e.g. proactive measures in response to an unfavourable weather forecast); and
- repair plans.

All of this should preferably form a part of planned inventories. Adaptation measures should ideally be undertaken together with planned maintenance or repairs.

Maintenance backlog

Proper maintenance, which ensures good functionality of drainage, erosion protection, etc., is a crucial part of adaptation to climate change. The level of maintenance that is practically feasible is, however, closely connected to the technical standard of the roads. Maintenance backlog is usually a problem. Eliminating the backlog and ensuring proper maintenance is at the same time adapting to climate change.

Winter operation

Winter maintenance is largely a day-to-day operation in which the operation models can be changed relatively quickly in order to suit the working environment. Planning should be done with a perspective of five to 10 years.

- In the near future there seems to be a need to refine the operation models of winter maintenance to optimise resources, working methods, and level of service for more intense snowfall, see 1.6.6.

- In Scandinavia, the use of salt will probably increase, which means that more attention must be paid to the environmental hazards of salt. This means closer monitoring of the groundwater resources and better groundwater protection. There is also a need to continue the R&D work for alternative solutions, see 1.6.6.
- Since available resources do not always allow for a good level of service, and climate change will increase the risk of incidents such as avalanches, there will be a need to improve incident management. This includes improving road-user information systems, risk assessment, traffic management, etc. Incident data can be included in in-car information, for example in GPS systems. Forecasts and risk information could also be included.

Managing risk of climate-related events: preventive measures, preparedness, and emergency plans

Since it is impossible to avoid all negative effects of climate change, it is necessary to be prepared for the consequences. Emergency plans are required to ensure operation and avoid losses. Such plans are mainly developed at regional or local level, but certain principles should be established at national level.

The main aspects of incident management are prediction models, and planning of the operation models for unexpected situations. It is also important to develop a plan for cooperation in case of emergency. All operators should know their roles and should act accordingly. Some of the most severe effects of climate change should also be rehearsed in advance.

Traffic management

Traffic management after an incident is an important tool for avoiding accidents, traffic jams, or other negative consequences for road users. This can be approached proactively by planning detour routes in the most vulnerable places.

For example, in Norway, calculations have already been used to decide which roads may be closed during the most severe winter weather. Similar calculations can be used to define other vulnerable assets and their importance to traffic.

The efficient communication of risks or danger to road users is an economical way of alleviating the consequences of incidents. Different stakeholders should work together to develop this information, especially in-car information.

Self-monitoring structures

For the most vulnerable assets it may be necessary to use more complex monitoring systems, which also utilise information collected from road users and communicate the risk.

Contractor requirements

In formulating maintenance contracts, it should be borne in mind that climate change can affect working conditions. The contracts should, therefore, state how the risk will be divided between the procurer and the contractor. A risk management tool can be used for this purpose. Climate change, or changing working conditions due to climate change, may be assessed as a risk. It is often necessary to reconsider and redefine the *unexpected* conditions, which do not have to be covered by the contractor, as opposed to the *standard* conditions, which form the basis of a contract.

Although the contractor is obliged to respond to standard conditions only, an alternative operation model, and an emergency plan for unexpected situations (i.e. situations requiring more equipment than is available) must be provided.

In some cases, maintenance contracts include inspection. A harsher climate will require more frequent and more detailed inspections, especially if the road is not designed to withstand today's climate. Special attention should be given to the climate parameters that are expected to have a greater effect in a changed climate.

2.4. The knowledge base for adaptation to climate change

All aspects of adaptation and all actions described in 2.3 are dependent on a good knowledge base, not only with respect to the road administrations' fields of work, but also from other professional fields, especially meteorology, hydrology, and geology. Although substantial research in these fields is undertaken, the results are not always suitable for practical application before they have been interpreted and adapted. The most important parameters are: rain intensity, projections of flood values, wind, storm frequency, and sea-level rise.

Developing a better knowledge base requires better monitoring of climate parameters. Some measurements are conducted by road administrations themselves, but coordination with other providers of data is necessary. In addition, good interface solutions are essential, such as web portals for weather and road data. Specific topics for development and innovation are, for example:

- better measurements of winds, short-term precipitation, flood levels and frequency;
- improving maps and GIS databases: flood maps, landslide risk maps, precipitation maps; and
- databases for landslide events and other disruptive events on the road network.

Furthermore, better knowledge about the costs of climate change and the costs and benefits of various adaptation measures is needed.

2.5. Topics for research

Research to gain better knowledge about the effects of climate and climate change

- climate and landslides, avalanches, 'wet' landslide types;
- effects of unfavourable combinations of weather parameters: e.g. intensive rainfall on frozen ground, including snowmelt. In addition, combined effects of sea-level rise, storm surge and coastal waves;
- better models for simulating the effects of climate on pavements and road sub-bases; and
- integrating regional climate and hydrological models.

Developing improved specifications

- risk-based functionality specifications; and
- criteria for defining acceptable risk levels (should be discussed nationally).

Coordination of research and education activities

- dissemination, knowledge transfer, and implementation of research results;
- coordination of research programmes, trans-European joint programming;
- better collaboration between on-going research projects;
- raising awareness among the general public and politicians; and
- ensuring that academic education includes adaptation issues.

2.6. No-regret actions

Regardless of the national administrative and climatic differences, there are some beneficial actions that can be carried out immediately.

Maintenance backlog

One certain no-regret action, however resource-intensive, is to clear the backlog of accumulated insufficient maintenance and repairs. The maintenance backlog and keeping up with planned maintenance is a challenge for almost all road networks. However, it is a crucial element in adaptation to climate change. The maintenance backlog increases vulnerability to climate effects, which in turn further increases damage and the need for repairs.

Improving the knowledge base

Collaboration with research environments in meteorology, hydrology, geology, etc., and communication of needs are important preconditions for reducing uncertainties in the future, see 2.4 and 2.5.

Improving the recording of weather-related events on the road network, documentation of maintenance or repairs undertaken, and data on 'small' assets such as culverts (which may be very important assets in a more demanding climate) will provide the NRAs with a better starting point for climate adaptation.

Improving preparedness

The climate as it is now can be very demanding. Better preparedness can prevent the loss of life and reduce damage and costs today.

Review of contracts

Maintenance contracts which include better information about risks, improved monitoring, inventory plans, and emergency plans are beneficial for management, both today and in the future climate.

3. Comparison of the ways forward

The challenges road networks face in a more demanding climate have been described through the effects of the main climate parameters (1.6), risk management (1.7), and costs (1.8), and with regard to working procedures (1.9). In Chapter 2 some adaptation measures within planning, design, construction, maintenance operations, and knowledge building have been suggested. In this chapter, some principal criteria for choosing and prioritising adaptation measures are described.

Managing uncertainty

Climate projections will always be uncertain. Some parameters are more uncertain than others, depending on the quality of the models and the quality of the measured data. Climate change projections also evolve; the process is continuous. Monitoring and regular updating of climate scenarios are, therefore, essential.

The task group advises the NRAs to act now, despite uncertainties in climate projections. The knowledge currently available is sufficient for the formulation of adaptation measures. However, these measures must be chosen rationally. Throughout the *service life* of a structure, *adequate* safety must be achieved for the *available* resources.

Required safety levels (or corresponding levels of acceptable risk) are difficult to define in general terms. However, a required safety level can and should be recognised in each particular case and should be part of the basis for making decisions concerning adaptation measures.

Some principles when making decisions concerning adaptation measures

These considerations will help in deciding what should be done first, what *can* wait, and what *should* wait:

- The design life of a new structure (or the remaining design life of an existing structure being assessed) must be seen in relation to the time aspect of climate change. It is not necessary to take into account climate aspects that will not be fully developed during the service life of a structure.
- The time aspect should always be seen in relation to the projected development in the most *detrimental* climate parameter: e.g. precipitation intensity for drainage capacity, sea-level rise for planning of sub-sea tunnels, etc. See Fig. 4.

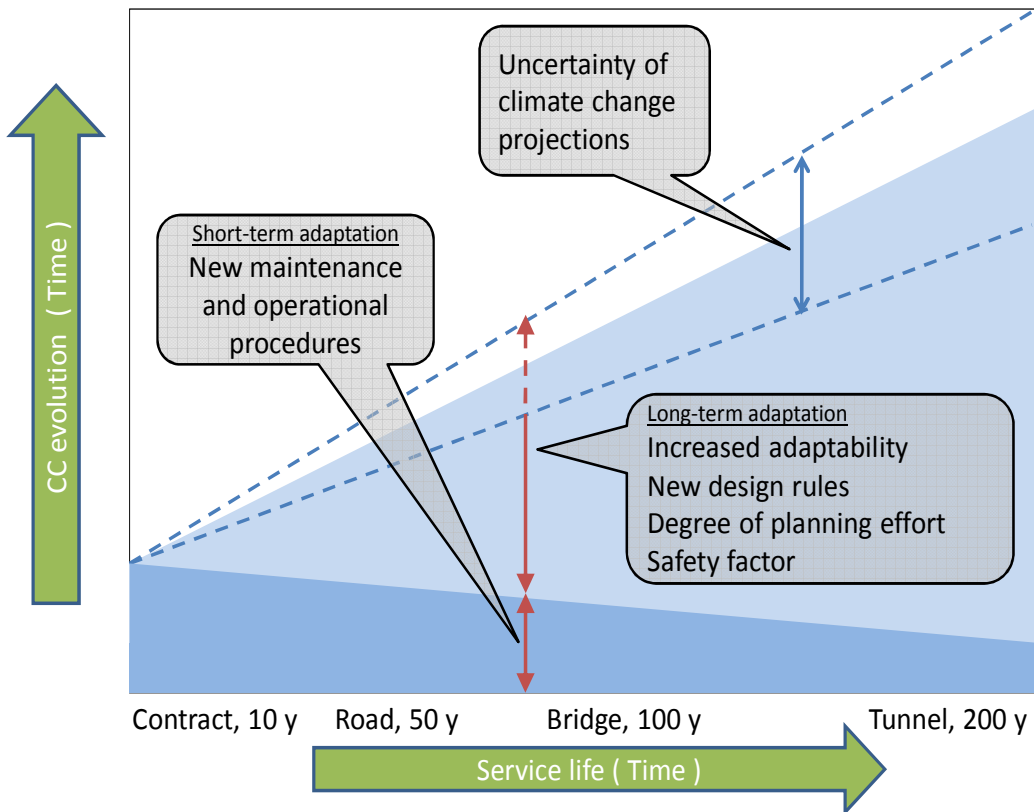


Fig. 4: Service life, climate change evolution, and short-term and long-term adaptation measures for maintaining the acceptable risk level

This idealised figure suggests how the service life of the particular object sets the criteria for the choice of adaptation strategy. Adaptation actions are seen as a combination of short-term and long-term measures. In the short term, adaptation can partly be dealt with through refined maintenance and operational procedures. In contrast, long-term adaptation needs to consider planning and design guidelines, safety factors, and other long-lasting measures that take account of the uncertainty of climate change projections.

Both the vertical and horizontal axes indicate time in the future. The vertical axis indicates magnitude of climate change developing with time. The horizontal axis indicates the planned service life of particular infrastructure objects or investment. As an example, at the far left of the horizontal axis, the apparent climate changes are small and the adaptation can often be handled through intensified maintenance. Hence maintenance contracts need to reflect this. On the other hand, in the case of new bridges, changes in the climate have become significant during the lifetime of the investment and the initial design must take into account the anticipated climate changes and uncertainties. A more robust design will ideally require less effort on the maintenance side, as the figure suggests.

For existing structures it is preferable to undertake adaptation measures as part of planned maintenance or repairs. When carrying out repairs, the measures should be designed on the basis of values that will be valid for the remaining service life of the structure.

- In some cases it may be better to accept a certain level of damage (and cost of repairs) than to avoid damage altogether. Cost-benefit analyses provide a good basis for decisions.
- If the acceptable level of disturbance has already been exceeded, it is not possible to wait. In addition, waiting is advisable only if it is followed up by monitoring of the condition of the structure and the development of the most important climate factors, or 'loads'. Good monitoring of climate parameters, documentation of the condition of assets, and registration of weather-related events on the road network improve the knowledge base for adaptation 20 or 30 years from now and ensure more reliable adaptation measures in the future.
- In formulating contracts for maintenance and operation, it may be difficult to define the 'normal' or *standard* situation. This increases the importance of deciding how risks and consequences of unfavourable weather will be divided between the authority and the contractor. Where there is a lack of up-to-date databases, the best practice is to have good contact with experts in meteorology and hydrology and improve the basis for decisions in each case.
- Experience from completed contracts should benefit new contracts. Undertaking the most necessary road repairs before a contract period provides better possibilities for good maintenance. Climate change makes this even more important!

4. Conclusions

The task group highlights the following effects of climate change as being the most important ones to address:

- flood and erosion;
- landslide, rockfall, and avalanches;
- droughts and high temperatures;
- effects leading to increased deterioration of roads;
- effects of sea-level rise;
- effects on winter conditions;
- risk assessment and management; and
- calculation of costs.

All implications of climate change should be addressed at the earliest possible stage.

Planning

- The alignment of roads (elevation at a flood-safe height, horizontal alignment), avoiding potential landslide risk, exposure to drifting snow and wind, etc.
- Holistic approach to management of run-off water (retention and sedimentation basins, good risk assessment concerning crossing waterways, and possible sediment transport)
- Consideration of the implications for maintenance

Design and construction

- Ensuring sufficient drainage capacity and erosion protection
- Revising design guidelines for adaptation to higher climate loads
- Developing models for more analytical risk assessment from landslides, not dependent on history
- Designing robust pavements, also resistant to high temperatures
- Managing environmental issues: pollution control, fauna, etc.
- Considering the implications of road design on maintenance
- Managing climate issues in construction contracts

Maintenance and operation

- Risk assessment in all phases, at all levels: identifying the most vulnerable assets according to predicted climate change, mitigating damage, prioritising needs
- Risk management related to weather-related events: preventive measures following forecast, preparedness, and emergency plans for managing situations after weather-related events;
- Dealing with maintenance backlogs, which are a drawback for adaptation and road management in general
- Preparing for more demanding conditions for winter operation: good contracts, emergency plans, etc.
- Traffic management, communication of risks from weather-related events and re-routing, use of good monitoring systems for traffic control

- Improving contracts: better to define the standard as opposed to the exceptional condition, define methods for sharing risk, set robust requirements for inspection routines and documentation

Improving knowledge

- Developing the knowledge base for adaptation: monitoring, mapping, and documentation of weather-related events
- Research: coordination of on-going work, more knowledge of the effects of climate change on the road network, developing ways of defining acceptable risk and risk-based specifications; and
- Raising awareness among stakeholders and the general public about the importance of adaptation.

Prioritising

Adaptation to climate change should begin during the planning phase of a road project and should be included in all other working procedures. For existing infrastructure, adaptation measures should be carried out as part of planned maintenance or repairs. The measures must be selected to ensure that adequate safety is achieved during the (remaining) service life of the structure. Postponing action is advisable only if it is followed up by monitoring of the condition of the structure and the development of the most significant climate factors. In some cases, accepting damage and the costs of repairs may be the best solution.

However, defining the *acceptable* level of risk is a difficult task. It is also difficult to define the standard or 'normal' climate applicable to the service life of a structure or for the duration of a maintenance contract. This accentuates the need for good contact with experts in meteorology and hydrology and for good contracts for maintenance and operation.

Appendix 1 Risks related to climate change

Appendix 2 Survey of on-going work on adaptation to climate change

Appendix 3 Examples of adaptation work and good practice relevant to adaptation to climate change

Appendix 1

Risks related to climate change



Norway

High temperatures

Probability 3

Severity of the risk 1

Only inland roads, during warm summers.

Is there a strategy for dealing with the problem?

NPRA guidelines require the use of a stiffer binder in pavements exposed to high temperatures.

Research need

Not a top priority.

±0 temperatures

Probability 3

Severity of the risk (Uncertain)

Is there a strategy for dealing with the problem?

Road deterioration:

General strategies for frost heave reduction in NPRA guidelines.

Friction:

Use of de-icing salt, standard for winter maintenance.

Actions taken

Road deterioration:

Restrictions for material composition.

Friction:

Improved guidelines for contractors responsible for operation, new winter maintenance standards. Improved salting strategies.

Data collection

Friction:

Data on actual use of road de-icing salt.

Research need

Road deterioration:

Mapping the movement of the ±0 isotherm.

Improvement of the modelling of deterioration caused by weather factors for better estimation of costs.

Friction:

Rain on snow and frozen ground—calculation of run-off.

Possibly: effect on rockfall (difficult to determine)

Wind

Probability 1

Severity of the risk (Uncertain)

Is there a strategy for dealing with the problem?

Emergency planning.

Actions taken

Improved emergency plans.

Data collection

Traffic safety measures, especially for bridges or mountain roads.

Research need

Design loads?

Storms

Probability 1

Severity of the risk (Uncertain)

Is there a strategy for dealing with the problem?

Emergency planning.

Actions taken

Improved emergency plans with better use of weather data. Proactive maintenance: action taken on the basis of weather forecast, i.e. before the storm.

Research need

Threshold values for precipitation.

Rain intensity

Probability 3

Severity of the risk 3

Insufficient drainage and erosion protection, effects on debris slides.

Actions taken

Improved guidelines for erosion construction and inspection.

Data collection

Improved registration of events, inspection data.

Probability
(3= verifiable risk, 2=probable risk, 1=slight probability, 0=improbable)

Severity of the risk
(3= extremely severe, 2=severe, 1=less severe, 0=not relevant)

Increased flow rate in rivers

Probability 2

Severity of the risk 2

Damage to bridges and culverts

Actions taken

Improved guidelines for erosion construction and inspection.

Data collection

Improved registration of weather-related events, inspection data are necessary.

Floods

Probability 3

Severity of the risk 2

Damages to roads, culverts, foundations. Bridge failure.

Is there a strategy for dealing with the problem?

- * Risk and susceptibility analyses
- * Inspection routines

Both are under development for better adaptation to a more severe climate.

Actions taken

Development of routines for risk and susceptibility analyses for bridges (focus on erosion protection and foundations). Improved inspection routines.

Data collection

The Water Resources and Energy Directorate is developing maps of flood areas (not complete).

Many gaps in flood frequency analyses, although data is collected.

Effort put into better accessibility of bridge data.

Research need

Better flood projections.
Better projections of intense rainfall.
In addition: development of engineering methods for avoiding floods: e.g. retention ponds.

Drought

Probability 1

Severity of the risk 1

Actions taken

Increased maintenance - dust control.

Research need

Mapping of areas that might need attention.

Landslides

Probability 2

Severity of the risk 2

Is there a strategy for dealing with the problem?

Regional plans for landslide protection, model for decision-making in terms of priorities.
Preparedness and emergency systems.

Actions taken

Development of landslide and avalanche risk model.

Development of better tools for predicting landslides (cooperation with Water Resources and Energy Directorate and Meteorological Institute).

Data collection

Hazard mapping, better registration of events.

Also, coordination of various databases, development of a national database, www.skrednett.no

Research need

Better understanding of where and when landslides occur, hazard mapping.

Better use of weather data for better prediction of landslides.

Avalanches

Probability 2

Severity of the risk 2

Is there a strategy for dealing with the problem?

Regional plans for avalanche protection, model for decision-making in terms of priorities.

Preparedness and emergency systems.

Actions taken

Development of landslide and avalanche risk model.

Development of better tools for predicting avalanches and avalanche alert systems (cooperation with Water Resources and Energy Directorate and Meteorological Institute).

Probability

(3= verifiable risk, 2=probable risk, 1=slight probability, 0=improbable)

Severity of the risk

(3= extremely severe, 2=severe, 1=less severe, 0=not relevant)

Data collection

Better registration of events.
 Also, coordination of various databases, development of a national database, www.skrednett.no

Research need

Better understanding of where and when avalanches occur, hazard mapping.

Better use of weather data for better prediction of avalanches.

Data collection

At national level, the need for a formal authority responsible for mapping development and future projections is recognised.

Research need

Better predictions of sea-level rise and storm surge—ways of defining critical height requirements in guidelines.

Better design of wave erosion protection.

Snowfall intensity

Probability 3

Severity of the risk 2

Is there a strategy for dealing with the problem?

Higher risk of avalanches:
 Not specifically considered.

Traffic safety issue:
 Emergency planning.
 Winter operation.

Actions taken

Higher risk of avalanches:
 Development of landslide and avalanche risk model.

Traffic safety issue:
 Improved emergency plans with better use of weather data.

New design guidelines for roads exposed to drifting snow.
 Traffic safety measures.



Finland

High temperatures

Probability 2

Not actually high temperatures but higher temperatures.

Severity of the risk 1

Frost heave damage increases and becomes more complex and more frequent, surface frost heave problems occur on a year-round basis, pavements wear more rapidly.

Actions taken

More money has been allocated for frost heave repairs.

Data collection

Finnish Meteorological Institute (FMI) collects meteorological data.
 Data collection from road weather system (RWS) frost heave, gravel road condition.

Research need

Effect on pavement condition (high temperatures are not critical in Finland but increased winter temperatures are). Surface frost-heave studies

Sea-level change

Probability 3

Predictions of level are uncertain.

Severity of the risk 2

or 3, towards 2100.

Is there a strategy for dealing with the problem?

The situation around several particularly exposed structures, including sub-sea tunnels, is being studied.

Actions taken

Requirements for height/level of structures and design rules for protection from wave erosion are under development.

Probability
(3= verifiable risk, 2=probable risk, 1=slight probability, 0=improbable)

Severity of the risk
(3= extremely severe, 2=severe, 1=less severe, 0=not relevant)

±0 temperatures

Probability 3

Severity of the risk 2

Affects maintenance and its costs.

Actions taken

Winter maintenance guidelines. Costs to secure the level of service have been estimated

Data collection

FMI network and Traffic Administration RWS.

Research need

Effect on pavement condition (critical).

Wind

Probability 2

Severity of the risk 2

Fallen trees block roads, snow drifting.

Data collection

FMI collects meteorological data.

Storms

Probability 1

Severity of the risk 2

Fallen trees block roads, snow drifting.

Data collection

FMI collects meteorological data.

Rain intensity

Probability 2

Proven, although intensity does not increase greatly, there is more frequent incidence of heavy rain.

Severity of the risk 2

Drainage problems more frequent, blocking of roads and lanes, damage to gravel road structures.

Data collection

FMI collects meteorological data.

Research need

Design standards for drainage should be reviewed, information needed.

Increased flow rate in rivers

Probability 2

Severity of the risk 2

Damage to bridges and culverts.

Floods

Probability 2

Although also probable without climate change.

Severity of the risk 2

Blocks and damage to roads, bridge condition, culverts.

Data collection

Flood areas are being mapped.

Research need

On-going research of flood areas.

Drought

Probability 1

Severity of the risk 1

Increased maintenance costs on gravel roads, subsidence of structures.)

Actions taken

Gravel road maintenance guidelines.

Data collection

Inventories of dusting from gravel roads are a part of quality monitoring in maintenance contracts.

Landslides

Probability 1

In certain areas, but risk is not necessarily increasing due to climate change.

Severity of the risk 3

Damage to roads and other structures, probably no increase in safety risks.

Avalanches

Probability 1

Severity of the risk 1

Snowfall intensity

Probability 3

More frequent heavy snow.

Severity of the risk 2

Traffic incidents more frequent.

Is there a strategy for dealing with the problem?

Incident management policy.

Actions taken

Incident management. Also included in winter maintenance (guidelines).

Data collection

Weather data, maintenance quality reporting.

Severity of the risk 2

Loss of frozen soil or permafrost as an important load-bearing capacity factor in northern Sweden, affects maintenance and maintenance costs.

Data collection

Data collection from road weather system and frost heave system.

Research need

See previous answer.
Effect on pavement condition.

Sea-level change

Probability 1

Severity of the risk 0

Actions taken

A 'Flood risk task group' in Finland has proposed that the 'lowest recommended building levels' from 1998 be revised according to latest knowledge.

Data collection

Finnish Environment Institute
Finnish Meteorological Institute Marine Weather

Wind

Probability 1

The regional scenarios from the Swedish Meteorological and Hydrological Institute do not indicate any obvious change in wind.

Severity of the risk 2

Storms

Probability Uncertain

Severity of the risk Uncertain



Sweden

High temperatures

Probability 2

Higher temperatures.

Severity of the risk 2

Loss of frozen soil or permafrost as an important load-bearing capacity factor in northern Sweden.

Data collection

Data collection from road weather system and frost heave system.

Research need

A socio-economic study concerning what model to use in the future: strengthen the roads, repair them afterwards, or not allow heavy traffic during the winter.

Rain intensity

Probability 3

Severity of the risk 3

Actions taken

Publication VVMB 310 *Hydraulisk dimensionering* (Hydraulic dimensioning (in Swedish)) includes a map of Sweden with values of a coefficient for calculating the values of runoff water.

Data collection

Data collection from road weather system.

Increased flow rate in rivers

Probability 2

Depends on which part of Sweden is under consideration.

Severity of the risk 2

±0 temperatures

Probability 3

Varies across the country. In the north, temperatures around 0 will occur more often than they do today. In the south they may occur less.

Probability
(3= verifiable risk, 2=probable risk, 1=slight probability, 0=improbable)

Severity of the risk
(3= extremely severe, 2=severe, 1=less severe, 0=not relevant)

Actions taken

Publication VVMB 310 *Hydraulisk dimensionering* (Hydraulic dimensioning (in Swedish)) includes a map of Sweden with values of a coefficient for calculating the values of runoff water.

Data collection

Bridge database (BaTMan) contains value for height over maximum flow rate (50-year value).

Research need

Floods

Probability 3

Severity of the risk 2

Data collection

Flood areas are being mapped on a national basis.

Research need

On-going production of new elevation data (laser scanning). On this basis, better flooding maps can be produced.

Drought

Probability 1

South-eastern parts of the country.

Severity of the risk 1

Landslides

Probability 3

Severity of the risk 3

Actions taken

A map of Sweden showing change in probability of landslides caused by climate change.

Research need

Inventory of quick clay location, which should then be related to changes in probability of landslides caused by climate change.

Avalanches

Probability 1

Severity of the risk 1

Snowfall intensity

Probability 1

Severity of the risk 2

Data collection

Data collection from road weather system.

Sea-level change

Probability 2

Severity of the risk 2

Research need

Localisation of low-lying ferry berths, tunnels, and road stretches, in comparison with sea level.



Denmark

High temperatures

Probability 2

Severity of the risk 2

Road deterioration.

±0 temperatures

Probability 1

A lower frequency of ±0 temperatures is expected.

Severity of the risk 1

Wind

Probability 2

Severity of the risk 1

Is there a strategy for dealing with the problem?

Strategy for all major bridges.

Actions taken

Improved emergency plans. Warning by ITS.

Storms

Probability 2

Severity of the risk 2

Is there a strategy for dealing with the problem?

Strategy for all major bridges.

Actions taken
Improved emergency plans. Warning by ITS.

Rain intensity

Probability 3

Severity of the risk 2

Actions taken
Use of drainage asphalt in risk areas (Blue Spots).
Improved emergency plans. Warning by ITS.

Research need
Better forecast of precipitation intensity and the location of the incident.

Increased flow rate in rivers

Probability 2

Severity of the risk 1

Actions taken
Mapping of risk areas (Blue Spot mapping), improved emergency plans.
Warning by ITS.

Floods

Probability 2

Severity of the risk 2

Actions taken
Mapping of risk areas (Blue Spot mapping).
Improved emergency plans.
Warning by ITS.

Drought

Probability 2

Severity of the risk 1

Landslides

Probability 0

Severity of the risk 0

Avalanches

Probability 0

Severity of the risk 0

Snowfall intensity

Probability 1

No increase in snowfall is expected.

Severity of the risk 1

Sea-level change

Probability 2

Severity of the risk 2

Is there a strategy for dealing with the problem?
Strategy for all sub-sea tunnels.

Actions taken
The entrances have been built above the expected sea level for the next 100 years.



United Kingdom

High temperatures

Probability 3

Severity of the risk 1

Is there a strategy for dealing with the problem?

Pavement design specification caters for predicted higher temperatures due to climate change.

Life expectancy of the temperature-vulnerable pavement means major maintenance should keep pace with climate change.

Actions taken
Addition of (French) pavement specification *Enrobé à Module Élevé* (EME2) asphalt capable of withstanding 60°C surface temperature.

±0 temperatures

Probability 1

Severity of the risk 0

Is there a strategy for dealing with the problem?
Full programme in place to manage winter resilience, recognising the variability of the UK climate.

Climate change predictions suggest wetter warmer winters.

Probability

(3= verifiable risk, 2=probable risk, 1=slight probability, 0=improbable)

Severity of the risk

(3= extremely severe, 2=severe, 1=less severe, 0=not relevant)



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Actions taken

Availability of a strategic salt reserve.

Most modern and high-specification winter vehicle fleet.

Winter driving advice to UK drivers.

Wind

Probability 1

Severity of the risk 1

Is there a strategy for dealing with the problem?

Forecasting of weather conditions is conducted by the Meteorological Office (Met Office) supplemented by actual wind speeds from weather stations mounted on exposed bridges.

Actions taken

Specific advice is given to drivers of heavy goods vehicles (HGVs).

Effective channels of communication exist with the freight and logistics industries.

Electronic pictogram signs are understood by foreign HGV drivers.

Data collection

Anemometer readings are monitored at Highways Agency control centres.

Storms

Probability 2

Severity of the risk 2

Is there a strategy for dealing with the problem?

Highway design standards and specifications allow for extreme events e.g. 100-year events.

With climate change, extreme events may become more frequent.

Actions taken

Greater frequency does not necessarily mean greater impact and may not even mean greater risk.

Conversely, however, what was once a 500-year event may become a more frequent, 100-year event, requiring revised standards and specifications.

Rain intensity

Probability 3

Severity of the risk 2

Is there a strategy for dealing with the problem?

UK climate change predictions (precipitation) were applied to historical data on rain intensity and drainage carrying capacity. Road drainage is a long-life asset which warrants earlier intervention at the design stage.

Actions taken

Road drainage standards were updated in 2006 adding up to 20% to the carrying capacity of the drainage system. New motorway management systems, signage, and signalling allow information, including driving conditions, temporary speed limits, and lane closure, to be shown to live traffic in real time.

Data collection

Drainage database system allows entry of flooding incidents, duration and cause to be recorded by asset service providers.

Increased flow rate in rivers

Probability 3

Severity of the risk 1

Is there a strategy for dealing with the problem?

Structural assessments of bridge scour risk.

Actions taken

Highways Agency to devise a new method for assessing future flood risk, including scour.

Floods

Probability 3

Severity of the risk 2

Is there a strategy for dealing with the problem?

For the construction of new road schemes, the drainage design takes into account the predicted increase in flooding.

Drought

Probability	2
Severity of the risk	1

Landslides

Probability	1
Severity of the risk	0

Avalanches

Probability	0
Severity of the risk	0

Snowfall intensity

Probability	1
Severity of the risk	1

Is there a strategy for dealing with the problem?
As above, full programme in place to manage winter resilience.

Actions taken
Strategic salt reserve.

Sea-level change

Probability	2
Severity of the risk	1

Is there a strategy for dealing with the problem?
Few of England's trunk roads are in very vulnerable coastal locations.

Actions taken
Awareness raised.



High temperatures

Probability	2
Severity of the risk	1

The average temperature during the period 2021–2060 will be 1–1.5°C higher compared to 1961–2000.

While the temperature will increase, it will not lead to intolerable temperatures, due to Ireland's low base temperature.

±0 temperatures

Probability	1
--------------------	----------

No scientific basis apparent, but 2010 led to very low temperatures during Nov/Dec and a couple of instances of snowfall which resulted in major traffic problems countrywide.

Severity of the risk	2
-----------------------------	----------

Is there a strategy for dealing with the problem?

Improved measures for ensuring preparation for low-temperature events. Salt ordering originally through individual local authorities but now centrally through NRA. Emergency response group established (NRA, airports, rail, Met etc.) to ensure any severe weather alerts are prepared for and managed properly.

Actions taken
As per strategy.

Wind

Probability	1
Severity of the risk	1

Storms

Probability	1
Severity of the risk	1

Rain intensity

Probability	3
--------------------	----------

Rainfall is expected to increase in winter by about 15% and summer projections range from no change to a 20% decrease. Extreme rainfall events are predicted to increase especially in autumn, with a 20% increase in two-day amounts.

Severity of the risk	2
-----------------------------	----------

Is there a strategy for dealing with the problem?
As per flood.

Actions taken
As per flood.

Data collection
As per flood.

Probability

(3= verifiable risk, 2=probable risk, 1=slight probability, 0=improbable)

Severity of the risk

(3= extremely severe, 2=severe, 1=less severe, 0=not relevant)



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Research need

As per flood.

Increased flow rate in rivers

Probability	1
--------------------	----------

Severity of the risk	1
-----------------------------	----------

Floods

Probability	3
--------------------	----------

2050: winter rainfall +10%, summer rainfall -12 to -17%.

2080: winter rainfall +11% to +17%, summer rainfall -14% to -25%.

Lengthier rainfall events in winter and more intense rainfall in summer (Sweeney et al 2007).

Severity of the risk	2
-----------------------------	----------

Is there a strategy for dealing with the problem?

Yes, in relation to design, where design standards for new roads indicate that rainfall intensities used in the design of drainage systems be increased by 20%, in order to allow for the future effects of climate change. In relation to maintenance, the approach tends to be reactive and temporary in nature rather than proactive.

Actions taken

Change to the drainage design standards for new roads and a move towards more sustainable drainage systems. Improved spatial planning at local authority level.

Data collection

Data collection undertaken by local authorities.

Research need

Research programmes are on-going in relation to:

- analysis and development of road drainage systems;
- impacts of river crossings; and
- impact of road drainage on groundwater.

No new research need.

Drought

Probability	1
--------------------	----------

Severity of the risk	0
-----------------------------	----------

Is there a strategy for dealing with the problem?

Independent water supply for new housing schemes (not roads-related).

Education on water consumption and water-metering.

Research need

Effect on groundwater of climate change (not roads-related).

Landslides

Probability	1
--------------------	----------

Severity of the risk	2
-----------------------------	----------

Avalanches

Probability	0
--------------------	----------

Severity of the risk	0
-----------------------------	----------

Snowfall intensity

Probability	0
--------------------	----------

Severity of the risk	0
-----------------------------	----------

Sea-level change

Probability	1
--------------------	----------

Severity of the risk	1
-----------------------------	----------



France

High temperatures

Probability	3
--------------------	----------

More frequent, long, and intense heat-waves.

Severity of the risk	1
-----------------------------	----------

Damage to road surface coating during the extended heat-waves and drought.

Is there a strategy for dealing with the problem?

Yes, a national plan for adaptation to climate change (PNACC) (2011–2015), including a dedicated plan for the transport network and infrastructure (see Appendix 3).

Actions taken

1. Inventory and adaptation of technical guidelines for construction, maintenance, and exploitation of transport network.

2. Climate change impact on transport demand and adjustment of services provided.

3. Development of a methodology to analyse vulnerability of transport network.

Data collection

Météo-France
Institut Pierre Simon Laplace (IPSL)
National observatory of climate change effects
(ONERC)

Research need

Study the behaviour of materials subjected to climate change, especially regarding effect of temperature and moisture cycles; freeze/thaw, moist/dry, etc.

±0 temperatures

Probability 2

Fewer days with frost. Less frequent cold spells, increase in the number of freeze/thaw cycles on the roads, causing the structure to become more brittle.

Severity of the risk 1/2

- 1
Frequency of slippery roads, winter maintenance of roads might be reduced.
- 2
In mountainous areas, risk is associated with the thaw of the periglacial area (mud flow). The risk level depends on local constraints.

Is there a strategy for dealing with the problem?
PNACC 2011–2015.

Actions taken

Observation of the cryosphere.

Data collection

Météo-France
Institut Pierre Simon Laplace (IPSL)
National observatory of climate change effects
(ONERC)

Research need

Study the behaviour of materials subjected to climate change, especially regarding effect of temperature and moisture cycles; freeze/thaw, moist/dry, etc.

Knowledge of the effect of thawing in the periglacial area.

Wind

Probability 1

Severity of the risk 1

Fallen trees blocking roads and risks for bridges.

Is there a strategy for dealing with the problem?

PNACC 2011–2015.

Data collection

Météo-France.

Storms

Probability 1

Mostly on the Atlantic coast, the English Channel, and north-western France.

There was no significant trend in storm intensity between 1950 and 2000.

Variability is expected to increase, thus extreme events such as storms will increase in frequency

Severity of the risk 2

Risk for roadside equipment, fallen trees blocking roads. Tropical areas overseas: risks from cyclones.

Is there a strategy for dealing with the problem?

PNACC 2011–2015.

Identified as a major risk.

Data collection

Météo-France
Institut Pierre Simon Laplace (IPSL)

Rain intensity

Probability 2

Increased frequency of heavy rain.
Heavier rain during winter on the Atlantic front; less rain during summer in the south (especially in Mediterranean areas).

Severity of the risk 1

Recharge of rivers and aquifers.

Is there a strategy for dealing with the problem?

PNACC 2011–2015.

Data collection

Météo-France
<http://pluiesextremes.meteo.fr/>
Institut Pierre Simon Laplace (IPSL)

Increased flow rate in rivers

Probability 1

In general, the mean flow rate in rivers will fall, especially in the summer and autumn.

Probability

(3= verifiable risk, 2=probable risk, 1=slight probability, 0=improbable)

Severity of the risk

(3= extremely severe, 2=severe, 1=less severe, 0=not relevant)



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More frequent and severe low water.
Increase of river flow rate in winter in the Alps and south-eastern France.

Severity of the risk 2

Flash floods.
Landslides.
Undermining.

Is there a strategy for dealing with the problem?

PNACC 2011-2015.

Identified as a major risk.

'Plan submersions rapides' (Flash flooding response plan), 2010, Ministry of Ecology, Sustainable Development, Transport, and Housing.

Actions taken

Integration of adaptation to climate change into the transposition of the Floods Directive; mapping of flood risk in coastal and flooded territories in 2013.

Data collection

Météo-France

Centre de géosciences, MINES ParisTech: development of hydro-meteorological model, use of the Safran-Isba-Modcou (SIM) chain.

Research need

Dealing with effects of climate change on hydrology, various research projects provide data: RexHYSS, CYPRIM, IMAGINE2030, CLIMSEC, EXPLORE2070.

Floods

Probability 2

Flash flooding could be as great as or even greater than current levels in Mediterranean areas.

Severity of the risk 2

In Mediterranean areas.
Glacial lake outburst flood.

Is there a strategy for dealing with the problem?

PNACC 2011–2015.

Actions taken

Pilot studies of the impact of climate change on flood risk management.

Data collection

Central Service for Hydrometeorology and Flood Forecasting Support (Service central d'hydrométéorologie et d'appui à la prévision des inondations, SCHAPI).

Ministry of Ecology, Sustainable Development Transport and Housing.

Drought

Probability 3

High levels of evaporation and reduction in rain and snow would lead to a greater and more rapid drying of the soil and diminished groundwater recharge.

Severity of the risk 3

Lower groundwater levels -> soil/clay expansion, stability concerns for certain structures.
Risk of wildfires.

Is there a strategy for dealing with the problem?

PNACC 2011–2015.

Data collection

Bureau de Recherches Géologiques et Minières (BRGM), <http://www.argiles.fr/>

Research need

Study the behaviour of materials subjected to climate change, especially regarding effect of temperature and moisture cycles; freeze/thaw, moist/dry, etc.

Landslides

Probability 1**Severity of the risk** 2**Is there a strategy for dealing with the problem?**

PNACC 2011–2015.
Identified as a major risk.

Actions taken

Monitoring of larger sites.

Data collection

BRGM, <http://www.bdmvt.net/>

Avalanches

Probability 1

Two hypotheses are put forward: a large number of slush avalanches and a reduction in the number of avalanches at low and middle altitudes.

Severity of the risk 1

Is there a strategy for dealing with the problem?
PNACC 2011–2015, identified as a major risk.

Data collection
Cemagref <http://www.avalanches.fr>
Météo-France, Pôle Grenoblois Risques Naturels

Snowfall intensity

Probability 2

Modification of tourism services in mountainous areas. Recharge of glacier and water supply during summer.

Severity of the risk 2

Is there a strategy for dealing with the problem?
PNACC 2011–2015.

Data collection
Météo-France.
Institut Pierre Simon Laplace (IPSL)

Sea-level change

Probability 3

Severity of the risk 2

Erosion of roads in coastal areas. 864 coastal cities affected by sea level rise (590,000 ha).

Is there a strategy for dealing with the problem?
Yes, PNACC (2011–2015).

'Plan submersions rapides' (Flash flooding response plan), 2010, Ministry of Ecology, Sustainable Development, Transport, and Housing.

Actions taken

29 risk protection plans dealing with coastal erosion have been approved.
46 risk protection plans dealing with sea level rise have been approved.

Integration of adaptation to climate change into the transposition of the Floods Directive; mapping of flood risks for coastal and flooded territories in 2013.

Data collection

Météo-France
GIEC - Les experts du Groupe intergouvernemental sur l'évolution du climat (Expert Group on Climate Change), report 2007

Ministry of Ecology, Sustainable Development, Transport, and Housing.

Research need

High-resolution modelling in order to forecast the sea-level development in coastal areas, at the Mediterranean Sea.

Assess the efficiency of natural and artificial protection.



Austria

High temperatures

Probability 2

Severity of the risk 2

±0 temperatures

Probability 3

Severity of the risk 2

Wind

Probability 1

Severity of the risk 1

Storms

Probability 1

Severity of the risk 1

Rain intensity

Probability 2

Increased flow rate in rivers

Probability 1

Severity of the risk 2

Probability

(3= verifiable risk, 2=probable risk, 1=slight probability, 0=improbable)

Severity of the risk

(3= extremely severe, 2=severe, 1=less severe, 0=not relevant)



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Floods

Probability 3

Severity of the risk 2

Is there a strategy for dealing with the problem?

Flood risk mapping and follow-up measurements.

Drought

Probability 3

Severity of the risk 2

Actions taken

Use of drought-resistant vegetation on slopes.

Landslides

Probability 2

Severity of the risk 2

Avalanches

Probability 2

Severity of the risk 1

Snowfall intensity

Probability 2

Severity of the risk 3

Is there a strategy for dealing with the problem?

Further investment in snow-clearing equipment.

Data collection

Applied winter management services (snow-clearing and application of defrosting salt) is documented in a GIS based database (Leistungsorientierte Steuerung/LOS: Performance-oriented Management and Control Tool)

Sea-level change

Probability 0

Severity of the risk 0



Hungary

High temperatures

Probability 3

All assessments concluded that temperatures would be higher in each season and the number of hot days would increase.

Severity of the risk 2

The rise in temperature will be greater than the global average.

±0 temperatures

Probability -

Severity of the risk -

Wind

Probability 2

Wind speed will slightly increase in the eastern part of the country, while no significant change or a slight decrease is predicted in other parts.

Severity of the risk 1

The severity is not great in itself, but even a slight increase in wind speed may have serious effects, if precipitation is significantly higher at the same time (the frequency of this negative combination will increase in the whole country).

Storms

Probability 3

The frequency of the simultaneous occurrence of heavy rainfall and higher wind speed (which is characteristic of storms) will increase throughout the country.

Severity of the risk 2

The severity may be influenced by regional increase in wind speed.

Rain intensity

Probability 3

Average precipitation will decrease, but as rainfall events will also decrease, this will result in an increase in rain intensity throughout the country.

Severity of the risk 2

The severity may be influenced by regional increase in wind speed.

Increased flow rate in rivers

Probability 3

This may increase at times due to the increase in storms and heavy rainfall. It may also be influenced by the changes in flow rate for the whole catchment area (partially outside the country's borders).

Severity of the risk 2

Floods

Probability 3

This may increase at times due to the increase in storms and heavy rainfall. It may also be influenced by the changes in flow rate for the whole catchment area (partially outside the country's borders).

Severity of the risk 2

Drought

Probability 3

Summer precipitation will decrease, resulting in droughts, especially in southern and eastern areas of the country.

Severity of the risk 1

Landslides

Probability 2

Increasing rain intensity will probably result in more landslides.

Avalanches

Not applicable.

Snowfall intensity

Probability 3

Snowfall intensity will increase due to the increase in winter precipitation and the fall in the number of snowfall events.

Severity of the risk 2

Sea-level change

Not relevant.



Italy

High temperatures

Probability 3

According to studies by CNR-ISAC³⁵, annual average temperatures have increased in Italy over the past 50 years by about 1.4 °C.

³⁵ Istituto di Scienze dell'Atmosfera e del Clima del Consiglio Nazionale delle Ricerche (Institute of Atmospheric Sciences and Climate of the Italian National Research Council).

The time-series analysis performed by ISPRA³⁶ (1961–2008) shows an increase in temperature from 1981 to 2008 of about 1 °C. The average temperature recorded in Italy in recent decades is greater than the global average.³⁷

Severity of the risk 2

Data collection

ISAC-CNR database: Italian historical series of meteorological parameters. The database includes thermometric measurement, rain gauge, barometric pressure, and cloud cover. SINANET-SCIA: national system for collecting, processing and disseminating climatological data of environmental interest.

Research need

Effects on the road paving and joints (indirectly, maintenance costs).

±0 temperatures

Probability 2

The snowfall trend for Alpine areas is generally, though not significantly, decreasing; in the Apennines, this only applies to stations located over 900–1,000 m, while others have generally recorded an increase in the incidence of snow in particular for stations located in the south. The decline is more evident in Sardinia and Sicily³⁸.

Severity of the risk 1/2

- 1 In the Alpine areas.
- 2 In the Apennines areas.

Actions taken

'Snow Plans' have been drafted.

Data collection

Air Force Meteorological Service, Centro Nazionale di Meteorologia e Climatologia Aeronautica, CNMCA Ainea—Interregional Snow and Avalanche Association

³⁶ Istituto Superiore per la Protezione e la Ricerca Ambientale (Institute for Environmental Protection and Research).

³⁷ The average temperature increase is significant everywhere from autumn 1970 to summer 1980, while in the period 1961–2006 it is significant in the north in winter and in the centre and south in spring.

³⁸ M. Fazzini, A. Giuffrida, G. Frustaci et al (2005), *Snowfall analysis over peninsular Italy in the last 20 years: first results.*

Probability
(3= verifiable risk, 2=probable risk, 1=slight probability, 0=improbable)

Severity of the risk
(3= extremely severe, 2=severe, 1=less severe, 0=not relevant)

Wind

Probability 1

Severity of the risk 1

Storms

Probability 2

Severity of the risk 1

Data collection

Air Force Meteorological Service.

Rain intensity

Probability 2

Slight decrease in precipitation and a significant change in its timing, with a reduction in the number of rainy days, an increase in the intensity of rainfall and an increase in the maximum duration of periods without precipitation.

Continuous time series available are, however, not long enough.

Data collection

ISAC-CNR database: Italian historical series of meteorological parameters.

The database includes thermometric measurement, rain gauge, barometric pressure, and cloud cover.

Air Force Meteorological Service.

Research need

Influence on the design parameters of drainage systems and maintenance costs.

Increased flow rate in rivers

Probability -

Severity of the risk -

Data collection

ISPRA SINTAI: Information System for Water Protection in Italy—the SINTAI system is designed and maintained by the Department for the Protection of Marine and Inland Waters of ISPRA.

Research need

Influence on the design parameters.

Floods

Probability 2

Severity of the risk 2

IRPI (Research Institute for Hydrogeological Protection).

River Basin Authorities (Autorità di Bacino).

Drought

Probability 1

The phenomenon is particularly evident in the southern regions and islands, where the dryness of the soil has increased since 1900, but especially in recent decades, in terms of both the extent of the areas concerned and the intensity. The arid, semi-arid, and dry sub-humid areas, currently affect 47% of Sicily, 31.2% of Sardinia, 60% of Puglia, and 54% of Basilicata.

Severity of the risk 1

Data collection

ISPRA–SIDES Project—Desertification.

The SIDES project (an integrated information system for the monitoring, assessment, and mitigation of desertification in areas particularly affected) has as its objective the establishment of an information system for the analysis and evaluation of the different types of data and information necessary for the study of desertification.

Landslides

Probability 2

Severity of the risk 2

Data collection

IFFI—inventory of landslides in Italy: provides a detailed overview of the distribution of landslides in Italy.

IRPI (Research Institute for Hydrogeological Protection).

Avalanches

Probability -

Severity of the risk -

Snowfall intensity

Probability 2

IRPI (Research Institute for Hydrogeological Protection).

Precipitation is expected to increase by 5-25% in winter and to be increasingly characterised by rainfall rather than snow, and to decrease by about 5-40% in summer.

The high sensitivity of snow coverage to changes in temperature is likely to result in a general reduction in coverage characterised by snow melting in early spring. It is estimated that a 1-°C increase in temperature could reduce the duration of snow coverage to a few weeks, even at higher altitudes. At the same time, it will also increase the altitude at which the snow tends to occur.

Severity of the risk 2

Sea-level change

Probability 1

The Mediterranean Sea (and therefore also the Italian seas), do not have the same projected behaviour as the oceans.

Severity of the risk 1

Data collection

ISPRA—Tidal Service, National Tidal Network.



Spain ³⁹

High temperatures

Probability 3

The climate models show a tendency towards temperature increases in the Iberian Peninsula for the next century. The warming is greater in inland areas than in coastal areas and on islands.

More days with extreme maximum temperatures in the peninsula, especially in summer.

Severity of the risk 2

In certain parts of Spain, this risk will be severe in summer. It will be less severe in the north of Spain.

The mean temperature increase is higher in summer than in winter.

Data collection

The Spanish State Meteorological Agency (AEMet) collects all national meteorological data.

The Spanish General Directorate of Traffic collects meteorological data on highways and roads.

The Spanish General Directorate of Roads has meteorological stations on some roads.

Research need

Effect on pavement conditions.

±0 temperatures

Probability 2

The climate models show a tendency towards temperature increases in the Iberian Peninsula for the next century.

Severity of the risk 1

Only severe in certain inland areas of the Iberian Peninsula and in mountain ranges. In most parts of Spain, this problem is less severe or not relevant.

Actions taken

Winter maintenance protocol.

Data collection

As for 'High temperature'.

Research need

Effect on pavement conditions.

Wind

Probability 1

The wind intensity may change, depending on the season.

Severity of the risk 1

The wind intensity may not be especially severe, but there may be occasionally severe wind.

Data collection

As for 'High temperature'.

Storms

Probability 2

Frequency and/or intensity may change.

³⁹ Information gathered from *Preliminary assessment of the impacts in Spain due to the effect of climate change* (Ministry of the Environment and Rural and Marine Affairs of Spain, 2005). A personal judgment was undertaken to quantify the probability and severity of the risk, according to the information given in this document.

Probability

(3= verifiable risk, 2=probable risk, 1=slight probability, 0=improbable)

Severity of the risk

(3= extremely severe, 2=severe, 1=less severe, 0=not relevant)



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Severity of the risk 1**Data collection**

As for 'High temperature'.

Rain intensity**Probability** 2

General tendency towards less rainfall. Heavy rains will become more frequent.

Severity of the risk 1

The average annual rainfall will decrease, especially in spring, and it will be less severe in summer.

Data collection

As for 'High temperature'.

Research need

Effects of heavy rain on drainage systems.

Analysis of return periods for heavy rainfall according to the climate change scenarios for the twenty-first century.

Increased flow rate in rivers**Probability** 2

Frequency of heavy rain and floods will increase, which means a higher flow rate. Nevertheless, in general, the flow rate in rivers may fall because of the reduction in rainfall.

Severity of the risk 1

The intensity of floods and heavy rain will probably rise, so the flow rate will increase in these cases (not in general).

Is there a strategy for dealing with the problem?

Directive 2007/60/EC on the assessment and management of flood risks is soon to be incorporated into Spanish national law.

Actions taken

Guidelines for the design of appropriate culverts and drains.

Data collection

Hydrographic Confederations gather information on flow in river basins.

Research need

Precipitation prediction and its spatial and temporal distribution.

Floods**Probability** 2

The most vulnerable places are located near to urban and tourist areas, especially in the Mediterranean area.

The frequency and intensity will increase in the Mediterranean Basin.

In the Atlantic Basin, the frequency may decline, but not the intensity.

Severity of the risk 1

The intensity of floods will probably rise. The floods are only expected to be severe only in certain places.

Is there a strategy for dealing with the problem?

The Directive 2007/60/EC on the assessment and management of flood risks is soon to be incorporated into Spanish national law.

Actions taken

The autonomous communities have flood plans:

- improvement of the protection systems, with structural and non-structural measures; and
- legislative control of urban and industrial plans.

Data collection

The Spanish General Directorate for Civil Protection has a flood inventory.

Hydrographic Confederations gather information about floods in river basins.

Research need

Research on simulations of hydrological models coupled to regional climate models.

Reconstruction of series of floods in the past and their analysis.

Drought**Probability** 3

General tendency for drought, due to lower rainfall and temperature rise.

Severity of the risk 2

Droughts will become severe in the coming years. The most affected areas are Mediterranean arid and semi-arid areas.

Is there a strategy for dealing with the problem?

Special action plans for high-alert situations, include drought in hydrological plans.

Actions taken

Water regulation.

Data collection

The Spanish State Meteorological Agency (AEMet) collects meteorological data.

The National Drought Observatory of the Ministry of the Environment gathers information about drought in Spain.

Research need

Research on simulations of hydrological models coupled to regional climate models.

Although no reduction in avalanches is expected, the size of the area where the avalanches occur will probably decrease.

In mountain ranges: Pyrenees, Cantabrian mountain range, and Betic mountain range.

Severity of the risk 1

There is uncertainty about severity, but it is likely to be sustained, albeit over reduced areas.

Actions taken

Reforestation of mountainsides and maintenance of indigenous species.
Control of new road planning.

Data collection

The Spanish General Directorate for Civil Protection has recorded all incidents since 2000, including avalanches.

Research need

Development of an avalanche database and early warning systems.

Landslides

Probability 2

The increase of heavy rain will also raise the number of landslides.

Areas:

- mountain ranges, especially in the Pyrenees, the Cantabrian mountain range, and the Betic mountain range; and
- banks of rivers in tertiary basins.

Severity of the risk 1

There is uncertainty about severity, but it is likely to be sustained, albeit over reduced areas.

Actions taken

Reforestation of mountainsides and maintenance of indigenous species.
Control of new road planning.
Reducing landslide risk by adequate road planning.

Data collection

Geological and Mining Institute of Spain

Research need

Relationship between rainstorms and landslides, improving the landslides database, historical relation between climate variability and landslides, downscaling of CC models, improving hydrology and mechanic models for landslides.

Snowfall intensity

Probability 2

As temperatures rise, the frequency of snowfall will probably decline.

Severity of the risk 1

The severity is expected to decrease in the long run. However, in mountain ranges the risk will continue to be severe. In other parts of Spain, the risk will be less or even not relevant.

Actions taken

Winter maintenance protocol.

Data collection

As for 'High temperatures'.

Research need

Snowfall prediction and its spatial and temporal distribution.

Sea-level change

Probability 2

Sea-level rise is expected in northern Spain, with a decrease or a stabilisation expected in eastern and southern Spain (although locally subsidence may hide this effect).

Avalanches

Probability 2

Probability

(3= verifiable risk, 2=probable risk, 1=slight probability, 0=improbable)

Severity of the risk

(3= extremely severe, 2=severe, 1=less severe, 0=not relevant)



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Severity of the risk _____ **1**

Less severe in southern and eastern Spain, although subsidence may increase this risk. Severe in northern Spain.

Actions taken

Coastal stability through sand dune stabilisation.

Data collection

General Directorate for Coasts (Ministry of Environment).

Research need

Historical sea-level database

Inventory of the infrastructures that may be affected by sea-level change.

Effects of sea-level change and swell





Appendix 2





Survey of on-going work on adaptation to climate change

Appendix 2

State of the work on adaptation to climate change

National level

	Norway 	Finland 	Sweden 	UK 	IE	DK
Do you have good projections of climate change in your country?	<p>Projections for 2071–2100 expressed in relation to model period 1961–1990.</p> <p>Regional climate scenarios are from the RegClim programme, based on both on A2, B2, and A1B.</p> <p>* At first, the work was based on a 2007 report from the Meteorological Institute. * In 2009, there was a renewed processing of the same data, leading to a new report, <i>Climate in Norway 2100</i> (in Norwegian). Norway is divided into five temperature zones and eight precipitation zones.</p>	<p>In Finland, we have mainly used the A2, B1, and A1B scenarios from SRES scenarios by IPCC (Nakićenović et al. 2000).</p> <p>ACCLIM project.</p> <p>Regional climate models (Jylhä et al. 2008). Other studies: Gregow et al. 2008, FINNADAPT (Ruosteenoja et al 2005) and some older studies.</p>	<p>In Sweden we have mainly used the A2 and B2 scenarios from SRES (IPCC, 2000).</p> <p>The global climate models used are HadAM3H and ECHAM4/OPYC3. As a regional climate model, RCA3 from the Rossby Centre at the Swedish Meteorological and Hydrological Institute is used.</p>	<p>The United Kingdom uses <i>UK Climate Projections (UKCP09)</i>. The Projections are presented for three different future scenarios representing high, medium and low greenhouse gas emissions. The types of climate information provided are:</p> <ul style="list-style-type: none"> - observed climate data (twentieth and twenty-first century historical information about temperature, precipitation, storminess, sea surface temperatures, and sea-level); - climate change projections (for temperature, precipitation, air pressure, cloud, and humidity); and - marine and coastal projections (for sea-level rise, storm surge, sea surface and sub-surface temperature, salinity, currents, and waves). 		

	 Norway	 Finland	 Sweden	 UK	IE	DK
<p>Is political initiative taken for adaptation to climate change?</p>	<p>1) Joint initiative of several ministries, web portal for information about climate change:</p> <p>http://www.regjeringen.no/en/dep/m/d/kampanjer/engelsk-forside-for-klimatilpasning.html?id=539980</p> <p>2) National action led by the Ministry of Environment for assessment of vulnerability and proposal of remedial actions.</p>	<p>Finland's National Strategy for Adaptation to Climate Change in 2005.</p> <p>Climate change policy (ILPO) 2009 Ministry of Transport and Communications</p>	<p>The final report from the Swedish Commission on Climate and Vulnerability: <i>Sweden facing climate change—threats and opportunities</i> (SOU 2007:60)</p> <p>http://www.sweden.gov.se/sb/d/574/a/96002</p>	<p>The Climate Change Act 2008 made the UK the first country in the world to have a legally binding, long-term framework to cut carbon emissions. It also created a framework for building the UK's ability to adapt to climate change.</p>		
<p>Does your country have a national strategy/plan for adaptation to climate change?</p>	<p>Not yet. However, the vulnerability analysis mentioned above might lead to a strategy for climate adaptation at national level. Norway does not yet have an adaptation plan, but a thorough analysis of society's vulnerability and its need to adapt to the consequences of climate change has been carried out (by a specially appointed committee) and reported on in November 2010.¹</p>	<p>The national strategy for climate change adaptation (2005) is co-ordinated by the Ministry of Agriculture and Forestry, with participation by all relevant ministries and institutions.²</p> <p><i>The climate change policy of the Ministry of Transport and Communications, ILPO (2009).</i>³</p>		<p>In August 2010, the government set out the principles of its approach to adaptation in a response to the Environmental Audit Committee's (EAC) enquiry on <i>Adapting to climate change</i> (published March 2010). The government response (PDF 315 KB) and the EAC's original report (PDF 1.5 MB) are both available.</p> <p>The central government Department for Environment, Food and Rural Affairs (Defra) leads on domestic adaptation policy.</p>		

1) The vulnerability analysis covers all sectors of Norwegian society, with emphasis on human health and safety, physical infrastructure and buildings, business and industry, the natural environment, and primary industries.

Climate change towards the end of the century is considered, i.e. based on climate projections for the last 30 years of the century to 2100.

The transport sector is a natural part of the analysis (and physical infrastructure is one of the focus areas). The analysis has not yet had any direct and formal impact on the road sector.

In addition, the road sector has not especially influenced the outcome of the analysis. The road sector (and transport sector generally) has been found to be generally robust (resilient), not because no action or adaptation is needed, but because the sector has the necessary preconditions for adapting to climate change: resources (material and human), knowledge basis, and organisational framework.

Topics indicated by the plan, concerning the transport and/or road sector:

- conducting a survey of vulnerable assets and good documentation of vulnerability, for better prioritising;
- making climate adaptation a set part of all working procedures (plans, contracts, surveys, design rules, etc.);
- prioritising maintenance and reducing accumulated maintenance need; and
- increasing and disseminating knowledge about the effects of climate change.

2) Sectors covered in the strategy are: agriculture and food production, forestry, fisheries, reindeer and game husbandry, water resources, biodiversity, industry, energy, transport, land use and communities, building, health, tourism and recreation, and insurance. The strategy includes adaptation plans to 2080, but most important are those scheduled for the years 2006–2015.

The most important measures to be taken by 2015 are:





- the integration of climate change adaptation into routine planning, implementation, and development processes;
- preparation for extreme events and assessments of the impacts of climate change incorporated into the planning of long-term investments;
- improvement and establishment of existing and new observation and warning systems;
- implementation of the Climate Change Adaptation Research Programme 2006–2010 (ISTO); and
- preparations for forthcoming changes in the international operating environment.





3) The Ministry of Transport and Communications plays an important role in the plan, with involvement from all subordinate agencies and institutions. The programme was for 2009–2020, but it was based on the government's climate and energy strategy for the years 2008–2050.


The most important measures to be taken by 2015 are:

- the renewal of the vehicle fleet;
- the improvement of energy efficiency in transport;
- the direction of growth in passenger traffic volumes in urban areas to more environmentally friendly transport modes;
- use of the information society and communications policy to help reach Finland's climate policy objectives;
- the making of a decision in 2012 on the financial steering methods used in the transport sector; and
- the taking of action to adapt to climate change (this is explained in more detail below).





National road administration level

	Norway 	Finland 	Sweden 	UK 	IE	DK
<p>What are the main issues in relation to climate change, and which areas in your country are most affected?</p>	<p>An increase in landslide risk in western and northern areas. Higher precipitation especially in western regions, but overall flood risk. Higher frequency of ± 0 temperatures in northern and inland areas, raising concerns about road deterioration during thaw periods, friction control, and rock fall.</p>	<p>Climate zones eligible for winter maintenance have been reassessed.</p> <p>The mapping of flood risk areas is on-going. Flood risk is not only due to climate change; vulnerable areas exist today.</p>	<p>The national analysis indicated south-western Sweden as the most vulnerable, due to the amount of rainfall, flooding, and sea-level rise.</p> <p>Another part of the road structure at risk is the drainage system, which will in future have to be able to handle water in greater quantities than today. This problem is common to most parts of the country. However, the first climate change impact to be noticed, according to the scenarios which have been formulated, is extreme weather such as cloudbursts. This will, for instance, affect slope stability and give rise to flooding. The problem is common to the whole country. Another problem caused by rising temperatures, in the longer term, is the loss of frozen soil or permafrost. In the north of Sweden, frozen soil is an important load-bearing capacity factor.</p>	<p>Key aspects of climate change presenting issues to the Highways Agency:</p> <ul style="list-style-type: none"> - changing precipitation patterns and increase in mean temperatures <p>Impact on business:</p> <ul style="list-style-type: none"> - defining and managing network strategy and planning; - design and construction of new and replacement assets; - maintenance and management of existing assets; - traffic management function; and - internal business management. <p>There are no significant regional variations to consider</p>		

	Norway 	Finland 	Sweden 	UK 	IE	DK
Do you recognise any beneficial effects of climate change and in which areas?	Less snow in lowland areas, easier winter maintenance in some areas. Reduction of snow avalanches in some places.		Road maintenance and operations will probably be less expensive during the winter in the southern parts of Sweden. Although, if studded tires are still used during the winter, the wear on the roadway will eliminate this benefit in economic terms.	An increase in average temperatures over winter months would bring about a reduction in winter maintenance activities, including the reduction in the use of salt and its subsequent effect on the environment. Reduction in road traffic incidents caused by ice, although the risk reductions of +/- 0°C are, as yet, unquantified. The road surface would be subject to less freezing resulting in improved pavement durability/condition.		
Does your NRA have a strategy for adaptation to climate change?	Not yet.	No. But a long-term plan where this issue is the main objective is being prepared .	Not yet.	The Highways Agency published its Climate Change Adaptation Strategy in 2009.		
Has your NRA calculated the cost of climate change damage, the cost of adaptation measures, and the cost of no action?	Not yet.	No.	Partly. During the work by the Swedish Commission on Climate and Vulnerability, the costs related to landslides, flooding, and erosion were estimated. The conclusion was that the cost will increase from today's value of ~ €8 million per year to ~ €14–20 million per year if no measures are taken.	No costing exercises have taken place.		

	 Norway	 Finland	 Sweden	 UK	IE	DK
<p>Is there concrete on-going action concerning adaptation to climate change?</p>	<p>The research and development programme Climate and Transport, 2007–2011. Objectives: to investigate the effect of climate change on the road network and recommend remedial actions concerning planning, design, construction, maintenance, and operation.</p> <p>www.vegvesen.no/klimaogtransport</p>	<p>Participation in the ERA-NET ROAD programme: Road Owners Getting to Grips with Climate Change.</p> <p>Making climate policy more efficient in road keeping (project ILMATIE²⁸).</p> <p>Climate change and goods traffic (project ITARA³⁰).</p> <p>Mapping of flood risks.</p>	<p>Participating in the ERA-NET ROAD programme: Road Owners Getting to Grips with Climate Change.</p> <p>A risk analysis method 'Risk analysis for selected road stretches (vald vägsträcka)' is on-going for the road network for which SRA is responsible. In this risk analysis vulnerabilities are highlighted and climate-related risks are a part of this. In the in-depth part, which is an implementation tool, the emphasis has been placed on:</p> <ul style="list-style-type: none"> • landslide and collapse risk; • risk of damage on roads and bridges with high water flow; • risk of flooding; and • risks due to accidents with dangerous goods. 	<p>Under the Climate Change Act (2008), the government has a range of powers to address climate change adaptation, including a power which is being used to direct companies to identify their risks from climate change and to put together measures to deal with these risks. This power of direction does not apply to central government departments and the executive agencies. However, the Highways Agency was highlighted as being at particular risk of climate change impacts and as having a key role to play in ensuring the UK's infrastructure is ready to adapt to the impacts of a changing climate. The Highways Agency therefore volunteered to report. The agency expects that this report will have a role in informing the National Adaptation Programme and UK Climate Change Risk Assessment. The agency's climate change risk assessment approach is about raising and understanding the possible implications of climate change to enable planning for timely interventions to protect the highway asset, contributing to safe and reliable journeys.</p>		

Background to adaptation

	Norway 	Finland 	Sweden 	UK 	IE	DK
Please identify the source(s) of information/database on road data in general.	<p>National road database. (Data of road pavement structures not included.)</p> <p>Register of road pavement structures (of an older date).</p> <p>Bridge database BRUTUS.</p>	<p>National road database; some structures have been included but only a small proportion have yet been inventoried.</p> <p>Maintenance databases, condition database, bridge database.</p>	<p>National road database (NVD). Data on road structures is not included.</p> <p>Bridge database (BaTMan)</p>	<p>In May 2011, the government published Climate resilient infrastructure: Preparing for a changing climate, which sets out the government's view on adapting infrastructure in the energy, ICT, transport, and water sectors to the impacts of climate change.</p> <p>It makes the case for action, identifies who needs to act, the challenges to acting, and the opportunities available.</p> <p>Recognising that infrastructure is largely private-sector-funded and operated, it sets out how government can assist others in adaptation work.</p>		
Please identify the main source(s) of data about past events related to weather.	<p>A national landslide database (www.skrednett.no) is in progress. In the future, landslide data will not be registered in the national road database.</p> <p>We are also working on better accessibility of data concerning road closure (no matter what the reason is) and coupling it to weather and flood data (see Appendix 3, 'Web portal: Føre</p>	<p>A flood risk area database is under construction.</p>	<p>At national level, there is a database that collects data on all kinds of larger-scale events related to weather. The SRA doesn't have any databases.</p>	<p>UK Climate Impacts Programme 2002 Report (UKCIP02). Intergovernmental Panel on Climate Change (IPCC) 4th assessment report (2007). Department for the Environment, Food and Rural Affairs (Defra). Stern Review.</p>		

	Norway 	Finland 	Sweden 	UK 	IE	DK
	var').					
Please identify the main source(s) of meteorological data.	The coordination of databases from the Meteorological Institute, road and railway administrations is in progress, for purposes of better accessibility but also better quality of data.	Finnish Meteorological Institute (FMI).	SMHI (Swedish Meteorological and Hydrological Institute).	Meteorological Office (Met Office).		
What are the research and development needs in this field?	There is a lack of data and projections on precipitation intensity. Existing calculated data is not available due to high uncertainty.	Not indicated.		There is a need to update risk assessment for the Highways Agency using the latest generation of climate predictions (UKCP09). Undertake at least a preliminary review of the climate change costs.		

Road management and operation





	 Norway	 Finland	 Sweden	 UK	IE	DK
Is a survey of vulnerable assets regarding climate change performed or planned and for which assets?	A large-scale risk and susceptibility survey is to be carried out, starting in 2009, however, with a general focus on maintaining traffic in cases of closure of road sections. In order to include climate vulnerability, 'Climate and Transport' contributes to that work by developing guidelines for assessment of risk related to climate effects.	No. None.	Risk analysis method 'Risk analysis for selected road stretches (vald vägsträcka)' is on-going for the road network for which the SRA is responsible. An initial analysis is to be done by the end of 2010.	Reference is made to Annex B.1 'Vulnerability schedule' of 'Climate Change Adaptation Strategy and Framework'		
Are climate adaptation measures a part of day-to-day operation and maintenance?	Not yet, but some positive changes have been noted since 2009.	Not yet, but in relation to winter road maintenance they are having a direct effect, since the same level of service must be ensured, although conditions are becoming more difficult. The design standards are slowly being renewed. Risk management has been fine-tuned: how to deal with unexpected weather conditions in every-day maintenance —clearing the roads after a storm, roles of different officials and contractors.	Not at an acceptable level.	Reference is made to Annex B.1 'Vulnerability schedule' of 'Climate Change Adaptation Strategy and Framework'		






	Norway 	Finland 	Sweden 	UK 	IE	DK
<p>Do you have tools for the <i>assessment</i> of risk related to climate change?</p>	<p>For existing infrastructure, under development:</p> <ul style="list-style-type: none"> - procedures for risk assessment related to climate change for <i>identifying</i> vulnerable assets on the road network. <p>Web portal Føre Var (under development, see Appendix 3), risk assessment based on increased use of weather data.</p>	No.	<p>Risk analysis method 'Risk analysis for selected road stretches (vald vägsträcka)' contains some tools.</p> <p>The design standards are slowly being renewed, for example, a new publication Hydraulic dimensioning, includes a map of Sweden showing variations in a coefficient for calculating increased water run-off.</p>			
<p>If yes, are they specific climate change risk assessment tools, developed and/or implemented by your country/organisation ?</p>				Highways Agency Adaptation Strategy Model (HAASM).		
<p>Do you have tools for the <i>management</i> of risk related to climate change?</p>	<p>For existing infrastructure, under development:</p> <ul style="list-style-type: none"> - procedures for managing vulnerable assets: calculation of the climate impact, effective capacity and formulation of recommendations for repair. <p>Web portal Føre Var (under development, see Appendix 3),</p>	<p>There is a tool for risk management at a strategic level which includes adaptation to climate change. At project level, risk management tools are used but they do not usually include the risk of climate change, since they are mainly managing the risks in carrying out the project.</p>	<p>For existing infrastructure, under development:</p> <ul style="list-style-type: none"> - tools to divert the traffic in case of closure of road sections; and - method to classify necessary adaptation measures identified by risk analysis. 			






	Norway 	Finland 	Sweden 	UK 	IE	DK
	planning preparedness based on increased use of weather data.	The risk management tool is no longer an NRA tool but some of the centres for economic development, transport and environment (former districts) still use it.				
If yes, are the assessment tools similar to, or the same as, the ones that apply to other known risk areas (for example seismic zones)?						
Do you have <i>alternatives</i> for managing the effects of climate changes in the long term?	Some steps taken in the direction of accepting controlled damage when necessary.	If it is an alternative, we allow the condition of the road network to deteriorate . In addition, for example, we have been discussing whether we should clear vegetation along the road sides, or accept removing damage after storms. So far it does not seem beneficial to clear in advance.	No.	No.		
Are climate change impacts being implemented in guidelines for planning, design, and construction?	In progress; drainage capacity, landslide protection, erosion protection, guidelines for inspections and maintenance etc. One of the main goals of the	In general, only observed weather changes have been taken into account.	Very little. The publication Hydraulic dimensioning has a map of Sweden with a coefficient for calculating increased water run-off.	An adaptation action plan is currently in development to ensure that climate change impacts are factored into the planning, design, and construction of highways		

	Norway 	Finland 	Sweden 	UK 	IE	DK
	'Climate and Transport' programme is to implement new knowledge into the NPRA's guidelines for planning, design, maintenance and operation.			infrastructure. This will be incorporated into a report of UK critical infrastructure due for publication in 2012.		
What are the research and development needs in this field?	Better knowledge about the effect of weather data on the occurrence of landslides and avalanches: threshold values for rain, snow, freezing, and thawing etc.	Drainage design guidelines should be updated. Our strategy includes the fact that guidelines etc. should take the issue into account.	<ul style="list-style-type: none"> • Risk-based functionality specifications should be introduced for all components in the whole road network. • Criteria for accepted risk levels should be decided. • The level of competence regarding the effects of climate change should increase in the Swedish Road Administration. 	Needs are based on individual cases.		

National level

	 France	 Austria	 Hungary	 Italy	 Spain
<p>Do you have good projections of climate change in your country?</p>	<p>Yes, the Jouzel <i>et al.</i> report states the results of climatic simulations for France based on the A2 and B2 scenarios. Regional simulations were performed with French models developed by Centre National de Recherches Météorologiques (model ARPEGE-Climat) and by Institut Pierre Simon Laplace /IPSL (model LMDz). Results are given for mainland France and are detailed for five large regions of France. Simulations of climate change in overseas territories will be documented in a future update. Results of simulations for other scenarios with high spatial resolution are expected during 2011.</p> <p>http://climat.meteofrance.com/chgt_climat/simulateur/</p> <p>http://climat.meteofrance.com/content/2009/10/21274-48.pdf</p>	<p>Mainly A1B scenarios are used.</p> <p>Projections of climate change based on the results of PRUDENCE and ENSEMBLES. Regional climate models were evaluated in the projects reclip:more and reclip:century</p> <p>www.foresight.ait.ac.at/reclip</p>	<p>Regional scenarios available for different periods and in various resolutions.¹</p>	<p>Scientifically-based projections are available for Italy.</p> <p>Global models are derived mainly from the CMIP3 programme (Coupled Model Intercomparison Project 3; Meehl et al., 2007). Also the model from CMCC (Gualdi et al., 2008) is used.</p> <p>IPCC B1, A1B and A2 SRES scenarios (2007) are mainly used.</p> <p>The latest set of climate change projections from regional models are derived from PRUDENCE (Coppola and Giorgi, 2010).</p>	<p>The National Climate Change Adaptation Plan, published in 2006, developed through work programmes. The first work programme describes projects to be carried out in the context of the plan. One of these projects is about generation of climate change scenarios in Spain.</p> <p>According to the 2008 First Monitoring Report, existing regional models are used, as are the results of the European PRUDENCE project and the STARDEX project (EU 5th Framework Project). In addition to this, new regional models will be developed for the next three to four years. The global information from the AR4-IPCC Report will be used, following the indications from:</p> <p>Programme for Generation of Regional Scenarios of Climate Change (2006).</p> <p>The studies for the Preliminary assessment of</p>

	 France	 Austria	 Hungary	 Italy	 Spain
					the impacts in Spain due to the effect of Climate Change considered A2 and B2 scenarios, from emissions scenarios SRES (Special Report on Emission Scenarios) by the IPCC. In addition, some regional models were used, such as PROMES, developed by a Spanish research group (Gallardo, 2001).
Is political initiative taken for adaptation to climate change?	<p>Numerous French organisations are managing research programmes dealing with the consequences of climate change, vulnerability, and adaptation in almost all sectors.</p> <p>A National Observatory of the Effects of Climate Change (ONERC) was created in 2001. It collects and circulates information from climate change and extreme climatic events studies. It also provides public authorities with recommendations regarding preventive and adaptive measures.</p> <p>A second report on adaptation to climate change</p>	<p>Decision of the Austrian government to create a National Strategy for Adaptation to Climate Change in 2008.</p> <p>National climate strategy.</p> <p>Various, politically motivated and co-financed, <u>scientific projects</u>:</p> <ul style="list-style-type: none"> • National project StartClim (www.austroclim.at/index.php?id=45) • Project FloodRisk • Interreg project AdaptAlp (www.adaptalp.org): influence of climate change on regional scale • Alp-Water-Scarce 	<p>Several decrees were issued to address adaptation to (and also mitigation of) climate change.</p> <p>See footnote for the most important ones (the parts dealing with adaptation are in italics).²</p>	<p>National Conference on Climate Change, September 2007, focus on adaptation, Ministry for Environment, Land and Sea, with the support of the Institute for Environmental Protection and Research (ISPRA, former APAT).</p> <p>The Ministry committed to drafting a national sustainable adaptation and land protection strategy and proposed the first 13 Actions for Sustainable Adaptation (No concrete and official actions yet).</p> <p>The Inter-Ministerial Committee for Economic</p>	<p>1) The Spanish Office of Climate Change is responsible for climate change policy. It is part of the Ministry of the Environment and Rural and Marine Affairs.</p> <p>2) The main policy for adaptation to climate change in Spain is the National Climate Change Adaptation Plan (2006, Ministry of the Environment and Rural and Marine Affairs).</p>

	 France	 Austria	 Hungary	 Italy	 Spain
	in 2009 focused on the cost of climate change.	<p>(www.alpwaterscarce.eu): availability of water in the alps</p> <ul style="list-style-type: none"> • Interreg IIIB ClimChAlp (www.climchalp.org): forestry adaptation technologies • Interreg programme AMICA (www.amica-climate.net) • Interreg IVB project CLISP: adaptation by spatial planning in the alpine space • and others. 		Planning (CIPE), chaired by the Ministry of Economy, has the task of approving the national programme for greenhouse gases emissions reduction. ³	
Does your country have a national strategy/plan for adaptation to climate change?	<p>The national adaptation strategy (2006) declared that adaptation must aim to:</p> <ol style="list-style-type: none"> protect people and goods by acting on security and public health; take into account social issues and avoid unacceptable risks; limit costs and make the most of advantages; and protect natural heritage. <p>The French National Adaptation Plan to the effects of Climate Change (PNACC), (2011–2015) aims</p>	<p>Not yet. The decision to create a National Strategy for Adaptation to Climate Change was part of the governmental programme in 2008. Work is currently on-going.</p>	<p>Parliamentary Decree No. 29/2008 (III. 20.) on the National Climate Change Strategy was adopted in 2008. The National Climate Change Strategy applies to the period 2008–2025, for which three main goals are defined:</p> <ul style="list-style-type: none"> - reduction of GHG emission; - adaptation to the inevitable consequences of climate change; and - enhancement of public awareness of climate 	<p>Italy does not have a National Adaptation Strategy/Plan. Despite the current lack of a strategy, some adaptation measures have already been implemented in the context of environmental protection, natural hazards prevention, sustainable management of natural resources and health protection, which could also be beneficial for adapting to climate change. They range from legal frameworks to</p>	<p>The National Climate Change Adaptation Plan (2006, Ministry of the Environment and Rural and Marine Affairs), which is developed through Work Programmes.⁵</p> <p>The Work Programmes are as follows: WP 1:</p> <ul style="list-style-type: none"> • generation of climate change scenarios in Spain; and • evaluation of climate change. Impacts on water resources, coast and biodiversity.

	France 	Austria 	Hungary 	Italy 	Spain 
	<p>to plan adaptation actions, ensuring cohesion of public policies on adaptation.</p> <p>More on PNACC in Appendix 3.</p>		<p>change in order to change human motivation.⁶</p>	<p>monitoring, surveillance of early impacts, and early warning systems to practical actions. These measures are generally aimed more at reducing vulnerability to current climate variability and extreme weather conditions (reactive adaptation) than at preparing for the potential adverse effects of projected climate change (proactive adaptation).⁴</p>	<p>WP 2:</p> <ul style="list-style-type: none"> • sectoral evaluation of impacts, vulnerability and adaptation to climate change; • integration of the adaptation to climate change in legislation in various sectors; • mobilisation of relevant stakeholders; and • establishment of impacts indicators.

1) Comment on regional scenarios in Hungary

Forecast period: 2001–2030 (as part of 1951–2050 period). Reference period: 1961–1990. Weather characteristics: average temperature and precipitation. Model: REMO, Scenario: A1B.

Forecast period: 2021–2050. Reference period: 1961–1990. Weather characteristics: average temperature and precipitation, frequency of extremities in temperature and precipitation models: ALADIN-Climate and REMO. Scenario: A1B.

Forecast period: 2071–2100. Reference period: 1961–1990. Weather characteristics: average temperature and precipitation, frequency of extremities in temperature and precipitation models: Regional climate models available in PRUDENCE project and ALADIN-Climate. Scenario: Variable, A1B, A2, B2.

2) Cont. Parliamentary Decrees in Hungary

Parliamentary Decree No. 29/2008 (III. 20.) on the National Climate Change Strategy was adopted in 2008. The National Climate Change Strategy has three main goals:

- reduction of GHG emission;
- adaptation to the inevitable consequences of climate change; and
- enhancement of public awareness of climate change in order to change human motivation.

Parliamentary Decree No. 60/2009 (VI. 24.) on the preparation of the Act on Climatic Protection was adopted in 2009. This decree has empowered the National Council on Sustainable Development to prepare the draft of the act, and has also defined the main goals of the act. The Act on Climatic Protection has not yet been adopted.

Parliamentary Decree No. 96/2009 (XII. 9.) on the National Environmental Programme for the period 2009–2014 was adopted in 2009. The National Environmental Programme includes an action programme on climate change. The main goals of the action programme include: reduction of GHG emissions, improvement of energy saving and energy efficiency, increased binding of GHGs by increasing and improving vegetation cover, mitigation of adverse ecological and social effects by enhancing adaptation capacity and preventing damage, protection of stratospheric ozone layer, and enhancement of awareness of climatic issues.

Government Decree No.1054/2007 (VII. 9.) on the National Sustainable Development Strategy was adopted in 2007. The strategy includes a chapter on preparation for climate change.

3) Comment on political initiative in Italy:

The first programme (National Programme for the Containment of Carbon Dioxide Emissions) was approved in 1994 with the aim of stabilising CO₂ emissions by 2000 at 1990 levels. Later the programme was enhanced and updated (CIPE deliberations of 1997 and 1998) and in 2002, when the Kyoto Protocol was ratified, an overall national strategy to meet the Kyoto Protocol target was approved (CIPE deliberation 123/2002). The financial support and legislative instruments to implement the strategy are identified through the Financial Law and allocated to the central and local bodies on the basis of respective competences.






The CIPE deliberation 123/2002 also established an inter-ministerial Technical Committee (CTE). The CTE includes representatives of the Ministry of Economy and Finance, the Ministry of Economic Development, the Ministry of Agriculture, Food and Forestry Policy, the Ministry of Infrastructure and Transport, the Ministry of Education, Universities and Research, the Ministry of Foreign Affairs, and the Ministry of Regional Affairs. The main task of the CTE is to monitor the emissions trend, the status of the implementation of the policies and measures identified in the overall national strategy, and to identify potential further measures to meet the Kyoto Protocol target, if needed. On the basis of the analysis performed, the CTE can propose to CIPE an update of the overall national strategy. The Ministry for the Environment, Land, and Sea has the leadership of the CTE. In 2009, the CIPE through its deliberation n.16/2009, decided to enhance the institutional framework by means of the reconstitution of the CTE at the level of director general and its integration with representatives of the prime minister's office.






- 4) Implemented adaptation is most developed in the fields of human health and coastal protection, agriculture, desertification, and water resources protection. **A first effort to quantify the expected costs of some adaptation measures** that are currently being explored or undertaken in Italy covers four vulnerable areas: the Alps and glacier ecosystems, coastal zones, arid areas and areas threatened by desertification, and zones prone to floods and landslides.
- Documents prepared for the National Conference on Climate Change.
Ministero dell'Ambiente e della Tutela del Territorio e del Mare—Agenzia per la protezione dell'ambiente e per i servizi tecnici (APAT), 2007. *Gli eventi preparatori della Conferenza – sintesi dei lavori*. ISBN 978-88-448-0399-5.
Ministero dell'Ambiente e della Tutela del Territorio e del Mare—Agenzia per la protezione dell'ambiente e per i servizi tecnici (APAT), 2008. *Sintesi dei lavori – Conferenza Nazionale 2007*. ISBN 978-88-448-0344-5.
APAT-FEEM, 2008. *Cambiamenti climatici e strategie di adattamento in Italia. Una valutazione economica*. A cura di C. Carraro. Collana su 'Ambiente e Sviluppo'. Ed. Il Mulino.
- 5) Spanish National Climate Change Adaptation Plan, PNACC:
- The sectors which are covered by the PNACC are the following: biodiversity, water resources, forests, agriculture, coastal areas, hunting and inland fishing, mountain areas, soils, fishing and marine ecosystems, transport, human health, industry and energy, tourism, finance/insurance policies, urban planning, and construction.
- Although the different scenarios included in the PNACC consider the horizon of 2100, the plan is implemented by means of work programmes that determine both the activities and projects to be carried out, as well as their schedules. The first work programme was approved in 2006 and lasted until the first half of 2010. Currently, the second work programme of the PNACC is being carried out. It was adopted in 2009 and has a time horizon of four years.
- The transport sector is integrated into the PNACC, although it is not considered as a priority sector in this plan. Thus, this sector has not yet been included specifically in any of the work programmes that the PNACC has carried out.
- The PNACC shows that the transport sector does not seem to be seriously affected by the increase in temperatures, although it will be affected by changes in precipitation, wind, and fog patterns. Furthermore, according to the PNACC, it might be necessary to modify infrastructure works, such as bridges and runways. In addition, impacts may be highly significant, specifically in ports, due to sea-level rise and changes to other climate-related parameters.
- It is worth mentioning that the state administration has promoted a research project included in the National R&D&I Plan 2008–2011. This project is about the climate characterisation of the Spanish marine ecosystem for the optimisation of harbour exploitation and maritime navigation. The project may be considered a first step in this direction, and may help to take the transport sector into account within the PNACC.
- The PNACC only takes into account one action line for the evaluation of risks, vulnerability, and adaptation in relation to the transport sector. This action line refers to mapping the vulnerability of land, air and marine transportation systems in terms of infrastructure safety.





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- 6) Sectors covered by the Hungarian climate change adaptation plan: nature conservation, human environment and healthcare, water management, agriculture (crop growing, animal husbandry), forestry, spatial development, spatial planning, municipal development, municipal planning, and the built environment.
- The transport infrastructure is integrated into the strategy. The probability of disturbances in the operation of road infrastructure (as part of the 'critical infrastructure') and consequently in the field of public services is expected to increase.
- New road alignments should be planned to benefit nature conservation aspects. In order to enhance ecological permeability, the construction of ecological passages (underpasses and bridges for wildlife) across trunk roads and motorways and the planting of native shrub and tree belts beside them is necessary.
- There should be a revision of construction standards, guidelines, and regulations, and the experiments and calculations necessary for this should be carried out.
- Complex risk analyses for the 'critical infrastructure' (including road network) should be made.

National road administration level






	 France	 Austria	 Hungary	 Italy	 Spain
<p>What are the main issues in relation to climate change and which areas in your country are most affected?</p>	<p>Some impacts of climate change on transport services and infrastructure have been described, but the subject requires further study.</p> <p>Development of the number of freeze/thaw cycles, winter maintenance, pavement surface in southern France and coastal erosion, etc. are expected impacts.</p> <p>A distinction must be made between damage resulting from extreme climatic events and risks resulting from climate change. The former may require specific tools and measures while the latter may be reduced by upgrading standards or undertaking maintenance.</p>	<p>Higher temperature rise than the global mean.</p> <p>Shift of precipitation from summer to winter with a more or less constant annual volume and higher number of extreme weather situations.</p> <p>Lowlands next to large rivers and roads next to streams in the alps: higher flood risk.</p> <p>Mountainous regions: higher risk of avalanches and rock-fall.</p>	<p>High temperatures contribute to deformation of asphalt pavements. The lowlands are affected most as they generally have a warmer climate.</p> <p>Heavy or permanent rainfall can have different consequences and different impact areas. Mud or debris flow may occur in the hilly areas. The increased flow rates in streams and rivers can damage culverts, bridges, and even the road itself mostly in the minor road network where drainage the system is less well developed. Flood water accumulates mainly in the lowlands and can damage roads there.</p> <p>Storms can occur anywhere but traffic problems (fallen trees, snowdrift, sand-drift etc.) arise mainly in areas lacking forests which would otherwise decrease wind speed.</p>	<p>Italy is highly vulnerable to flood and landslides. Landslides are extremely widespread throughout Italy and represent, after earthquakes, the most frequently occurring natural disaster that is responsible for the highest number of victims. Landslides are therefore a major problem concerning the safety of the population and damage to residential areas, infrastructure, and service networks.</p> <p>Coastal systems and low-lying areas are already prone to erosion and are projected to be increasingly at risk over the coming decades. Areas particularly at risk are the Adriatic regions. Key concerns include sea-level rise, coastal erosion, changes in storms and flooding events, and habitat loss.</p> <p>The melting of glaciers and the loss of permafrost in the mountainous areas are</p>	<p>There is a significant increase in flooding (especially in the Mediterranean Basin) and landslides (in mountain ranges and the banks of rivers in tertiary basins). In addition, there is soil erosion and risk of desertification, mainly in inland areas and southern Spain. Sea-level rise and coastline regression are also expected.</p>






	<p>France</p> 	<p>Austria</p> 	<p>Hungary</p> 	<p>Italy</p> 	<p>Spain</p> 
				<p>responsible for the higher risk of avalanches and rock-fall. The main effects of climate change on transport system may include the following:</p> <ul style="list-style-type: none"> - changes in the stability and resistance of the transport system and infrastructures, as well as in the choice of transport modality directly dependent on temperature rise, which thus indirectly affects the overall quality of transport; and - possible inaccessibility or disruption of the transport network due to SLR and more frequent and intense precipitation, mainly in relation to floods. 	




	France 	Austria 	Hungary 	Italy 	Spain 
<p>Do you recognise any beneficial effects of climate change and in which areas?</p>	<p>Probably the frost index for winter maintenance.</p>		<p>Some benefits, such as a reduction in frost damage to structures and a reduced number of accidents caused by ice on pavements, may arise from the shorter winter frost period, which will be experienced throughout the country.</p>	<p>No.</p>	<p>More efficient technologies and renewable energies will be used. Environmentally friendly vehicles will be promoted.</p>
<p>Does your NRA have a strategy for adaptation to climate change?</p>	<p>Yes, as part of the PNACC, the French NRA has defined a strategy for adaptation to climate change. It consists of</p> <ul style="list-style-type: none"> i. reviewing and updating all the technical guidelines; ii. assessing the impact on transport demand and adjusting the service provided; and iii. defining methodologies for the identification and reduction of the vulnerability of the transport system and infrastructures. <p>More on PNACC In Appendix 3 (1.5.3).</p>	<p>Not yet.</p>		<p>Not yet.</p>	<p>The policy on adaptation to climate change in Spain is the National Climate Change Adaptation Plan (2006, Ministry of the Environment and Rural and Marine Affairs).</p>

	France 	Austria 	Hungary 	Italy 	Spain 
Has your NRA calculated the cost of climate change damage, the cost of adaptation measures, and the cost of no action?	Some costs have been calculated (studies were conducted to estimate the costs of sea-level rise and heat-waves).	Not yet.		No.	Not yet.
Is there concrete on-going action concerning adaptation to climate change?	Yes, actions which have been defined as part of the PNACC. See PNACC example sheet 1.5.3 in Appendix 3.	No.		A number of Italian administrations take part, within the Alpine Space Programme , in projects focusing on adaptation to climate change in the transport sector, such as the following ones: - AlpCheck, http://progetto-alpcheck.regione.veneto.it - iMONITRAF!, http://www.imonitraf.org - TRANSITECTS, http://www.transitects.org	Participation in the ERA-NET ROAD programme : 'Road owners getting to grips with climate change'.






Background to adaptation

	 France	 Austria	 Hungary	 Italy	 Spain
<p>Please identify the source(s) of information/datab ase on road data in general.</p>	<p>National road database. Pavement quality index. Bridge quality index</p>	<p>Online traffic information. Online weather and road condition sensors /cameras, GIS-based information on technical infrastructure, vegetation, and service applied.</p>	<p>National Road Management Company</p> <ul style="list-style-type: none"> - national road database (technical data); and - road traffic information centre (traffic and weather conditions). <p>Coordination Centre for Transport Development</p> <ul style="list-style-type: none"> - asset inventory; and - GIS applications. 	<p>The organisations responsible for the administration of the various sections of the road network communicate their data to the Ministry of Infrastructure and Transport, which summarises the most important information each year in the National Transport Accounts.</p>	<p>There are a number of databases relating to Spanish roads held by the Spanish General Directorate of Roads and the General Directorate of Roads of the Autonomous Communities. They include information on the road network, bridges, tunnels, road security, etc.</p>
<p>Please identify the main source(s) of data about past events related to weather.</p>	<p>Data may exist but it is not centralised or collected in such a way as to enable assessment of the risk of the climate change</p>	<p>GIS-based database (LOS) of applied services data from online weather and road condition sensors/cameras.</p>		<p>SCIA is the national system for collecting, processing and disseminating climate data of environmental interest and providing indicators representing the conditions of the climate and its development.</p> <p>http://www.scia.sinanet.apat.it/scia.asp</p> <p>A national landslide inventory (IFFI Project – Inventario dei fenomeni franosi in Italia) has been produced. The inventory identifies and maps the</p>	<p>The General Directorate of Traffic has information about winter road maintenance.</p> <p>In relation to floods, the Spanish General Directorate for Civil Protection has a flood inventory and the Hydrographic Confederations gather information about floods in their basins.</p> <p>The Spanish State Meteorological Agency (AEMet) has information about storms, rainfall,</p>

	France 	Austria 	Hungary 	Italy 	Spain 
				<p>landslides in accordance with standardised and shared methods. It also represents an important tool for landslide risk assessment and land-use planning.</p> <p>ISPRA— National Tidal Service.</p> <p>The National Tidal Network provides information on systematic measurements and analysis of marine climate data, the state of shorelines and sea level, the systematic publication of observed and processed elements and mapping.</p> <p>http://www.mareografico.it/</p>	<p>snowfall, etc. In the case of roads, the General Directorate for Traffic and the General Directorate of Roads collect meteorological data on some roads.</p> <p>The National Drought Observatory, which is part of the Ministry of Environment, gathers all the information about droughts in Spain.</p> <p>The Spanish Geological and Mining Institute has an inventory of landslides.</p> <p>As regards other events related to weather, the General Directorate for Civil Protection has recorded all incidents since 2000, for example, avalanches, fires, and seismic events.</p>
<p>Please identify the main source(s) of meteorological data.</p>	<p>Météo-France, IPSL.</p>	<ul style="list-style-type: none"> • weather forecast based on national climate and weather institute; • online weather condition sensors; and • hydrological statistics 	<p>Hungarian Meteorological Service.</p>	<p>The main source of meteorological data is the Air Force Meteorological Service</p> <p>(http://www.meteoam.it/)</p> <p>Meteorological data is also collected by some regional environment agencies and</p>	<p>The Spanish State Meteorological Agency (AEMet) is in charge of meteorological observation in Spain and the data archive.</p> <p>In relation to roads, the General Directorate for</p>

	France 	Austria 	Hungary 	Italy 	Spain 
		from the Austrian hydrographic service.		other institutions.	Traffic and the General Directorate of Roads also collect meteorological data on highways and roads.
What are the research and development needs in this field?	Definition of good indicators of impacts of climate change on infrastructure, and organising the collection of data in order to assess the cost of damage and to propose appropriate adaptation measures.			* Improvement of harmonisation of data collection and processing methods. * Strengthening of climate modelling research at national and local level.	-

Road management and operation

	France 	Austria 	Hungary 	Italy 	Spain 
Is a survey of vulnerable assets regarding climate change performed or planned and for which assets?	Yes, but not in detail. Critical issues of temporary closing of roads versus upgrading the standards.	No. Not yet.		No. None.	No. No.
Are climate adaptation measures a part of day-to-day operation and maintenance?	Directly linked with climate change: not yet. But meteorological risks are always taken into account in maintenance procedures.	Design standards for roads are constantly adapted by using updated long-term hydrological statistics.		No	One of the roles of the General Directorate of Roads is to control the operation of the national road network. It includes the maintenance of the road network in general and winter road maintenance in particular. In relation to this, there is a Protocol for coordination of action in extreme weather events . Its purpose is to strengthen the coordination systems between the different bodies of the General State Administration when snowfall and other extreme weather events occur.

	France 	Austria 	Hungary 	Italy 	Spain 
Do you have tools for the <i>assessment</i> of risk related to climate change?	Not yet. The GeRiCi tool has been developed and tested (risk assessment and management tools focused on infrastructure), see Appendix 3. A general vulnerability assessment methodology will be developed.	No. A small part of a general risk assessment planning tool.		No. No.	The main tool is the National Climate Change Adaptation Plan (2006, Ministry of the Environment and Rural and Marine Affairs). There are also national plans on floods and seismic zones in general, but not related to climate change. In addition, there are plans developed by each Autonomous Community.
If yes, are they specific climate change risk assessment tools, developed and/or implemented by your country/organisation?				No.	
Do you have tools for the <i>management</i> of risk related to climate change?	Not yet. The GeRiCi tool has been developed and tested (risk assessment and management tools focused on infrastructure).	No.			The main tool is the National Climate Change Adaptation Plan (2006, Ministry of the Environment and Rural and Marine Affairs of Spain). There are also national plans about floods and seismic zones in general, but not related to climate change. Also, there are plans developed by each Autonomous Community.

	France 	Austria 	Hungary 	Italy 	Spain 
If yes, are the assessment tools similar to, or the same as, the ones that apply to other known risk areas (for example seismic zones)?				No.	
Do you have <i>alternatives</i> for managing the effects of climate changes in the long term?	Not yet. It is linked to the implementation of the action plan and prioritising.			No.	No.
Are climate change impacts being implemented in guidelines for planning, design, and construction?	Not yet, the updating of the guidelines is one the planned actions as part of the PNACC.			No.	No.
What are the research and development needs in this field?	Methodological development to assess and manage climate change risks.				The climate change impacts must be implemented into the Spanish guidelines for planning, design, construction, and maintenance. ³

3) Research needs as listed by Spain, but of general interest:

Research is needed on:

- precipitation and temperature prediction and its spatial and temporal distribution;
- a general improvement of the database;
- simulations of hydrological models coupled to regional climate models, adapted to the Mediterranean and Atlantic basins;
- the development of an avalanches database;
- the effect of high temperatures on pavement conditions;
- the effect of heavy rain on drainage systems;
- the improvement of the landslide database and a better estimation of damage related to landslides;
- the relationship between rainstorms and landslides;
- the relationship between climate variability in the past and landslides;
- the downscaling of the situations predicted in the climate change models;
- the improvement of the hydrology and mechanic models on landslides;
- historical sea-level database
- the effects of sea-level change and swell; and
- inventory of the infrastructures which may be affected by sea-level change.

Appendix 3

Examples of adaptation work and good practice relevant to adaptation to climate change

1.5.3

Climate adaptation plan Theme: transport infrastructure	Current practice France
Field of application: Transport infrastructure	
Beneficial for: Adaptation work	
Climate change aspect included: All climate parameters and associated effects	
Time aspect: Towards the end of this century	
Summary: <p>The French National Plan for Adaptation to Climate Change (PNACC) was launched in 2011. The plan was developed after a consultation undertaken by a wide range of experts and stakeholders and includes around 200 recommendations. The most important tasks relating to transport issues are to:</p> <ul style="list-style-type: none"> • update technical guidelines and emergency plans; • promote research on all technical innovations, allowing better and less expensive responses to climate change problems; • increase communication and stakeholder awareness; • develop a methodology for vulnerability and risk assessment; and • cope with consequences of sea-level rise 	
Publications: <p>'Le plan national d'adaptation au changement climatique' (PNACC)/The French National Plan for Adaptation to Climate Change, 2011-2015. http://www.developpement-durable.gouv.fr/Le-Plan-national-d-adaptation,22978.html http://www.developpement-durable.gouv.fr/The-national-climate-change.html</p>	

In 2010, France defined a National Plan for Adaptation to Climate Change (PNACC). Actions listed in the plan have been being implemented since the beginning of 2011.

1. Recommendations resulting from a large-scale national consultation on adaptation to climate change

First, a large national, regional, and overseas consultation on the issue of adaptation to climate change was conducted. In 2010, five groups (elected representatives, employees' unions, employers' unions, NGOs, and administration), in addition to experts and citizens (via an Internet appeal), were mobilised to discuss the issue.

This led to the formulation of 202 recommendations dealing with biodiversity, water resources, natural hazards, health, agriculture, energy, infrastructure, tourism, planning, finance, governance, information, and research. Recommendations 115–121 deal with transport issues (details provided below). They are organised around the five following items.

1.1. The updating of existing procedures and guidelines

Assess, analyse, and adapt emergency plans and resources, on the relevant territorial scale, in order to coordinate the players involved in infrastructure and transport systems.

List and adapt technical guidelines dealing with construction, maintenance, use and safety of transport networks in mainland France and the overseas departments and territories.

1.2. Support for research

Promote scientific research on materials and structures that could provide solutions to climate change issues and on means or technical solutions allowing better and less expensive responses to climate change problems. Study the consequence of climate change on transport demand and the need for adjusting the service provided.

1.3. Communication and stakeholder awareness

Educate, communicate, and provide information about consequences of climate change and measures designed to implement adaptation to the general public, users, and different stakeholders concerned with transport systems.

1.4. Develop risk and vulnerability assessment

Define a methodology to perform a vulnerability diagnosis of infrastructure and transport systems, which could be provided to local authorities, network managers, and transport companies.

State the transport network vulnerability on the relevant spatial scale, taking into account evolution of the environment, structures, energy, water, and safety supplies.

Assess the vulnerability of airport infrastructures in mainland France and the overseas departments and territories.

Develop global and territorial strategies to find adapted and progressive answers to confront climate change issues. Identify elements that must be prioritised. Develop alternative servicing if possible.

1.5. Cope with sea-level rise consequences

Develop risk analysis and assessment tools for coastal areas.

- Modelling swell effects and coastal erosion.
- Produce a map taking these effects into account and the efficiencies of artificial and natural protections (sea wall, sand dune, mangrove swamp, coral reef, wet areas, etc.) to protect the coast, estuaries, and transport infrastructure in mainland France and the overseas departments and territories.
- Develop swell and coastal erosion modelling in order to identify areas that could be submerged.

Develop efficiency assessment tools:

- to assess the efficiency of artificial and natural protections previously mentioned to protect the coast, estuaries, and transport infrastructures in mainland France and the overseas departments and territories; and
- to assess the role of offshore bars in relation to the swell effects. Analyse their effects (erosion) and the aggravation of their impacts.

2. National plan for adaptation to climate change (PNACC)

During the first half of 2011, France produced the first national plan for adaptation to climate change (PNACC). It was established by Article 42 of the Law of 3 August 2009, 'Grenelle 1'. It will be immediately applicable and will run for five years. It is a national plan, rather than a state plan, i.e. it is written by the state but on the basis of a large-scale consultation.

It will bring together guidance on topics as diverse as flood defences, adaptation of coastal areas, development of forests, water issues, and economic adjustment. For transport, the plan aims to make the following available to public operators, property owners, and network managers:

- information, studies, and research findings to clarify the impact of climate change and to provide climatic parameters and values. This data will enable technical guidelines to be checked and vulnerability assessments to be performed;
- methodological tools that allow stakeholders to evaluate their responsibilities concerning climate change and to take the measures necessary to adapt. If required, the state, which is in charge of standardisation and has the power to make regulations, supported by its institutions and technical network, will be involved in the revision of French and European (Euro-codes) technical guidelines.

The plan also aims to:

- list the technical guidelines dealing with construction, maintenance, and the use and safety of transport networks; and
- encourage the vulnerability assessment of transport systems and the definition of adaptation strategies by providing data and methodological tools.

It should be noted that the effects of temperature increase, sea-level rise, and precipitation change are relative to the mean climate data of France but the effects could also have significance on regional and local scales.

1.6.1.a

SWAMP Storm water prevention—methods to predict flooding on and near road pavements in lowland areas	R&D project ERA-NET ROAD
Climate change challenge addressed: GIS tool (geographical information system) to analyse and predict flooding of roads	
Purpose of the work: <p>The result of the project's first stage is an overall guideline on how to identify the places that create most problems on or near existing roads, called blue spots, i.e. places where flooding occurs in extreme precipitation events.</p> <p>The result of the second stage of the project is a step-by-step guideline on the inspection, maintenance, and repair of the drainage system that is identified as a possible blue spot.</p>	
Beneficial for: All road administrations	
Time aspect: A continuous cycle	
Summary: <p>The SWAMP project targets the critical issue of identifying the most vulnerable parts of the road network and how to prepare them for flooding. The uncertainties inherent in predictions of future climate are significant. The climate research community is convinced that there will be a change, but admits it is difficult to precisely quantify the changes, for example, in terms of magnitude and frequency of rainfall. However, floods have always occurred throughout history and always will. Hence, identifying and improving road sections vulnerable to flooding is of great value irrespective of the severity of climate change.</p> <p>Areas close to roads that are prone to flooding are referred to as 'blue spots' in the SWAMP project reports (corresponding, for example, to the term 'black spots', which denotes areas where serious accidents occur on the road network). Given the vast distances covered by roads, an effective tool to assist in finding the weak sections would be very useful. Thus the objectives of the SWAMP project were 1) to determine the structure and requirements of a model to identify blue spots; and 2) to produce guidelines on how to reduce vulnerability to flooding at blue spots.</p>	
Publications: <p>The Blue Spot Concept, Danish Road Institute Report 181-2010</p> <p>Background Report, Danish Road Institute, Report 182-2010.</p> <p>The Blue Spot Model Report, Danish Road Institute Report 183-2010.</p> <p>Inspection and Maintenance Report, Danish Road Institute Report 184-2010</p> <p><i>Blue spot konceptet rapport 185</i> (Danish version), 2010.</p>	

Contact:

Project co-ordinator: [Danish Road Institute, Denmark.](#)

Blue Spot method

The main product of the project is the Blue Spot method.

In this study, three events/processes that can cause flooding of roads are considered:

- water accumulates in depressions due to a lack of capacity in the drainage system (or perhaps a complete lack of a drainage system!). The contributing drainage areas may be upstream catchments, as well as direct drainage from the road;
- the flooding of rivers, caused by insufficient downstream capacity; and
- flooding of low lying areas by rising sea-level

A method that can identify flood-sensitive areas in the road network is proposed. We refer to these as 'blue spots'. They are defined as areas where flooding is expected to take place in the event of extreme rainfall. The blue spots can be identified on the basis of previous experience, but new spots will appear on the road network as and when precipitation increases.

The analysis is divided into three levels, where each level helps to provide a better overview of the actual flood risk. As knowledge gradually increases, the numbers of risk areas will decrease.

The following figure shows an example of a Level-2 analysis, where the rain sensitivity of individual terrain depressions is evaluated. The Level-1 analysis considers elevation of terrain depressions only, and in Level 3, a hydrodynamic model of surface reservoirs and depressions is applied.



1.6.1.b

<p>Blue spot map</p> <p>Storm water prevention—methods to predict flooding on and near road pavements in lowland areas</p>	<p>Development of practice</p> <p>Denmark</p>
<p>Climate change challenge addressed:</p> <p>Increase in flood risk due to higher precipitation and sea-level rise</p>	
<p>Purpose of the work:</p> <p>Mapping areas especially prone to flooding</p>	
<p>Beneficial for:</p> <p>Planning, operation, maintenance, and repair</p>	
<p>Time aspect:</p> <p>A continuous cycle</p>	
<p>Summary:</p> <p>The work described here is a demonstration project within the SWAMP R&D programme, which is also described in 3.6.1.</p> <p>One of the aims of SWAMP was to develop guidelines on how to identify the places that create most problems on or near existing roads, called 'blue spots', i.e. places where flooding occurs during extreme precipitation events.</p> <p>The demonstration project described here shows the necessary data and procedures for developing a map based on the blue spot method. The same method can be used to develop the flood map for Denmark, which is planned for the near future.</p>	
<p>Publications:</p> <p><i><u>The Blue Spot Concept</u></i>, Danish Road Institute Report 181-2010</p> <p><i><u>Background Report</u></i>, Danish Road Institute, Report 182-2010.</p> <p><i><u>The Blue Spot Model Report</u></i>, Danish Road Institute Report 183-2010.</p> <p><i><u>Inspection and Maintenance Report</u></i>, Danish Road Institute Report 184-2010</p>	
<p>Contact:</p> <p>Project co-ordinator: Danish Road Institute, Denmark.</p>	

Data used in the analysis



The red rectangle indicates the study area, which includes 875 km of national roads.

The areas at risk of flooding were calculated on the basis of laser-scanned elevation data for a large part of Mid-Jutland. Laser scanning gives a rough terrain model, digital surface model (DSM), including buildings, vegetation, etc. The DSM model is then modified so that elements such as buildings and trees are removed.

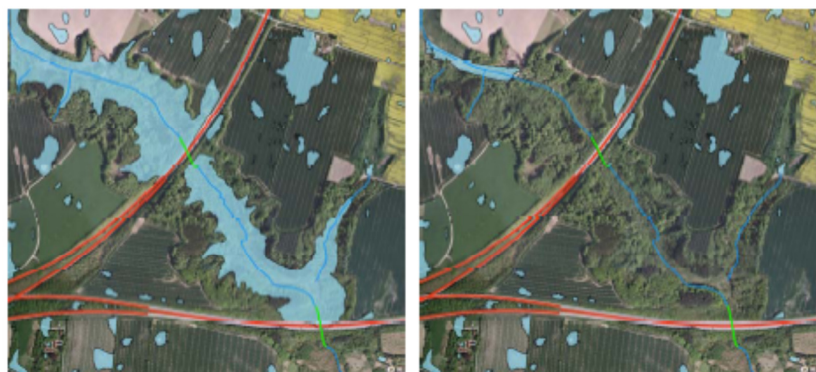
The result is a digital terrain model (DTM). Bridges, tunnels, viaducts, and waterways will not always appear with information about underpass in the terrain model. It is therefore necessary to assess whether there is the possibility of free passage of water through these or not. For this assessment the GIS layers used contain information on locations of bridges on the national roads in Denmark. Furthermore, there are

maps showing the location of watercourses, and aerial photos are used for evaluation of bridges and underpasses.

Elevation data was provided by the Danish Road Directorate in 75 sections of 10 x 10 km each. Grid data is available at 1.6 x 1.6 m (commonly used in Denmark) and a height accuracy of 10–25 cm on well-defined LIDAR surfaces. The analysis is performed at the highest level of detail equal to the density of the LIDAR scanning data (1.6 m x 1.6 m grid). To perform the analysis in this project, it was necessary to divide the total terrain model (75 x 10 x 10 km = 7,500 km²) into three parts. This was done because of the calculation speed and limitations in the software used. Where national roads cross boundaries, the results are uncertain.

Data processing

Risk areas are identified solely on the basis of depressions in the terrain. Ranking in relation to precipitation, basin area, soil conditions, and possible transport through drainage systems is thus not included. Only depressions with a minimum volume of 10 m³ are included in the study. All depressions are filled with water and, by calculating the difference in height compared to the original terrain and the spatial distribution of the depressions, it is possible to calculate the total volume of the depression. Bridges over water features, roads, or railways often remain in the DTM. Bridge removal is therefore necessary when doing flood modelling. If bridges are not removed they will appear as 'dykes' where water is likely to accumulate, thereby creating false blue spots. To verify this DTM-GIS layer, information from a database of locations of bridges on the national roads in Denmark was used. In addition, maps showing the location of streams, rivers, and orthophotos were applied.




Bridges and other crossings of rivers and

Blue spots before the barrier in the DTM was removed around Sønderjyske highway and Taulov motorway (left). Distribution of blue spots after an underpass has been introduced in the DTM (right).

streams will also appear as obstacles in the terrain model. These barriers are removed as well. An example of the effect of including these underpasses is shown in the figure below. In the left hand image the motorway appears as an obstacle for the river. This is corrected in the right-hand image where the obstacle is removed manually in the DTM and the river can pass. By doing this manually, however, errors may be introduced. For example, the river may discharge more water than the opening under the bridge can handle. In that case a potential blue spot would be removed.

The effect of sea-level rise is assessed by use of the DTM and a water-level value representing sea level. The terrain model can provide information as to where water from the sea can move into the coastal area, accumulate, and cause damaging flooding. For the calculations and visualisation of results, a method was developed that uses the facilities in the ArcGIS environment software from ESRI (www.esri.com). In addition, a number of other analytical tools were developed, including add-on programs for ArcGIS Desktop and proprietary programs that make it easier to handle large volumes of data.

1.6.1.c

National Flood Register	Current practice UK
Field of application: To improve emergency post-flood response.	
Beneficial for: Planning and design	
Climate change aspect included: Flood	
Time aspect: Current	
Summary: <p>The Highways Agency has already identified motorways and trunk roads vulnerable to flooding and has recruited emergency planning managers. The agency launched the National Flood Register in 2009 and is undertaking schemes to provide better emergency access to motorways. The National Resilience Team acts as national coordination for the Highways Agency in managing the National Risk Register.</p> <p>The Highways Agency responded to the Pitt Review (a response to severe flooding experienced in the UK in 2007) by working through Local Resilience Forums to further consider motorway and trunk road vulnerability. As a result they are improving their Emergency Customer Welfare Strategy to provide delivery of basic emergency welfare to stranded motorists.</p> 	
Publications: <u>Learning lessons from the 2007 floods - The Pitt Review</u>	

Contact:

ha_info@highways.gsi.gov.uk

Case Study: Highways Agency and Cumbria floods 2009

In November 2009, Cumbria suffered extreme rainfall, which contributed to one of the worst flooding events in the UK in recent years. Homes were evacuated and people temporarily rehomed in local welfare centres, which had been established by the emergency services. In addition, roads were closed and bridges severely damaged, which led to many local towns becoming isolated from the local area's infrastructure, such as shops, schools and hospitals.

Much of the flooding in Cumbria took place on the local road network, operated by the local authority, and parts of the all-purpose trunk road, which is managed by the Highways Agency's Area 13 service provider. The M6, which passes through Cumbria, was largely unaffected and traffic continued to travel on both carriageways during the event.

The Highways Agency was part of the Infrastructure Recovery Group, which included our service providers, Cumbria County Council (and its service providers), the emergency services, the military, utility companies, and district councils.

In November 2009, the agency offered the following assistance to the council:

- geotechnical engineers
- fluid engineers (modelling floods and impact - potential solutions)
- topographical surveys
- project managers
- vehicles/plant
- lighting units/generators
- access to the Highways Agency supply chain

The council took up the offer of vehicles, plant machinery, and lighting units/generators, but did not need to take up the remainder of the assistance offered. The agency provided the council with an under-bridge inspection unit (a significantly large and specialised piece of machinery) capable of giving access to the underside of bridges. This was sourced and delivered to-site, from Brighton, within 12 hours of the request and remained in place for a week.

1.6.1.d

Design rule adjustments for climate change adaptation	Current practice Denmark, Norway, Sweden
Field of application: Design and dimensioning of drainage in small catchments	
Beneficial for: Ensuring drainage capacity, flood protection	
Climate change aspect included: More rain and more intense rain episodes	
Time aspect: 30–50 years, corresponding to the service life of drainage systems	
<p>Summary:</p> <p>Several countries have carried out an adjustment of their drainage design rules to allow for more intense rainfall and generally more run-off. Climate change increases the importance of measuring run-off volumes and performing flood frequency analyses. However, in most cases, the necessary capacity will be calculated on the basis of precipitation levels and assumptions concerning surface properties.</p> <p>In the following, adjustments of drainage standards are defined through:</p> <ul style="list-style-type: none"> - adjustments of the return periods for precipitation; - the introduction of climate factors or similar; - the source of data for precipitation and precipitation intensity; and - requirements for minimum dimensions. 	

Denmark

Drainage design standards in Denmark were revised in 2009 (Vejdirektoratet, 2009. Vejkonstruktioner, Avvandingskonstruktioner).

Updates were given for return periods of critical events and a climate safety factor was introduced.

- For the design of pipes, culverts, and basins on the most important roads, the minimum return period for critical water levels (e.g. water levels exceeding road pavement level) is set at 25 years.
 - In addition, flood situations demanding full utilisation of the cross-sectional area of culverts should not occur more than once a year.

- Dimensioning precipitation is based on data series up to 2005. To compensate for increased precipitation in the future, a climate uncertainty factor is introduced. Recommended values for the climate factor originate from guidelines published by the Danish Society of Engineers, Water Pollution Committee (SVK guidelines no. 29). The values are the same as described in the Norwegian guidelines above: 1.3 when run-off calculations are based on a 10-year return period and 1.4 for a 100-year period.
- Independently of the climate factor, another factor is added, considering uncertainties rising from statistics and methods. This model factor should normally be in the range 1.1–1.5 based on the quality of available data.

Norway

Revised specifications for the design of drainage structures on the Norwegian road network are presented in the latest version of *Handbook 018* (issued in January 2011). The most important issues are listed below.

- The dimensioning return period is increased; 100 years in most cases. Run-off calculations are based on statistical methods using best-quality available data. Updated precipitation values are retrieved from web portal eklima.no.
- Plans for alternative flood paths should be considered when consequences of failure exceed acceptable risk level.
- Revised demand for absolute minimum dimension of culverts, depending on road class.
- Increased focus on existing structures with respect to latest design criteria and possible changes in land use within the catchments.
- Calculated run-off for small catchments based on precipitation measurements to be increased by a climate factor to compensate for expected climate change, K_f :

$$Q = C \times i \times A \times K_f$$

- The climate factor for structures with a designed lifetime of 100 years is given the value 1.3 when run-off calculations are based on a 10-year return period and 1.4 for a 100-year period.
- The run-off coefficient, C , is increased depending on the return period: by 10% for 25 years, 20% for 50 years and by 25% for a 100-year return period.
- For larger catchments, use of various alternative methods is encouraged to reduce uncertainties. Supplementary measurements should be considered:
 - Run-off measurements for a shorter period can be compared to long measurement series from another catchment for calibration. This allows long-term statistics to be converted to the catchment in question.
 - Measurement of short-term precipitation for comparison with run-off measurements

Sweden

Swedish design rules for drainage are given in VVMB 310 Hydraulisk dimensionering, 2008:61.

- Dimensioning precipitation is based on historical values, therefore a factor compensating for anticipated increase in future precipitation is introduced (see map to the right).
- The minimum return period should generally be 50 years. A risk analysis should be conducted for all projects.
- For exceptionally severe consequences, the 50-year flood values should be increased by 20%, giving a return period of approximately 200 years.

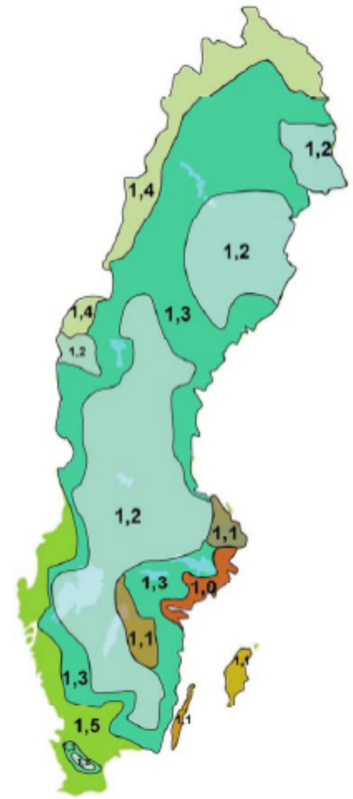


Figure: Geographic distribution of the climate factor for precipitation in Sweden.

1.6.1.e

Disastrous alumina sludge spill in 2010	Event in Hungary
Climate change challenge addressed: Heavy rainfall, flood	
Beneficial for: Planning, emergency plans	
Time aspect: Current climate, and future challenges	
Summary: This event was not caused by climate conditions and, in particular, not by climate change. However, floods due to intensive precipitation made the situation worse. This is used as an example of uncontrollable environmental effects in a wetter climate.	
Publications:	
Contact:	

On 4 October 2010, one corner of a sludge reservoir of the alumina plant in the town of Ajka broke and about 1 million m³ of liquid waste spilled out. The spilling sludge formed a wave of one to two metres in height and flooded half of the village of Kolontár, one-third of the town of Devecser, and a small part of the village of Somlóvásárhely, damaging about 50, 250, and 20 houses respectively. The sludge was extremely alkaline (pH value of 13) and caused the death of 10 people, who either drowned or suffered chemical burns. About 150 people with chemical burns were taken to hospital or given medical care.

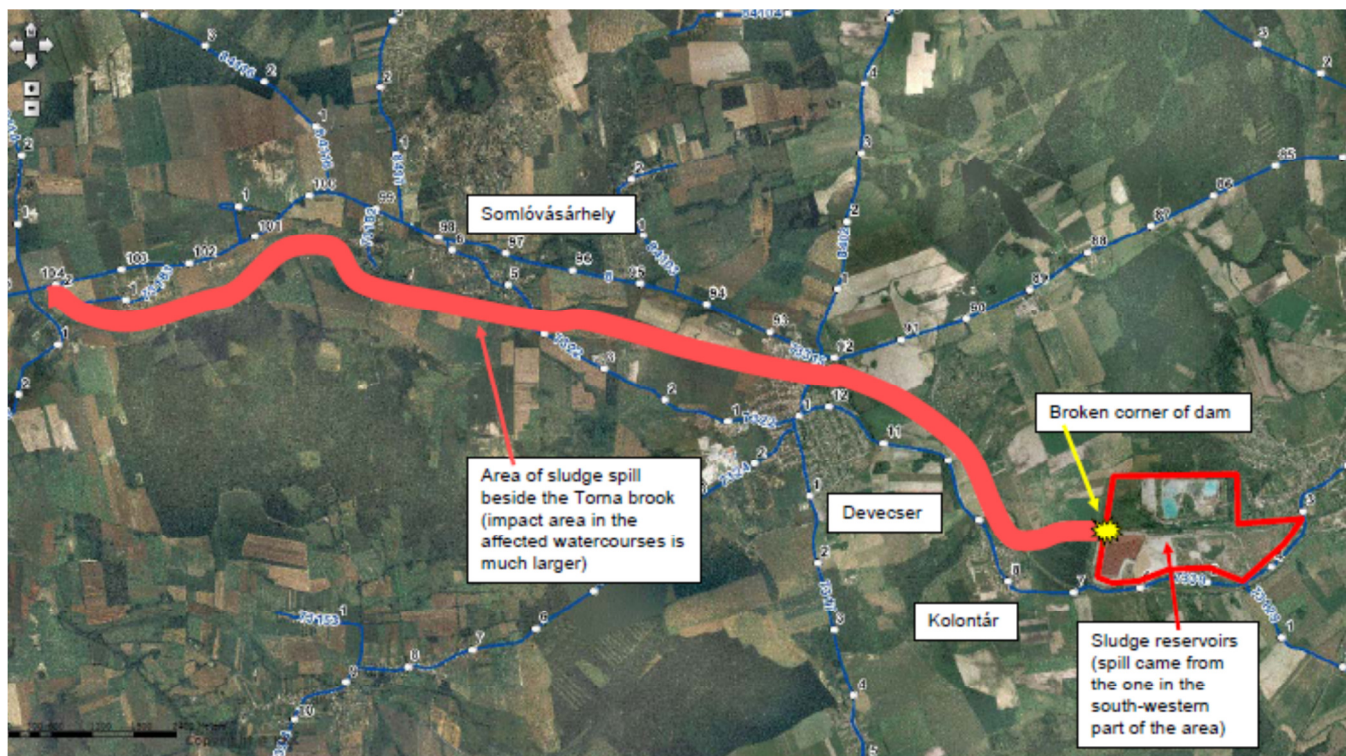
The flow of the sludge followed the watercourses and had a serious effect on some surface waters. All life was extinguished in the Torna brook and in the Marcal river downstream from the inflow of the Torna brook. Larger rivers, such as the Rába and the Danube, were affected by a pH value of only 9–10 due to the higher rate of dilution of the alkaline liquid, but even this lower concentration killed part of the fish population. The alkaline liquid content of another reservoir was neutralised by acids a day after the dam-break and was released into the Torna brook in order to dilute the contaminated water. Thanks to this intervention, it was possible to reduce the impact on the Rába and Danube rivers. The regeneration of waterways will be a natural process and may take years.

The sludge flooded about 10 km² of land. The heavy metal contamination was not significant; emission values were under the thresholds. The main effect on the soils was the high alkalinity that extinguished all life in the topsoil.

More than 2 million m³ of devastated soil has to be regenerated, therefore soil exchange is not viable. A two-stage method was applied: first an acidic treatment to neutralise the pH value of the soil, followed by a bacterial infusion to revitalise the soils' microbiological activity. Crops for human food or animal fodder will not be grown on these lands for a period.

After the flood, the deposited mud was washed off, removed from the contaminated surfaces, and transported to reservoirs.

Roads were affected only at some distance from the dam-break and, therefore, no significant damage was done to them. However, surface cleaning was necessary. The railway embankment was closer to the disaster and suffered greater damage as it was washed away by the flood in places.



It is difficult to say to what extent the weather contributed to the disaster.

The disaster occurred after a period of unusually rainy weather. The weather conditions were by no means the cause of the accident. In any case, the reservoirs containing dangerous substance (in such enormous quantity and so near to settlements) should have been designed, maintained, and operated in a way that would make such a fatal event impossible. However, weather conditions probably made the consequences more severe. A lot of rain in 2010 must have exerted an extra load on the bearing capacity of the dam and also the clay and soil layers underneath.

This example shows how dangerous industrial technology can be when it is not accompanied by protective measures that are adequate even in extreme weather conditions.

1.6.2.a

Landslide risk model	R&D project Norway
<p>Climate change challenge addressed:</p> <p>Risk assessment tool</p> <p>Enables assessment of risk from landslides and avalanches independent of landslide and avalanche history.</p>	
<p>Purpose of the work:</p> <p>Developing a way of describing risk from landslides and avalanches that is not based on historical events, but on analyses of physical factors that affect the probability of landslides and avalanches occurring, and factors that describe the possible consequences. Climate factors can be taken into account. This model is still at the investigation stage.</p>	
<p>Beneficial for:</p> <p>Comparing landslide and avalanche risk, including climate factors in risk evaluation</p>	
<p>Time aspect:</p> <p>Takes into consideration climate projections as far ahead as required, for example, by increasing the precipitation level.</p>	
<p>Summary:</p> <p>In the risk model, all types of landslides and avalanches can be included by developing a fault tree, with factors describing the release of landslides and avalanches. The fault trees include factors describing exposed terrain, geological parameters, weather conditions, and others. All these factors are given a score and weight contributing to the risk value calculated for a particular road section.</p> <p>Consequences are expressed in relation to the traffic volume and consequences for road users.</p>	
<p>Publications:</p> <p>Heidi Bjordal and Jan Otto Larsen, Norwegian Public Roads Administration (NPRA), Oslo, Norway: <i>Avalanche risk in a changing climate—development of a landslide and avalanche risk model</i>, International Snow Science Workshop, Davos 2009.</p> <p>Two reports in Norwegian available at: www.vegvesen.no/klimaoogtransport</p>	
<p>Contact: Heidi Bjordal, NPRA, heibjo@vegvesen.no</p>	

Higher winter temperatures will lead to less snow in low-lying and coastal areas. A reduction in the frequency of snow avalanches in some areas can already be observed. On the other hand, increasing precipitation and storm frequency will lead to a higher probability of snow avalanches in higher mountain areas where temperatures still remain cold. These effects could also trigger avalanches with increasing mass/volume, giving a longer run-out than previously recorded.

In order to improve the basis for studying how changes in weather will affect landslide and avalanche risk, it was decided to develop a landslide and avalanche risk model. One of the conditions in the development of the model was to go beyond the statistics and create a tool that can be used independently of where landslides, rockfalls, and avalanches have so far occurred. This will provide a model that is more robust in relation to climatic variations that might lead to greater hazards in some areas, and lower hazards in other areas. In the risk model, landslides and avalanches are described by factors affecting their probability.



The factors represent exposed terrain, geological conditions, weather conditions, and others. Each of them is given a score and weight factor which contribute to the total risk value on a particular road section. Consequences are similarly described with factors representing the traffic volume, amount of heavy traffic, presence of pedestrian traffic, importance of the road, and re-run time on the bypass road. The first use of the risk model will be to compare different road sections regarding risk level. The model will subsequently be used to develop a proposal for classification of probability and consequence. Finally, in order to evaluate climate change, the model can be used to consider changes in hazard due to climatic variations.

For the time being, the model is being tested on eight to ten landslide- and avalanche-exposed road sections in different geographic and climatic areas in order to see how differences are reflected, and to identify the need for further work on the calculation model.

1.6.2.b

Landslide and avalanche alert system	R&D project Norway
<p>Climate change challenge addressed: An increasing number of incidents related to weather and climate requires better collaboration and greater effort in preventing casualties.</p>	
<p>Purpose of the work: The Directorate of Water and Energy Resources (NVE) is establishing services that will warn of avalanche danger at regional level with the aim of reducing the number of accidents, casualties, and damage caused by avalanches on roads, railways, and close to buildings. A full-scale service will be established prior to winter 2012–2013, based on an ongoing test period from 2010 to the end of 2012.</p>	
<p>Beneficial for: Tourism, roads and railways, public safety.</p>	
<p>Time aspect: Dynamic data/current situation. Beneficial for adaptation to climate change.</p>	
<p>Summary: Target groups for the investigation are people who travel in avalanche terrain, municipalities, police, rescue groups, the military, ski resorts, and transportation authorities. The Meteorological Institute of Norway (www.met.no) will issue avalanche bulletins on behalf of NVE. A bulletin will be prepared on the basis of the cooperation between NVE, met.no, the Norwegian Public Roads Administration, the National Railway Administration, as well as consulting companies. The project partners contribute by sharing data, methods, and working hours. Two Norwegian web portals under development, Vegvær (sharing of weather data) and FøreVar (incident data and alert maps), are based on the approach of open data sharing. Observations from both paid observers and volunteers will be shared among the collaborating partners, and all registrations will contribute to a better forecast. This R&D project is inspired by methods applied in Switzerland, Canada, and the USA. It is however specific to Norway that the areas covered by this service are large and complicated to evaluate. Few weather stations pr km² require the involvement of additional observers and broad cooperation.</p>	
<p>Publications: For more information on avalanche alert, see www.nve.no/avalanche alert.</p>	
<p>Contact: Norwegian Public Roads Administration Tore Humstad, tohums@vegvesen.no</p>	

Point observations



1) Observations of avalanche activity and risk evaluations undertaken from a distance (i.e. from roads/villages), by road contractors, railway companies, municipalities, and local observers.

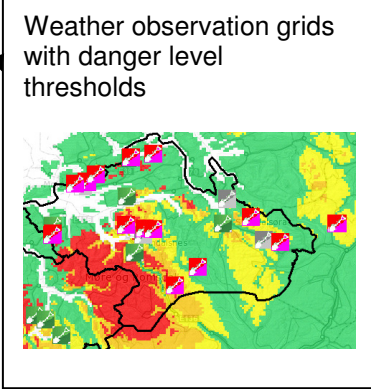
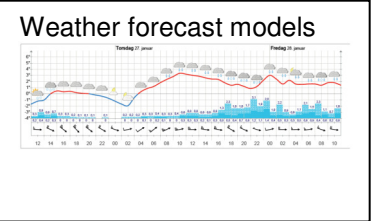


2) Snow measurements and weather observations, undertaken by:
 a) local inhabitants, such as farmers, park rangers, and employees of municipalities, or
 b) a coordinated network of official and automatic weather stations owned by the Meteorological institute, the Road and Railway administration



3) Stability tests of the snow pack in avalanche terrain, undertaken by avalanche experts, but also mountain guides, skiers, and park rangers who receive basic training.

Models and tools



Online registration system
www.nve.no/regobs

Avalanche expert group

Regional forecast and alert

Skredvarsel for regional testvarsling Romsdalen-Trollheimen

Dagens skredfare - **3 Markert**

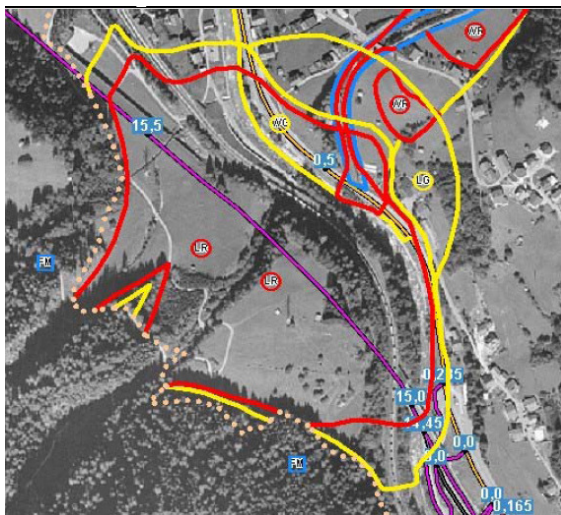
Mest utsatt himmelretning: Mest utsatt høydenivå: alle høyder

1.6.2.c

Hazard zone planning	Current practice Austria
<p>Field of application: In Austria, along larger rivers, in their surroundings, in streams exposed to debris flow, and hazard zones for avalanches.</p>	
<p>Beneficial for: Optimum combination of active and passive protection against natural hazards by taking into account the economic context. Tool to find the best alignment of new infrastructure with respect to natural hazards.</p>	
<p>Climate change aspect included: The risk assessment of natural hazards takes into account probable risk developments due to climate change (e.g. diminished stability of mountain rocks caused by the melting of permafrost). The time perspective is long enough to cover rare and very severe events as well.</p>	
<p>Time aspect: Natural hazards in a long-term perspective (up to 150 years) are taken into account.</p>	
<p>Summary: Along larger rivers, in their surroundings, along streams exposed to debris flow, in hazard zones for rockfall and avalanches, where it is not possible to move settlements and other land use into largely unchallenged areas, efforts are made to protect those areas with adequate technical measures against natural hazards and, at the same time, to take these hazard zones into consideration in the planning phase. The goal of hazard zone planning is the optimum combination of active and passive protection against natural hazards, taking into account the economic context. Hazard zone plans are developed in such a way that the level of risk is apparent in every location, and the borders are clearly defined, beyond which certain land uses are no longer justifiable (mainly the construction of buildings where people are constantly or temporarily present). The planning is evaluated and adapted after each major event and regularly every few years. Protective measures are planned on the basis of hazard zone plans. They can be divided into permanent and temporary measures.</p>	
<p>Publications:</p>	
<p>Contact: Klaus Gspan, ASFINAG klaus.gspan@asfinag.at</p>	

Hazard zone planning in Austria has its origin in the mid 1970s. It is carried out by an Austrian ministerial institute and provides the public with a general overview of probable hazards (rockfall, landslides, avalanches, and flooding) and a grade of risk. The planning is evaluated and adapted both after each major event and regularly every few years. In terms of future planning, consideration is taken not only of very frequent events, as was the case in the past, but also of those events that are less frequent (e.g. which only occur around every 150 years), but which are then more severe. The main criteria for taking an event into consideration is that it represents an essential threat to life and property (commonly referred to as a 'catastrophe' or a 'disaster').

Hazard zone plans are developed in such a way that the level of risk is apparent in every location and that the borders are clearly defined, beyond which certain types of land use are no longer justifiable (mainly the construction of buildings where people are constantly or temporarily present).



The hazard zones are marked in five different colours. The most relevant of these are:

Red danger zone: this area is endangered by natural hazards to such a degree that constant use for settlement or traffic is not possible, or only with a high level of investment.

Yellow danger zone: the area is endangered by streams exposed to debris flow and avalanches to such a degree that constant use for settlement or traffic is impaired.

Brown advisory zones: areas are denoted in which natural hazards exist due to mass-movements (rock- and stonefall, mud-flow).

*Example of hazard zone planning. Hazard zone maps are designed on a scale of 1:5,000.
 Source: www.tiris.at (web-based geo-information-system for the Austrian province of Tirol)*

Protective measures are planned on the basis of hazard zone plans. They can be divided into permanent and temporary measures. Permanent measures can be:

- technical measures that hinder landslides, rockfalls, or avalanches in the release area or protect infrastructure from being damaged;
- forest protection measures that include the maintenance, care, and recovery stage of assembled and mixed forests; and
- spatial planning measures ('hazard zone planning').

Examples of temporary measures are warnings, road blocking, evacuation, and active avalanche release.

Being responsible for the planning and construction of the Austrian highways, ASFINAG considers hazard zone planning when planning the alignment of a new road. A detailed simulation of all the probable risks in the relevant area is made during the planning phase. New simulations are based on a landscape model that is now created on the basis of laser scans.

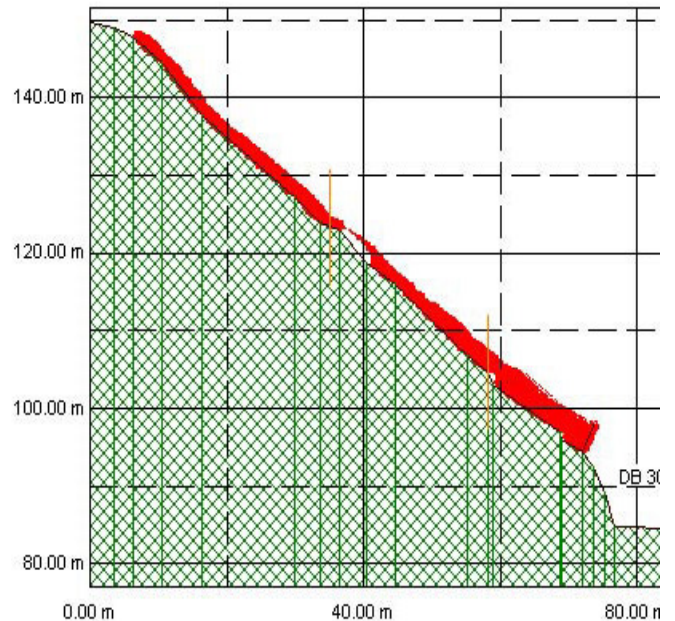
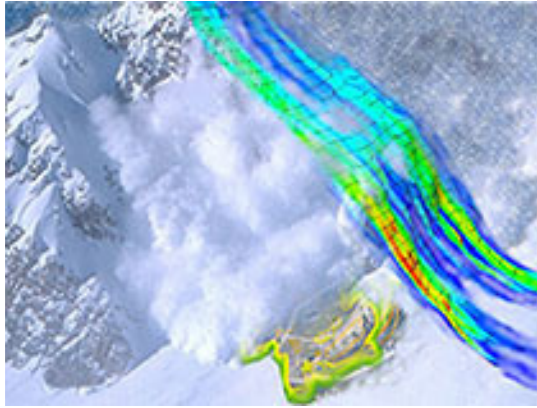
1.6.2.d

Simulation and prognosis of natural hazards	Current practice and R&D Austria
Field of application: Worldwide. Examples are given from Austria.	
Beneficial for: The use of simulation models contributes significantly to the improvement of protection measures and the prognosis of hazardous events.	
Climate change aspect included: R&D projects are dealing with climate change – factors and their influence on natural hazards.	
Time aspect:	
Summary: The use of simulation models contributes significantly to the improvement of protection measures and the prognosis of hazardous events. Reliable software is presented. An Austrian prognosis and documentation programme is presented. The R&D-projects GALAHAD, RIMES, and PARAMount are briefly described.	
Publications:	
Contact: Klaus Gspan, ASFINAG klaus.gspan@asfinag.at	

Simulation

The use of simulation models for avalanches in general and of **SamosAT** in particular contributes significantly to the improvement of protection measures. In addition to conventional methods (Chronicles etc.), they are used for hazard zone planning. With SamosAT (successor to the tried and tested SAMOS99), avalanches can be calculated in three dimensions.

For mud and debris flow as well as mass-movements, the 3D distinct element simulation programmes PFC2D and PFC3D (Particle Flow Code) are successfully used at the University of Vienna.



Left: Avalanche-simulation with SamosAT

Right: Result of a simulation with the program 'Rockfall'. The red area shows the area of influence, which is stopped by a protection system (net), to prevent rocks falling onto the road (B 416).

Prognosis

Avalanche Diagnosis System (ADS)

ADS supports decision-makers in assessing the risk of avalanche. Using mathematical methods, weather and snowpack data are analysed and the risk of avalanches is calculated. All important information—such as weather, snow cover, avalanche events, and the calculated risk of avalanches—are brought together in ADS, and clearly displayed.

Current data that is available in digital form can be automatically imported into ADS. When the programme is started, the current situation and the developments of recent days are displayed. The user can then enter snow cover data that cannot be levied automatically and document the events. The interpretation of the decision and additional information are also stored in the database.

The Austrian damaging avalanches database

The damaging avalanches database records avalanches resulting in injury or property damage. In this way, catastrophic avalanches can be distinguished from so-called 'accident avalanches' or 'tourist avalanches'. Catastrophic avalanches cause damage in urban areas (residential areas and business premises) and transportation-infrastructure. 'Accident avalanches' or 'tourist avalanches' occur when skiers and climbers are exposed in open terrain. The Austrian avalanche database is used as the basis for virtually the entire field of research and also as guidance for both active and passive natural hazard and crisis management measures.

R&D projects

The EU R&D project GALAHAD (Advanced Remote Monitoring Techniques for Glaciers, Avalanches and Landslides Hazard Mitigation), is a Specific Targeted Research Project under FP6-2004-Global-3. GALAHAD addresses landslide-, avalanche-, and glacier-related hazard mitigation, through the development of advanced monitoring techniques and the improvement of forecasting methods and tools. The GALAHAD project aims to develop innovative and fundamental functionalities of remote monitoring techniques, namely ground-based SAR interferometry, derived from satellite applications, and terrestrial laser scanning, enabling the improvement of reliability, precision, and operative usefulness of the measurements and the forecasting capacity of the interpretation tools.

RIMES: climate change and natural hazard risk management in the energy sector

Goals to be achieved:

- to identify climate change factors and their influence on natural hazards, and
- to develop a standardised method for integrated risk management in the energy sector, including a potential for damage analysis/system vulnerability analysis and a comparison of possible protective measures (permanent and temporary)

PARAMount ('imProved Accessibility: Reliability and security of Alpine transport infrastructure related to mountainous hazards in a changing climate'):

This research project aims to improve hazard management strategies for infrastructure protection through the adaptation of existing tools and practices for the transport sector (debris flow, avalanche, rockfall).

1.6.3.a

Pavements with a bituminous mix and high temperatures: the experience in Spain during the 1970s	Current practice Spain
Field of application: Road pavements for regions exposed to high temperatures	
Beneficial for: Pavement management, when previous bituminous pavement mixtures experience excessive rutting due to high temperatures	
Climate change aspect included: Adaptation to more frequent and higher extreme temperatures	
Time aspect: Regional differences. Already a challenge in Northern Europe.	
Summary: <p>The hot-mix asphalts technique was already established in Spain as a mature technique in the 1970s. Gradually, ordinary pavements were no longer dry bound macadam pavements, whether coated or uncoated with chippings. They were replaced with pavements made of asphalt mixtures on aggregate base layers of continuous grading or, where heavy truck traffic was more intense, pavements laid over cement-bound graded aggregate. This option has been especially developed since the 1973 oil crisis.</p> <p>However, in pavements with a bituminous mix, an unexpected problem began to emerge with worrying frequency: ruts. Once the problem surfaced, the Spanish NRA made a considerable effort to solve it, since it affected many kilometres of the national road network.</p> <p>For this reason, a systematic study had to be undertaken of bituminous mixes used and their formulation parameters. The problem was solved in 1975 through modified specifications for mixes, which included, among other changes, gradings of aggregate less sensitive to variations of the parameters involved, more limited use of bituminous binder, harder asphalt bitumens, higher percentages of filler and higher requirements for aggregates to increase internal friction.</p> <p>However, solving the ruts problem caused some side effects, which persisted until the turn of the century. Rut-resistant mixes proved to be too rigid, less resistant to fatigue and, above all, aged relatively rapidly. The durability of bituminous mixes in Spain proved to be shorter than mixes used in other countries. Since the 1975 specification changes and over the following 30 years, it has been possible to identify Spanish asphalt pavements with the naked eye, compared to those of other countries, not only due to the higher numbers of cracks, but above all due to their conspicuously paler colour, as a result of the lower asphalt bitumen content compared to other European countries.</p>	
Publications: <i>Los pavimentos en las carreteras españolas del siglo XX (Pavements of Spanish roads in the twentieth century), (in Spanish), M. A. del Val, Revista de Obras Públicas, Nº 3,482, November 2007.</i>	
Contact:	

It should be noted that the technology used in Spain at that time originated from the Asphalt Institute of the United States. However, the specific Spanish conditions meant that this imported technology should have been adapted before using it on Spanish roads. These conditions include, in particular, the high temperatures reached in the Spanish summer, in combination with some other specific features of the road network:

ascending gradients with:

- long *and* steep road sections;
- vehicles with high loads per axle (13 tons per axle);
- higher air pressure in tyres than permitted in other countries; and
- significant increases in heavy truck traffic

In some cases, the existence of pavement base layers treated with concrete triggers an anvil effect, speeding up rutting.

1.6.3.b

Costing the impacts of climate change linked to heat-waves on the transport infrastructure	R&D project France
Climate change challenge addressed: Temperature rise, especially higher summer temperatures	
Purpose of the work: Quantifying costs (to the order of magnitude) of high temperature on transportation networks	
Beneficial for: Risk management related to climate change for infrastructure Investigating the need for adjustments of design rules for pavements	
Time aspect: Estimated cost now and at the 2100 horizon	
Summary: An assessment of damage due to heat-waves was conducted in 2008.	
Publications: <i>Source: Rapport du groupe de travail interministériel—Groupe Infrastructures de transport et cadre bâti. Rapport de la seconde phase. Partie III – Rapports des groupes sectoriels.</i> (Report of the interdepartmental working group – Infrastructure and build frame group. Second phase report. Part III – sectorial group reports. (<i>in French</i>)) Paris 2009.	
Contact: andre.leuxe@developpement-durable.gouv.fr	

Because of the availability of data, discussions focus on the major national infrastructure networks in mainland France managed by the state. Thus although only 1.2% of the total length of the French road network was taken into account, this section represents over one-quarter of total traffic on French roads.

The rise in mean temperature leads to loss of rigidity in bituminous material and a reduction in its resistance to fatigue. When the mean temperature rises and heat-waves last longer, observed degradation includes creeping and bleeding tracking. Cracking from the bottom was also observed due to soil drying.

In France, the capping layer of roadways is designed in a uniform manner (it is similar in northern and southern parts of the country). However, the surface layer differs and must be adapted to different types of climate. In any event, climate change is expected to lead to an over-classification for the surface layer, in order to anticipate the consequences of more frequent heat-waves. The economic impact of the change in formulation does not seem significant.

Climate change could have a negligible effect on roadways, except on roads that cater for between 300 and 750 trucks per day. Altitude is also important, indeed when it comes to the pavement, frost plays at least as important a role as high temperatures

According to the expert working group, the disturbances observed following the 2003 heat-wave in France were too small and the uncertainty about their causes too great to justify changes in the specifications for pavement construction and maintenance. However, the effects of drying soil (especially clay soils), in the case of climate change and repeated heat-waves, would result in disruption to the maintenance of structures and would require repairs of an entirely different order of magnitude to what was observed in 2003. There is a lack of experience and data on the effects of an extreme temperature threshold in terms of consequences for the structure of roads with heavy traffic intensity, and repetitive effects of heat-waves or a succession of periods of excessive heat.

An estimate of the average cost (€10 million/km) for roads and the cost of rehabilitation (€250,000/km depending on network conditions) is provided. The historic average cost is the cost of reconstruction, but there are wide fluctuations in costs depending on geographic region and exposure to hot climates and heavy traffic. The costing of heat-waves based on a percentage derived from the UK case (15% of the annual maintenance budget to repair the damage due to heat-waves) leads to the range varying from €64 million to €70 million per year of heat-waves and a maximum overhead cumulative by 2100 of between €1.7 billion and €3.5 billion (assumptions of the working group in relation to repeated heat-waves). As a precautionary measure to take into account future effects of drought on soil structures, it is possible that this aggregate may be multiplied by two or three.

1.6.4.a

Pavement Performance and Remediation Requirements following Climate Change [P2R2C2]	R&D project ERA-NET ROAD
Climate change challenge addressed: Deterioration of road pavements due to climate change	
Purpose of the work: <ul style="list-style-type: none"> • to study the likely differences in moisture (water) condition in the pavements of roads in Europe, from the Alps and northwards, as a consequence of climate change; • to estimate the likely consequences for pavement and subgrade material behaviour and for whole pavement needs; • to perform this study for a range of representative pavement types and representative climatic zones; • to assess uncertainties to permit risk/vulnerability to be evaluated; • to define options for responding to the changes; and • to perform cost-benefit analyses to allow road owners to determine best options for their own situations. 	
Beneficial for: Pavement designers and pavement maintainers	
Time aspect: Anticipated climate change in Europe over a 110-year period from the mean climate in 1960–1990 to the mean climate in 2070–2100 was estimated using two (emissions) scenarios (A2 and B2) and two computational approaches.	
Summary: <p>Literature reviews, materials assessments, pavement design computations, and seepage flow calculations were carried out to determine the likely effect of the changes in water condition and temperature on typical pavement constructions.</p> <p>Temperature and precipitation increase will cause rutting and stripping and cracking from the top of the pavement. Less frost will have beneficial effects, apart from roads where frost is relied on for bearing capacity. Raised water tables may be a challenge in low-lying or coastal areas.</p> <p>Necessary responses are material requirements, and design criteria, sufficient drainage capacity, self-cleaning and easily inspectable systems, and stabilisation of unsealed pavements.</p>	

Publications:

Nine project reports available to download from:

<http://www.nottingham.ac.uk/~evzard/P2R2C2>

Contact:

Professor Andrew Dawson, Project Coordinator, University of Nottingham, UK.

The project was performed by a combination of literature review, laboratory evaluation of materials, computational studies of pavement structural and hydrological performance, and by the development of recommendations suitable for implementation by national road owners into their specifications and design guides.

Anticipated climate change in Europe over a 110-year period from the mean climate in 1960–1990 to the mean climate in 2070–2100 was estimated using two (emissions) scenarios (A2 and B2) and two computational approaches. The likely impact of the resulting changes in climate was then estimated for a range of pavements and pavement-related infrastructure, north of the Alps, in order to determine the consequences for road owners.

The predictions of climate change showed considerable local variation, but predicted principal manifestations of climate change in the study region can be summarised as: hotter summers in the southern edge of the study area, and a reduction in the length of winter in the far north, with longer periods of unfrozen pavement surface in much of the Nordic and adjacent countries. Greatest rainfall increases are anticipated in the Atlantic coastal areas of Norway and Scotland, proportionately to current rainfall levels, 20–30%. In addition, increased precipitation in the Alps and increased rainfall intensity in most areas are expected.

Possible expected effects on pavements are:

- In areas where rainfall is unchanged, subgrades and aggregate layers should be drier on average, improving somewhat. Even in wetter areas, the increased rainfall intensity is likely to result mostly in greater run-off, thus not causing damage.
- Temperature and rainfall increase will be a challenge for asphalts. Softer materials more prone to rutting and stripping can be expected. Increased cracking from the top of the pavement downwards is highly probable.
- The length of the frozen period will decrease in the far north with a reduced length of spring thaw—a mixed problem and benefit. To the south, in much of the Nordic area, frozen winter road structures may disappear altogether in some years. Periods during the winter season when the surface layers of the pavement are not frozen will become normal.
- In coastal and low-lying areas, raised water tables may be experienced due to points at which flood waters collect or due to raised sea levels.

However, the life cycle of the pavement is much less than the time span over which climate change will have a statistically dependable influence on pavement performance. This allows for gradual adaptation to climate change at times of future major pavement rehabilitation.

Required responses

The research team found that the considerable anticipated changes in climate would necessitate significant and deliberate responses. However, many such adaptations may be achieved economically. Adaptations include:

- routine material formulations, which can be employed during the next reconstruction event;
- adoption of new design criteria regarding temperature and return period of storm flows;
- obtaining sufficiency of drainage systems, self-cleaning and easily inspectable;
- resurfacing of 'perpetual pavements' with more rut-resistant and stripping-resistant materials; and
- stabilisation of many of the unsealed pavements in the mid and southern parts of the Nordic countries, or overlaying them with bound layers.

However, concentrating on these technical issues is unlikely to be a significant problem, nor a great economic challenge when compared with the necessary response from highway engineers to the wider social, economic, technical, and political impacts on pavements that can only be guessed at over the next 110 years.

1.6.4.b

ROADEX 'Implementing Accessibility'	R&D project European initiative
Climate change challenge addressed: Focus on general road condition management issues in harsh climates	
Purpose of the work: Technical exchange and cooperation across the road districts of the European Northern Periphery. Development and demonstration of new technologies.	
Beneficial for: All road administrations	
Time aspect: Continuous cycle	
Summary: The ROADEX project is part-funded by the Northern Periphery Programme. Since 1998, four successive projects have addressed the unique problems of roads servicing communities in harsh climates and conditions, and produced outputs specifically designed to improve the conditions of Northern Periphery rural roads. Although initially not focusing on climate change, the project covers various challenges related to climate change. ROADEX IV includes a subproject covering climate change. The subproject includes studying best practise. The project report will include a comprehensive checklist of risks and actions.	
Publications: Many reports and online e-learning modules, see www.roadex.org	
Contact: Climate change subproject leader: Ron Munro, Munroconsult Ltd, Park Terrace, Brora, KW9 6ND, Scotland Finnish representative on the project: Eira Järviluoma, Centre for Economic Development, Transport and the Environment Lapland, Finland	

The ROADEX Pilot Project, 1998–2001

ROADEX began in 1998 as a pilot project with the aim of 'Creating an effective technical exchange & cooperation across the road districts of the European Northern Periphery'.

The project brought together the ROADEX partner network from northern Finland, Norway, Scotland, and Sweden, and started the collaboration. Two subprojects were chosen to prove that sharing of roads-related information could work across the Northern Periphery area. These were:

- Subproject A, Road Condition Management; and
- Subproject B, Winter Maintenance.

The main objectives of these were:

- to minimise differences in winter maintenance standards between neighbouring countries;
- to reduce the number of weight restriction delays on Northern Periphery roads;
- to reduce environmental impact; and
- to increase accessibility for road users.

A special focus of the project was the minor, 'low-volume roads', i.e. those roads with limited traffic flows of fewer than 500 vehicles per day. The success of the pilot project inspired the partners to apply for a second project, ROADEX II.

ROADEX II, 2002–2005

The aim of the project was to develop 'Interactive and Innovative Road Management Practices for Low Traffic Volume Roads'.

The project commissioned basic research into the unique problems of roads servicing communities in harsh climates and conditions, and produced outputs specifically designed to improve the conditions of Northern Periphery rural roads:

- new monitoring techniques, new survey methods, and new analyses to identify trends in road condition;
- new road design and maintenance methodologies specifically suited to the climates, ground conditions and traffic flows of northern Europe; and
- new policies and protocols for politicians and decision-makers to give greater weight and funding to rural roads.

ROADEX III, 2006–2007

The aim of the project was to 'disseminate, transfer, and use the new ROADEX knowledge across the Northern Periphery area'. Examples of dissemination works include:

- the www.roadex.org website to share the collected information;
- practical manuals for working engineers in the six partner languages; and
- an e-learning training package on 'permanent deformation'.

ROADEX IV, IMPLEMENTING ACCESSIBILITY, 2009–2012

This three-year project aims to change construction and maintenance of rural roads across the Northern Periphery by demonstrating what is possible when the new ROADEX technologies are used.

Demonstration projects of the ROADEX methods will be carried out in the local partner areas, supported by a new pan-regional 'ROADEX Consultancy Service' and Knowledge Centre. Through them, roads administrations will be able to experience directly the benefits and cost savings available and so encourage their adoption through their organisations. Joint research and development will also continue in the areas of climate change, road widening, and the health issues that can arise from poorly maintained roads.

1.6.4.c

Survey of surface frost heave problems	R&D project Finland
<p>Climate change challenge addressed:</p> <p>Due to climate change, frost heave problems may become more frequent in areas that previously had stable winter conditions. In particular, surface layer problems during winter are more common because the period without freezing conditions has increased.</p>	
<p>Purpose of the work:</p> <p>The purpose of the work is to specify the material and conditional factors that cause frost heave. The study also aims to find out how to identify these factors and presents preventive actions.</p>	
<p>Beneficial for:</p> <p>Maintenance, reconstruction, and construction of gravel roads</p>	
<p>Time aspect:</p> <p>Dynamic. There are already problems but they will be more frequent in the near future.</p>	
<p>Summary:</p> <p>The study was published in December 2008 by the Finnish Road Administration. It was performed in cooperation with Sito Oy Tampere, Tampere University of Technology and Destia.</p> <p>The study included three stages:</p> <ol style="list-style-type: none"> 1. field investigation: mapping the scale of the problem in Vaasa and Häme region; 2. laboratory tests of problematic material; and 3. recommendations for management actions. <p>It was common for all the materials in problematic roads that the quantity of biotite mica was high and dielectricity was high. The material also often had weak wear resistance. Other factors that cause frost heave and were examined in this study were wearing course thickness and profile.</p> <p>On the basis of the study, the authors and the work group recommended some essential actions.</p>	
<p>Publications:</p> <p>Taina Rantanen, Kari Pylkkänen, Teuvo Kasari: <i>Survey of surface frost heave problems</i> (in Finnish only); Tiehallinnon selvityksiä 12/2008, ISSN 1457-9871; ISBN 978-952-221-047-0</p> <p>http://alk.tiehallinto.fi/julkaisut/pdf2/3201092-v-pintakelirikkoselvitys.pdf</p>	
<p>Contact:</p> <p>Anne Valkonen, Centre for Economic Development, Transport and the Environment Pirkanmaa; PL 297, 33101 Tampere, Finland. Tel. +358 40 5797939</p>	

Results of the survey

The model for preventing surface frost heave problems:

- A Existing problems
 - 1 Identifying the problems with the help of visual surveys
 - 2 Actions on identified problems: improving the profile within maintenance, narrowing the road, other maintenance actions
- B Preventing problems
 - 1 Material choice
 - 2 Improving drainage
 - 3 Improving profile
 - Removing edge curls
 - Maximum width 6–6.5 m
 - Minimum crossfall 4–5%



Figure 1: Surface frost heave problems on a gravel road

On the basis of the survey, the authors and the work group recommend the following essential actions:

- proper design of the profile and maintenance of the profile;
- ensuring the functionality of the surface drainage system;
- inventory of the surface frost heave problem with a three-level scale; and
- contracts should include requirements for wear resistance and for the quality of fine fraction of material in areas where frost heave is a problem.

Recommendations for material in contract documents:

- 1 tube suction factor < 16
- 2 maximum amount of soft minerals 30%
- 3 ball mill test requirement 22, or equivalent MicroDeval–value 15
- 4 new standard range for grading curve, especially for amount of filter < 2%

1.6.5.a

Vulnerability of transport infrastructure to coastal hazards	R&D project France
Climate change challenge addressed: Sea-level rise	
Purpose of the work: Identification of the low-lying areas that may be impacted by coastal flooding Simulation of the effect of climate change by investigating the consequences of sea-level rise	
Beneficial for: Government and managers of infrastructure networks: planning of new infrastructure, risk assessment, and maintenance of existing infrastructure	
Time aspect: Anticipation Projections to simulate the situation in a context of climate change	
Summary: In 2007–2009, an interdepartmental group assessed the impacts of climate change, adaptation, and associated costs in France. In this context, the vulnerability of infrastructure to sea-level rise and submersion were assessed. Low-lying areas were identified and mapped along the coast of the French mainland. Road and rail networks were then added to the map. The linear transport infrastructure affected by centennial sea level was estimated to be close to 17,000km.	
Publications: Pons, F.; Roux, I.; Desiré, G.; Boura, C.; Perherin, C.; Roche, A., <i>Vulnérabilité du territoire national aux risques littoraux</i> , CETMEF, 2009. (In French) Le Cozannet, G., Lenôtre, Nacass, P.; N.; Colas, S.; Perherin, C., Vanroye C; Hajji, C.; Poupat, B.; Azzam C. Chemitte, J.; Pons, F., <i>Impacts du changement climatique, adaptation et coûts associés en France pour les risques côtiers; rapport du groupe de travail 'risques naturels, assurances et adaptation au changement climatique'</i> , BRGM RP 57141. April 2009. (In French)	
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The vulnerability of transport infrastructure to coastal hazards was assessed through two parallel approaches:

- identification, throughout France, of the areas that may be affected by coastal flooding (areas below the centennial sea-level extremes) and simulation of the effect of climate change on these areas; and
- on the scale of the Languedoc-Roussillon region, assessment of the consequences of permanent flooding of areas, which could result in destruction of some infrastructure capital.

In both cases, the mapping of risk areas has been infused with data on road and rail infrastructures.

Determination of the low-lying areas

The vulnerability of coastal zones is determined by mapping of low areas. The 'lowlands' fit with topographic zones beneath the current centennial extreme levels. The impact of climate change on the extent of these areas of vulnerability is identified through the mapping of areas that lie below the current centennial extreme levels +1 m. This simulates the areas potentially flooded by a centennial event if the sea-level rise was 1 m.

Three scenarios are identified to assess the impact of sea-level rise over low-lying areas: a rise equivalent to 'centennial level -1 m', 'centennial level' and 'centennial level +1 m'. Coastal development and dams on estuaries are not included in the study.

Transport infrastructure

Data from road and rail databases were used to supply the map with infrastructure. Moreover, ecologically valuable areas were taken into consideration by including the low water areas (ponds and marshes), as they can be crossed by roads or railways, and are often included in the ecological zoning.

Roadways are prioritised and ranked as motorways, highways, main roads, and others. Railways are identified as portions of tracks for TGV tracks, main tracks, other tracks, and marshalling yards. Identified road and rail track sections are overlaid with low-lying areas at the three centennials sea levels.

Results

Along the coast of the French mainland, the linear transport infrastructure affected by centennial sea levels is close to 17,000 km.

Some regions are more affected than others.

	Location of structures:		
	Below the centennial sea level -1m	Between centennial sea level -1m and centennial sea level	Between centennial sea level and centennial sea level +1m
2.1. Highways % of <i>national</i> length of roads	160 1.30%	301 2.50%	355 2.90%
National roads % of <i>national</i> length of roads	79 0.70%	148 1.30%	198 1.70%
2.2. Departmental roads 2.3. % of <i>national</i> length of roads	2074 0.50%	3314 0.90%	4338 1.10%
2.4. Other 2.5. % of <i>national</i> length of roads	7032 1.12%	11559 1.84%	15522 2.47%
2.6. Railways 2.7. % of <i>national</i> length of rails	812 2.16%	1482 4.80%	1967 6.3%

Table: National road and rail infrastructures located in low-lying areas (in km)

1.6.6.a

Winter resilience	Current practice UK
Field of application: To review the preparedness of the Highways Agency to manage adverse winter conditions	
Beneficial for: Network operation, including accessibility to the network and the safety of road users	
Climate change aspect included: Adverse winter conditions, including +/- 0 temperatures and snowfall intensity	
Time aspect: Current	
Summary: <p>An independent review* into the resilience of England's transport system to severe winter weather was published in October 2010. The report recognised the Highways Agency's successes in this area.</p> <p>Following the harsh winter conditions of recent years, the guidance on treating roads has been updated. The agency's modern fleet of efficient pre-wet salt spreaders use around 25% less salt than the fleet of vehicles they replaced. It is, therefore, expected that the agency should consume less salt in the years ahead.</p> <p>On 1 December 2010, the Secretary of State asked David Quarmby CBE to carry out an urgent audit of how well the highway authorities and transport operators in England, including the Highways Agency, had been coping with the unexpectedly early and severe spell of winter weather.</p> <p>Despite the severe weather conditions in 2010, the vast majority of our network remained open. The agency's winter fleet and service providers worked around the clock with continuous salt treatment and snow ploughing where required. Where incidents occur on the network, the agency's traffic officers, service providers, and maintenance teams work with the police to re-open lanes as soon as it is safe to do so.</p> <div data-bbox="557 1697 1136 2018" data-label="Image"> </div>	

Publications:

*[The resilience of England's transport systems in winter, an independent review, October 2010](#)

Contact:

ha_info@highways.gsi.gov.uk

1.6.6.b

<p>IRWIN</p> <p>Improved local winter index to assess maintenance needs and adaptation costs in climate change scenarios</p>	<p>R&D project</p> <p>ERA-NET ROAD</p>
<p>Climate change challenge addressed:</p> <p>Temperature rise and freeze-thaw fluctuations; winter maintenance and bearing capacity applications</p>	
<p>Purpose of the work:</p> <p>Using the database and widely accepted climate models and scenarios, the new improved winter index will downscale the large-scale climate variations to local road network scale. Winter maintenance needs and cost/benefit analyses can thus be assessed with better spatial resolution in the current and future climates.</p>	
<p>Beneficial for:</p> <p>Winter maintenance, road management during periods of thaw-weakening</p>	
<p>Time aspect:</p> <p>A continuous cycle</p>	
<p>Summary:</p> <p>The main objective of IRWIN is to develop an improved winter road index capable of assessing the implications of climate change in various weather parameters and also related road maintenance actions. The idea is to combine the best traditionally made climate scenarios with the much more accurate spatial data from field stations in the Road Weather Information Systems (RWIS) in Sweden and Finland.</p> <p>The need for maintenance operations will change in the different regions as the climate changes. A warmer climate can mean both greater need for salting due to more slippery roads, but at the same time fewer ploughing events when precipitation falls as rain instead of snow.</p> <p>The index developed in this study has proved to be a useful tool for future maintenance operations. It can give valuable information to stakeholders as to where and when measures need to be taken. Possibilities were also investigated of using road weather data from other ERA-NET countries to perform similar calculations.</p> <p>With well-defined interfaces, the new system can easily be adapted to other countries outside the project test areas in Sweden and Finland.</p>	
<p>Publications:</p> <p>IRWIN Final Report, 2009.</p>	
<p>Contact:</p> <p>Project co-ordinator: FORECA, Finland.</p>	

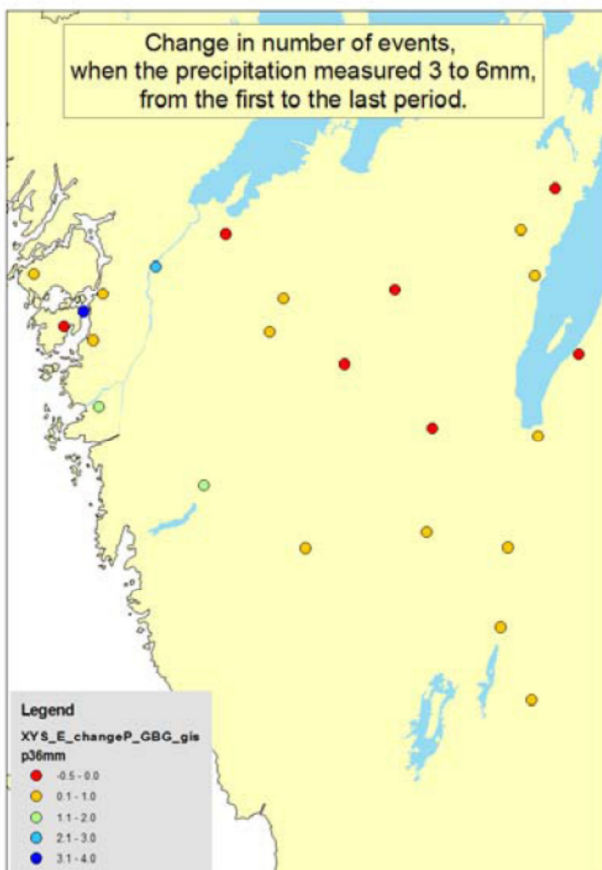
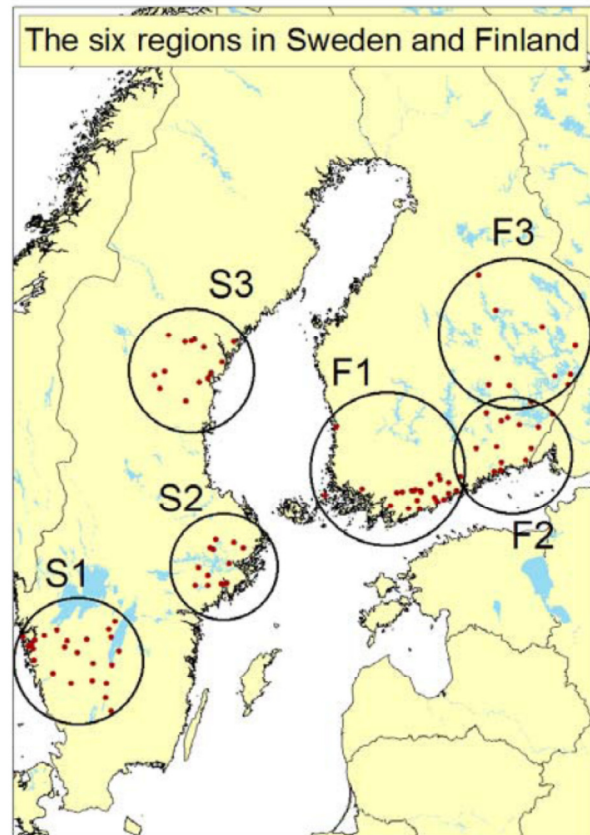
Demonstrating the new IRWIN winter index

Precipitation

Historical observations were analysed to understand the actual climates in the study areas, to see the natural variations in climate both within and between the six different regions (shown in the figure to the right), and to be able to compare the observed values to the future modelled changes. Data from 1 October to the 31 March, 1997 to 2008, were studied, and it was on the basis of this historical data that the modelled future scenarios were done.

In the map below, extreme precipitation changes are plotted from the first 30-year period (1980 to 2010) to the last 30-year period (2025 to 2055) in southern Sweden (the S1 region). The western areas will experience more extreme precipitation in the future compared to today. The changes for the inland and more easterly stations are not as great, although an increase is expected for most areas.

The figure shows extreme precipitation changes in mean number of events (30-minute periods) from the historical to the future period in S1 region.



User benefits

Using a more accurate index such as IRWIN, many benefits are expected:

- better representation of weather and climate of the road network gives better linkage between weather and maintenance needs;
- the IRWIN index provides a better understanding of local weather variations;
- IRWIN is a user-friendly tool when assessing the impact of climate change on maintenance needs;
- the IRWIN index provides better coverage of extreme events, such as heavy snowfall or strong winds; and
- after assessing the potential change of maintenance needs and actions compared to the present, it is straightforward to assess the monetary implications to road owners in the changing future climate.

1.7.a

RIMAROCC Risk management for roads in a changing climate	R&D project ERA-NET ROAD
Climate change challenge addressed: Risk analysis and management tool	
Purpose of the work: To develop a method to support decision-making concerning adaptation measures in the road sector	
Beneficial for: All road administrations	
Time aspect: A continuous cycle	
<p>Summary:</p> <p>The RIMAROCC project is one of four pan-European projects initiated under the ERA-NET ROAD initiative 'Road Owners Getting to Grips with Climate Change' completed in 2010. The objective of the RIMAROCC project was to develop a common method for risk analysis and risk management with regard to climate change.</p> <p>The purpose is to support decision-making about adaptation measures in the road sector. To facilitate the work of end users, the method is based upon—or is at least compatible with—general existing methods of risk analysis (and management) within the ERA-NET ROAD funders and other relevant methods. The project focuses on risk analysis (with risk assessment, risk management in cost-benefit analysis, and level of acceptable risk) and on risk management options.</p> <p>The project resulted in a complete guidebook on the proposed method. 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 optimum action plans that maximise the economic return to the road owner, taking into account construction cost, maintenance, and environment.</p>	
Publications: <i>Risk management for roads in a changing climate. A Guidebook to the RIMAROCC Method, 2010.</i>	
Contact: Project coordinator: SGI, Sweden.	

The RIMAROCC method is designed to be general and to meet the common needs of road owners and road administrations in Europe. The method seeks to present a framework and an overall approach to adaptation to climate change. It is based on existing risk analysis and risk management tools for roads within the ERA-NET ROAD member states and others.

The RIMAROCC guidebook

The main product of the project is the RIMAROCC guidebook.

The guidebook consists of three parts.

Part 1: Basis for climate and risk management

Part 1 provides the reader with useful background information for understanding the subsequent 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

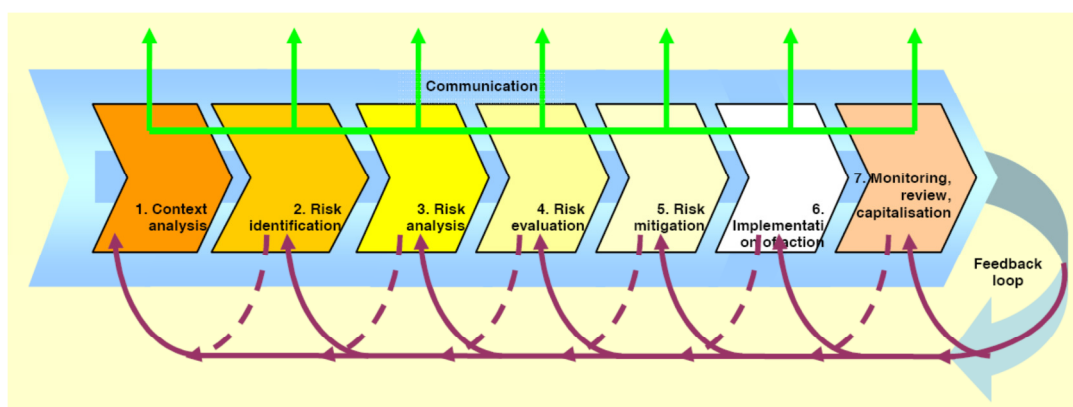
The RIMAROCC framework is presented step by step. The framework consists of seven steps, each with a number of sub-steps. All steps are presented in the same way, starting with a summary of the step and a list of the sub-steps. The sub-steps are structured as follows:

- 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

Part 3 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 and what the possible adaptations of the overall methodological framework could be as well as the method, scope, and limitations.

The step-by-step procedure suggested by the RIMAROCC method:



1.7.b

GeRiCi project ⁴⁰	R&D project France
<p>Climate change challenge addressed: Risk assessment and risk management tool, applicable for all climate parameters and related hazards</p>	
<p>Purpose of the work: To develop a model that assesses vulnerability of all sensitive components of an infrastructure, based on a risk analysis</p>	
<p>Beneficial for: Risk assessment and real-time monitoring for emergency planning</p>	
<p>Time aspect: A continuous cycle. The method can be applied with any chosen climate scenario or weather event.</p>	
<p>Summary: A GIS-based risk assessment tool was developed by the GeRiCi project. The tool can be used for systematic screening of infrastructure with respect to vulnerability to different climatic threats. The tool is used both in simulation and on alert. In the case of a simulation, it verifies the weak links in the infrastructure during specific climatic conditions. Based on the issues that occur, preventive action can be initiated. On alert, the tool displays the direct impact of the anticipated climate event on infrastructure, allowing road administrators to react in time. The risk analysis method used in GeRiCi is based on several existing approaches, such as those described in PIARC publications, or the FMECA (Failure Modes, Effects, and Criticality Analysis) method. The method is also based on the established standards and guidelines, especially the French FD X50-252 guideline for risk assessment and management issued in February 2006. It has applied lessons learnt from risk management in highly sensitive domains such as the nuclear industry.</p>	
<p>Publications: Hervé Guérard and Michel Ray: <i>Le projet GeRiCi: gestion des risques liés au changement climatique pour les infrastructures</i> (The GeRiCi project: management of risks related to climate change for infrastructure), RGRA N° 854, December 2006.</p>	
<p>Contact: EGIS Group, GeRiCi project manager: Hervé Guérard.</p>	

⁴⁰ Based on the text from the RIMAROCC report *Existing methods for risk analysis and risk management within the ERA-NET ROAD countries - applicable for roads in relation to climate change*, June 2009.

The GeRiCi project was conducted by a consortium of partners: Egis Group, two groups operating highways under concession (Sanef and ASF), two governmental agencies (Météo-France and Laboratoire Central des Ponts et Chaussées), and a GIS consultant (ESRI France). The project was funded by the Ministry of Public Works in France.

On the basis of a socio-economic analysis, the GeRiCi approach provides assistance to the authorities responsible for structuring and establishing priorities for future investment, and in the case of the prediction or announcement of an exceptional event, defining the process for taking the most relevant emergency measures in collaboration with the other partners, including the emergency services.

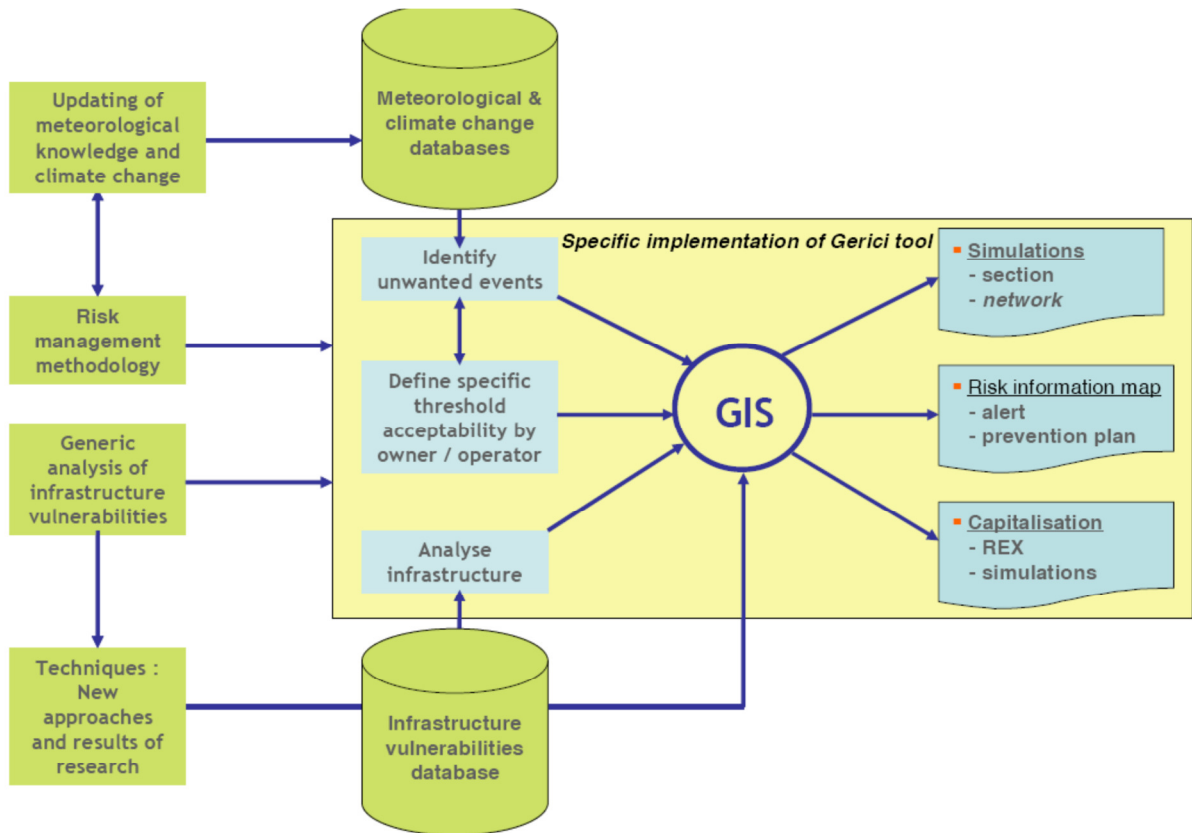
The systematic approach implemented by GeRiCi highlights the links between the elements of hazard and risk. The project has made it possible to model the danger in more general terms, as a process chain leading a source of danger to trigger disastrous effects on infrastructure, users, residents, the environment, etc.

Main steps in the approach

The different steps in the approach are described below. A synthesis of the GeRiCi approach is shown in the figure below.

1. Establish context: as a basis for the research work involved, it is necessary to measure and define requirements, introduce a common vocabulary comprehensible to all, and determine the elements to be integrated into the GIS tool.

2. Identification of risk factors: the risk factors are divided into three groups: climatic factors, infrastructure-intrinsic factors, and site factors. The climatic factors included in GeRiCi are rain, floods, wind, snow, and low and high temperatures. They are regarded as long-term sources of hazard for the infrastructure and its components, continuity of service, and residents. Examples of intrinsic factors are: mistake in design, lack of maintenance on hydraulic pipes, etc. Examples of site factors are: development of urbanisation, waterproofing of soils, etc.



3. Risk analysis: risk analysis is undertaken qualitatively or quantitatively, depending on the possibilities and requirements. In order to characterise vulnerability, the infrastructure (motorway) is divided into seven areas: major hydraulics, minor hydraulics and drainage, engineering structures, equipment, geotechnical, environment, and pavement. In each area, the components of the infrastructure are classified in families, according to their degree of sensitivity to the unwanted events. Three typical thresholds are established for each element: dimensioning level, critical level, and breaking level. The infrastructure analysis is conducted in cooperation with road operators and experts.

4. Risk evaluation and risk map: the infrastructure is digitalised into a number of geo-referenced objects in the form of a table, which also contains technical and vulnerability characteristics for each object. The information is then displayed in a GIS. When applying a meteorological event of a defined type and intensity to a chosen infrastructure section, each object sensitive to the selected event is displayed in graphic form, using a colour code, according to the sensitivity level that is likely to be reached during the event. Results are analysed in light of their foreseeable consequences on: costs, infrastructure durability, continuity of service for users, user safety, and environmental effects. Critical scenarios are identified and displayed in a frequency/severity risk matrix.

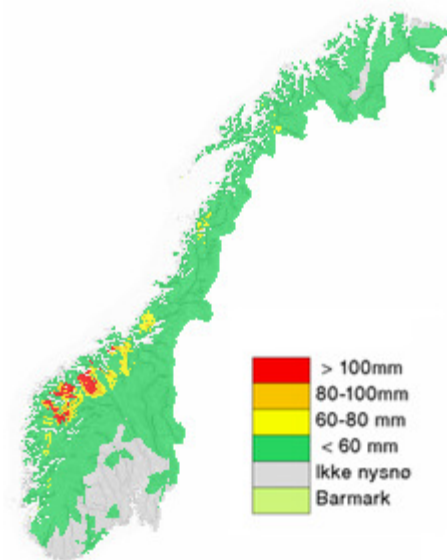
1.7.c

Føre Var web portal	R&D project Norway
Climate change challenge addressed: Risk management tool Emergency planning based on good weather data, ground data, and history of events	
Purpose of the work: Dynamic use of weather data for better road operation and better prediction of weather-related events	
Beneficial for: Everyone working with operation and emergency systems, contractors, and producers of avalanche and landslide bulletins	
Time aspect: Dynamic. Real-time weather information and weather forecasting. There is a possibility of introducing climate change projections to simulate the situation in a changed climate.	
Summary: The Norwegian Water Resources and Energy Directorate (NVE) cooperates with the Norwegian Meteorological Institute, the public roads administration, and the railway administration, in order to make a dynamic web-based map system to present information about dangerous weather conditions. The development was initiated during the Climate and Transport Project 2007–2010 and will continue as an integrated part of a new avalanche and landslide warning project in the period 2011–2012. This project is managed by NVE.	
Publications:	
Contact: Norwegian Public Roads Administration, Tore Humstad, tore.humstad@vegvesen.no	

In the web-based, dynamic map portal, Føre Var, which was developed by the Norwegian Water Resources and Energy Directorate (NVE), in cooperation with the Norwegian Meteorological Institute, the public roads administration, and the railway administration, Norway's weather situation is presented in a map of 1x1 km² grid cells. For each cell, certain selected weather parameters are generated from interpolations of precipitation, temperature, and snow depth data. The data sources are 155-455 weather stations throughout the country. Based on combinations of this data, a distinction is made between precipitation as snow or rain. In addition, derived data, such as ground-water level, snowmelt, and snow cover conditions, are appointed to each cell, based on hydrological models.

Both observations (analysis tool) and prognosis (awareness tool) are presented at a resolution of one day. The project partners have developed a specification for how to use the above-mentioned data and present them relative to threshold values instead of absolute data. The idea of presenting the weather parameters relative to different threshold values is to identify extreme weather conditions and weather conditions that present a challenge in terms of keeping roads and railways operating. These threshold values are mainly related to weather which, empirically, has led to avalanches, snow disasters, landslides, and rock falls. Achieved threshold values are presented by a colour scale of yellow, orange, and red, where red corresponds to the greatest hazard. A green area on the map indicates that weather conditions are favourable. Grey grid cells indicate that the unfavourable weather condition is non-existent.

The following figure is an example of a map showing 'Snowfall in the last three days' from a snowy day, which presented several snow avalanches in the red-coloured area on 1 January 2011.



The development of the tool was initiated by the Norwegian Public Road Administration through the Climate and Transport Project during 2009–2010. The themes mentioned in the table below were included. Experiences from the project show that there are clear links between some of the map themes and problems recorded on the roads and railways. Other themes are less clear. It has also proved to be necessary to level the inter-relationship of the different threshold values, so that the same colours represent more or less the same danger level in the different themes included.

	Themes	Data sources	Possible hazard mitigation related to
1	Water supply last 24 hours	Precipitation/rainfall, snowmelt, and snow cover	Debris flows
2	Water supply last 24 hours	Precipitation/rainfall, snowmelt, and snow cover	Debris flows
3	Snowfall last 24 hours	Precipitation/snowfall	Snow disaster
4	Snowfall last 24 hours	Precipitation/snowfall	Snow disaster and avalanches
5	Freezing, thawing and water supply last 10 days	Temperature variation, precipitation, rainfall, snowmelt, and snow cover	Rockfalls and rockslides

For 2011–2012, the development of the web portal will continue with a snow avalanche and landslide warning project managed by Norwegian Water Resources and Energy Directorate (NVE).

1.7.d

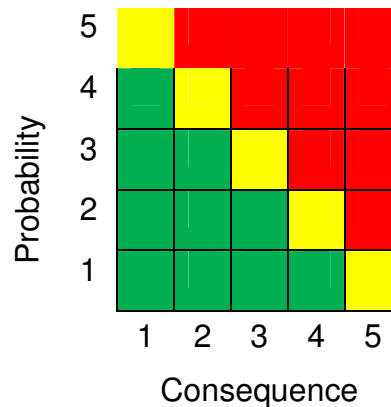
Risk and susceptibility analyses of assets on the road network	R&D project Norway
<p>Climate change challenge addressed: All aspects</p>	
<p>Purpose of the work: To define procedures for better risk and susceptibility analysis which consider weather and climate-related challenges with focus on climate change. Methods to identify vulnerable assets on roads are developed, focusing on structures especially exposed to climate factor, including bridges, culverts, and drainage structures, and sections of road structure. Procedures involve defining requirements for inventory, inspection routines, revision of dimensioning flow rates, definition of functionality regarding selected risk criteria, and maintenance tasks.</p>	
<p>Beneficial for: Risk assessment and management, and road maintenance.</p>	
<p>Time aspect: This depends on the service life of the road/structure and the particular climate parameter. This should be a continuous process in a changing climate. Application to the entire road network is desirable but priority should be given to the most important and exposed sections/routes.</p>	
<p>Summary: As part of the comprehensive risk assessment for the Norwegian transport system (SAMROS), the initiative described here will ensure that the influence of climate change on assets on the road network is included.</p> <p>Main aspects:</p> <ol style="list-style-type: none"> 1. A complete inventory of relevant items is an important factor for this procedure. The database must include relevant information on technical details concerning capacity and robustness. Observed state of functionality and up-to-date dimensioning criteria should be included. 2. Bridges are listed in the existing Norwegian databases for bridge inventory (BRUTUS), and smaller drainage structures (culverts) are included in the national road database (NVDB). These will be updated to include the relevant information for this procedure, such as erosion protection and measurements of the river profile. 3. Assessing exposed assets according to position and climate. 4. Assessing the features of culverts and bridges that contribute to greater vulnerability. 	

5. Suggesting methods to estimate future run-off values in basins where precipitation and flow data is limited or missing.
6. Calculating the necessary capacity: methods, data.
7. Maintenance routines.

Publications:

NPRA guidelines: (1) Methodology for performing risk analysis of road infrastructure concerning weather-related events and climate change; (2) Risk analysis of bridges; (3) Risk analysis of drainage culverts; and (4) Risk analysis of road structures and pavements.

Contact: Arne Gussiås, NPRA / arne.gussiaas@vegvesen.no



Bridges and culverts

Separate guidelines were developed for risk and susceptibility analyses with respect to bridges and culverts on the road network. Although specifically tailored to each of these types of structures, the procedures are based on several common factors. The guidelines describe the procedure, necessary data, and documentation for performing risk and susceptibility analyses of bridges and culverts with respect to weather-related events. The risk assessment is based on a risk matrix for the evaluation of probability and severity of adverse events that can lead to failure or road closure.

Risk analysis, evaluation, and management are described for three successive levels of assessment. Depending on the availability and quality of the inventory and other data, structures may pass each level with 'green' or otherwise move up to the next level of analysis.

Level 1: General recognition of vulnerable assets. Analysis at this level is done on a network or section scale.

Level 2: Investigation of individual structures. This step includes in-situ inspection, estimates of hydraulic capacity, and simplified run-off calculations.


Level 3: Special analysis. Includes detailed calculation of water flow and erosion risk and estimate of the effects of climate change. It suggests an action plan for risk reduction for structures not passing the acceptable risk threshold.

Road structure and pavements

The guidelines for road structures and pavements describe the procedure, necessary data, and documentation for performing risk and susceptibility analyses of road stretches (pavements) with respect to weather-related events. A number of possible actions for adaptation and risk reduction are provided.



1.7.e

Severe Weather Plan	Current practice UK
Field of application: Operational procedure	
Beneficial for: Traffic management	
Climate change aspect included: Wind, precipitation, flooding, temperature	
Time aspect: Current	
Summary: <p>The Highways Agency has a Severe Weather Plan in place with all its service providers. There are direct links to the Met Office through the National Traffic Control Centre at Quinton to anticipate severe weather and the potential for flooding. Regional Traffic Control Centres and the Traffic Officer Service, together with the emergency services, provide the capability to put in place plans to deal operationally with specific severe weather threats.</p> <p>Service providers provide the necessary expertise to examine and inspect particular parts of the Agency's infrastructure: bridges, pavements, drainage, earthworks, and ancillary facilities and equipment. Risk and resilience planning is undertaken and communicated into wider government initiatives; this is coupled with scenario planning to develop appropriate contingency measures.</p> 	
Publications: N/A	
Contact: ha_info@highways.gsi.gov.uk	

Example: mitigating the risks posed by high winds

When mitigating the effects of high wind, it is fundamental that the potential for problems is identified as early as possible. This will typically be through the provision of weather forecasts and other information sources e.g. the Met Office National Severe Weather Warning Service.

There are two bridges that cross the River Severn, the M4 between junctions 22 and 23, and the M48 between junctions 1 and 2. Both bridges allow traffic to travel from England to Wales. There are agreed protocols between the Highways Agency South West Regional Control Centre (SWRCC), the Highways Agency Traffic Officer Service, Gwent Police, Avon and Somerset Police and the service provider.

Wind speeds on the M4 are monitored by Gwent Police, who will instruct either Traffic Wales or the SWRCC when speed restrictions/closures are required. The wind speeds on the M48 are monitored by the SWRCC, which will set speed restrictions/closures where required. VMS signage is used to support the speed restrictions/closures.

1.8.a

Assessing the cost of climate-change-related sea-level rise on the transport networks	R&D project France
Climate change challenge addressed: Sea-level rise	
Purpose of the work: To quantify costs of sea-level rise on transport networks	
Beneficial for: Risk management related to climate change for infrastructure Planning, maintenance	
Time aspect: The end of the century	
Summary: In 2007–2009, an interdepartmental group assessed the impacts of climate change, adaptation, and associated costs in France. From the data relating to infrastructure below the centennial sea level +1 m, and considering an estimate of the mean monetary cost of road asset loss of €10 million/km and of reclamation of temporary submerged road of €250,00/km, the sea-level rise would cost up to €2 billion for national roads (excluding highways and loss of use).	
Publications: Observatoire national sur les effets du réchauffement climatique, 2009. <i>Changement climatique, coûts des impacts et pistes d'adaptation</i> ; La Documentation Française, 193pp.	
Contact: anne-laure.badin@developpement-durable.gouv.fr	

Climate change could lead to damage and disruption to transport networks. An assessment of damage due to (permanent and temporary) submersion resulting from sea-level rise was completed in 2008. Due to data availability, the discussions focused on major national infrastructure networks in mainland France that are managed by the state. Thus only 1.2% of the total length of the French road network was taken into account. Nevertheless this portion of the road network is responsible for over one quarter of total traffic on French roads.

The risk assessment was carried out with reference to centennial flooding. The vulnerability was related to the cost of submersion. However, the cost of damage caused by an event is far less than the cost of the total destruction of property. Two alternating approaches are therefore defined: 'temporary submersion' and 'permanent submersion'.

The mapping of low-lying areas was used as a relevant indicator to understand the vulnerability of coastal areas to submersion. Extreme sea levels were superimposed on coastal topography to highlight low-lying areas. They were defined along the entire coastline and could be affected by coastal submersion. The length of the infrastructures present in each of these areas was quantified and served as a basis for assessing the cost of submersion of vulnerable roads. Permanent submersion was considered when the corresponding structures were located at a level corresponding to centennial sea level - 1m. The costs reflect the loss of asset value. Temporary flooding was assumed when structures were located at a level corresponding to centennial sea level + 1m. The cost was assessed by applying a unit cost of damage to the linear infrastructure concerned (determined by reference to reclamation costs).

Given the uncertainty of the topographic data and in order to reflect the impact of sea-level rise, several areas were identified: i. below current centennial sea level -1 m, ii. below current centennial sea-level, and iii. below current centennial sea level +1 m. Disparities emerge depending on the study areas, notably the extent of low-lying areas and the density of infrastructure.

Assessment of the costs of submersion on national roads and highways

Table: Consequences of the three scenarios of submersion: length of submerged roads and estimated costs of the road asset loss

In km In € millions (2008)	Structures located at		
	Up to centennial sea level -1m	Between centennial sea level -1m and centennial sea level	Between centennial sea level and centennial sea level + 1m
National roads (in km)	79	69	50
Highways (in km)	160	141	54
If the submersion is permanent: asset loss Monetary mean value in € millions (2008): €10 million/km			
National roads (in km)	€790 million	€690 million	€500 million
Contracted and not contracted highways (in km)	€1,600 million	€1410 million	€540 million
If the submersion is temporary: asset loss Monetary mean value € millions (2008): from €0.25 to 0.50 million/km and / submersion			
National roads (in km)	€4.75 to 9.5 million	€17.25 to 34.5 million	€12.5 to 25 million
Contracted and non-contracted highways (in km)	€40 to 80 million	€35.25 to 70.5 million	€13.5 to 27 million

The majority of marine structures are not designed to withstand a water rise of +1m (except for structures specifically designed to protect against high water levels). The presence or absence of structures does not change the vulnerability of infrastructure located behind; these structures will no longer provide protection if they are not resized. Thus, if it is assumed that the existing structures do not change, it must be considered at this stage that the current protected area could be at risk of permanent submersion.

The lower areas will always be the most vulnerable. Areas that are currently unprotected could be exposed to either permanent or temporary submersion.

For coastal submersion, it seems reasonable to consider that the overall sea level rise of 1m would mean costs for national roads in mainland France (excluding highways and other roads) of up to €2 billion, excluding loss of use. This approach highlights a potential vulnerability, which is greater on departmental and municipal roads and highways, as a percentage of the network potentially affected.

Fitting of the centennial submersion ratings and coastline +1m ratings is an issue and represents great difficulties for cost assessment. It was necessary to perform arbitrary approximations on the basis of currently available data. Another problem is that ratings for protection have not yet been identified.

1.8.b

Estimating costs related to climate change	Vulnerability analysis Sweden
Climate change challenge addressed: Increase in temperature and precipitation causing higher flood levels Erosion and landslide risk	
Purpose of the work: The work belongs to a national survey of risks and vulnerability undertaken in 2007	
Beneficial for: planning, prioritising	
Time aspect: Climate change projections towards the end of the century	
Summary: The Swedish Road Administration carried out a general risk and susceptibility analysis of the road network with respect to climate changes as part of the national survey in 2007. The main effects of the studied climate scenario on the road network are expected to be higher precipitation and flood leading to erosion and scouring of bridges, and landslides. Sea-level rise will require adjustments for ferry traffic and low tunnels. North of Stockholm the land rise will compensate for the expected sea-level rise. The NRA estimated the costs of anticipated damage and mitigation measures coming from erosion, flood, and landslide. Only larger-scale damage is included, while smaller repairs are assumed to be included in the routine maintenance.	
Publications:	
Contact: hakan.nordlander@trafikverket.se	

The costs are given in SEK at 2007 levels. The aim of presenting them here is to show the relative costs, the aspects included, and the assumptions on which the calculation was based.

Type of damage	Mitigation measures /short term ¹⁾	Mitigation measures /long term	Increase of costs of damage/long term (with no mitigation measures)
Larger-scale flood and erosion damage (current annual cost approx. SEK65 million)	SEK150–500 million	Total cost SEK1,000–2,000 million, mitigation measures against larger flood, erosion and landslide damage ²⁾	SEK50-150 million/year
Landslide (current annual cost approx. SEK15 million)	>SEK200 million		SEK20-50 million/year
Larger landslides (seldom today)			Increase in number of large landslides
Earlier replacement of bridges (before expiry of service life)		Approx. SEK720 million during the time period ³⁾	

1) The estimate of costs is based on the following calculation assumptions:

- Assets corresponding to 10–30% of costs of flood and erosion are identified. Remedial measures reduce the risk by 90%, and the corresponding costs of damage by SEK6–18 million/year. If it is further assumed that the measures are economically justified, that they are undertaken once, and that they do not lead to an increase in maintenance costs, the costs of measures will be < SEK150–500 million.
- The same assumptions apply to the costs of reducing landslide risk: < SEK35–100 million. The calculation is based on the mean value of recent costs of landslide protection, but excluding personal injuries, which should be included in a more detailed risk assessment. In the event of extremely high risk, measures must be taken, regardless of the cost. This is why costs can amount to SEK200 million.

2) The increase in costs due to climate change will be lower in cases where measures are performed as a part of planned maintenance and reconstruction, and not as separate measures. However, long-term exposure to the effects of a changing climate (flood, higher pore pressure) will inevitably lead to extra cost. The cost estimate is based on the following assumptions:

- Measures that reduce the damage costs by 50% are carried out as part of ordinary maintenance or reconstruction, with the cost corresponding to 10% of the costs it would involve as a separate measure. Further assumption as in (1) above.
- Measures that reduce the damage costs by 25% are carried out as separate measures. These measures would not be significantly cheaper if performed as part of ordinary maintenance or reconstruction.
- The calculation gives a total cost of SEK500–1500 million for remedial measures, including protection measures against large landslides. The calculation example indicates a cost of approximately SEK1,000–2,000 million.

3) The costs for bridges are calculated as the costs for early replacement of 20% of the bridges in south-western Sweden, with a free height over highest high-water level (HHW) lower than 0.5 m, and 20% of the bridges in the whole of Sweden which have a free height over HHW lower than 0.3 m.

Short-term mitigation measures (erosion and landslide risk) are primarily motivated by the fact that not all structures comply with current requirements and that some current requirements should be made more rigorous with respect to the susceptibility of the assets and the consequences of damage. The potential effects of climate change and the effects of the changes that have already taken place compared to the design situation are a secondary motivation.

The effect of climate change on the costs of maintenance of pavements due to rutting is expected to increase by 5%, except for the northern parts of the road network, where the costs are expected to be 5% lower, for low-traffic roads. The costs due to unevenness are assumed to be 10% lower. This gives an overall reduction of costs for pavements.

The comparison of costs is based on the maintenance performed, and not the actual *need* based on documented road standard. The future costs of maintenance will therefore mostly depend on the way the documented standard of roads affects maintenance investments and to a lesser degree on anticipated climate change.

1.8.c

The effect of climate change on the routine and periodic maintenance of roads	R&D project Finland
Climate change challenge addressed: Increase in temperature, increase in rainfall and rain intensity. Increase of water flow and flood risk. Shorter periods of snow-cover and temperatures below 0. Decreased frost depth.	
Purpose of the work: To find out how climate change is affecting the routine and periodic maintenance of roads and also to assess the expenses of these effects. Furthermore, the objective is to present necessary changes to maintenance guideline policies.	
Beneficial for: Maintenance experts and decision-makers mainly at national level and researchers	
Time aspect: The results are already beneficial when estimating the effects of warmer winters, which already exist, but benefit is mainly anticipated for the future when warmer winters are expected to be more frequent.	
Summary: The results are based on a literature research, analyses of the effects of two warm winters (2006–2007 and 2007–2008), and expert assessments. The results show that the need for short-term capacity for snow removal increases, while the number of snow removals stays the same or decreases. The need for de-icing is increasing. Salting is apparently likely to decrease only after the middle of the current century. Winter maintenance costs are expected to increase slightly. Rutting and wearing of pavements will increase. The load-carrying capacity of low-volume roads will be reduced. By the end of the five-year period, the maintenance costs will increase by €10–20 million if forthcoming winters are mild and wet. Structural thaw weakening will become more complicated. The maintenance costs of gravel roads are will increase by €5–10 million by the end of the next decade.	
Publications: <i>The effect of climate change on the routine and periodic maintenance of roads</i> (in Finnish, summary in English) Helsinki 2009. Finnish Road Administration, Central Administration. Finnra reports 8/2009, 66 p. + app. 8 p. ISSN 1459-1553, ISBN 978-952-221-172-9, TIEH 3201122-v.	
Contact: Vesa Männistö, Finnish Transport Agency; Vesa.Mannisto@fta.fi ; PO Box 33, 00521 Helsinki, Finland; Tel. +358 20 637 3569.	

It is estimated that the average temperature in Finland will increase by over 2°C and rainfall by 5–10% by the year 2040. Both the temperature rise and the increase in rainfall will be more intense during the winter than the summer. The thermal and snow-covered winter (winter period with temperatures below 0 degrees and snow-cover) will shorten and the number of days with temperatures above 25°C in summer will increase. The frost depth will decrease significantly by the end of the century.

The objective of this study has been to find out how climate change is affecting the routine and periodic maintenance of roads and also to assess the costs of these effects. Furthermore, the objective is to present necessary changes to maintenance guidelines. The results are based on a literature research, analyses of the effects of two warm winters (2006–2007 and 2007–2008), and expert assessments.

The winter maintenance procedures applied in southern Finland are being transferred to the northern parts of Finland. Winter storms are becoming more common, which increases the required short-term capacity for snow removal, but overall the number of snow removals is remaining the same or decreasing, as winters are getting shorter. The need for de-icing is increasing in central and northern Finland. The need for salting is apparently expected to decrease only after the middle of the current century. Winter maintenance costs are anticipated to increase slightly due to climate change.

During winter, bare road surfaces are becoming more common. Warm and rainy winters accelerate the rutting of pavements. Greater numbers of freeze-thaw cycles increase pavement wear and pavement defects. Due to increasing rainfall, the groundwater table will rise, which reduces the load-carrying capacity of low-volume roads and accelerates the increase of ridge height on minor roads. It is estimated that, by the end of the five-year period, maintenance costs will increase by €10–20 million if forthcoming winters are mild and wet. The condition of the road network must be continuously monitored.

The increasing rains and mild winters are complicating structural thaw weakening. The recommendations given in the new maintenance policies for gravel roads are also strongly advisable for eliminating the effects of climate change. Maintenance costs are set to increase by €5–10 million by the end of the next decade due to climate change.

Table: The costs of road maintenance in 2009 and the estimated effect of climate change.

	costs in 2009		The effect of the climate change	
	Million €/year	%	Direction	Explanation
Routine maintenance, sum	230.1	44		
Winter maintenance	101.6	19	+	Snow removal stays the same, but de-icing will become more complicated and more expensive
Maintenance of transportation environment	64.6	12	0	
Maintenance of gravel roads	28.7	5	++	Longer maintenance period for gravel roads. More complicated autumn ballast
Ferries and ice roads	35.2	7	-	Thinner ice is easier for ferries. Traffic from ice roads move to ferries
Periodic maintenance, sum	235.4	45		
Paving	68.3	13	++	Pavements have snow cover for shorter periods, and are susceptible to wear
Pavement patching	65.5	12	++	Increasing number of freeze-thaw cycles weathers the pavements
Road marking	15.3	3	0	Bare roads and markings are more vulnerable, but decreasing need for snow removal decreases the wear on markings
Bridge repair	46.4	9	+	Increasing use of salt accelerates corrosion. Flooding
Frost heave repair	15.4	3	+	The groundwater level will rise due to increased rainfall.
Maintenance of road side equipment	20.2	4	0	
Small transportation environment improvements	4.3	1	0	
Operational traffic management	7.4	1	0	The need to forecast freezing rain, winter storms, and floods will increase
Regional investments	25.9	5		
Planning and designing	29.5	6		
OVERALL	528.3	100		

When planning new roads and bridges, preparation must be made for increased erosion and flood risks caused by more rain and water flows.

1.9.a

The National Road Database	Current practice Norway
<p>Field of application: This database contains information about all state, county, municipal, private, and forest roads in Norway (206,000 km of road in total).</p>	
<p>Beneficial for: Asset management, adaptation to climate change through good data on weather-related events, position and properties of drainage structures, landslide protection, etc.</p>	
<p>Climate change aspect included: All aspects of climate change benefit from a good database.</p>	
<p>Time aspect: Valuable basis for both dynamic studies and studies of the effects of weather according to climate projections</p>	
<p>Summary: The National Road Database (NRDB) is an information system developed for the purpose of securing optimal management, maintenance, and development of Norwegian roads. It is also used to secure an effective information system for the road owner and road users about traffic and incidents on the road network. The NRDB stores information about the road network geometry and curvature, restrictions such as speed limits and permitted axle load, road equipment such as railings, signs, ditches, basins and sinks, traffic volumes and the consequences of road traffic such as noise and pollution, and events such as landslides and traffic accidents. For adaptation to climate change, it is a great advantage to have access to good information concerning drainage systems (position, dimensions of assets, etc.), which then enables calculation of necessary capacity and for evaluating vulnerability. In addition, good information about weather-related events on the road network makes it possible to explore the effect of weather conditions in general and to identify future situations that present a hazard to traffic safety.</p>	
<p>Publications: H. Wethal, T. Hovland, NPRA: <i>Development of a National Road Database in Norway</i></p>	
<p>Contact: Per Roald Andersen, NPRA.</p>	

For the road administration (internal use), areas of application are: road planning and design, maintenance and operation, environmental aspects (pollution from noise and dust, landscape planning) and traffic safety issues, i.e. traffic accident statistics.

In addition to this, there are a large number of external users, such as government agencies and local authorities (county and municipality authorities, police, National Bureau of Statistics, Norwegian Mapping Authority), transport companies, consultancy companies, and research organisations.

The database has a feature catalogue where all features are defined with attributes, code lists, and associations. Data must be stored according to the feature catalogue, and the feature catalogue may also be used in other systems in combination with data from the NRDB.

Data can be exported into and presented in predefined or user-defined reports with the standard report tool (oracle reports), and can also be viewed and analysed in standard GIS tools.

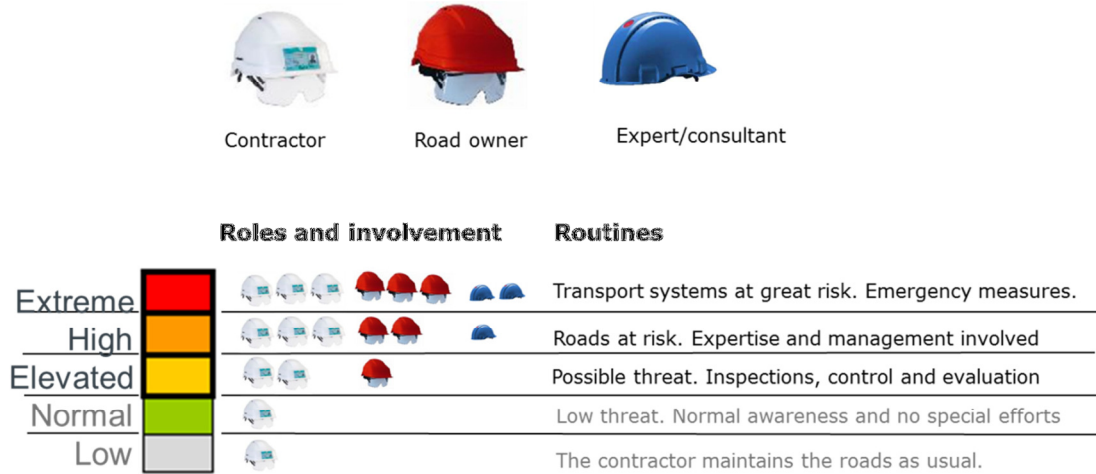
For adaptation to climate change, issues that require good basis data are, for example, the position and size of drainage structures, type, repair history, possible accidents, and other events.

The functionality of the NRDB as a tool for adaptation to climate change has been evaluated by the R&D programme Climate and Transport 2007–2010. The conclusion was that good functionality could be achieved with minor changes, e.g. more precise placing of drainage structures in the road profile or adding a few features, such as longitudinal slope of culverts. However, the critical factor is the lack of recorded input data.

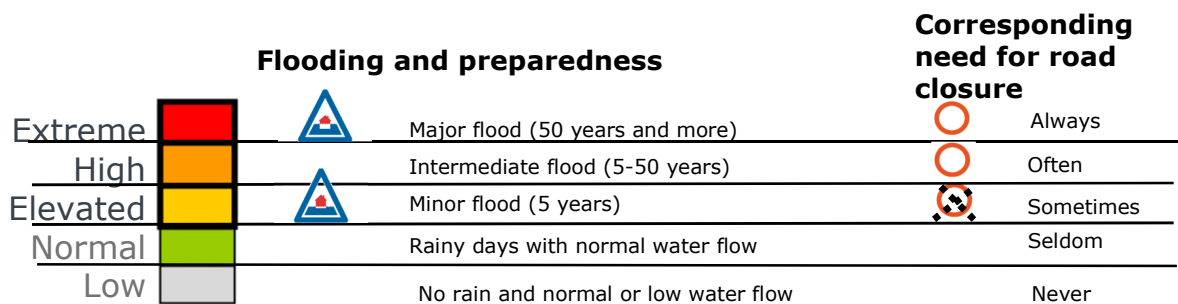
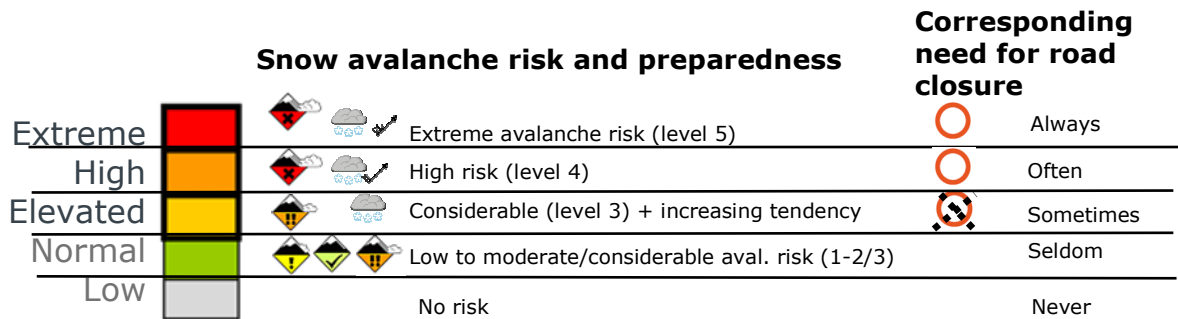
1.9.b

Successive preparedness system	Current practice Norway
Field of application: Risk management in demanding weather conditions	
Beneficial for: Road owners, especially in relation to cooperation with contractors responsible for operation and maintenance of roads	
Climate change aspect included: More frequent and more intense precipitation, risk of landslides and avalanches, risks from flooding	
Time aspect: Dynamic data Beneficial for adaptation to climate change	
<p>Summary:</p> <p>The successive preparedness system defines three degrees of preparedness in addition to the normal authority preparedness. They are coloured in accordance with colour codes from the European warning system at www.meteoalarm.eu:</p> <ul style="list-style-type: none"> - Yellow: meaning possible threat under special conditions and elevated preparedness. - Orange: dangerous weather that could cause damage in some places and requires a high level of preparedness. - Red: meaning dangerous weather in several places that requires an extremely high level of preparedness. <p>This system ensures better potential for proactive preparedness, so that weather conditions and risk are actively evaluated and remedial measures set up before excessive damage happens.</p> <p>A set of weather criteria will be introduced to each contractor's preparedness plans. Warning systems for flood, avalanche, and landslide risks, which are under development, will be an important input to the system.</p>	
Publications:	
Contact: Norwegian Public Roads Administration, Tore Humstad, tohums@vegvesen.no	

The concept of the successive preparedness system and how it relates to the avalanche and flood warning systems are briefly explained in the figures below.



Examples of how other warning systems could be used as input for the evaluation of preparedness level:



1.9.c

Information technology systems for communicating risks and alerts	Current practice Norway
Field of application: Communication of risk to road users and re-routing in case of road closure. Maintaining operation and safety in demanding or extreme weather conditions.	
Beneficial for: NRAs (operation) and road users	
Climate change aspect included: Storms, sudden rain or snowfall, landslide risk, etc.	
Time aspect: Current weather, beneficial for future climate conditions	
Summary: The application of information technology systems (ITS) for communicating weather and road conditions to road users is undergoing active development. The more experience collected on the performance of IT systems, the better the chances of improved solutions that are adapted to local conditions. Norway has developed national guidelines for establishing ITS solutions along the road network, which include communicating information and alerts in cases of difficult weather conditions. The national guidelines will also contribute to a broader application of ITS. In relation to climate change, it is especially interesting to investigate and develop possibilities for improving information about risks from high tides and waves, landslides and avalanches, and strong winds. This comes in addition to ITS routines for communicating road condition (friction, visibility), information about on-going repair work, congestion, and alternative routes.	
Publications: <i>ITS på veg—En veileder for innføring av vegbaserte ITS-løsninger</i> (Intelligent Transport Systems on Roads – Guidelines for introduction), ISBN:978-82-91228-28-0 <i>Handlingsplan for ITS 2009–2013</i> (Action plan for ITS)	
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Roads in Norway are often exposed to weather that causes problems for traffic. Some situations require special attention, and ITS can be used to obtain better safety and better mobility for road users. Examples of hazards for road users include waves, the risk of landslides, and strong winds.

An alert system for roads exposed to **waves** is being installed on a road section on the Lofoten Islands. The road section is frequently 'washed over' by waves. Accidents have already occurred; cars have been thrown into the sea and two people injured. The system measures the tide, wave height, and wave direction. This data is then processed and is used to automatically close the road before the waves impose a threat to safety. The road stretch in question was ideal for the installation of such a system. Systems for wave alert may not be easy to install in many other places on the road network. However, this example shows the possibilities provided by ITS for enhancing safety.



Europe route no. 6, Lofoten Islands, Hamnøy is often exposed to high tide and waves

There is a threat of **landslides and avalanches** in many places on the road network. The purpose of installing an alert system is to prevent cars from driving into an area exposed to an acute hazard from landslide, rockfall, or avalanches. Combined with other technology, it is possible to identify the number of vehicles already present in the risk area. A separate task is stopping traffic *after* a landslide or avalanche has occurred.

Strong winds and turbulence in rough terrain and mountain areas can pose challenges for traffic, especially on bridges. The purpose of installing an alert system on bridges is to inform road users of the danger and the need to reduce speed, or alternatively to close the bridge to traffic. Strong wind combined with a slippery road surface is a particular threat to traffic safety.

The aim of the special alert systems is to enable *automatic* road closure so that no vehicles can enter areas exposed to risk. However, the staff at the NRA's traffic station will receive information from the alert systems and can overrule decisions and monitor the development of the situation by means of cameras.

