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Climate Change Adaptation

A Report on Climate Change Adaptation Measures for Low Volume Roads in the Northern Periphery

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ROADEX
Implementing Accessibility

Northern Periphery Programme 2007–2013

Innovatively investing in Europe's Northern Periphery for a sustainable and prosperous future

European Union
European Regional Development Fund

Adriána Hudecz

CLIMATE CHANGE ADAPTATION

A Report on Climate Change Adaptation Measures for Low Volume Roads in the Northern Periphery

ABSTRACT

The European Union ROADEX Project 1998 – 2012 was a trans-national roads co-operation aimed at developing ways for interactive and innovative management of low traffic volume roads throughout the cold climate regions of the Northern Periphery Area of Europe. Its goals were to facilitate co-operation and research into the common problems of the Northern Periphery. This report is an output of the ROADEX "Implementing Accessibility" project (2009-2012). It gives a summary of the results of research into adaptation measures to combat climate change effects on low volume roads in the Northern Periphery. The research was carried out between January 2000 and March 2012.

One of the biggest challenges that mankind has to face is the prospect of climate change resulting from emissions of greenhouse gases. These gases trap energy in the atmosphere and cause global surface temperatures to rise. This warming in turn causes changes in other climatic variables such as rainfall, humidity and wind speed that impact on the functioning of infrastructure such road networks.

This paper discusses the climate changes predicted by the world's meteorological organisations and considers how these may impact on the public and forest road networks of the Northern Periphery. It includes:

- A summary of the projected climate changes
- A discussion on how these changes could impact of the road networks of the Northern Periphery
- Good practice and adaptation measures that can be used

The paper reports the results of a Questionnaire circulated to the ROADEX Partners to get their views and concerns on how climate change might impact their local low volume road networks.

KEYWORDS

Climate change, temperature, precipitation, impacts, road maintenance, adaptation measures, Northern Periphery

PREFACE

This is a final report from Task RE1 of the ROADEX "Implementing Accessibility" project, a technical trans-national cooperation project between The Highland Council, Forestry Commission Scotland and the Western Isles Council of Scotland; The Northern Region of The Norwegian Public Roads Administration; The Northern Region of The Swedish Transport Administration and the Swedish Forest Agency; The Centre of Economic Development, Transport and the Environment of Finland; The Government of Greenland; The Icelandic Road Administration; and The National Roads Authority and Department of Transport of Ireland. The lead partner in the project was The Northern Region of The Swedish Transport Administration and project consultant was Roadscanners Oy from Finland.

The report summarises recent published researches on climate change and its possible impact on low volume roads in the Northern Periphery. Its aim was to produce a practical guidance document for local engineers to help them to manage potential effects of climate change on their local road networks.

The implications of climate change are considered over 4 chapters:

1. A summary of the predicted changes for the ROADEX Partner countries
2. The results of a questionnaire issued to the ROADEX Partners
3. The possible impacts of the predicted climate changes as they affect the Northern Periphery, and
4. A discussion of good practice and adaptation measures being implemented in ROADEX partner countries.

The report concludes with an appendix of recommended of good practice and adaptation measures which are considered suitable for use in the ROADEX partner areas.

The report was prepared by Adriána Hudecz of the Arctic Technology Centre (ARTEK) at the Technical University of Denmark (DTU). Ron Munro, Project Manager of the ROADEX "Implementing Accessibility" Project, checked the language. Mika Pyhähuhta of Laboratorio Uleåborg designed the report layout.

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Finally the author would like to thank Arne Villumsen of DTU, Timo Saarenketo of Roadscanners, Ron Munro of Munroconsult Ltd, the ROADEX "Implementing Accessibility" Project Partners, and the Project Steering Committee for their guidance and encouragement in this work.

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CONTENTS

1. INTRODUCTION

1.1 CLIMATE CHANGE ADAPTATION

The Earth's climate is predicted to change to an uncertain degree. Trends are stated to be developing but the current level of the science is not sufficiently advanced to be definitive in how much the change will be, or when it will happen. The natural variability of weather patterns makes general conclusions difficult.

The ROADEX Partners recognise this uncertainty in the predictions of climate change and as a result do not take a formal position on it one way or the other. The only position that the Partners take is to be prepared to take such steps as considered reasonable to deal with the circumstances happening now, rather than ignore the topic altogether. As part of this approach the ROADEX Partners consider it sensible to review what can be done to modify their current road construction and maintenance practices to meet the predicted changes. The precautionary principle dictates that the absence of certainty should not be used an excuse for inaction.

Road maintenance has never been a static activity that could be ruled by a fixed set of instructions. Maintenance operations have always reacted and adapted to meet the changing demands and challenges thrown up by the road networks and their users. The current practices of modern operations are the result of evolutions in practices over years, and of individual decisions made by individual maintenance engineers to meet the prevailing conditions at the time.

Dealing with the effects of climate change can be expected be no different in this respect. Changes in conditions will be met over time as they arise, step-by-step, by the Partner organisations. Local engineers should however be aware of what could happen, and be ready to mitigate the impacts on the local road networks, as they have always done.

The aim of this report will be to offer a summary of the climate changes currently projected for the Northern Periphery and how they might impact the low volume road networks of the ROADEX Partners, as well as considering possible measures on how to deal with them.

It is hoped that the report will be a trigger for greater sharing of climate change information and experiences of good adaptation practice between the Partners, to the benefit of all.

1.2 THE ROADEX PROJECT

The ROADEX Project is a technical co-operation between road organisations across northern Europe that aims to share road related information and research between the partners. The project was started in 1998 as a 3 year pilot co-operation between the districts of Finland Lapland, Troms County of Norway, the Northern Region of Sweden and The Highland Council of Scotland and was subsequently followed and extended with a second project, ROADEX II, from 2002 to 2005, a third, ROADEX III from 2006 to 2007 and a fourth, ROADEX "Implementing Accessibility" from 2009 to 2012.

Figure 1-1 The Northern Periphery Area and ROADEX Partners

The Partners in the ROADEX "Implementing Accessibility" project comprised public road administrations and forestry organisations from across the European Northern Periphery. These were The Highland Council, Forestry Commission Scotland and the Western Isles Council from Scotland, The Northern Region of The Norwegian Public Roads Administration, The Northern Region of The Swedish Transport Administration and the Swedish Forest Agency, The Centre of Economic Development, Transport and the Environment of Finland, The Government of Greenland, The Icelandic Road Administration and The National Roads Authority and The Department of Transport of Ireland.

The aim of the project was to implement the road technologies developed by ROADEX on to the partner road networks to improve operational efficiency and save money. The lead partner for the project was The Swedish Transport Administration and the main project consultant was Roadscanners Oy of Finland. The project was awarded NPP funding in September 2009 and held its first steering Committee meeting in Luleå, November 2009.

A main part of the project was a programme of 23 demonstration projects showcasing the ROADEX methods in the Local Partner areas supported by a new pan-regional "ROADEX Consultancy Service" and "Knowledge Centre". Three research tasks were also pursued as part of the project: D1 "Climate change and its consequences on the maintenance of low volume roads", D2 "Road Widening" and D3 "Vibration in vehicles and humans due to road condition". All of the reports are available on the ROADEX website at www.ROADEX.org.

2. CLIMATE CHANGE

This chapter will summarise the results of the existing climate prediction models for the Northern Periphery. First, the global problem will be shortly explained and further the projected changes of each ROADEX land, namely Sweden, Norway, Finland, Iceland, Scotland, Ireland and Greenland and in addition Alaska and Canada will be detailed. Greenland, Alaska and Canada are studied together due to the similarities.

One of the biggest challenges, the mankind has to face with is the climate change resulting from emissions of greenhouse gases. The concentration of carbon dioxide in the Earth's atmosphere is rising rapidly due to emissions from human activities. Atmospheric greenhouse gases trap energy in the atmosphere and this has caused global surface temperatures to rise. The warming is in turn causing changes in other climatic variables such as rainfall, humidity and wind speed. However, it has some positive effects, but they are not as pronounced as the negative ones.

A wide range of national and international research programmes and publications exist for the prediction of climate change and its effect on infrastructure, economics, environment and people, with a number of prediction scenarios, such as A1, A2, B1 and B2 (see Figure 2-1). None of these can be guaranteed and most authorities assume a scenario(s) in the mid-range for contingency planning measures.

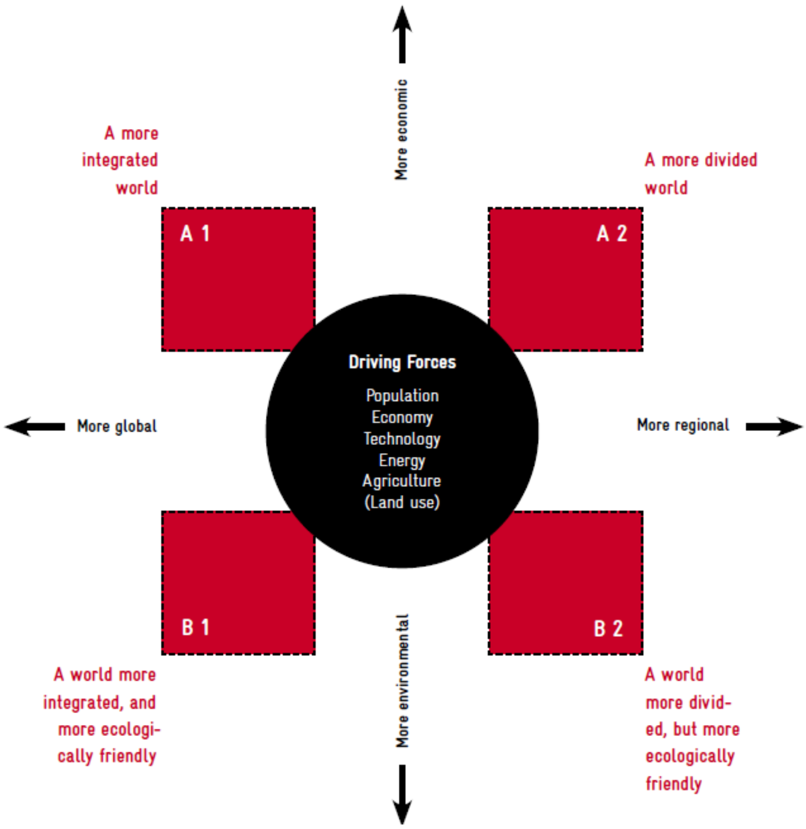


Figure 2-1 Storylines for the emission scenarios [1]

The A scenarios place more emphasis on economic growth, the B scenarios on environmental protection, the number 1 scenarios assume more globalization, the number 2 scenarios more regionalization [Figure 2-2]. The comparison of these scenarios can be seen in Table 2-1. It can be seen that B1 is the best case scenario while A2 is the worst. The same can be concluded from Figure 2-2.

Table 2-1 Main scenarios [2]

Scenario	Population growth	Economic	Development	Other
A1	Slightly	Rapid growth	New technology and renewable energy	Depends on the fuel used
A2	Major	Slow growth	Weak technological	Major variation in regional development
B1	Slightly	Comprehensive change	Comprehensive change	
B2	Fairly large		Sustainability	

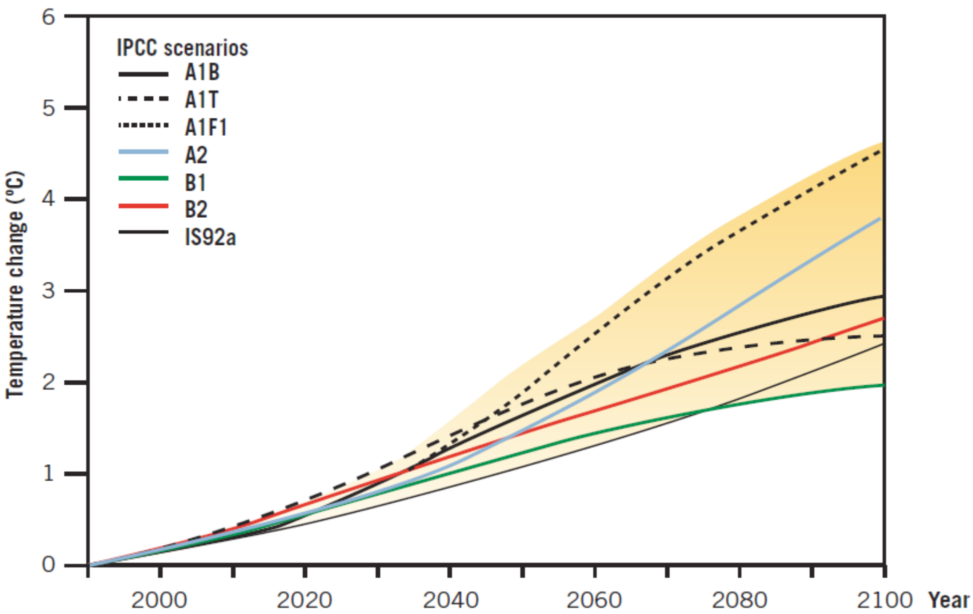


Figure 2-2 Different scenarios of average surface temperatures. [2]

Across these scenarios it is predicted that the surface temperature across the world will rise by 1.4-5.8 °C. The Arctic is already feeling the effects the most. Average temperatures in Alaska, western Canada, and eastern Russia have risen at twice the global average so far. As a result of this increase it is predicted that the sea level will rise by between 9 and 88 mm by the end of the century, although both boundaries are very unlikely. In Europe, one of the common natural disasters is river flooding, which is expected to be more intense and frequent due to increased frequency and magnitude of storm events [3, 4].

The above climate change scenarios do not of course take into account the natural variability of weather systems across regions and countries. These can be significant from year to year, and season to season as recent storm events in the Northern Periphery can testify. These periods of natural weather variability are likely to continue into the future placing further uncertainty on to the underlying effects of climate change.

Short discussions on the predicted effects of climate change on the ROADEX partner countries follow.

2.1 SWEDEN

According to the research of the Swedish Commission on Climate and Vulnerability [5], average temperatures in Sweden will increase by around 2°C by 2020, mostly during winter. By 2080s, warming will be around 3-5°C, mostly in the north-eastern part of the country. The country will experience warmer winters and summers during the century. The average temperature in January will increase by 1.5-2.5°C by 2020 and 5-7°C by 2080s in the case of the A2 scenario (see Figure 2-3). This is predicted to cause a reduction in the duration and thickness of snow cover.

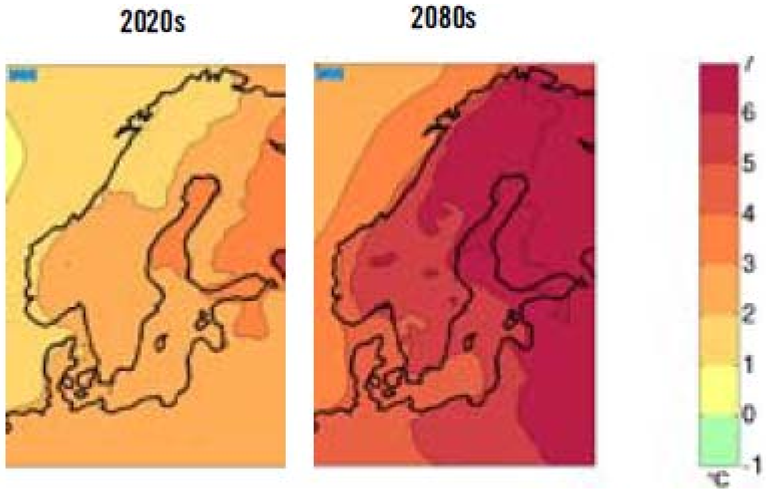


Figure 2-3 Change in average temperature in January, A2 scenario [5]

The A2 scenario also predicts that the average temperature in July will increase by 0.5-1.5°C by the 2020s and by around 2-4°C by the 2080s. In comparison, the B2 scenario predicts that the surface temperature will rise by 0.5-1.5°C by the 2020s, but then level out and stop increasing by the 2080s , see Figure 2-4.

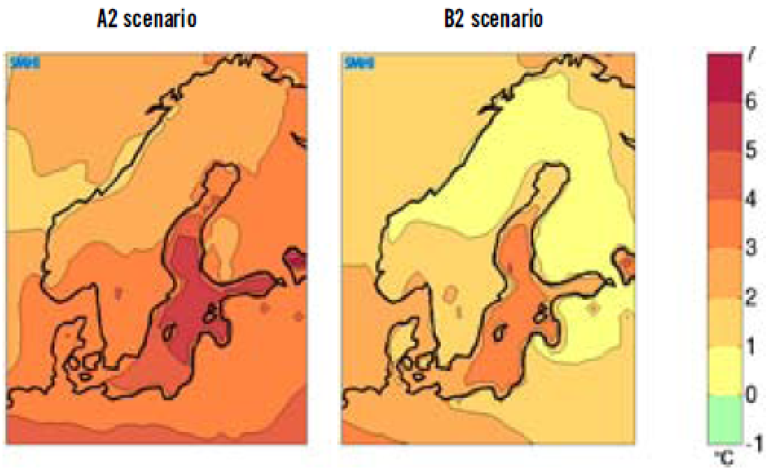


Figure 2-4 Comparison of change in average temperature in July by the 2080s for the A2 and B2 scenarios [5]

The number of hot days and tropical nights will increase in the A2 scenario, especially in the southern part of the country. "Hot days" means the number of days in summer with a maximum temperature above 20°C. According to the A2 scenario the number of these days will rise by approximately 10 days by the 2020s, and by up to 40 days along the coastline of southern Sweden by the 2080s. In the B2 scenario the increase is predicted to be less, around 30 days by the end of the century. These predicted warmer summers will also mean that heatwaves will become more common. Nowadays, it is very rare to have tropical days in Sweden although it sometimes happens, especially on the coast.

The trends show that precipitation is expected to increase generally, but mostly in western Sweden and during the winter, and that summers are expected to become drier especially in the south. According to the A2 scenario, precipitation will increase by approximately 50% in January by the 2020s, i.e. a rise around 20-50mm. By the 2080s, the increase is predicted to be more than 50mm. The amount of rain rises significantly over almost the whole country during winter. By the end of the century, snow becomes rare on the south coast. Figure 2-5 shows these changes. The predictions also suggest that there will be less precipitation in southern Sweden during the summer.

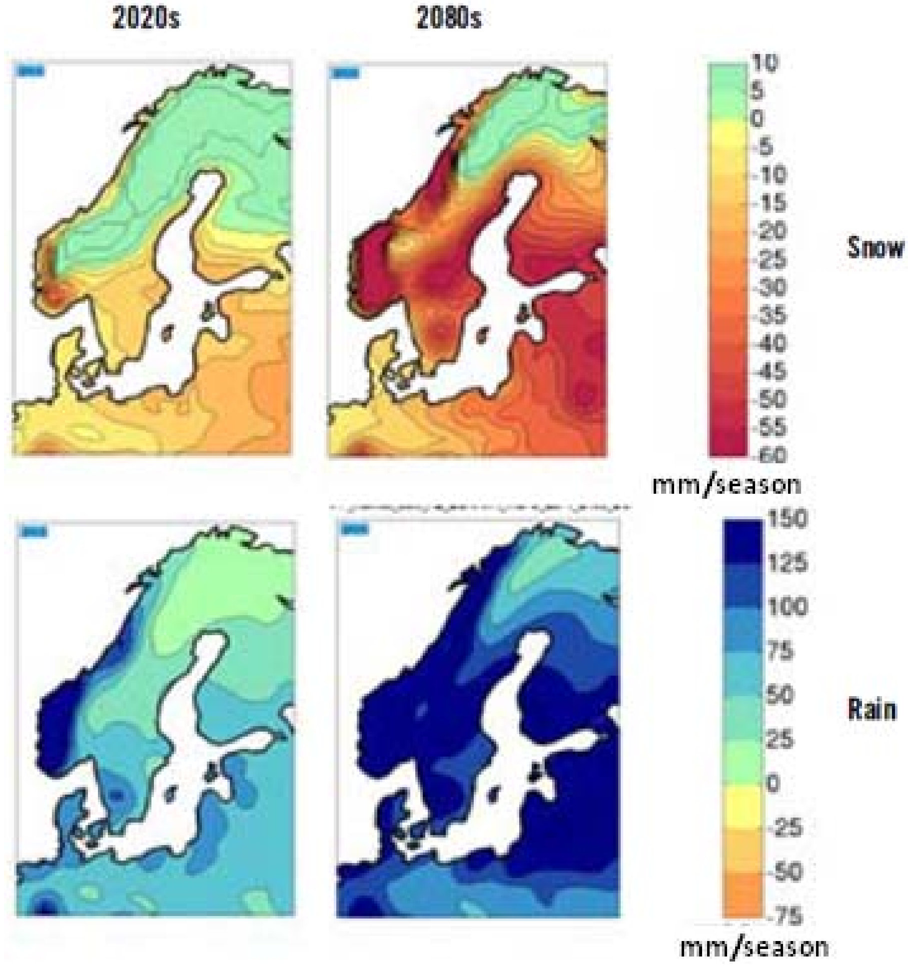


Figure 2-5 Changes of precipitation falling as snow and rain during winter in mm/season by the 2020s and 2080s according to A2 scenario [5]

An increase will be experienced in the most intensive rainfalls, especially in the western parts of the country. This will cause higher flows and more frequent floods.

2.2 NORWAY

In Norway the impacts of climate change is a relatively new research topic [6]. According to RegClim (Regional Climate Development under Global Warming) scenarios published in 2000, the regional estimated changes in temperature and precipitation from 2000 to 2050 can be summarised in Table 2-2.

Table 2-2 Regional estimated changes in temperature and precipitation 2000-2050 [6].

		Temperature change (°C)	Precipitation change (mm/day)	Precipitation change (percent)
Northern Norway	whole year	1,6	0,3	7,8
	spring	1,4	0,2	5,0
	summer	1,2	0,1	1,5
	autumn	1,7	0,8	18,2
	winter	2,0	0,2	5,2
Western Norway	whole year	1,0	0,8	13,5
	spring	0,9	0,1	1,2
	summer	0,7	1,0	18,2
	autumn	1,1	1,5	23,5
	winter	1,2	0,6	9,3
Eastern Norway	whole year	1,1	0,2	4,3
	spring	1,0	-0,1	-4,1
	summer	0,6	0,1	1,7
	autumn	1,3	0,3	6,9
	winter	1,3	0,4	13,1

Norway is predicted to have a warmer and wetter climate in the future, with more strong winds and more frequent storms along some parts of the coastline. It is expected that the average annual temperature will increase by 0.2–0.5°C each decade, and the average annual precipitation increase by almost 10%. Minimum temperatures are expected to rise during winter resulting in a shortening of the cold season [7].

Figure 2-6 to Figure 2-8 summarise the results of the Norwegian climate research programmes. These figures show that the surface temperature will rise significantly by the end of the century in the A2 scenario, while in the B2 scenario the increase will be smaller.

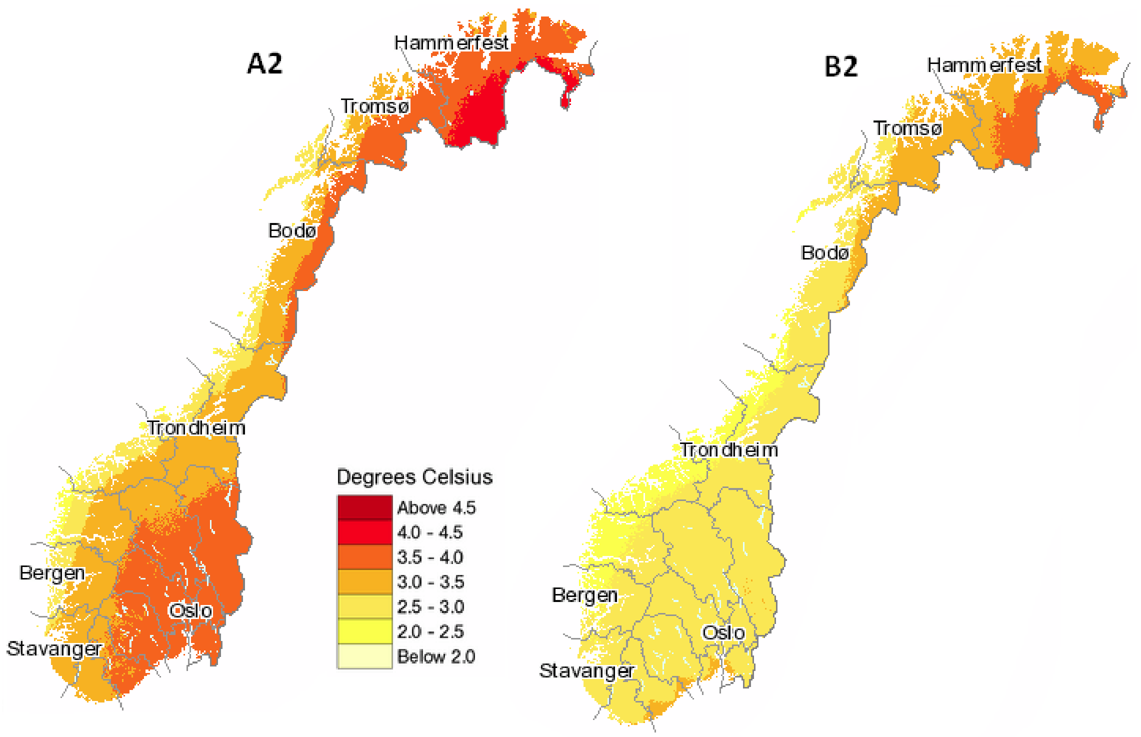


Figure 2-6 Change in mean annual temperature from 1961-1990 to 2071-2100 for A2 and B2 scenarios. The results are based on the global climate model HadAM3H [8]

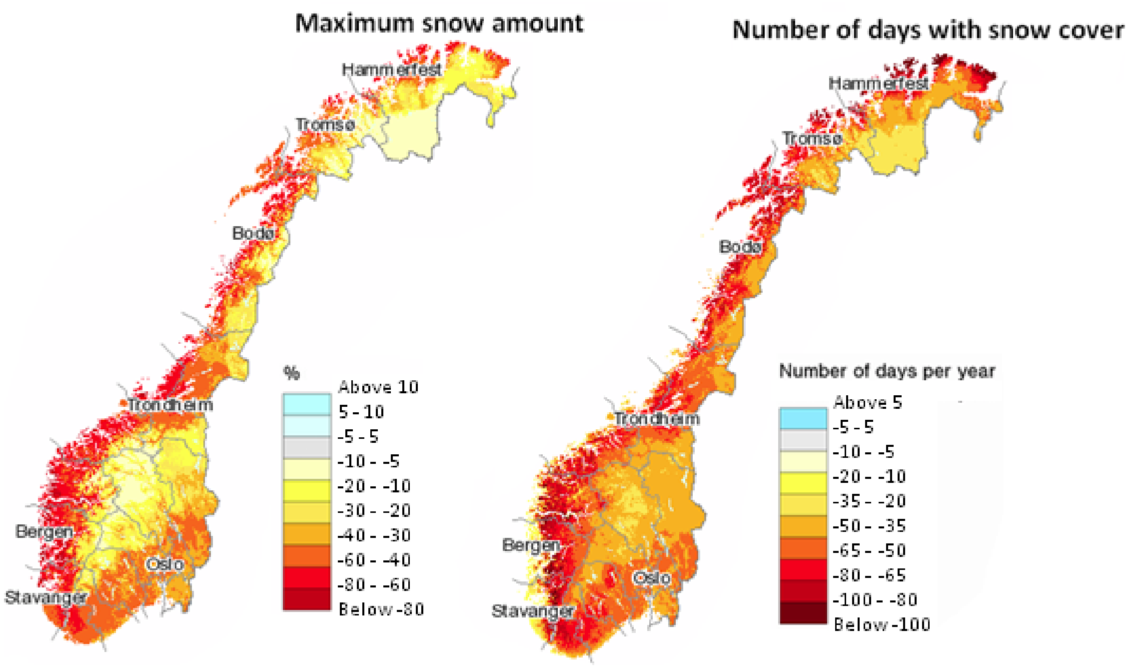


Figure 2-7 Change in average annual maximum of snow amount in % and mean number of days with snow covered ground from 1961-1990 to 2071-2100. [8]

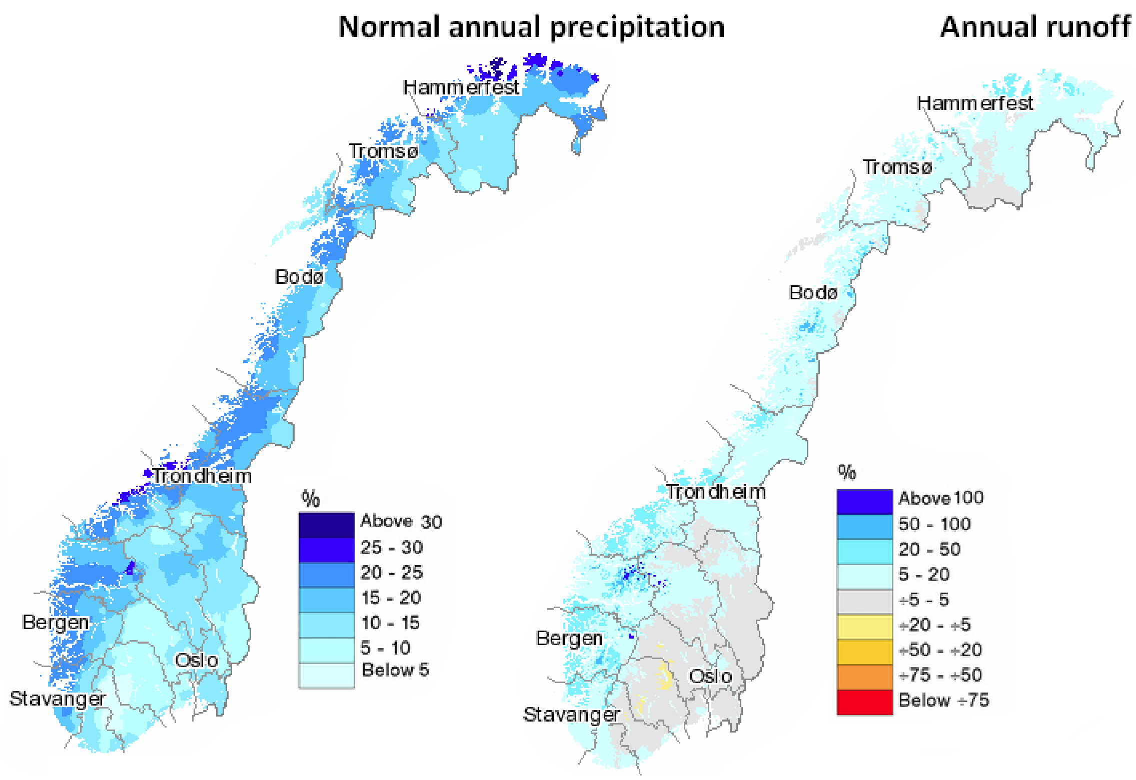


Figure 2-8 Change in normal annual precipitation in % and annual runoff in % from 1961-1990 to 2071-2100. [8]

2.3 FINLAND

It is estimated that the temperature in Finland will rise faster than the global average [9]. Projections for annual mean temperature the period 2000–2100, relative to the reference period of 1971–2000 are set out in the curves shown in Figure 2-9 [10,11]. These are given for the three greenhouse gas scenarios of A2, A1B and B1.

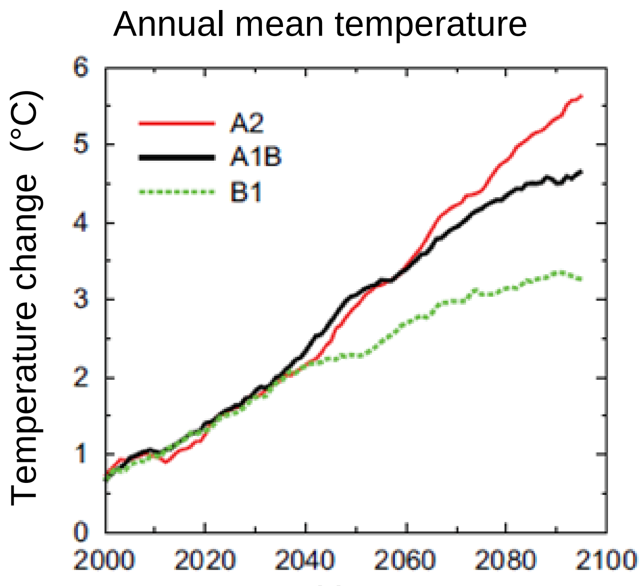


Figure 2-9 Projections for annual mean surface air temperature in °C for Finland relative to the mean of the reference period 1971-2000. The curves shown are 11 year running averages for the whole of Finland [11].

By the end of the century the temperature in Finland is expected to increase over the whole country as shown Figure 2-10 and Figure 2-11. In winter, the greatest rise (+6°C) is projected to be in north-east Finland and the least (+4°C) in the south-west.

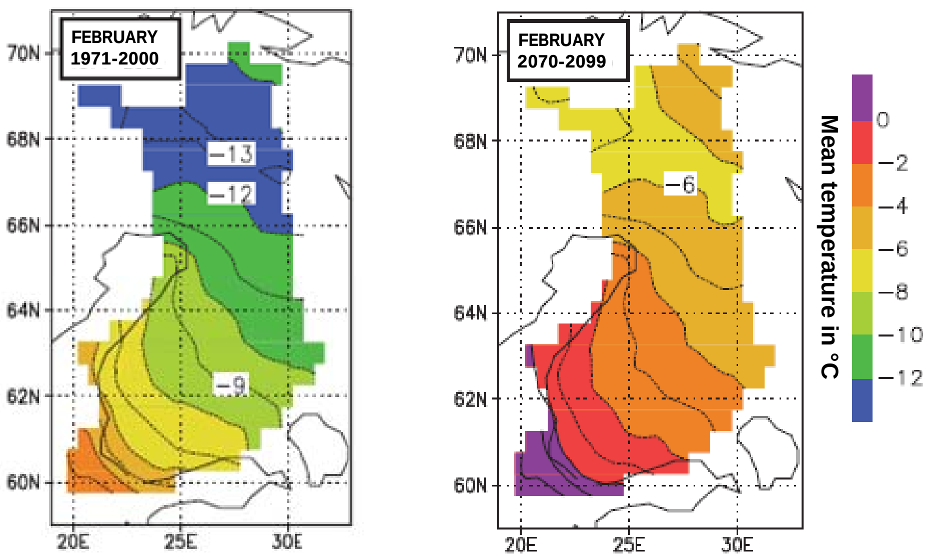


Figure 2-10 February daily mean temperature changes for Finland for the period 2070-2099 relative to the baseline period 1971-2000. The 1971-2000 mean temperatures are derived from observations. The 2070-2099 projection is the mean of all global climate models [11].

By contrast in summer, warming is predicted to be marginally greater (+3°C) in the south-west of Finland.

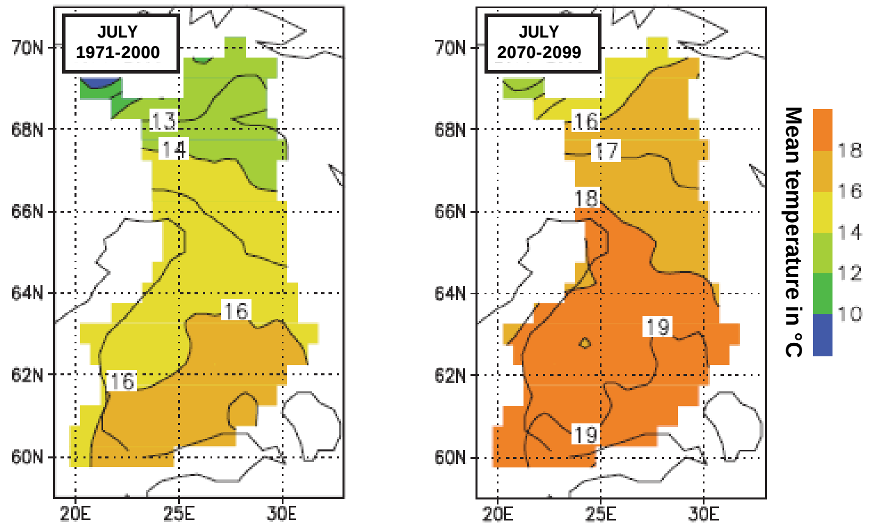


Figure 2-11 July daily mean temperature changes in °C for Finland for the period 2070-2099 relative to the baseline period 1971-2000. The 1971-2000 mean temperatures are derived from observations. The 2070-2099 projection is the mean of all global climate models [11].

Hot summer days are expected to be about four times more common than nowadays in Finland and the frost-free period in summer is expected to lengthen by at least two months [11].

Precipitation is expected to increase by 20-30% in winter over the whole country by the end of the century, Figure 2-12, and snow cover is projected to decrease by 20 to 40% of its present levels.

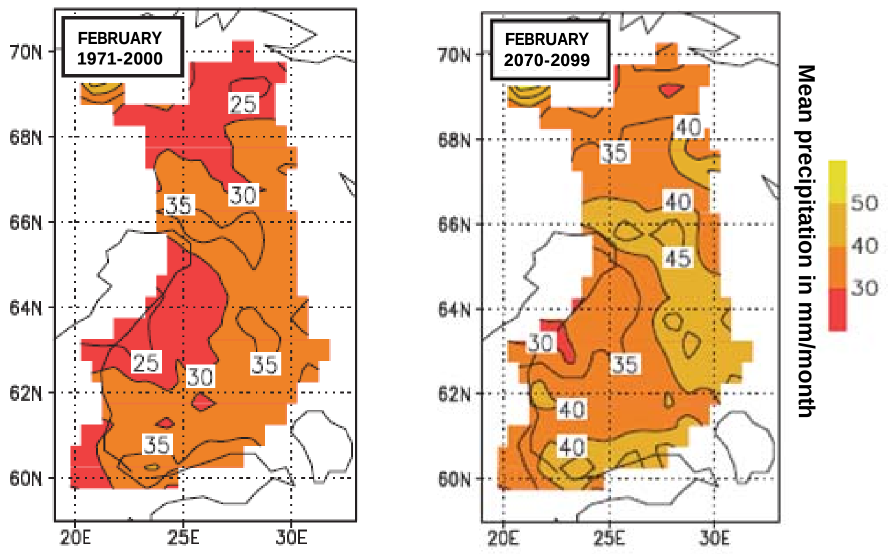


Figure 2-12 Mean precipitations (in mm/month) for February for the period 2070-2099 relative to the baseline period 1971-2000. The 1971-2000 mean precipitation is derived from observations. The 2070-2099 projection is the mean of all global climate models [11]

In summer, the increase in precipitation is expected to be around 10-20% in the north as shown in Figure 2-13.

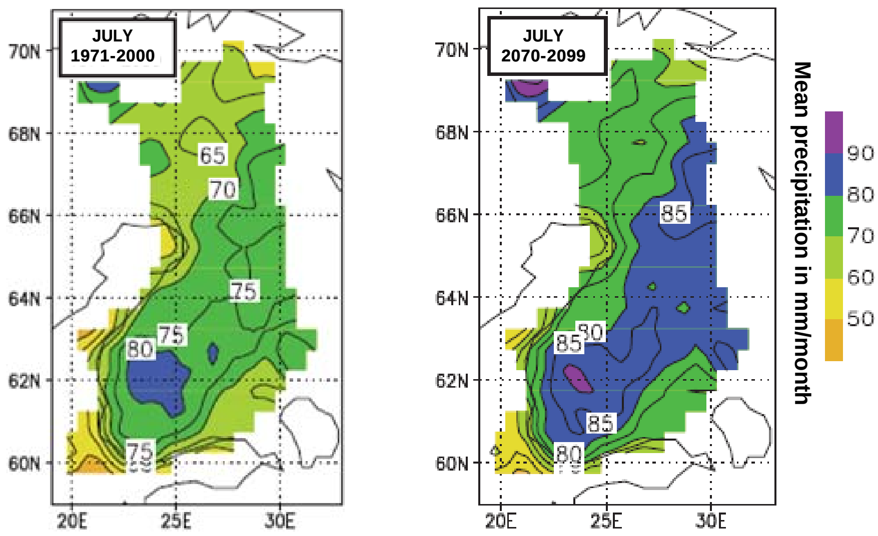


Figure 2-13 Mean precipitations (in mm/month) for July for the period 2070-2099 relative to the baseline period 1971-2000. The 1971-2000 mean precipitation is derived from observations. The 2070-2099 projection is the mean of all global climate models [11]

Heavy rainfall will occur more often and the number of rainy days will increase. Due to the increased precipitation and melting of snow, the largest floods will occur to the same extent, or to a greater extent, as today in southernmost Finland [12].

2.4 ICELAND

Climate change is expected to have a pronounced effect on glaciers, and it is predicted that glaciers will disappear in 100-200 years. In Iceland, the climate change scenarios predict an approximately sinusoidal temperature variation with a maximum of +0.3 °C per decade in the winter and a minimum of +0.15 °C per decade in summer [13], see Figure 2-14. Precipitation is not, or just slightly, expected to change in the summer, but is expected to rise in winter by 0% to 1.6 % per decade [14].

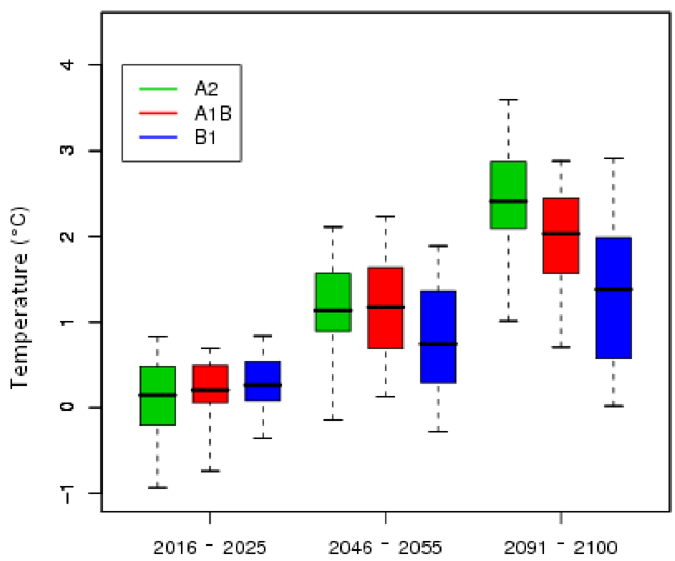


Figure 2-14 Change in mean annual temperature of Iceland in the century [15].

2.5 SCOTLAND

Climate change is predicted to have a significant effect in Scotland. Summers are expected to become warmer and winters milder. In eastern Scotland the summers will become drier, and winters wetter. More very dry summer days are expected and also high-intensity rainfalls [16]. Accumulated temperature, a measure of the degree of warmth for plant growth throughout the growing season, is expected to increase significantly [16], see Figure 2-15.

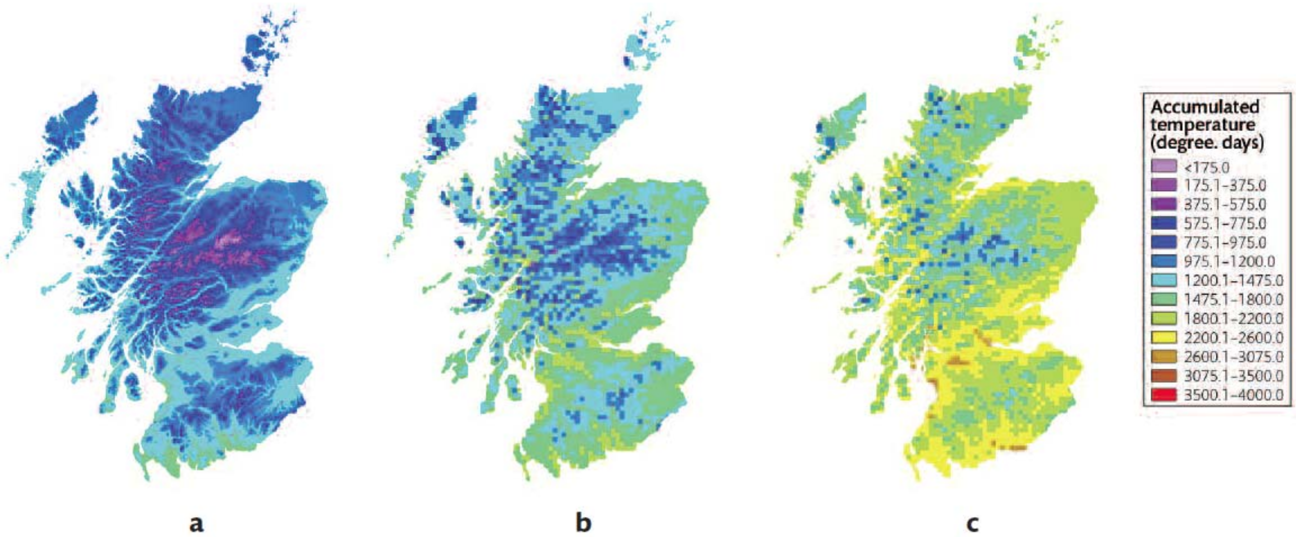


Figure 2-15 Accumulated temperature distribution of Scotland's climate: a) baseline climate, 1961–1990; b) projection for 2050; c) projection for 2080 [16].

The predicted temperature and precipitation changes by the 2080s under the medium and high emissions scenarios can be found in Figure 2-16 and Figure 2-17, respectively.

2080s MEDIUM EMISSIONS	EASTERN SCOTLAND	NORTHERN SCOTLAND	WESTERN SCOTLAND
Summer average Temperature	+3.5°C (+1.8°C to +5.7°C)	+3.0°C (+1.5°C to +4.9°C)	+3.5°C (+1.8°C to +5.4°C)
Winter average temperature	+2.3°C (+1.0°C to +3.7°C)	+2.2°C (+0.9°C to +3.6°C)	+2.6°C (+1.4°C to +4.0°C)
Summer average precipitation	-16% (-33% to 0%)	-11% (-29% to +4%)	-15% (-33% to +1%)
Winter average precipitation	+12% (+1% to +25%)	+17% (+4% to +35%)	+21% (+6% to +42%)

Figure 2-16 Scottish climate projections by the 2080s under medium emissions [17]

2080s HIGH EMISSIONS	EASTERN SCOTLAND	NORTHERN SCOTLAND	WESTERN SCOTLAND
Summer average Temperature	+4.3ºC (2.2ºC to 7.0ºC)	+3.7ºC (1.9ºC to 6.0ºC)	+4.3ºC (2.4ºC to 6.8ºC)
Winter average temperature	+2.6ºC (1.3ºC to 4.2ºC)	+2.5ºC (1.2ºC to 4.1ºC)	+3.1ºC (1.9ºC to 4.8ºC)
Summer precipitation	-21% (-40% to -1%)	-16% (-36% to +4%)	-20% (-39% to -1%)
Winter precipitation	+19% (+6% to +36%)	+24% (+9% to +45%)	+30% (+12% to +55%)

Figure 2-17 Scottish climate projections by the 2080s under high emissions [17]

2.6 IRELAND

A simulation of future climate for Ireland shows a general warming with mean monthly temperatures increasing typically between 1.25 °C and 1.5 °C. The largest increases are expected to take place in the south-east and east in July [18], see Figure 2-2.

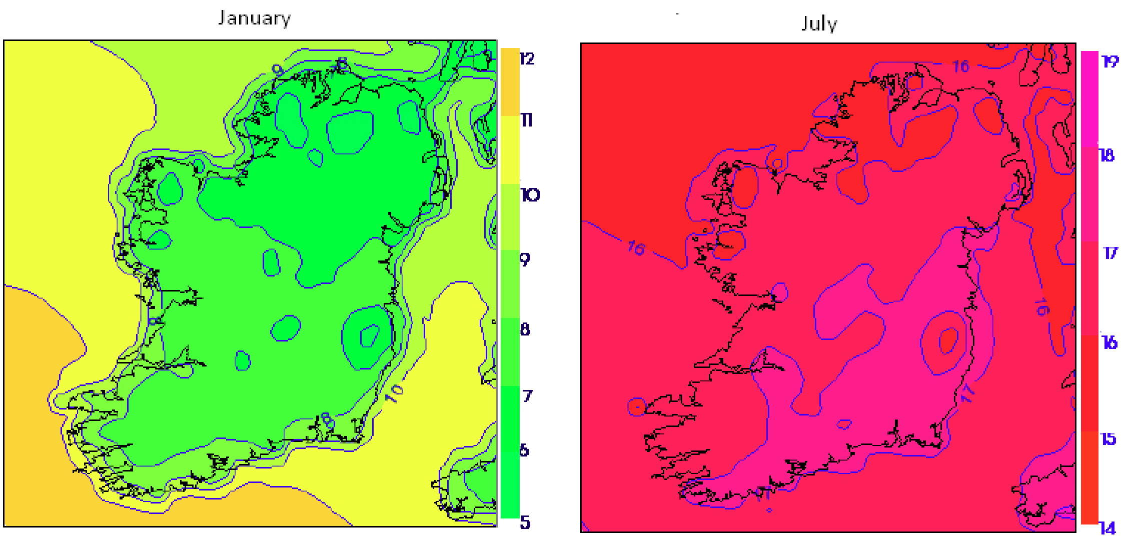


Figure 2-18 Regional Climate Model simulation for 2021–2060, average 2-metre temperature for January (left) and July (right). [18]

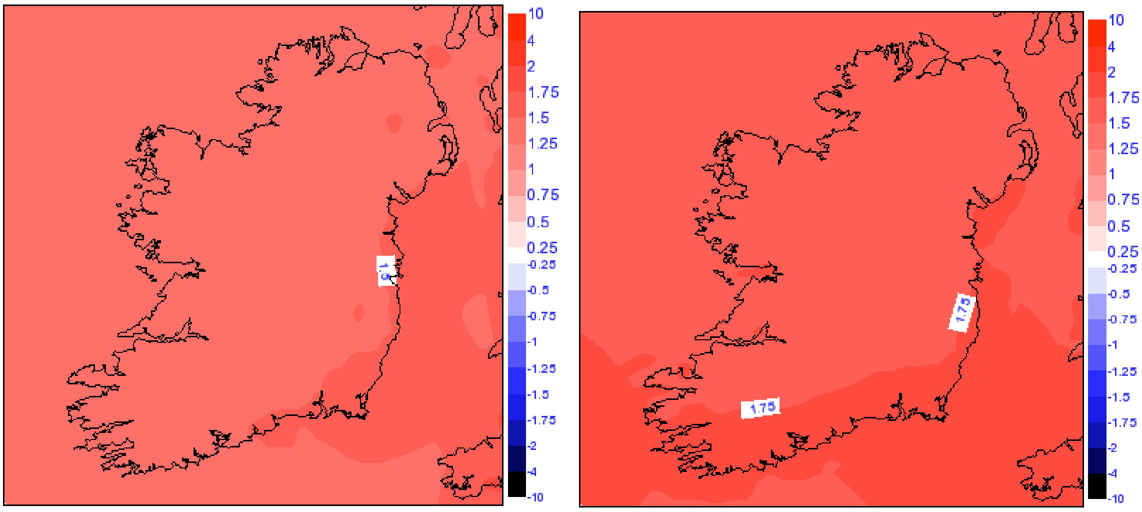


Figure 2-19 Regional Climate Model simulation for 2021–2060: differences for January (left) and July (right) relative to the reference (1961–2000). Units: degrees Celsius. [18]

Autumn and winter are expected to become wetter: a 5-10% increase in mid century, increasing to 15-25% by the end of the century [19]. June and December are predicted to have significant changes in average monthly precipitation [18], as shown in Figure 2-20. December shows the largest increase with changes ranging from around 10% in the south-east to 25% in the north-west. Storm events are likely to increase in frequency in autumn and winter.

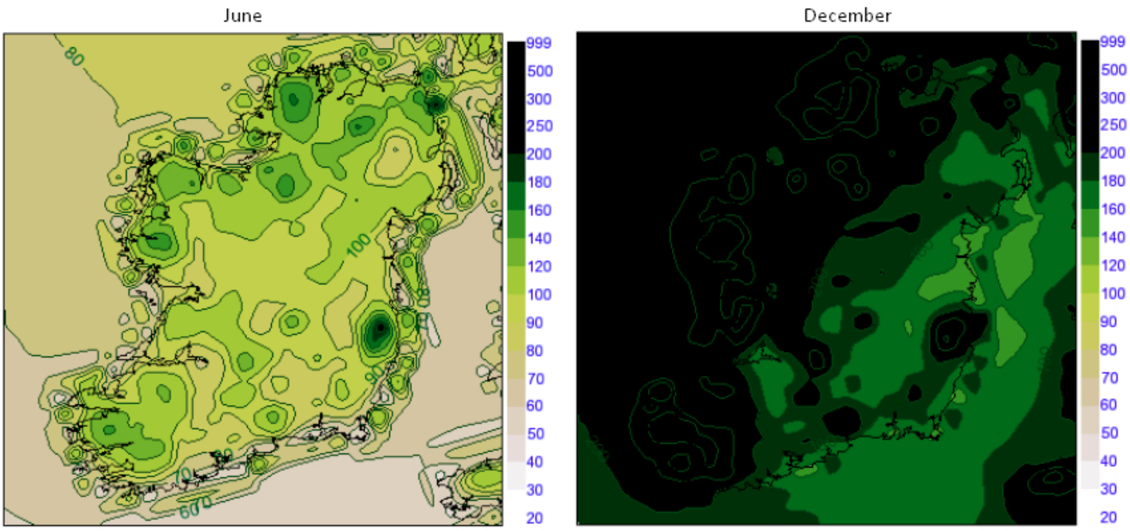


Figure 2-20 Regional Climate Model simulation for 2021–2060 monthly rainfall accumulation for June (left) and December (right). Differences relative to the reference (1961–2000). [18]

2.7 GREENLAND, ALASKA AND CANADA

These three regions were studied together for the purposes of this report due to the similarities. Climate change in the Arctic is unique and is expected to have a significant impact there. These impacts can be both positive and negative depending on one's interest. On the positive side, the reduced sea ice may open historically closed shipping lanes and increase marine access to region's resources, such as fish or oil [20].

There is already a clear warming trend in the Arctic and records of increasing temperatures, melting glaciers, reductions in extent and thickness of sea ice, thawing permafrost and rising sea level providing strong evidence. In most places, temperatures in winter are rising more rapidly than in summer. In the B2 scenario, over the next 100 years, annual average temperatures are projected to rise 3-5 °C (Figure 2-21). The maps on Figure 2-22 show the predicted annual and winter temperature change from the 1990s to the 2090s in the B2 scenario.

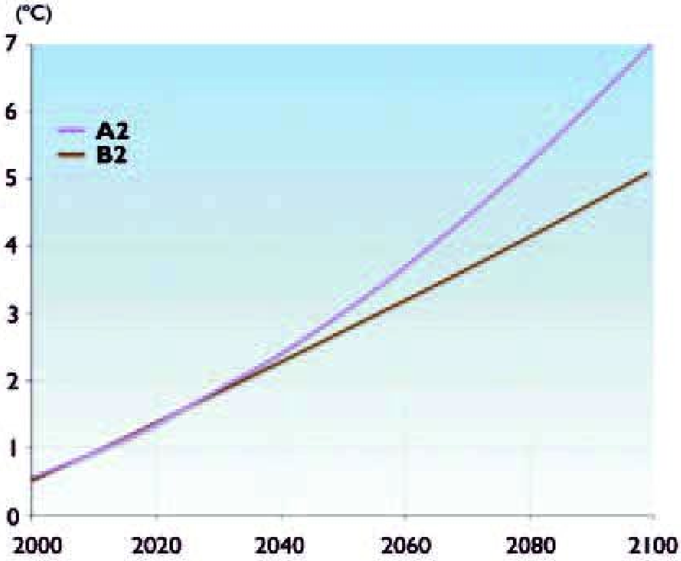


Figure 2-21 Increases in annual average temperature in the Arctic relative to 1981-2000. [20]

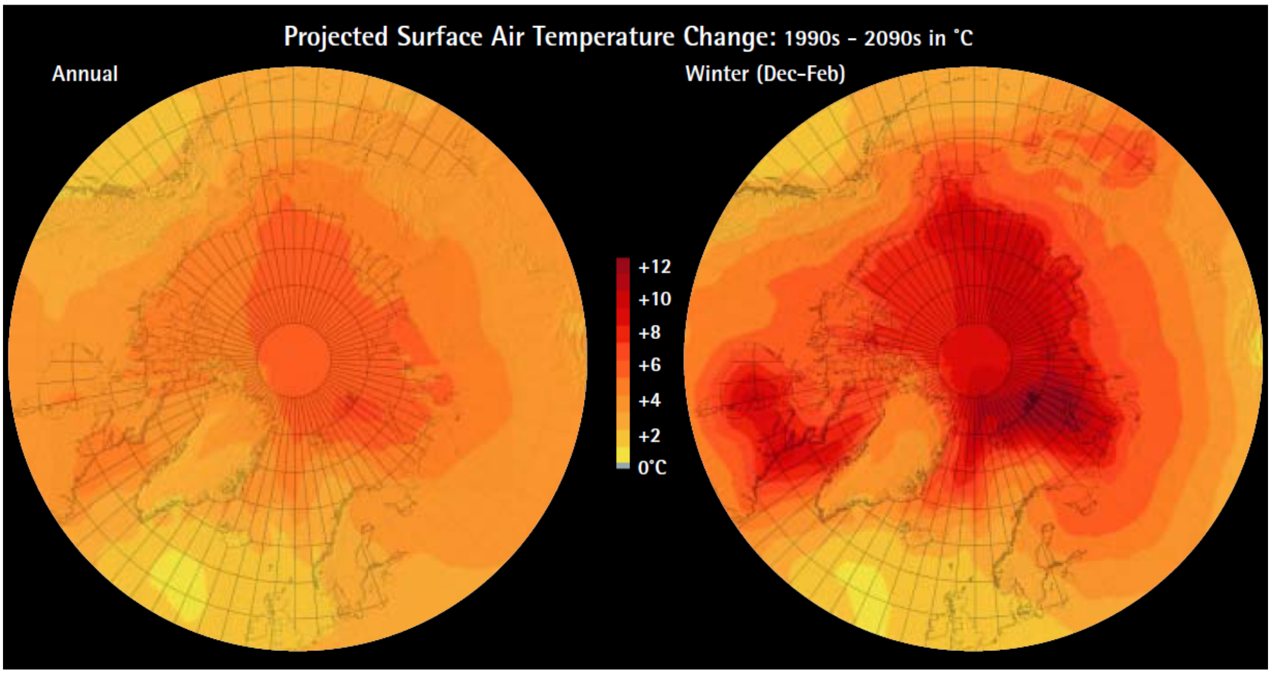


Figure 2-22 Predicted annual and winter temperature change from the 1990s to the 2090s in the B2 scenario [21].

The Greenland Ice Sheet is the dominant land ice in the Arctic. Here the maximum surface-melt area has increased by 16 % over the average in the last 20 years [20]. If this trend continues in this century, it could cause a significant increase in the global sea level, see Figure 2-23. Loss of sea ice is larger during summer. It is predicted, that the annual average decrease in sea ice will be more than 50% by the end of the century.

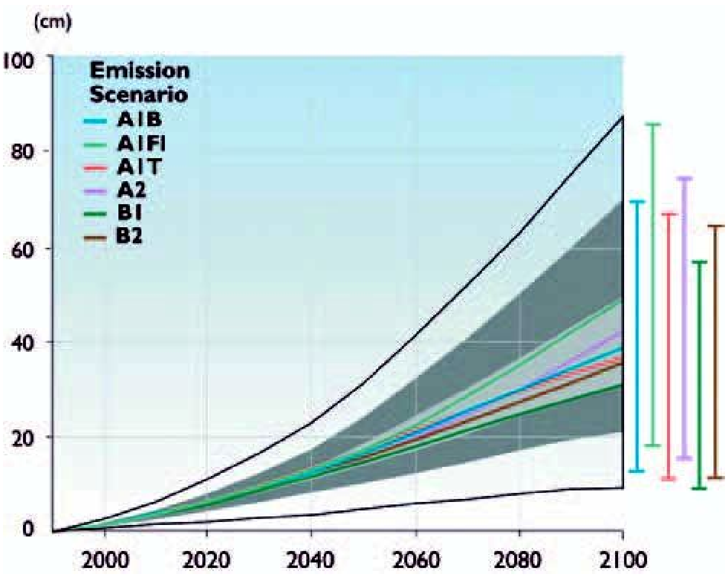


Figure 2-23 Projected global sea level rise [20].

Annual total precipitation over the Arctic is projected to increase by around 20% by the 2090s. Most of it is rain. Precipitation is projected to be most concentrated over coastal regions and in winter and autumn. The increases in these months are expected to exceed 30 % [21]. The maps on Figure 2-24 show the predicted precipitation change in mm per month from the 1990s to 2090s.

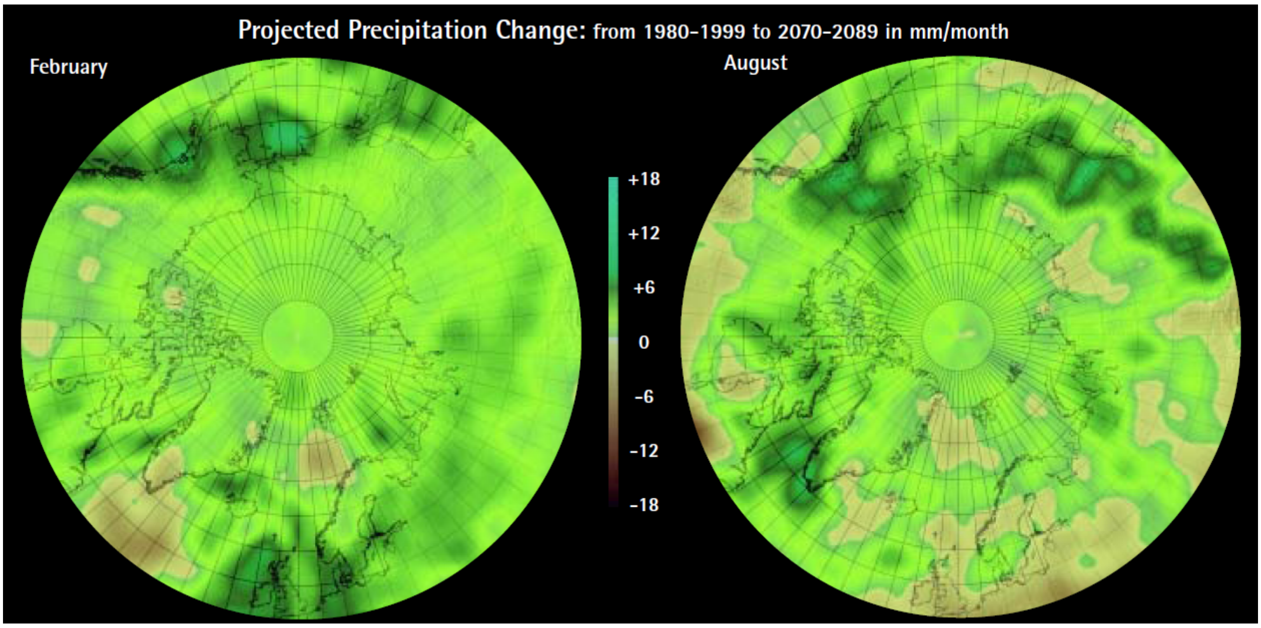


Figure 2-24 The predicted precipitation change in mm per month in February and August from the 1990s to 2090s [21].

2.8 SUMMARY

The Earth's climate is predicted to change. Increasing levels of greenhouse gases are expected to cause a rise in temperatures across the world and lead to a change in global weather patterns. The degree of change is uncertain, and it is not possible to be definitive in how much the likely climate change will be, or when it will happen. The natural variability of weather patterns will add further uncertainty to the accuracy of predictions.

The ROADEX Partners recognise that the subject of climate change, and what to do about it, is controversial. They do not take a formal position on it one way or the other. The only position that the Partners take is that it is prudent to take such steps as considered reasonable to deal with the circumstances happening to the local road infrastructure now, rather than ignore the topic altogether.

All prediction scenarios considered indicate that the annual precipitation and temperature across the Northern Periphery are likely to increase. This is likely in turn to result in a range of impacts, such as a greater frequency of storm events, more frequent freeze-thaw cycles, more frequent and vulnerable floods and landslides, and others. Local engineers should be aware of these threats, and be ready to meet them to mitigate their impacts on the local road networks, as they have always done.

3. ROADEX QUESTIONNAIRE AND ANALYSIS

In order to get the Partner view of the possible impacts of climate change across the Northern Periphery ROADEX launched a questionnaire, *"Impacts of Climate Change on Infrastructure in the Northern Periphery"* on the internet in the spring of 2010. Its aim was to identify how the Partner Organizations felt about the likely impacts and what national strategies/policies were being promoted in their countries.

A request was sent out to the Partners in early May and 25 responses were collected by 1st November 2010. Figure 3-1 summarizes the distribution of replies among the countries.

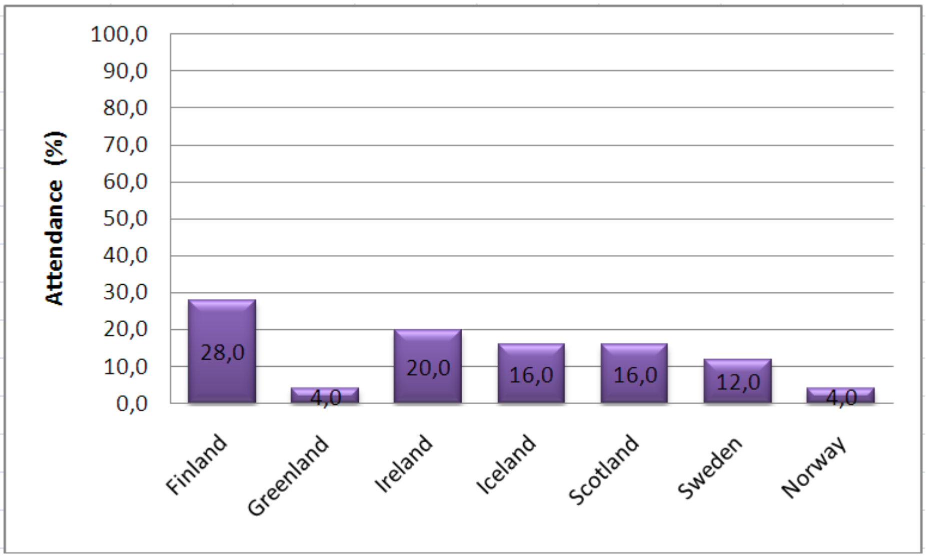


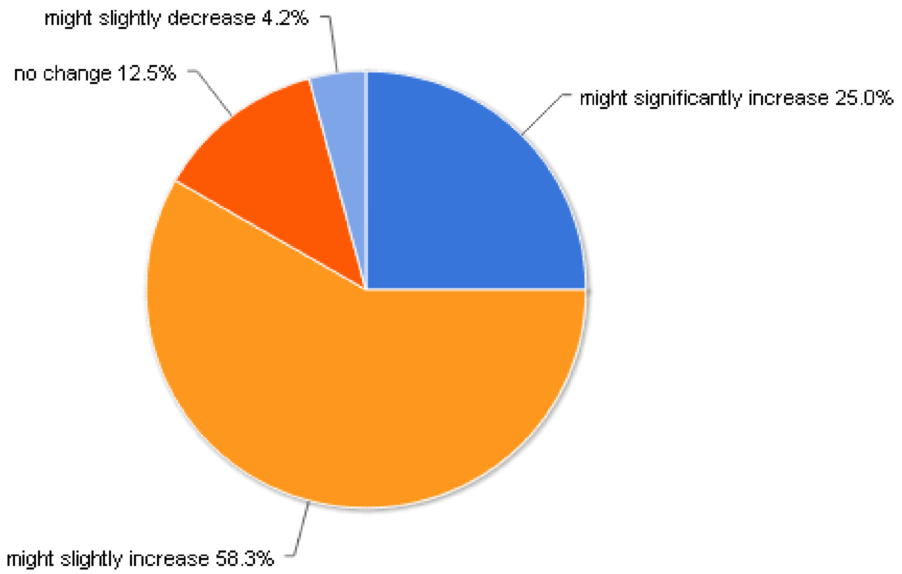
Figure 3-1 Diagram showing the distribution of results in % based on the originating countries.

The questionnaire itself can be found in Appendix 7.1 and its results are presented in the following sections. The questionnaire was an interactive questionnaire. All the possible road related climate change impacts were illustrated by photos, so users, who were not familiar with the technical descriptions, could recognize the impacts.

3.1 ANALYSIS OF ROADEX CLIMATE CHANGE QUESTIONNAIRE

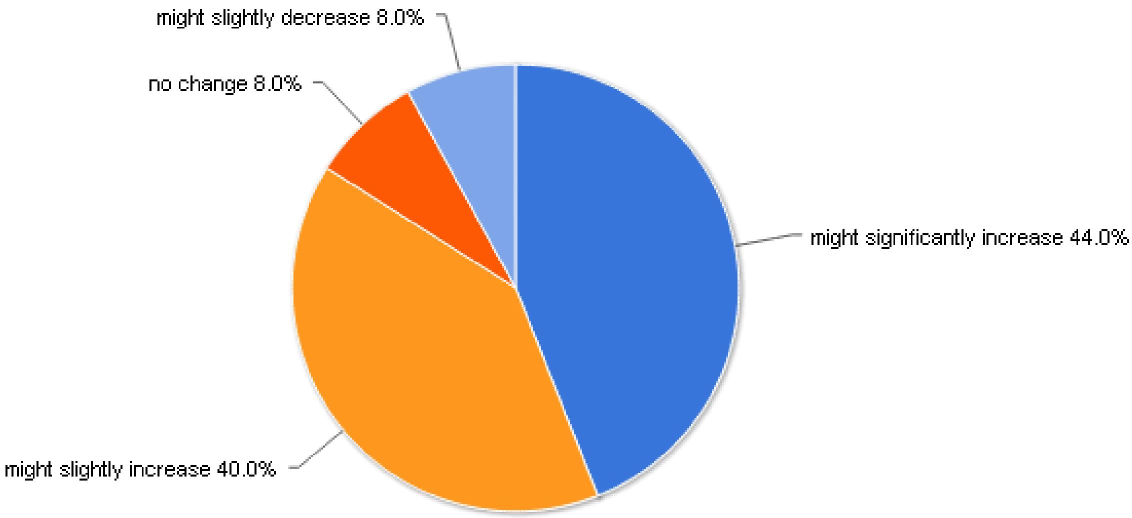
The results of the collected replies are summarized in pie charts. Unfortunately due to the low number of replies, it was not possible to distinguish the results between countries. So these results represent the concern of the ROADEX Partners as a whole.

Stability problems of road embankments



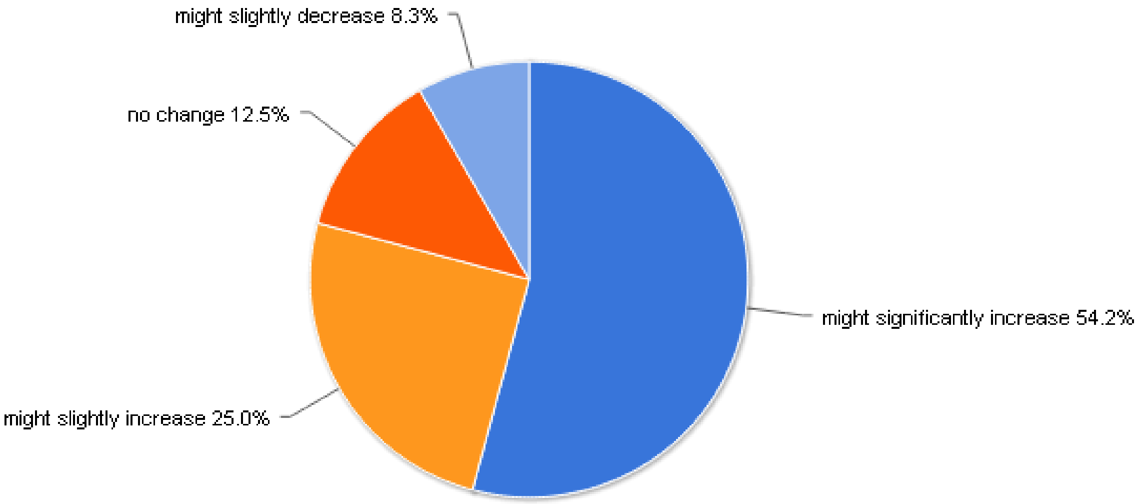
Stability problems in road embankments are a common feature in most of the ROADEX countries. 19 responses out of 23 said that this problem might increase in the future.

Freeze-thaw cycles of paved roads



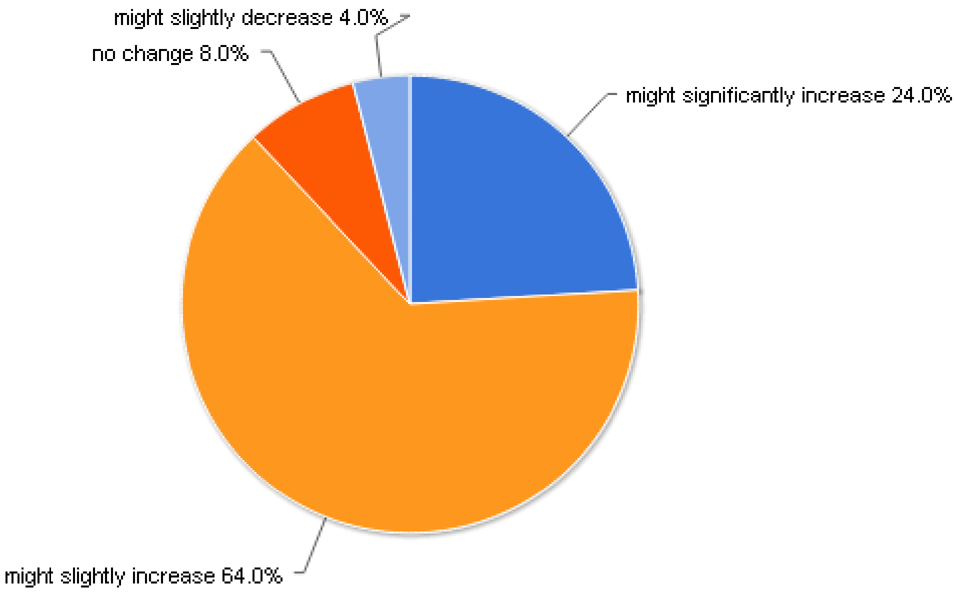
Increasing frequency of freeze thaw cycles is a very likely impact of climate change. Respondents reported that they had experienced it in the recent years in their areas, where it had not been common problem before. It was expected that there would be more and more problems in the future on roads as a result of changing freeze-thaw cycles, especially unpaved roads.

Freeze-thaw cycles of unpaved roads



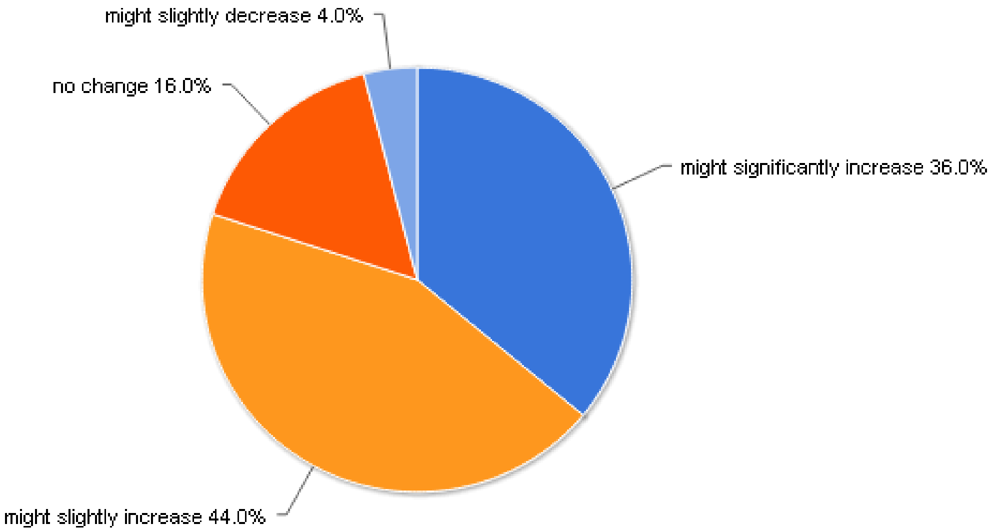
Similar prognosis was found in the case of unpaved roads where more significant problems are expected, especially for forest roads. Forest roads have to carry large weights early in spring time, which is the worst period due for freeze-thaw cycles.

Rutting due to spring thaw weakening of paved roads



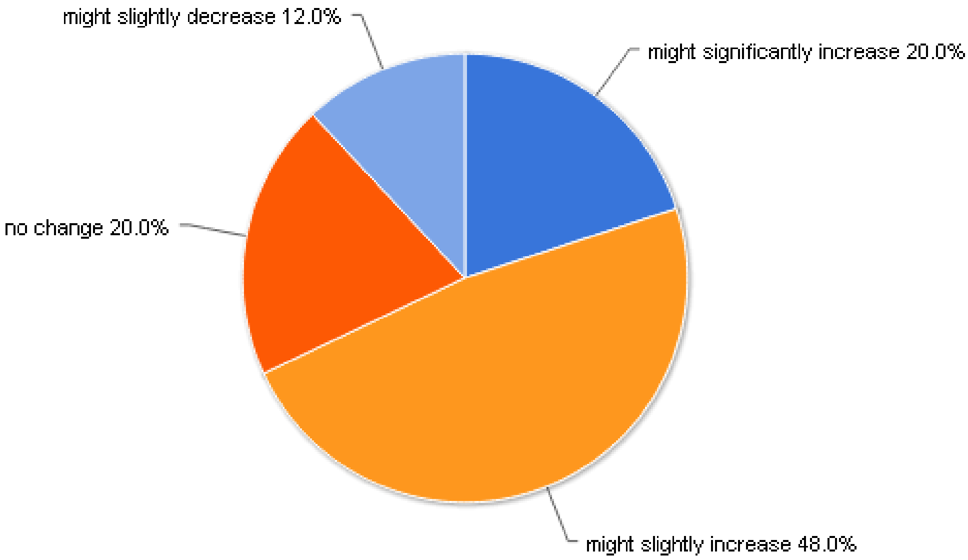
Rutting is a very common problem in low volume roads due to poor construction and heavy truck traffic. Spring thaw weakening of both paved and unpaved roads was expected to increase significantly in the future.

Rutting due to spring thaw weakening of unpaved roads



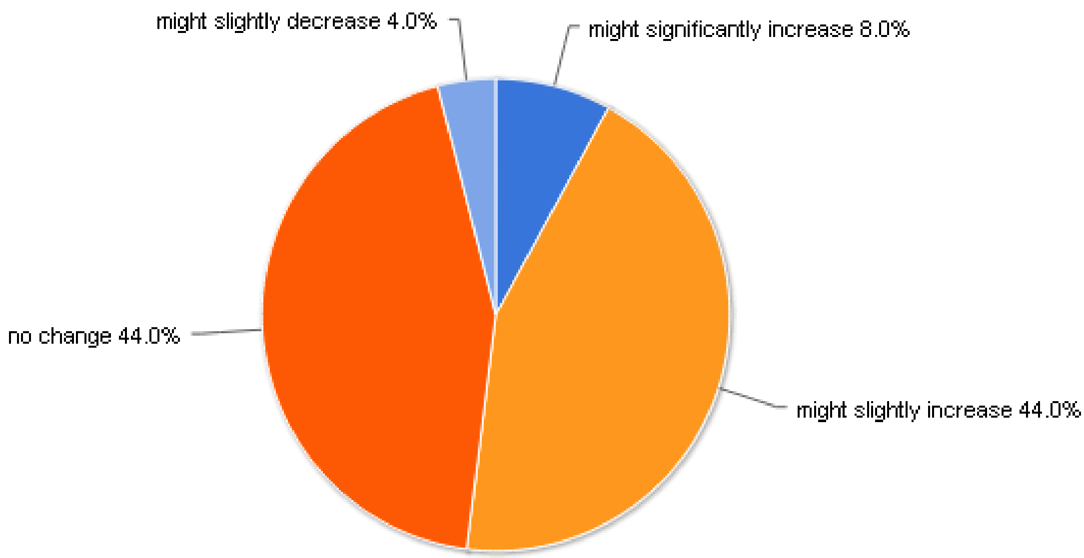
Rutting of unpaved roads is a significant problem in the Northern Periphery. Respondents expected this to increase in the future causing serious problems, particularly on forest roads.

Differential frost heave



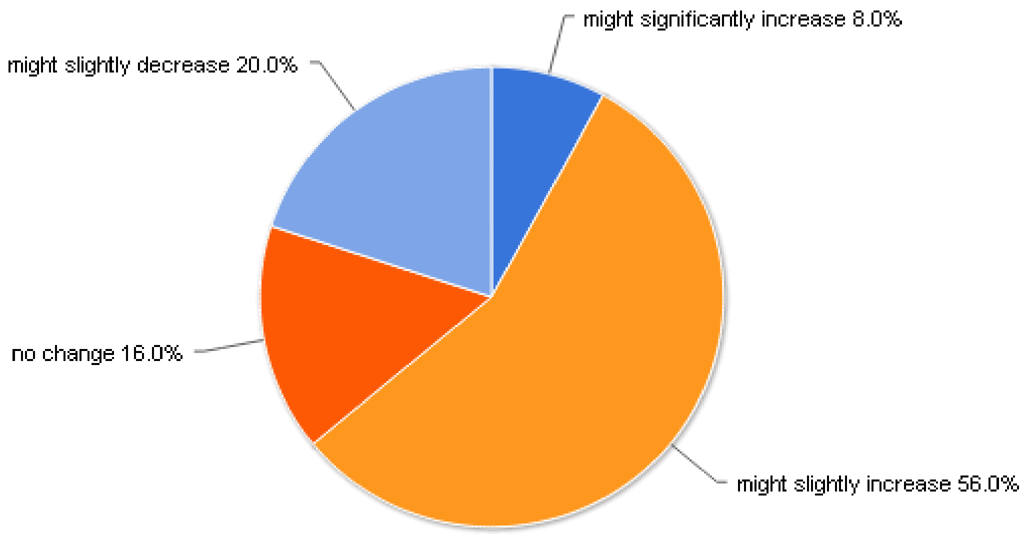
Respondents expected differential frost heave to slightly increase in the future.

Settlement due to permafrost



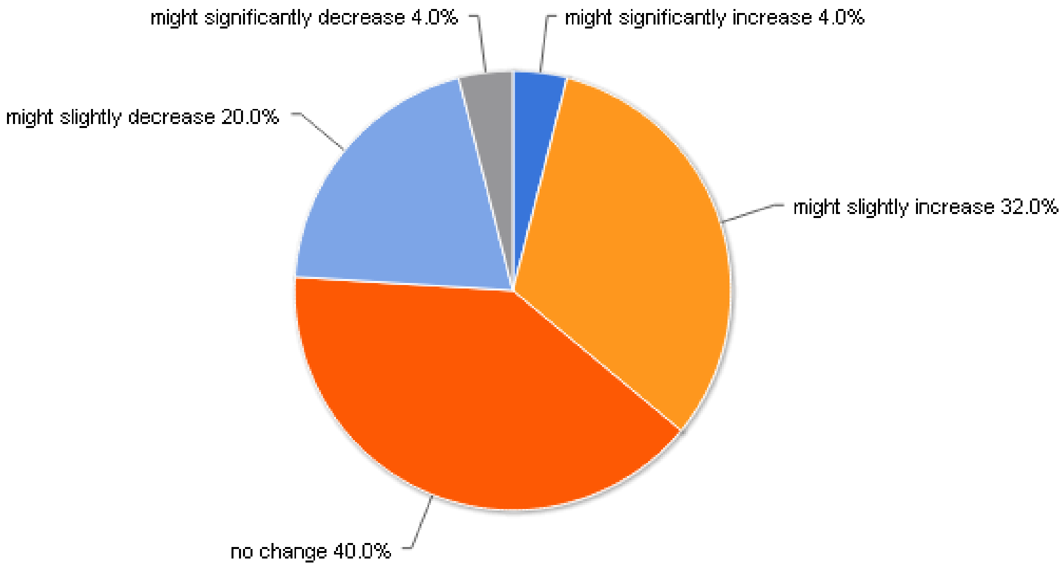
Settlement due to permafrost was expected to increase in the future in those areas where permafrost existed. 44 % of the respondents said that they expected “no change”. These responses were from the Partner countries where permafrost was not a problem.

Sheet ice problems



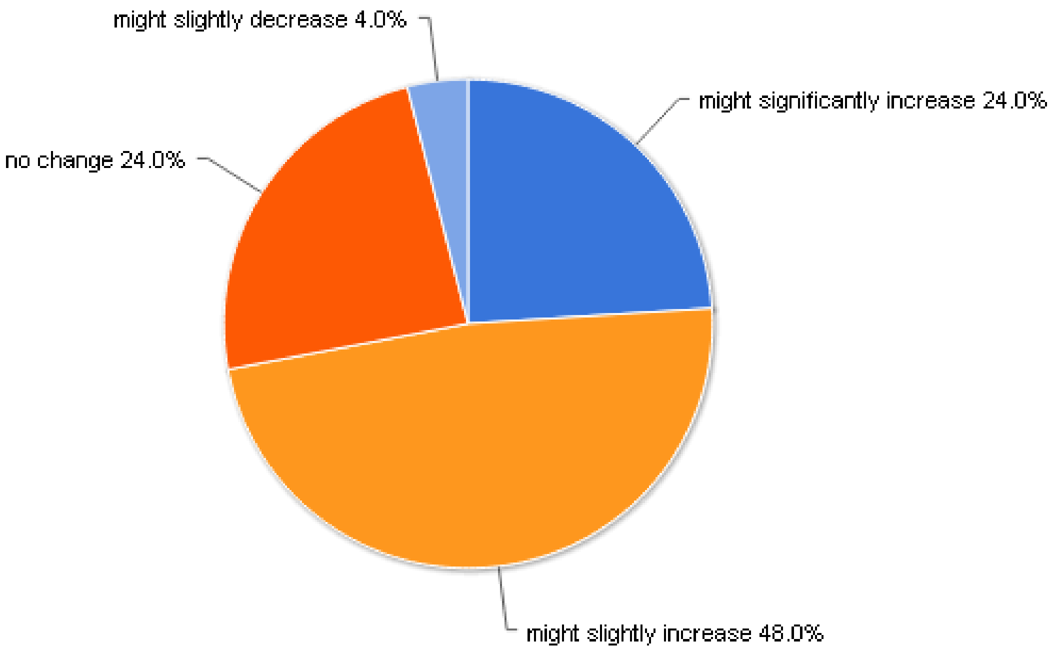
Respondents reported that they expected an increased frequency of icy roads despite winters being predicted to become milder.

Winter maintenance problems due to drifting snow



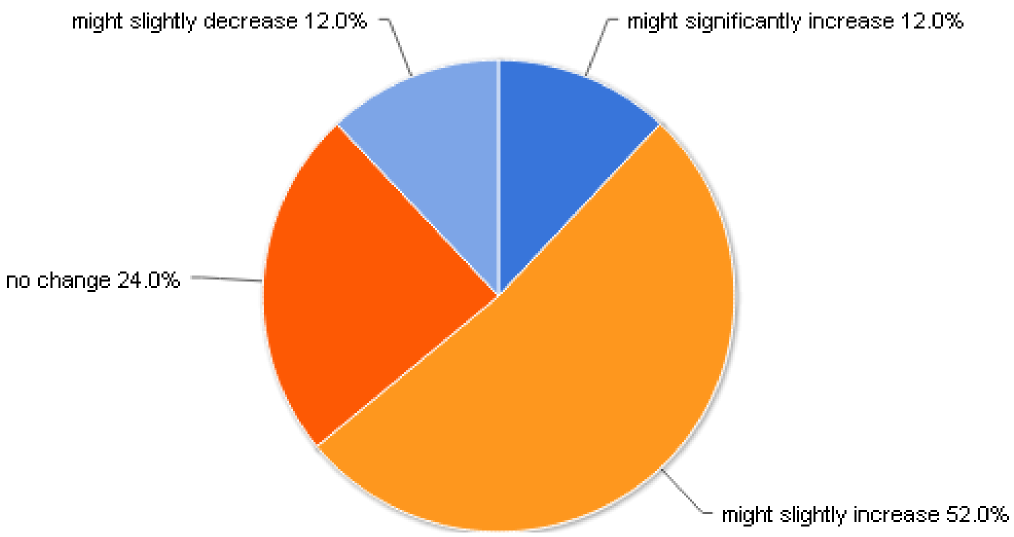
Snow drifting was not expected to increase in the future. A possible reason for this is that winters are predicted to become milder and less snow fall is probable.

Winter maintenance problems due to icing



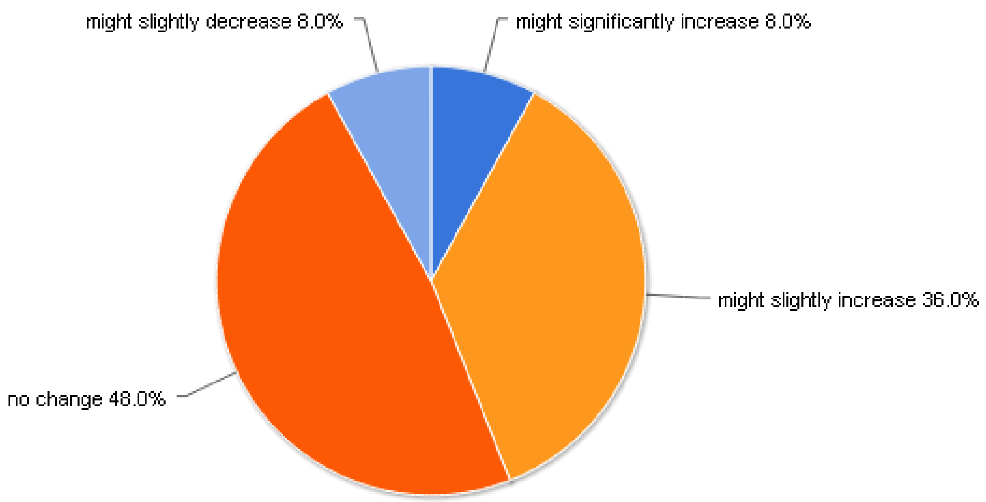
Respondents reported that they expected winter maintenance problems to increase as a result of more icy roads.

Winter maintenance problems due to salt



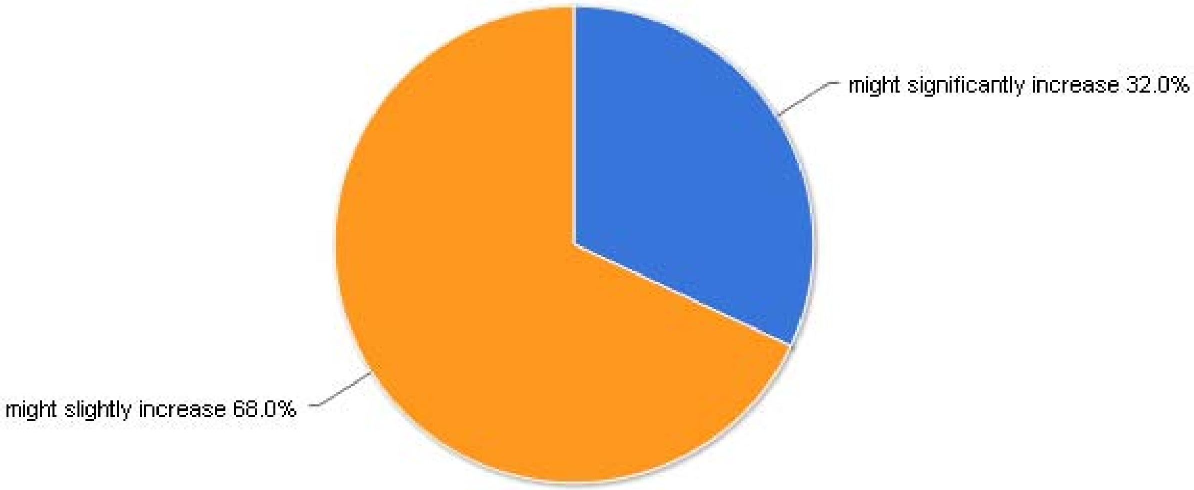
Winter maintenance problems, and salt usage, were expected to increase. It considered that salt would be needed in areas where it had not been used before due to reductions in snowfall. This was despite all Partners looking to reduce salt usage

Avalanches



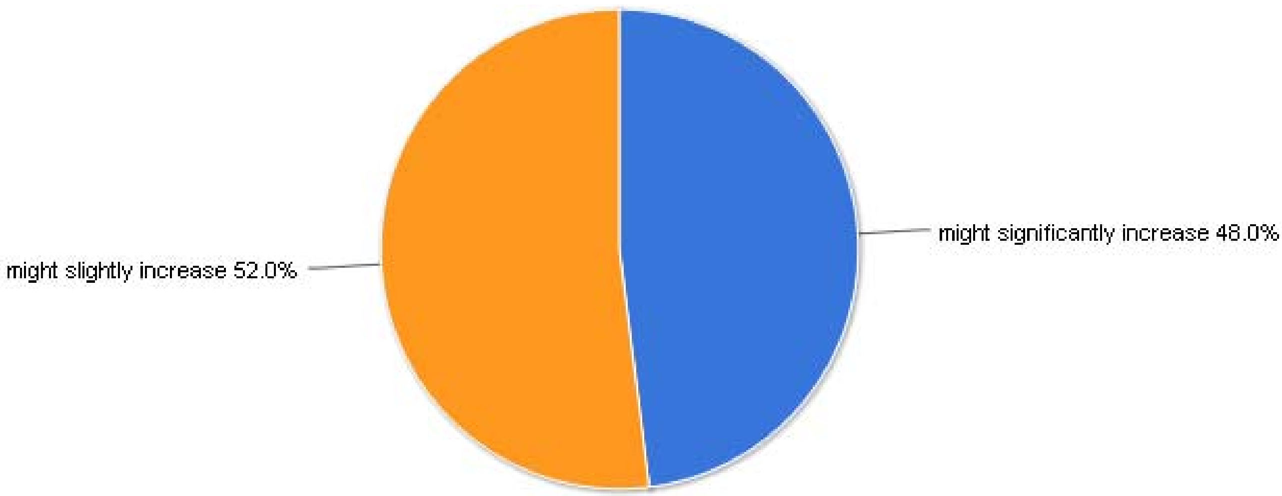
Respondents expected the intensity of avalanches to change in the future, due to the milder winters.

Erosion of paved roads due to heavy rains



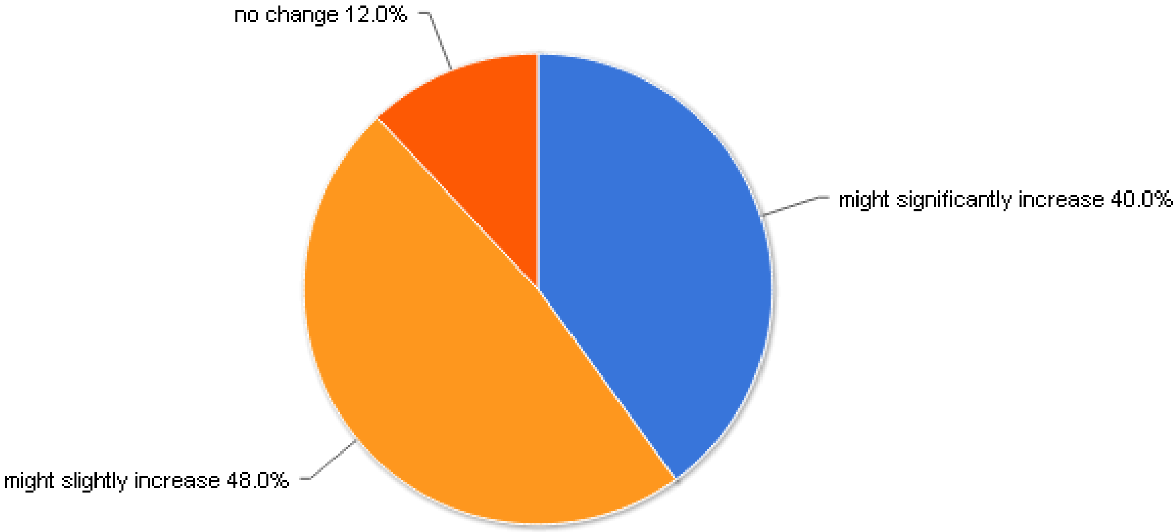
The erosion of paved and unpaved roads was predicted to increase in the future in all the ROADEX countries. This problem was considered to be one of the most important problems, and a result of poor drainage on rural roads.

Erosion of unpaved roads due to heavy rains



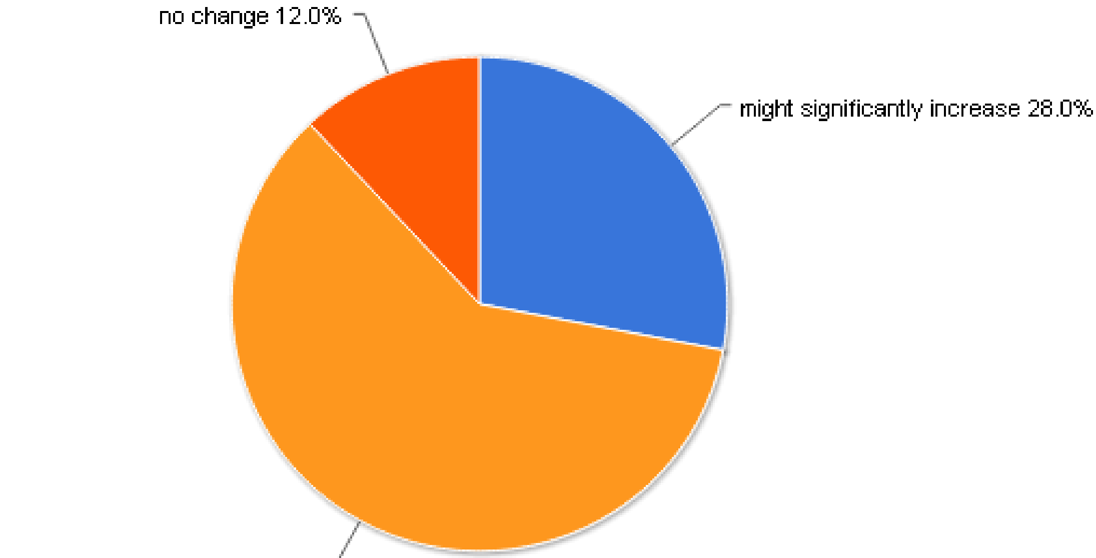
Respondents did not have a clear opinion on this subject, probably as it was already a known problem.

Flooding



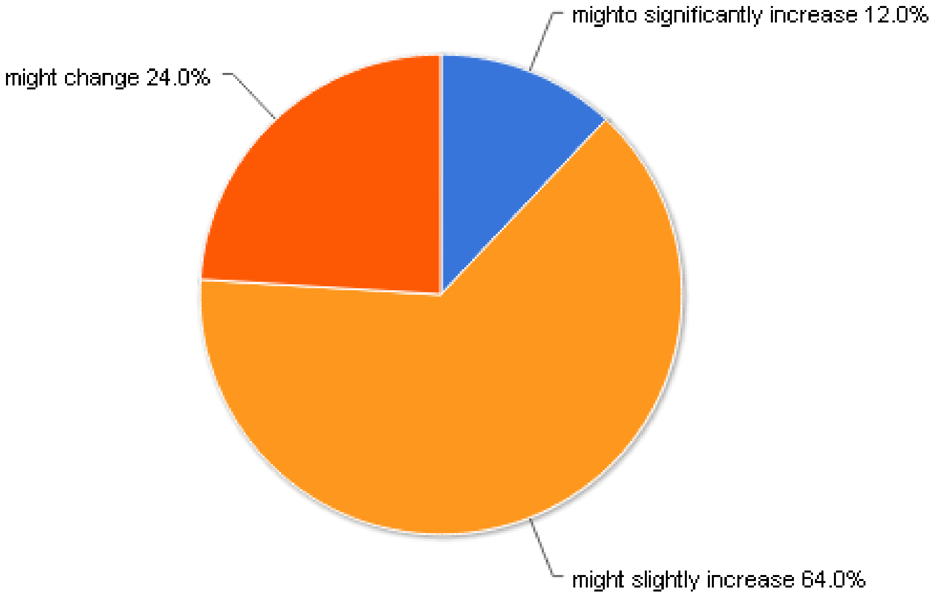
Flooding was expected to increase in the future in all the ROADEX countries due to the increased amount of precipitation. This problem was considered to be one of the most important problems.

Landslides



Landslides were expected to increase in the future in the ROADEX countries. Some respondents stated that flooding had not been a common problem in the past, but it was expected to be a problem in the future. Flooding was considered to be one of the most important problems facing the Partners.

Rise of sea level



Respondents reported that rising sea levels were a concern in all of the coastal areas.

Overall analysis

A rating system was devised to analyze the results of the questionnaire. Ratings were awarded from -2 to 2 for each response and a summary of the results in tabular form is presented in **Error! Reference source not found.**. The rating system comprised:

- Might significantly decrease: -2
- Might slightly decrease: -1
- No change: 0
- Might slightly increase: 1
- Might significantly increase: 2

Table 3-1 Rating of the climate change impacts

Impacts	Might significant decrease	Might sightly decrease	No change	Might sightly increase	Might significant increase	*Rate*
Stability problems with road embankments	0	1	3	14	6	25
Freeze-thaw cycles problem with paved roads	0	2	2	10	11	30
Freeze-thaw cycles problem with unpaved roads	0	2	3	7	12	29
Rutting due to spring thaw weakening of paved roads	0	1	2	16	6	27
Rutting due to spring thaw weakening of unpaved roads	0	1	4	11	9	28
Differential frost heave	0	2	5	13	5	21
Settlement due to permafrost	0	1	11	11	2	14
Sheet ice problems	0	5	4	14	2	13
Winter maintenance problems due to drifting snow	0	6	10	8	1	4
Winter maintenance problems due to icing	0	1	6	12	6	23
Winter maintenance problems due to salt	0	3	6	13	3	16
Avalanches	0	2	12	9	2	11
Erosion of paved roads due to heavy rains	0	0	0	17	7	31
Erosion of unpaved roads due to heavy rains	0	0	0	13	12	37
Flooding	0	0	3	12	11	34
Landslides	0	0	3	15	7	29
Rise of sea level	0	0	6	16	3	22

A bar chart summarizing these ratings is given **in Figure 3-2 below.**

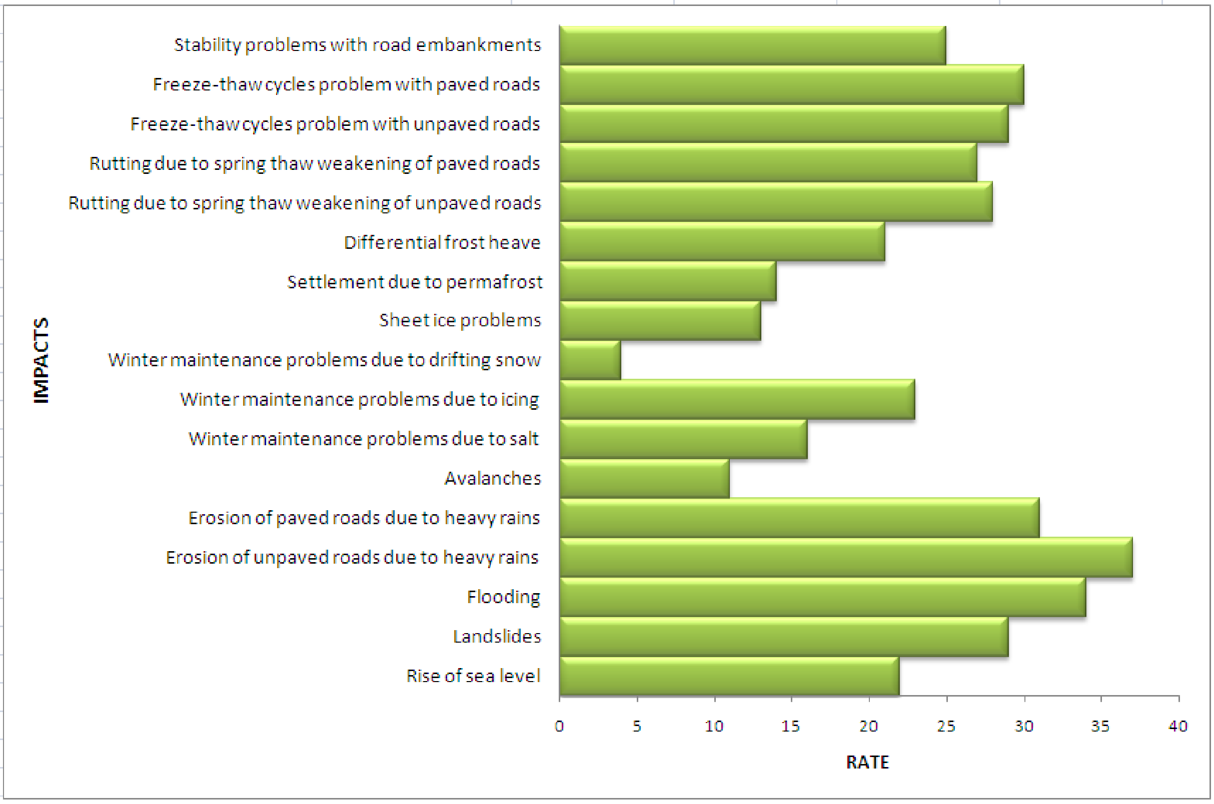


Figure 3-2 Bar chart summary of Partners concerns for climate change impacts

Figure 3-3 represents the Partners' greatest concerns about impacts of climate change. Even though thawing of permafrost and avalanches are the end of the list, these are large threat in areas where they are common problems, such as in Norway, Greenland or Iceland.

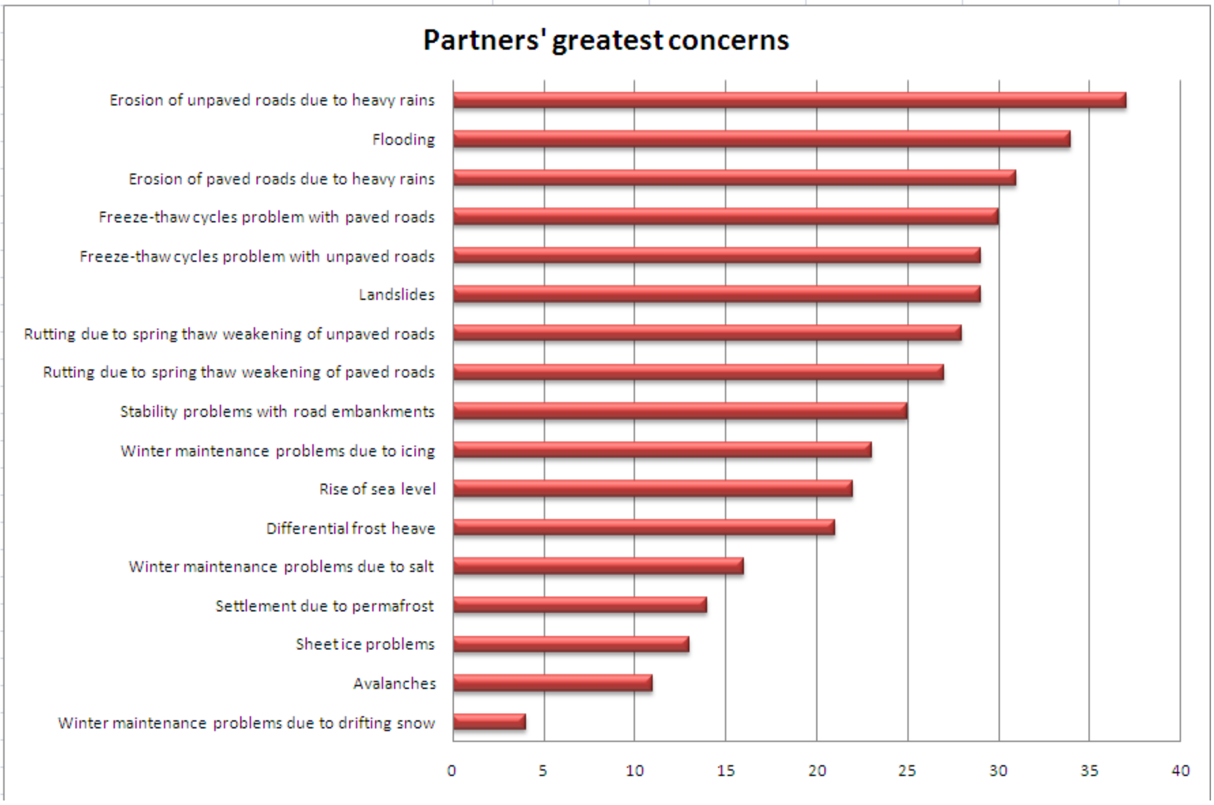


Figure 3-3 Bar chart of Partners' greatest concerns for climate change

3.2 SUMMARY

A number of preliminary conclusions can be drawn from the Partners' responses to the Questionnaire:

- All Partners were concerned about possible increasing levels of precipitation and their consequences, especially the erosion of roads and flooding;
- Northern districts, subject to possible movements to milder winter conditions, were concerned about more freeze-thaw cycles, greater frost heave effects, cracking and potholing;
- Partners with hilly districts were concerned that the increasing precipitation levels would result in increasing frequencies of landslides;
- Partners with coastal districts had concerns about rising sea levels which, when combined with storm surges, could lead to flooding and road closures.

4. PREDICTED CLIMATE CHANGE IMPACTS

Chapter 2 described how the world's climate is changing and how it is predicted to change in the future. Chapter 3 summarised the Partner's concerns of how their road practices may be affected. This Chapter will review the published literature on the impacts of predicted climate change and consider how they might affect the low volume roads networks of the Northern Periphery. These impacts can be summarized as below ("*The Changing Climate: Impact on the Department of Transport*", 2004).

- Disruption of the network by storm events (rain, snow, high temperatures)
- Damage to roads through deterioration, deformation and subsidence
- Flooding from rivers, seas and inadequate land drainage
- Severance of routes by erosion, landslides and avalanches
- Damage to roadside infrastructure by high winds
- New challenges to road safety

Not all roads are expected to be affected by the predicted changes. Modern well designed, high speed, main roads with thick asphalt layers are expected to survive the changing climate relatively well. These should be able to accommodate the predicted impacts with some minor adjustments to their inspection and maintenance regimes. Low volume rural roads with thin pavements on the other hand are unlikely to be able to cope with the increased risks in their present state. Some adaptation measures are likely be necessary for these types of roads to assure that they remain serviceable for the longer term. The good news is that current maintenance cycles are likely to be sufficient to permit roads organisations to react to changes in events as they arise. This should enable authorities to avoid the pitfalls of overdesigning any measures.

This section of the report will consider the predicted impacts under the headings of "Temperature" and "Precipitation":

4.1 TEMPERATURE

Small changes in temperature are not expected to have a significant effect on the road infrastructure of the Northern Periphery. By the end of the century however, some regions are predicted to be subjected to substantial warming that could result in a range of measurable impacts including:

- Hotter summers
- Milder winters
- Changes in the frequency of freeze-thaw cycles
- Increases in sea-levels due to melting of ice in the Arctic areas
- Thawing of permafrost areas

These impacts, where they occur, are likely to cause problems for Northern Periphery low volume roads and create great challenges for road maintenance operations. For example, the predicted shortening of winter seasons is expected to lead to a reduction in snow and ice removal frequency and a possible saving in winter maintenance costs. However, the predicted increase in freeze-thaw cycles is also likely to increase the occurrence of frost heaves, and potholes, leading to a consequent increase in the need for road maintenance, and an increase in road maintenance costs. Similarly warmer summers and milder winters are likely to lead to a lengthening of the growing season for roadside vegetation leading in turn to
an increase in the amount and frequency of cyclic maintenance, such as grass cutting.

The possible temperature impacts of climate change are therefore important to the sustainability of Northern Periphery road networks. In this section temperature impacts will be considered under the following headings:

- Summer pavement performance
- Frost damage (including freeze-thaw cycles and frost heave)
- Thawing of permafrost
- Milder winters
- Sea level rise

4.1.1 Summer pavement performance

The summer performance of pavements is not thought to be issue with climate change. Higher summer temperatures and solar radiation may affect the long-term durability of pavements, and gravel roads, but the effects are unlikely to be significant [25]. These could include an increase in top-down cracking, some increase in rutting, a slight increase in asphalt aging, decreased thermal cracking. The current view is that the lifetimes of the majority of pavements and overlays in the Northern Periphery will be shorter than the timespan of any predicted climate change effects. The only pavements that might possibly be affected by climate change are those high volume, high speed pavements designed for the longest lives, or those lower layers in roads that will not be touched by future rehabilitations.

For the majority of the rest of the pavements in the Northern Periphery, and particularly for the pavements of low volume roads, the present design practices of the Partners are likely to be sufficient, provided that the surface and sub-surface drainage systems of the road are effective. If any modifications are necessary it is expected that they should be able to be made at the next reconstruction/rehabilitation event in line with established good practice. One possible group that may require review is that of unsealed pavements in milder winters. These may require upgrading or stabilisation to ensure that they provide an acceptable bearing capacity to meet all winter conditions [70].

4.1.2 Frost damage

Frost damage is a major issue for roads in cold climates around the world. Seasonal changes, freeze-thaw cycles and the damage they cause are significant factors affecting the road condition of northern cold climate road networks. Up to 60% of distresses can appear during the springtime even though traffic volumes are low [27].

Although winters are predicted to get warmer, and frost penetration in pavements is predicted to decrease, frost actions will inevitably continue [22]. The magnitude of any effects will be dependent on the local climate and precipitation rates [23]. Typically frost damage on roads can be seen as:

- Uneven frost heaves (Figure 4-1)
- Longitudinal and transverse cracking (Figure 4-2)
- Softening of the road structure (see Figure 4-3)
- Permanent deformation (Figure 4-2)

These forms of damage will in turn permit road surface water to enter the road construction layers to freeze and thaw with increasing damage and roughness.

4.1.2.1 Freeze-thaw cycles

All the main climate change scenarios predict more freeze-thaw cycles and shorter frozen periods for the winter seasons of the ROADEX countries. These changes, when taken together, are likely to result in an increased aggregated length of thawing period over the winter and an increased risk of road deterioration [24]. This impact is predicted to be a major problem for most of the ROADEX countries, especially in those areas where it was not typical before.

Freeze-thaw cycles occur during the winter months when the mean temperature is near 0˚C. During a typical freeze-thaw cycle, the moisture in the road and subgrade soil freezes and thaws causing a volume change within the materials. During the process a strong cryo-suction force develops at the freezing front. This has the capability to adsorb and trap water molecules far beneath the freezing front where free water is available. This expands the pores and loosens the aggregates in the road. When this material subsequently thaws, excess water is produced in the layer which makes it weaker and sensitive to deformation [25]. This results in the de-compaction of the road aggregates and subgrade with consequent damage to the structure of the road. Such thaw weakening can accelerate the deterioration of the roads, decrease their bearing capacities, and result in frequent imposition of axle load restrictions [26, 27].

Surface dressings are especially prone to damage by freeze-thaw cycles as they are normally thin compared to bound layers and have a binder that is exposed to direct frost action. This action can result in the binder becoming brittle and losing its ability to seal the pavement allowing moisture to penetrate the pavement. A brittle binder can also make it easier for the aggregate dressing to be dislodged by traffic, and the dressing ravelling or stripping. An increase in freeze-thaw actions in the future is likely to increase this problem

4.1.2.2 Frost heave

Frost heave is the term used to describe the effects of the thawing process on the ground and ground supported structures [27, 28]. It occurs in winter and early springtime in cold climates. Frost heave is caused by formation of ice lenses in the soil below the pavement. Not all frost heave is necessarily detrimental to a pavement. Uniform frost heave along a road may not in fact be noticeable. Normal frost heave is however generally uneven due to the variability of road

structures and subgrade conditions along a road. This form of differential frost heave can cause increased roughness and cracking of the pavement surface [29].
Frost heave is usually most noticeable at:

- Transitions from cut to fill
- Sections of roads with poor drainage
- Above and around culvert pipes
- Places where there is an abrupt change in subgrade material or pavement thickness.

Figure 4-1 Frost heave on a city street in central Sweden. [http://pavementinteractive.org/index.php?title=Frost_Action]

Figure 4-2 Examples for cracking in Norway [http://www.vg.no/bil-og-motor/artikkel.php?artid=584406 and http://www.abcnyheter.no/nyheter/100408/veiene-verre-enn-pa-mange-ar]

Figure 4-3 Frost damage on a gravel road in Raattama, Finland (photo J. Leskinen) [www.tiehallinto.fi]

4.1.3 Thawing of permafrost

Permafrost, and the thawing of permafrost areas, is a major concern for roads organisations in the sub-Arctic. In Finland for example, permafrost under roads on peat poses a particular problem. Overlying the permafrost is a thin active layer that thaws every summer and freezes the following winter. Both physical measurements and modelling have shown that active layer thicknesses have increased during the last decades indicating that the permafrost is generally degrading as a result of climate warming. This is likely to result in an increased depth of the seasonal thaw layer, a warming of the frozen zone and a reduction in the bearing capacity of the ground [57]. Permafrost temperatures increased during the last 20–30 years in almost all areas of the Northern regions. Warming of permafrost has also been reported in areas with mountain permafrost [30]. This is a consequence of the increasing summer temperature and a thicker snow cover during the winter months which acts as an insulation layer on the ground [31, 32].

Thawing of permafrost areas can have serious consequences for local communities. Today, approximately one-fourth of the Earth's land areas are underlain by permafrost [33], see Figure 4-4, with areas of discontinuous permafrost being more likely to degradation than those with continuous permafrost.

Figure 4-4 Circumpolar distribution of permafrost in the Northern Hemisphere (from the International Permafrost Association) [http://www.lter.uaf.edu/bnz_permafrost.cfm]

When permafrost begins to thaw, ice lenses in the soil melt resulting in settlements and thermokarst [32]. Permafrost close to the melting point is particularly sensitive to climate change. Even a small increase in ground temperature can cause instability and serous damages on roads, embankments, bridges, harbours, power-lines and pipelines. It also can lead to a significant increase in both scale and frequency of landslides [33]. Knowledge of the ground temperature in permafrost zones is therefore essential for the design of infrastructure, estimating environmental impacts of these developments and the planning of possible mitigation techniques. It is also important to understand how climate warming is likely to impact permafrost temperatures as the thermal state of frozen ground is linked to its physical stability [34].

In roads, permafrost thaws first from under the shoulders and the edges of the road, which results in cracking down the centre of the carriageway. At this stage a central core of permafrost may remain in the middle of the road which may rotate due to the changes in temperature during the year causing further damages. The drainage system of the road may also fail causing local drainage problems and flooding [35].

4.1.4 Milder winters

Winters in the Northern Periphery are predicted to become milder with shorter snow and frozen periods in the future. Springs are expected to be earlier, with earlier thawing, leading to spring maintenance schedules being earlier also. In addition for snowfall areas, snow melt from previously frozen catchments may add to runoff volumes by releasing water previously held in frozen states [25].

Snow and ice will therefore continue to pose problems and dangers to road networks, and sound winter maintenance procedures will continue to be necessary to assure the availability, reliability and safety of road networks. Increasing frequencies of freeze-thaw cycles are likely to pose problems for those areas where longer frozen periods were common. In these areas the incidence of “black ice” may become an increasing problem leading to an increased use of de-icing chemicals [57]. The ROADEX partners have already noticed that warmer weather conditions are moving up from southern regions countries in winter, especially in Norway, Sweden and Finland. It is projected that the future climate in the north of these countries may be similar to the present climate in the south requiring similar winter maintenance operations.

Milder winters are also likely to cause significant problems in the operation of ice roads (See Figure 4-5). Ice roads are temporary roads. They only function during the frozen period of winter time. They are created either from a mixture of soil, snow and/or ice or on the frozen surface of lakes and rivers. These roads are not passable during warmer weather. The main predicted effect of climate change is the shortening of the periods that these kinds of roads can be used. With increasing temperatures the thickness of the frozen layer of lakes and rivers is likely to decrease, making ice roads less viable for transportation in the future with the consequent inconvenience to local industries and communities [35].

Figure 4-5 Ice road across Tana river towards Rustefjelbma [http://www.panoramio.com/photo/19664109]

4.1.5 Sea level rise

The predicted rises in sea level due to climate change may pose increased threats to the coastal areas of the ROADEX countries. Where they happen these rises, when coupled with increased wave action from more frequent storm surges, could impact on coastal road networks. (They may also be mitigated to some extent in Northern Periphery countries if land is rising as a result of isostatic rebound after the removal of the weight of ice of the last ice age.)
For roads in the Northern Periphery, this could mean:

- Flooding of low-lying coastal roads
- Erosion of roads and embankments along the coastline
- Flooding and erosion of causeways

Coastal flooding (example on Figure 4-6) can occur when storms produce heavy rains and drive ocean water onto coastal land. Inundation can also be produced by wave action created by storms, earthquakes or volcanoes but this is not considered as part of this report. Coastal flooding on roads can cause similar impacts as river flooding (section 4.1.6), but with the additional threatening action of the salt content of the coastal water on the structure of the road. As with all form of flooding of roads, standing water on the road surface can create a hazard for road users.

With sea levels already increasing, and predicted to increase, more coastal floods can be expected in future, and in areas where it was not common before.

Figure 4-6 An example for coastal flood from Norway [Norwegian Public Roads Administration]

Causeways are a particular concern for climate change (Figure 4-7). Rises in sea level adjacent to causeways can threaten the survival of the communities they serve. Usually such causeways are lifeline routes with no alternative route other than an emergency ferry crossing. Their survival is therefore a major concern for roads organisations responsible for their maintenance into the future. This is especially the case when higher sea levels combine with storm surges. This can not only damage the causeway embankment it can also be damaging to the structure of the pavement it carries.

Figure 4-7 Lifeline coastal causeway on the Isle of Harris, The Western Isles, Scotland

PRECIPITATION

Precipitation, and the intensity of precipitation, is a key concern for all engineers involved in the design and maintenance of all classes of roads, particularly in the ROADEX Partner areas where "heavy rain" and "flooding" rank as the top 3 concerns of the respondents to the ROADEX questionnaire.

The general prediction for precipitation in the Northern Periphery, with some exceptions where drought conditions may increase, is that precipitation is likely to increase in all areas, particularly in the form of rain. This increase in precipitation, on the balance of probability, is also likely to bring an increase in the frequency and magnitude of storm events which are expected to result in a range of impacts and damage to roads [25]. These are likely to include:

- Flooding
- Surface water drainage problems
- Erosion of roads and bridges
- Slope failures, landslides and avalanches

These impacts are discussed in greater detail the following sections.

4.1.6 Flooding

Flooding is expected to be one of the most important impacts of climate change in ROADEX countries according to the results of the ROADEX climate change questionnaire and personal interviews. Its magnitude is generally dependant on a number of factors, climatic and non-climatic, but will normally be a combination of the intensity, volume, timing and phase of precipitation. As was shown in Chapter 1, precipitation in the Northern Periphery is very likely to change, which will result in flooding in some areas and droughts in others.

Examples of recent floods caused by heavy rains in some of the ROADEX countries can be seen in Figure 4-7. These types of events can be expected to increase in the Northern Periphery in the future if the predicted climate changes come to pass.

Average annual run-off is also likely to change as a result of the changes in temperature and precipitation. The predicted warming is expected to affect the seasonality of river flows, especially where the winter precipitation is mainly snow. Winter flows are predicted to increase as a result of early snow melt [1], and spring flows are expected to decrease. The potential for flooding will be dependent on the ability of the ground to absorb the increased water [37].

Flooding is an important consideration for the serviceability of road networks and needs to be robustly addressed in management plans for roads assets. A common cause of flooding is the blocking of ditches, culverts and bridges by waterborne detritus, leading to water flows backing-up and seeking alternative routes. Such road floods carry significant risks and can have a great impact on the safe operation of the road network. It is likely therefore that the frequencies of the following events may increase in the future [38]:

- Bridge / culvert capacities reduced or exceeded, causing upstream flooding to occur
- Overtopping problems of structures
- Scour problem of structures, especially bridge piers and abutments
- Inundation of roads on flood plains
- Erosion of roads and embankments

These effects are likely to require the use of larger drainage structures to convey the higher flow rates predicted during the more extreme storm events [56].

Figure 4-7 Flooding in some of the ROADEX countries (Ireland [http://z.about.com/d/goireland/1/0/1/J/-/-/flooding_athlone.jpg], Scotland [http://www.flood-pictures.com/flood-occurs-in-kintore-sotland-november-2009/], Iceland [http://i.dailymail.co.uk/i/pix/2010/04/14/article-1266038-0922918F000005DC-723_468x286.jpg], Finland [http://yle.fi/uutiset/news/2010/04/some_ostrobothnian_rivers_still_rising_1597102.html]), Sweden 2010

4.1.7 Surface water drainage problems

Ever since the first ROADEX project, road drainage, and the effectiveness of drainage, has been a major concern for all the road authorities of the Northern Periphery. The drainage regime of a road directly influences the condition of the road by the way that it deals with rain and snow, and the materials within the pavement and subgrade. The ASTO pavement project in Finland has shown that in warm and rainy winters, when the pavement surface is wet most of the time, the wear rate of asphalt pavements can be 1.5 - 3 times higher than that of "cold" winters when the asphalt surface is frozen.

A good drainage regime quickly removes water from the road surface and ensures traffic safety. Standing water on road surfaces is a main hazard to traffic and a frequent contributing factor in road accidents. Drainage also provides effective drainage for the sub-surface to maximize longevity of the pavement and protect the underlying earthworks [25].

The increases in rainfall intensity and frequency predicted by climate change will supply greater quantities of water to local catchments than previously, leading to higher ground water levels and greater infiltration of surface water into road structures if not intercepted quickly. This is likely to be especially the case in springtime where increased levels of melt water could pose significant problems to sub-grades and drainage systems. If not dealt with quickly, these could result in increased water contents in the pavements and a reduction in the bearing capacities of roads. This could be a particular problem for gravel road networks with poorly performing drainage systems and will be a critical factor in the future should precipitation levels increase [51]. A typical drainage related problem can be seen in Figure 4-8.

Figure 4-8 Damage to A9 Raigmore Slip Road, Inverness, 2002, following heavy rainfall. Photo by BEAR Scotland Ltd.

An increased number of drainage related problems can therefore be expected in the future due to the predicted increasing rainfall and intensity, and greater attention will need to be given to road drainage systems to ensure that they can be capable of draining the expected larger quantities of water in shorter periods of time [57].

Problems are also likely to occur during the spring, when winter snows start to melt and roadside ditches are still filled with ice and snow, preventing any excess water flowing away from the pavement structure. Further details of this problem can be found in the ROADEX report “Managing spring thaw weakening on low volume roads” [69]. An increase in drainage problems can also be expected in areas with vegetation on the road verges. Increases in temperature and precipitation will encourage growth in the vegetation that will tend to further block surface water from draining naturally off the road. Where this happens the surface water will be forced to drain through the pavement structure, reducing the bearing capacity of the road and producing deformation (see Figure 4-8) [52].

4.1.8 Erosion of roads and bridges

Erosion of roads and bridges is a serious problem that has to be dealt with quickly in order to avoid serious consequences later. Erosion of bridges, “scour”, can occur at the foot of piers and abutments where sediment (sand, stones) is washed away from the river bottom [39, 40]. This can be particularly strong during flooding and any increase in flooding frequency can only increase the likelihood of increased scour. Areas where floods were not typical previously, with structures that have not necessarily been designed to handle flooding problems, may need to be more closely monitored in future.

Figure 4-9 Bridge scour, Serkeland, Telemark, 2007 [photo from the Norwegian Public Roads Administration]

Erosion of the carriageways of roads can involve erosion of the surfacing layer (especially in case of gravel roads) and erosion of the road structure, such as the embankment, cutting, side slope or shoulder. All of these problems can occur during and /or after heavy, sudden rains, and are likely to increase in the future if the predicted climate changes take effect.

4.1.9 Slope failures, landslides and avalanches

Slope failures, landslides and avalanches are considered together in this section due to their similar nature.

The mass movement of material can be basically classified into the three main categories of falls, slides and flows. All can involve rock, debris, mud, soil, peat or snow [41, 42]. Slope failures and landslides normally occur where a slope is (a) overfilled, (b) the materials involved are insufficiently compacted, or (c) where a cutting contains zones of weak materials [43].

Large volumes of surface water can erode land surfaces and cause changes to groundwater levels. Both can reduce the stability of embankments and cuttings and so contribute to the likelihood of landslides [44]. Climate change is predicted to increase the level and intensity of rainfall events and is therefore expected to result in increased risks of landslides in the future [25, 45, 46, 47, 48].

Avalanches on the other hand are expected to decrease in the Northern Periphery as a consequence of predicted milder winter conditions. This should lead to a lower risk of avalanches overall, albeit with the particular hazard of an individual occurrence remaining the same.

Examples of landslides in Scotland and Norway can be seen in Figure 4-10 and an avalanche threat to a road in Norway in Figure 4-11.

Figure 4-10 Examples for landslides from Scotland [http://www.robedwards.com/2008/10/revealed-the-380-kilometres-of-road-most-at-risk-of-landslides.html] and Norway [http://www.aftenposten.no/english/article2402918.ece].

Figure 4-11 Avalanche in Norway [49]

A less frequent, but equally important form of landslide is that of a 'quick clay' slide. Quick clay slides occur in marine clays that have an unstable structure. Even a smaller disturbance of this type of structure can cause a massive reduction in strength, which can then destabilize the slope allowing failure on an even lower slope angle. A quick clay landslide can be very dangerous, as it can develop suddenly without warning and can be extremely rapid. This type of slide has an ability to transport everything, even houses, over long distances [50]. Quick clay slides are serious problems in Norway and Sweden, see an example in Figure 4-12 from Norway.

The frequency of quick clay slides is likely to increase in the future if climate change projections of increasing numbers of heavy and sudden precipitation events come to pass.

Figure 4-12 Quick clay slide in Norway [http://www.aftenposten.no/nyheter/iriks/article2976858.ece]

5. ADAPTION MEASURES AND GOOD PRACTICE

The management of low volume roads has never been a static activity ruled by fixed instructions. Practices have had to constantly adapt over the years to meet the changing demands of the networks and users. The current practices of modern operations are the result of evolution, and of decisions made over time in order to deal with the prevailing conditions. Adaptation to meet the perceived threats of climate change will be no different in this respect. The new threats and impacts being projected by the world's meteorological organisations will be met over time, step-by-step and event-by-event, by responsible authorities.

This section of the report aims to give guidance on good practice measures to the ROADEX Partners to help them manage the impacts of climate change on their low volume road networks. A summary of the current national climate change strategies for each ROADEX country is attached at Appendix 7.2 for information.

Climate change, and what to do about it globally, is controversial. The lengthy discussions at the 2011 United Nations Climate Change Conference [73], and the final agreement reached to aim for a legally binding treaty by 2015, only go to reinforce how diverse the current global views on climate change are. This report does not take a position on this one way or another. The ROADEX partners do however consider it to be prudent to take such steps as necessary to deal with the circumstances happening now, rather than ignore them altogether. The final decisions on what to do with weather events, and what measures should be taken to mitigate them, is firmly in the hands of the reader.

The suggested measures that follow have been gathered from published reports, national guidelines, ROADEX workshops and meetings, personal discussions and others. They are not an exhaustive list of all options available but are considered to form a fair summary of current and proposed practices across the Partner organisations.

The "*Guiding Principles for Adaptation to Climate Change in Europe*" prepared under contract of the European Environment Agency [53] recommends that all adaptation measures need to be:

- "Effective", in reducing the impact that they are addressing
- "Efficient", so that the benefits outweigh the costs
- "Equitable", to be focused on the those parts of the network where the likelihood and consequences are seen to have the greatest effect

In addition the 2011 PIARC report on "*How to deal with Effects of Climate Change on Road Pavements*" offered the very sensible systematic approach to conducting risk and vulnerability assessments on road infrastructure:

Step 1: Identification of potential climate change effects

Step 2: Assessment of the impact of climate change on the vulnerability of elements

Step 3: Appraisal of risks and identification of potential solutions and strategies to address vulnerabilities

Step 4: Implementation of adaptation plans and strategies

Step 5: Monitor and review

Many adaptation measures can be implemented at relatively low cost with surprisingly high benefits. The adaptation measures within this report will be considered in the order below. Summaries of the measures under each heading will be given in boxes at the end of each section.

5.1 TEMPERATURE

5.1.1 Summer pavement performance

Section 4.1.1 discussed why increased temperatures in summer are unlikely to pose a problem to Northern Periphery low volume roads due to the likelihood that any temperature change will be gradual and long term. Soft pavement materials may be prone to rutting and stripping but any adaptation measures necessary should be able to be made at the next rehabilitation/reconstruction event in line with established good practice. For this it may be possible to learn from the experiences from other areas to the south who are already dealing with warmer temperatures, or those to the west who are already dealing with wetter conditions. This could include the use of pervious wearing courses where the open structure can help cooling, surface dressings, and micro-surfacings [57].

Effective surface and sub-surface drainage will continue to be a key to ensuring pavement performance, and in particular the ability of the pavement and road infrastructure to deal with increases in precipitation (see Section 5.2). Damaged, crazed and cracked pavement will require to be sealed quickly to prevent trapped surface water infiltrating down into the road construction layers. Similarly increased vegetation growth brought on by a longer growing season will require to be removed from the road shoulders to ensure raid run-off of surface water.

One possible area that may require review is that of unsealed pavements in milder winters. These may require upgrading or stabilisation to ensure that an acceptable bearing capacity is provided for all winter conditions

Good practice maintenance measures to prevent or reduce frost damage in roads arising from climate change can therefore include:

- keeping the road drainage in good condition by Implementing the ROADEX drainage maintenance strategies and guidelines [63]
- sealing of cracked and distressed areas
- removal of roadside vegetation
- Increase frequency of grass cutting, etc

Possible adaptation measures for managing pavements for increased summer temperatures include:

- reviewing pavement material compositions at the next rehabilitation/reconstruction event
- building on well-working practices from areas with warmer temperatures
- using more rut-resistant and/or stripping-resistant resurfacings
- surface dressing and micro-surfacings, especially with chippings with higher reflectivity
- pervious wearing courses
- improving surface and sub-surface drainage systems
- stabilisation of unsealed pavements

5.1.2 Frost damage, freeze thaw cycles and frost heave

Frost damage is the most significant problem on both paved and unpaved roads in the Northern Periphery, especially those roads with a thin surface dressing. Although it is much easier and cheaper to repair unpaved, gravel roads [27], frost damage on these roads can still involve substantial maintenance works. In case of gravel roads, this can mean grading, improving and ditch cleaning all year around [51].

The thawing performance of a road in spring, or after a freeze-thaw cycle, is heavily dependent on the general condition of the road and moisture content at the time of freezing. Once frozen the road's condition is "locked-in" until it is released again by thawing. It is therefore important to make sure that any roads that are likely to be susceptible to frost damage are in the best possible condition before they freeze, so that they can have the best chance of survival when they thaw again.

Good practice in managing freeze-thaw cycles in roads is to try to ensure that the affected roads are in a sufficient condition to resist the temperature changes involved. This means getting the road drainage correct so that the road structures can be as dry as possible, and if necessary carrying out strengthening or rehabilitation to any weak road sections that may be susceptible to freeze-thaw action. Good practice drainage measures are discussed in the ROADEX III report "Developing Drainage Guidelines for Maintenance Contracts" [65] and the ROADEX elearning lesson on drainage. A summary of drainage best practice is attached at Appendix 3.

Frost heave can be managed by a number of means. Highly susceptible soils can be stabilized, or if this is not possible, susceptible soils can be replaced. Frost penetration can be reduced by increasing the thickness of the granular sub-base or by installing a frost insulation layer, such as polystyrene. This can be costly depending on the availability of material but has proven to offer an acceptable solution in northern areas [27, 29, 54]. Absorption of the ground water table into the base course can be prevented by lowering the ground water table using deep drainage [54]. In all of these cases, any rehabilitation or improvement should be accompanied by a similar improvement of the drainage of the road.

To decrease the effect of differential frost heave on a pavement, the failure strain of the asphalt concrete can be increased, or a softer asphalt binder may be used. The use of a steel mesh or a geogrid within the road construction layers can also provide an increase in the tensile strength [54].

Road surface water can penetrate down to the lower layers of a pavement through cracks in the pavement and it is therefore good practice to seal all pavement cracks after the winter period, to prevent this ingress of water.

The road surface should be kept in good repair to prevent water entering the pavement layers [55]. After a harsh winter, cracks and potholes can appear on the surface of the road. These cracks and potholes should be sealed and repaired at the end of winter to avoid serious damages occurring to the road. Crack sealing should also be carried out during the frost season when cracks are open. Badly cracked pavement surfaces may require a surface dressing later in the year to re-seal the surface and provide a new surface texture to the road [56].

Depending on the likely scale and scope of frost damage the ROADEX project offers several policies and techniques for managing roads during the spring thaw weakening period. In general these can be summarised as [27]:

1) maintenance techniques to reduce the effect of spring thaw
2) load restrictions and tools to minimize the problems caused by load restrictions
3) strengthening weak road sections so that load restrictions can be avoided or used only in extreme conditions and
4) co-operation with transportation organizations using heavy vehicles.

Managing vehicle numbers and/or applying axle load restrictions on a road are an established way of reducing damage to a frost susceptible road. Load restrictions can prevent heavy vehicles damaging road sections when they are at their weakest, but they also have the disadvantage that they can disrupt access to the communities and businesses served by the road. For this reason, restrictions should be used sparingly, and only when strictly necessary.

The weakest sections of roads may need restrictions every year, unless they can be strengthened, but most will only have problems during the most severe winter freeze-thaw cycle periods or during spring thaw weakening periods. These can be managed by a number of techniques. For example, a local maintenance contractor in Sweden has given “time slots” to heavy trucks wishing to use a sensitive road. Based on the strength of the road structures, time slots can be given either in 6 or 8 hours intervals. Axle load restrictions are normally announced in advance of the expected adverse conditions based on weather forecasts in combination with real-time road monitoring systems [26, 27] to minimize disruption to affected communities and industries.

In all of these measures it is important to make sure that the underlying conditions are fully understood before strengthening or rehabilitation measures are implemented. In particular the primary reasons for the problems on the road should be clearly identified and understood before the solution is selected to take care of the problems. A drainage condition analysis and drainage improvement should always be carried out at the same time as the remedial works.

Good practice maintenance measures to prevent or reduce frost damage in roads arising from climate change can therefore include:

- keeping the road drainage in good condition by implementing the ROADEX drainage maintenance strategies and guidelines [63]
- Keeping ditches and culverts free of snow and ice by means of good winter maintenance practices
- Managing the vehicle numbers using the road
- Applying axle load restrictions where necessary
- Surfacing and/or regrading gravel roads to provide good crossfalls

Adaptation measures that can be also be considered to improve road sections likely to suffer frost damages are listed below:

- Designing and repairing frost damaged roads in accordance with ROADEX guidelines for roads suffering from spring thaw weakening [69]
- Lowering the groundwater table within the road embankment with deeper drainage
- Sealing pavement cracks immediately after the winter period
- Strengthening and rehabilitating weak road sections
- Increasing the thickness of structural layers
- Replacing any frost susceptible materials in the road structure with non-frost susceptible materials
- Installing steel grids in the road structure
- Providing frost insulation
- Soil stabilisation / homogenisation
- Raising the carriageway out of the snow field

and for paved roads only

- Improving the asphalt specification to increase its failure strain
- Converting the paved road back to a gravel road

These measures are discussed in detail in the ROADEX e-learning lesson on “Permanent Deformation” on the ROADEX website, www.roadex.org.

5.1.3 Permafrost

The degradation of permafrost globally is unlikely to be stopped. Some limited actions may be possible locally however to slow down the local rate of degradation. The main impacts of the degradation of permafrost are drainage related problems, bearing capacity problems, landslides, etc. These are discussed in Section 3.1.2. An example of a permafrost caused problem is shown in Figure 5-1.

Figure 5-1 Rutting due to thawing of permafrost in Greenland

Where permafrost is known to exist below a road it is first necessary to determine the risk to the road due to the presence of the permafrost through monitoring the thickness of the thawing layers. This is especially important in the case of new roads. Once the rate of thawing and risk to the road has been established a number of practices can be used to protect the permafrost, with the aim of keeping the permafrost frozen. Monitoring and risk evaluation over time is necessary in order to act in time.

Increasing the vegetation cover can slow down the local rate of degradation of the permafrost by providing local shading to the ground [34, 36]. Forest cover will provide more shade than shrubs and bare ground.

One solution that has been used to combat the local degradation of permafrost is to increase the thickness of the road embankment. This increases the insulation layer above the permafrost, and thus the depth that needs to thaw before the permafrost is affected. Insulation layers can also be introduced into the embankment with a similar aim of preserving the local temperature of the permafrost. Insulation layers are best installed during winter when the permafrost is at its coldest [29]. Trials of increasing the solar reflectance ("albedo") of the road surface have been carried out in Greenland. Here test panels on the road surface have been painted white to increase the reflectance of the road [29]. Solar reflectance has been shown to be a main determinant of a road's maximum surface temperature [57].

Other methods currently being trialled to preserve permafrost areas include: air ducts, thermosyphons, air convection embankments and heat drains. These are based on the active removal of heat from underneath the embankment in order to ensure stable permafrost conditions [29].

As always, a well working road drainage system will help keep the road construction dry and earthworks free of water, as well as reducing the potential for local flooding.

Current good practice for managing permafrost includes:

- Increasing vegetation/forest cover to protect the permafrost
- Good drainage, similar to those recommended for drainage related problems
- Increasing the thickness of the road embankment
- Keeping records for establishing trends and needs
- Monitoring to detect potential problem areas, e.g. GPR, and risk evaluation over time

Adaptation measures that can be also be considered:

- Mapping of the permafrost areas, and understanding and managing the risk
- Excavating the frozen icy material and replacing it with thaw-stable fill
- Using open graded rockfill in embankments to improve heat transfer
- Installing insulation into the embankment
- Increasing the reflectivity (albedo) of dark surfaces
- Artificial cooling and/or extracting heat from the embankment

And for new roads a further option is

- Avoiding the permafrost areas altogether

5.1.4 Milder winters

Despite winters being projected to become milder and shorter, efficient winter maintenance operations will still be required to keep road networks free from snow and ice. Preventative maintenance steps could include measures to keep the road structural layers free from moisture. These include crack and joint sealing, impermeable surface dressings and effective road drainage amongst others [57].

The predicted increase in winter storm events will strengthen the need for snow removal equipment in the Partner areas to keep roads open. Milder winters are also likely to result in the need for enhanced de-icing operations to cater for the change in road conditions [58]. ROADEX Partners have already noticed that winter maintenance procedures previously applied in the southern areas of their countries are slowly being adopted in the more northern parts as a result of milder conditions.

The winter maintenance practices of the ROADEX countries were discussed in the pilot ROADEX report *"Winter Maintenance Practice in the Northern Periphery"*. Snow removal both from the road surface and the ditches was considered to be a key element of winter maintenance operations. This was executed by trucks, snow blowers or graders, with or without the use of salt. Snow removal from ditches was considered to be particularly important to prevent melting water flowing out onto road surfaces and re-freezing during cold nights, causing slippery surface conditions. Snow walls and snow banks close to roads were recommended to be removed as they arose in order to ensure that road widths were maintained and water flows across the road prevented [27]. Snow fences were also seen to be a well established practice in the ROADEX areas for influencing the patterns of snow drifting on roads. Their aim is to deposit the snow out of the wind before it can reach the road. The height and location of snow fences should be designed to suit the local snow depth and wind conditions [27].

New assessment tools such as the ERA-Net "IRWIN" index [72] are likely to be part of the future for roads managers. These are combining climate change scenarios with actual information from field stations being captured in the Road Weather Information Systems (RWIS) held in most national authorities.

Winter ice roads over frozen lakes and estuaries were mentioned in Section 4.1.4 and their use in the Northern Periphery is likely to decrease as a result of increasing temperatures. Where ice roads are no longer practical due to milder winters alternative crossing methods may need to be provided to assure a road service, e.g. ferry transport or all weather bridges [59].

Good practice in winter maintenance to meet the threat of milder winters will include:

- Preventative pavement maintenance
  - Sealing pavement cracks and joints to prevent ingress of water
  - Using surface dressings and micro-surfacings to provide an impermeable surface layer
  - Keeping surface and sub-surface drainage systems effective
- Keeping records for establishing trends and needs
- Reviewing winter maintenance operational practices in to meet prevailing circumstances
- Removing snow promptly from road surfaces, shoulders and roadside ditches
- Keeping culverts free of ice
- Removing snow walls and snow banks close to the road
- Erecting snow fences where necessary to influence snow drifting
- Keeping records for establishing trends and needs
- In the case of existing winter ice roads, identifying alternative crossings

5.1.5 Sea level rise

Section 4.1.5 considered the problems that could occur along coastal roads if sea levels were to rise in the future. It was concluded that the impact of flooding, and any erosion, resulting from the sea level rise would be dependent on the local topography and conditions. Some ROADEX Partners are already developing numerical models to predict the extent of flooding and potential erosion. This is considered to be an example of good practice on which to base mitigation and adaptation actions. [59]

Raising the level of roads and causeways (Figure 5-2) can be a solution to a rise in sea level. Raising a coastal road by an amount similar to the expected rise in sea level should keep the risk of flooding to that of today. In some cases, it may be less expensive to raise the road to meet the predicted rise in sea level, than keep it at today's elevation and accept that maintenance will be required each time that flooding occurs.

An advantage of this solution is that the road can remain in place in the same position without the need for an alternative route. Also, the existing drainage system may be able to stay in place, provided that it can accommodate the new heightened circumstances. Problems may arise however if the new elevated road becomes too high relative to the surrounding area, especially adjacent to urban areas. The rise in the sea level is however very uncertain at the present time and it may therefore be prudent to delay any significant investments until the need is proven [60].

Figure 5-2 Damaged causeway in Scotland [http://coastadapt.org/Outer-Isles/index.html]

Other measures that can be considered for sea level rise are warning signs, edge-strengthening, or the introduction of new sea-defences in those places where it was not necessary before [38].

Areas which are, or are likely to be, threatened by the increasing sea level should be mapped. Protection against the impact of a rise in sea level generally involves some form of physical reinforcement of the coast line to protect against wave action. These can be either "hard measures", such as seawalls, rip rap or groynes, or "soft measures", such as vegetation.

Hard measures are the most common sea defence. They are normally designed based on historic records of sea levels, storm surge, and wave action. Some examples of possible sea-defence structures can be seen in Figure 5-. Hard measures are generally more expensive than vegetation, and require more maintenance and inspection [59].

In extreme cases of sea level rise, together with storm surge, a new route may need to be constructed away from the hazardous area, or causeways replaced by bridges. In all cases of new construction, the likely effects of climate change must be considered and the design made sufficiently robust to include its likely impacts over the lifetime of the structure.

Good practice to meet the threat of flooding and erosion due to a rise in sea level include:

- Mapping likely threatened areas
- Installing warning signs
- Upgrading coastal drainage systems to meet threats

Adaptation measures that can be also be considered include:

- Edge-strengthening of road embankments
- Physical reinforcement of the coast line to protect against wave action
- Raising the level of roads and causeways to meet the threat
- Using submergible pavements

For new roads:

- numerical models to predict the extent of future flooding and potential erosion
- new sea-defences, especially in places where they were not necessary before

- new construction to take account of predicted sea level changes, especially in low lying areas
- in extreme cases, provide alternative route away from the hazardous area

For causeways:

- construction of all year bridge

5.2 PRECIPITATION

5.2.1 Flooding

The predicted increase in storm events and flooding is a main concern of climate change. Many ROADEX Partners have already started to draw up flood maps to identify flood prone areas, both river and coastal flood, taking account of the predicted effects of precipitation and sea-level changes. This information is included in their in-house Geographical Information Systems (GIS), so that all parties involved can see which areas are at most risks of storm incidents. A good example of this is already in place in Norway [46]. Where road closures are likely to be necessary to avoid permanent damage of saturated roads [38], the GIS can also contain the pre-agreed alternative routes for local and trunk road traffic.

Flood area mapping can also be helpful in avoiding possible construction sites with high flood risk. The recently published ERA-NET SWAMP report suggests identifying flood sensitive areas in the road network with the so called "blue spots" [55, 62]. A "blue spot" is defined as a "part of a road that is vulnerable to flooding, either by precipitation, catchment water or sea level rise". An example of "blue spot" screening of an area is shown in Figure 5-3, from the ERA-NET "Road Owners Getting to Grips with Climate Change" project. This shows the areas that are likely to be flooded under the expected weather conditions, together with any impacts on the local road network.

Figure 5-3 Example of a "blue spot" screening exercise of an area of potential flooding.

All drainage structures on the road network need to be designed to meet the required performance levels as a failure of any item, even small drains, can have significant knock-on effects and consequences. Major watercourse structures, in particular, should be designed to meet the likely water flows over their full lifetime, including any allowance deemed necessary to deal with the effects of climate change.

This means that the current storm event return periods need to be reviewed and the predicted changes in rainfall intensity taken into account, particularly for new watercourse structures. So far such structures have invariably been designed using historic precipitation records and experience with return periods of between one storm event in 50 years and one in 100 years, but Partners are now reviewing these in the light of recent experiences and predicted climate change.

For example, Scottish partners recommend that return periods for design storms for watercourse structures should be increased from the present practice of one storm event in 100 years to one in 200 years [25], and that an individual risk based approach should be used for particularly sensitive or critical sections of the road network [68]. It has been suggested that the risk based approach could be based on the projected 90 percentile rainfall, which could result in an increase of 40% on current design flows.

Swedish practice also recommends adjusting the calculated capacities of watercourse structures which so far have been based on historical data [61]. A variable climate factor is used which is specific for a geographic area, see Figure 5-4. The adjusted figure is used for the design of new structures and the maintenance of existing ones.

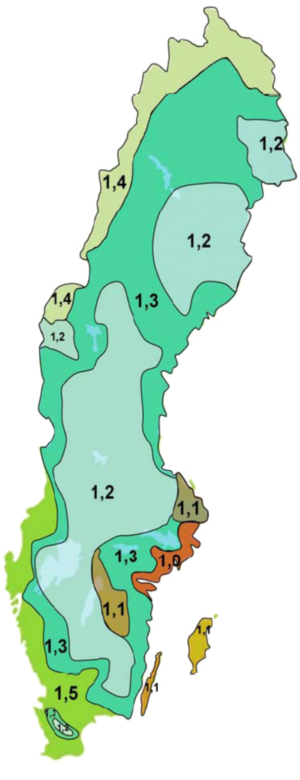


Figure 5-4 The distribution of adjustment factor in different regions of Sweden [61]

Local flooding caused by blocked ditches and culverts can cause serious problems during and after heavy rains. For this reason it is important that all ditches and culverts are regularly inspected and cleared as part of a good practice management system. Any failures should be documented, including taking record photographs, so that they can be analysed and referred to in future events [55, 62]. ROADEX recommends that essential watercourses and ditches should be inspected one or two days before, and after, storm events to ensure that they are properly functioning. Any debris blocking watercourses during these inspections should be removed [63].

An essential part of planning for flood events is to ensure that the drainage system of the road is properly maintained. In extreme cases of regular flooding, the only solution may be the re-routing of roads from the hazardous areas.

ROADEX Partner areas can normally predict short term flooding events. Good practices to minimise the effects of increased flooding on local road networks include:

- Inspecting watercourses regularly
- Cleaning out debris from clogged ditches and culverts
- Cleaning out watercourses and structures in flood prone areas ahead of predicted heavy rainfall
- Keeping records of flooding events and locations
- Preparing contingency/emergency plans

Adaptation measures that can be considered are:

- Reviewing storm water drainage requirements
- More frequent clearing of ditches and culverts
- Resizing drainage systems to meet threat
- Paving ditches to reduce erosion
- Drawing up maps of flood prone areas, considering increasing precipitation and sea-level (Blue Spot Model)
- Keeping in-house Geographical Information Systems (GIS) up to date
- Reviewing design storm return periods in the light of new weather information
- Extreme case: rerouting

5.2.2 Surface water drainage

This section addresses similar impacts to the adaptation measures of Section 5.2.1. As with flooding, road damage by surface water is expected to increase in the future as a consequence of the predicted increases in general rainfall, and more frequent heavy storm events. ROADEX Partners have already started to review their existing surface and sub-surface drainage systems to determine if they can handle the larger quantities of water predicted and some have already revised their drainage design parameters away from the former practice of using historic records of rainfall.

Initial recommendations in Scotland are that the surface water design storm for short duration events should be increased from the present one storm event in one year and one storm event in 5 years' events to one in 2 years and one in 10 years' events respectively [25, 68]. The Scottish partners consider that the present standards in Scotland of one storm event in 1 year and one in 5 years pose a risk of surface water drainage systems being overwhelmed during storm conditions. Similar recommendations have been given in Ireland whereby the present rainfall intensities for surface water drainage systems are recommended to be increased by 20% in order to allow for climate change [64].

Good practice requires efficient systems of drainage inspection and thereafter drainage maintenance focussed on those places that need it. The ROADEX Project has developed a robust drainage assessment method that classifies the existing road drainage arrangements and landscapes, and identifies those critical road sections where drainage is deficient [65]. Examples of ROADEX baseline drainage surveys and recommendations for improvements are shown in Figure 5-5 and **Error! Reference source not found.**.

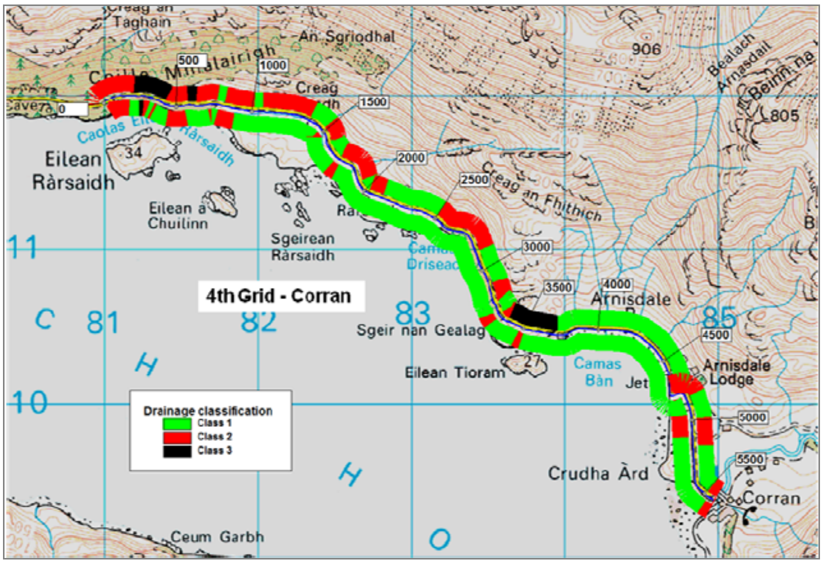


Figure 5-5 Example of a drainage survey showing drainage class on the C46AW road in Lochalsh area of Highland in Scotland. Class 1 drainage means that the drainage was in good condition, Class 2 means that the drainage was in adequate condition, and Class 3 means that the drainage was in poor condition.

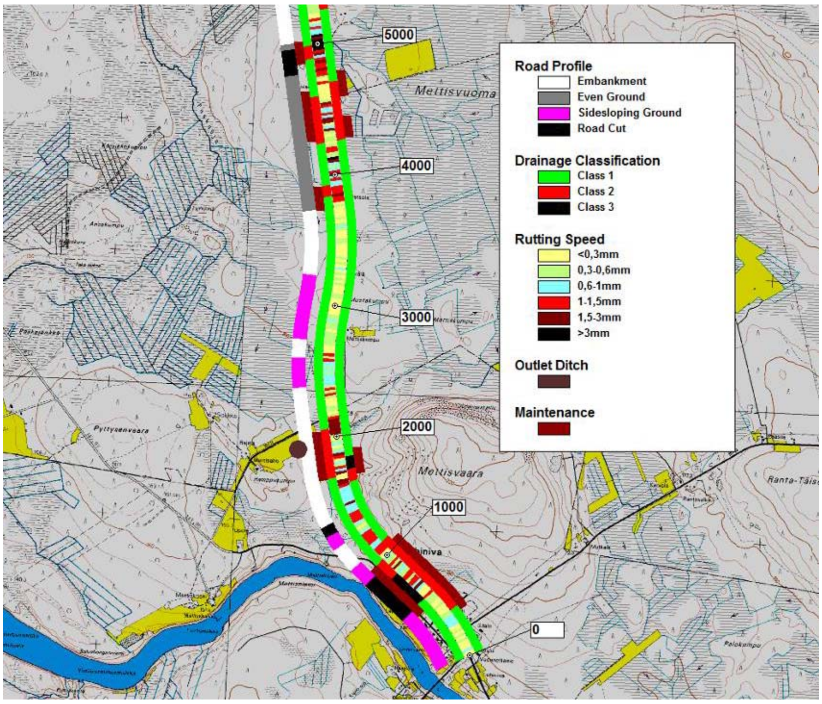


Figure 5-6 Example of ROADEX drainage survey from Finland showing the parameters assessed: road cross-section ("profile"), existing drainage classification, rate of pavement rut development, locations of outlet ditches, and identified areas requiring drainage maintenance

Good practice drainage maintenance should address the full range of road drainage issues not only watercourses. Effective drainage maintenance can be carried out relatively cheaply and can deliver great benefits. Good crossfalls across the road are important to ensure that road surface water is quickly shed to from the carriageway into the ditches [55]. Similarly well functioning sub-surface drainage is essential to keep the road construction layers dry and ensure their durability [25]. Filter drains in particular may have to deal with higher drainage flows from more intense precipitation events. These devices may need to be re-designed and replaced to cope with the higher flows and the risk of groundwater flooding [57].

Mud, debris and vegetation should to be removed from ditches and inlets and outlets of culverts in order to maintain open drainage paths. Some authorities recommend vegetation should not be entirely removed as this can bare soil that can then be sensitive to erosion [25, 52, and 55]. A solution to this is to pave ditches with impermeable linings such as concrete.

Vegetation on the shoulders of roads can inhibit the free flow of water from the road surface. The potential lengthening of the growing season caused by climate change may increase the growth of roadside vegetation and the problems that it can cause. One solution to this can be to increase the number of cuts of vegetation or to use slow-growing plants [25, 52]. Erosion and stability of road shoulders and slopes can also pose problems and where this is evident it is important to identify the reason(s) for the problems and carry out the necessary remedial actions [55].

Watercourses, ditches and culverts should be inspected one or two days before and after storm events to ensure that they are properly functioning. If necessary any debris or build-up of materials should be removed from watercourses and culverts to ensure that they remain at full capacity.

Good practice maintenance measures to manage drainage on roads are:

  - keeping the road drainage in good condition by Implementing the ROADEX drainage maintenance strategies and guidelines [63]
  - carry out drainage surveys and evaluations;
  - identify the areas requiring special drainage measures;
  - instruct work and monitoring the performance of contractors;
  - keep records of problem areas.
- Inspecting watercourses regularly
- Cleaning out debris from clogged ditches and culverts
- Cleaning out watercourses and structures in flood prone areas ahead of predicted heavy rainfall
- Keeping records of flooding events and locations
- Checking outfalls of sub-surface drainage systems
- Cutting grass and vegetation adjacent to roads/ ditches/ culverts

A summary of typical drainage related problems and their recommended solutions is given in Appendix 8.4

Examples of possible adaptation measures are:

- Increasing the frequency of cleaning culverts and ditches Providing deeper and greater volume drainage where necessary
- Cutting grass and vegetation more frequently in the vicinity of roads/ ditches/ culverts
- Good winter maintenance practices as listed in “Milder winters”
- Sealing pavement cracks immediately after the end of winter conditions
- Reviewing the return periods of storm events in the light of new weather information
- Revising design parameters/recommendations. ROADEX Partners are generally increasing waterway areas by 20%.
- Improving sub-surface drainage systems and roadside drainage measures (These may require additional land to be acquired alongside the existing road for some Partners)

5.2.3 Erosion of roads and bridges

The erosion of roads and bridges is a major issue for the ROADEX Partners that can lead to substantial damage to structures, or even collapse. For this reason erosion, and the potential for erosion, should always be a primary consideration in the planning of structures. In particular, the potential effects of long term climate change should be taken into account in the preparation of any maintenance works, and appropriate measures taken to ensure that the identified effects can be accommodated.

Scouring can never be totally eliminated in every case but its effects can be mitigated through careful design. Scour protection should always be provided to the piers and abutments of bridges [40]. This normally takes the form of a hard protective layer of stone or concrete, or a flexible protective mattress. Protective mattresses are usually used in those cases where suitable rock is not readily available, or where the flexibility of the mattress is a particular requirement. Many kinds of proprietary mattresses are available on the market, from block mattresses through to cell mattresses filled with sand or gravel. An "armour" protection layer can also be a very effective solution to scour. The armour layer can be constructed with rock armour, riprap (graded rock), concrete blocks or various shapes and dimensions, or sack gabions, see Figure 5-7.

**Figure 5-7 Examples for elements of different armour protection systems,
top left: concrete A-jacks [http://www.rocla.com.au/Popup_Gallery.php?id=458&category=ajacks],
top right: gabion sacks [http://www.maccaferri-india.in/erosion-control-products.htm],
bottom left: tetrapods [http://videohive.net/item/japan-tetrapods-2/1791603],
bottom right: rock armour [http://www.rintoulcivil.co.nz/projects5.php].**

The surfacing layer of gravel roads is highly susceptible to erosion during heavy rains. In a typical storm event the rain removes the upper layer of the surface and washes the material away into the roadside ditches and watercourses causing sedimentation. This effect can be reduced by stabilising the road surface with a treatment agent, re-compacting the road surface and improving the drainage. Stabilisation of gravel roads is discussed in the ROADEX III report "Treatment of Moisture Susceptible Aggregates" [66].

In extreme cases, the erosion of the road surface of a gravel road can be cured by paving the road. Erosion of the surface of a paved road can be avoided by good surface water drainage and ensuring that all surface water can flow immediately off the road. This means good crossfalls across the road and road shoulders.

Erosion of steep road sideslopes can be tackled by cutting back the slope, "terracing" or "benching" the slope, and/or vegetating the slope to provide an organic reinforcement of the surface layers. If none of these options are possible, the slope can be modified and supported by a retaining structure. These can be of rock, concrete, masonry, reinforced earth, gabion boxes, stone mattresses, etc. Gabion and stone walls are widely used as they can be made of locally available and are generally more aesthetic than concrete walls.

Figure 5-8 Example of retaining wall made of gabion sacks [http://www.feutzcontractors.com/feutz/jobs/misc.htm]

Good practice measures to manage erosion in roads infrastructure are:

- Gravel roads:
  - stabilisation in accordance with ROADEX material treatment guidelines [66]
  - improved compaction and drainage
- Paved roads:
  - improved drainage
- Side slopes:
  - installing interception drains
  - terracing
  - vegetation/rock blanket
  - providing a retaining wall at the toe
- Provision of armour protection to embankments on exposed coasts

- Bridges and structures
  - Inspecting before and after flooding events
  - Providing scour protection around piers and abutments
  - Underwater inspections with qualified divers where necessary
  - Providing armour protection against wave action where necessary

5.2.4 Slope failures, landslides and avalanches

Precipitation has the potential to trigger significant material slides. Historically there has been a clear correlation between adverse weather events and landslides, and it is likely that the future will be the same. Good practice in identifying the potential for local landslides and avalanches is to understand the effects of weather, the local soil (or snow) structures and the geotechnical risks attached. In the case of landslides this can be done by geological mapping and sampling, supplemented by data from past events. Hazard maps can be prepared of the areas being reviewed and the likely impacts of climate change taken into account. Such maps, and the mapping of risk, can be very useful in the management of landslides and the planning of new constructions, such as roads and roads infrastructure [45, 46, 47, 48, 49, 42]. Hazard maps can also be used to rate the risk of landslides/avalanches as low, medium or high in a specific area. Using this information, and geotechnical risk management, appropriate measures can be planned and actions taken.

One action is to do nothing. This option can be applied in areas where there is a very low risk of landslides, or where the landslide will not cause a significant impact. In other cases some actions will be required. The mapping of landslide prone areas is particularly important for quick clay areas, as quick clay slides can develop rapidly without any warning.

Figure 5-9 Avalanche in Møre and Romsdal – March 2010 [photo from the Norwegian Public Roads Administration]

The Norwegian Public Roads Administration has a research programme to trial possible climate change adaptation measures for Norwegian roads [71]. One part of the programme focuses on using available weather and terrain data to predict the risk of avalanches, landslides and rockfalls. This uses "*relative threshold values*" to identify unfavourable and extreme weather conditions that could result in impacts to roads and railways. Figure 5-10 below gives an example of a map of landslide risk produced for a criterion of "*water supply over the last 3 days*" for a day that had several actual debris flows in the red and orange areas.

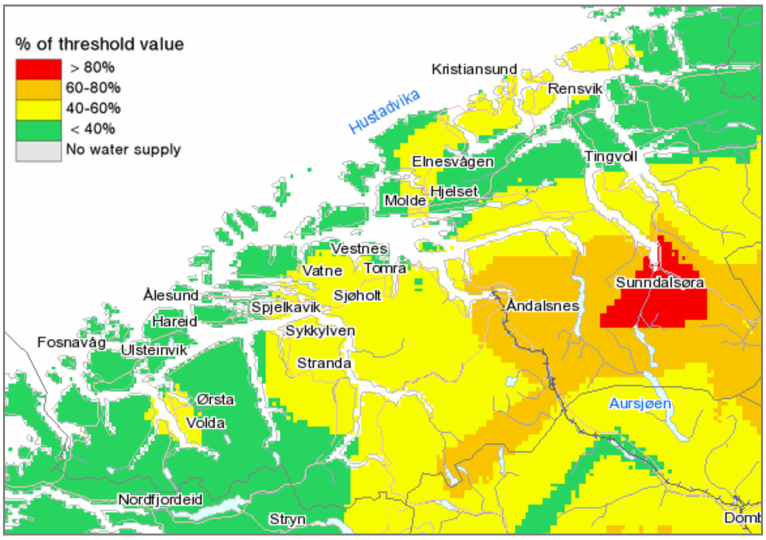


Figure 5-10 Map of landslide risks based on calculated threshold values [71]

It is possible to mitigate the impacts of landslides on road infrastructure through structural and non-structural means. Structural mitigation can include terracing, planting and the use of drainage systems to protect the slope from movement. Non-structural mitigation involves retreat from hazard, land-use planning, early warning, alternative routes and emergency management [45].

Other options include constructing gabion or concrete walls at the toe of slopes. An effective, but possibly costly, option is the use of protection structures to reduce the speed of the debris flow and the run-out distance [45, 42]. Rock slides can be highly dangerous close to roads, and should be prevented if at all possible. Loose rocks can be secured using bolts and by cladding the rock face with safety nets. Shotcreting or concrete buttressing of identified areas can also be carried out. Rolling rocks on slopes can be intercepted by rockfall safety fences erected on steel posts and strained wire ropes.

In cases of large potential rock slides, roads can be completely removed from the hazardous areas by placing them in tunnels [67]. These kinds of structures are suggested for areas where there is a very high risk of landslides [45, 42]. In case of new construction, it is normal to try to avoid landslide and avalanche risk areas, if possible.

Good practices in reducing the potential for landslides and avalanches include:

- cutting back the slope to a shallower angle
- terracing or benching the slope
- vegetating the slope to provide an organic reinforcement of the surface layers
- covering the slope with a rock blanket
- support the slope with a retaining structure

Possible adaptation measures are

- Implementing a system of geotechnical risk management
- Mapping landslide and avalanche prone areas, including underlying geology
- Carrying out risk assessment of identified areas determination
- Structural and non-structural mitigation, e.g. catch fences

For new construction: avoid landslide risk areas

6. SUMMARY

A number of issues and recommendations have been made in this report or fall out from what has been mentioned. These are:

- The Earth's climate is predicted to change. For Northern Periphery areas this could mean that the future could bring hotter and drier summers, and warmer wetter winters with increasing frequencies of storm events. The degree of change that may happen is uncertain and the natural variability of normal weather patterns may make any trends difficult to establish.
- These climate changes, if they are not mitigated by actions across the planet, could have a significant effect on road networks. The ROADEX Partners consider it prudent to consider what can be done now to deal with effects being seen rather than ignore the subject altogether.
- Dealing with changing circumstances in road construction and road maintenance is not new. Roads operations and managers have historically had to react and adapt to meet the changing demands and challenges thrown up the road networks and road users. Managing the effects of climate change should be no different in this respect. They should be able to be similarly met, step by step to meet the circumstances at the time.
- In assessing the vulnerability of infrastructure to climate change effects it is recommended that assessments are carried out in accordance with the PIARC 5 step process [57], i.e.

  Step 1: Identify the potential climate change effects

  Step 2: Assess the impact of climate change on the vulnerability of elements

  Step 3: Evaluate the risks and identify potential solutions and strategies to address the vulnerabilities identified

  Step 4: Implement the chosen adaptation plans and strategies

  Step 5: Monitor and review
- Records should be kept of extreme weather events and any actions taken.
- Adaptation measures should be cost-effective and sustainable, and not add to the underlying problem. Good adaption is part of a continuous process that needs to be regularly reviewed and updated so that it can be kept focused on the problem and be effective. New information will continually come to light and this will need to be incorporated into adaptation where it can bring a benefit.
- Design parameters and inputs should continue to be reviewed in the light of developing experiences and actions. These could include:
  - Storm return periods
  - Levels of precipitation
  - Investigations and survey technologies
  - Construction methods
  - Materials
  - Monitoring systems
- It is recommended that climate change considerations should be brought into daily engineering management, and integrated into policies and regulation in the same way that health & safety and environmental issues are currently considered. For this the general awareness of the potential effects of climate change will require to be raised and knowledge shared on good adaptation measures and experience.

7. REFERENCE LIST

1. Kropp, J., Scholze, M. (2009). "Climate Change Information for Effective Adaptation. A Practitioner's Manual." Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH. Climate Protection Programme. 57pp
2. Swedish Environmental Protection Agency (2004). "Clear facts about climate change." http://www.naturvardsverket.se [Online: 28/07/2010]
3. van der Linden, P., and Mitchell, J. F. B. (eds.) (2009). "ENSEMBLES: Climate Change and its Impacts: Summary of research and results from the ENSEMBLES project". Met Office Hadley Centre, FitzRoy Road, Exeter EX1 3PB, UK. 160pp
4. Ciscar, J. C. (ed.) (2009). "Climate change impacts in Europe". Final report of the PESETA research project
5. Swedish Commission on Climate and Vulnerability (2007). "Sweden facing climate change – threats and opportunities". Final report from the Swedish Commission on Climate and Vulnerability, Stockholm 2007
6. Schjolden, A. (2004). "Towards assessing socioeconomic impacts of climate change in Norway" CICERO Report 2004:03
7. Torvanger, A., Alfsen, H. K., Kolshus, H. H. and Sygna, L. (2001). "The state of climate research and climate policy." CICERO Report 2001:02
8. seNorge.no. Climate Change Scenarios. http://senorge.no/mappage.aspx [Online: 28/06/2011]
9. Ministry of Agriculture and Forestry (2009). "Adapting to climate change in Finland". Ministry of the Environment, Helsinki, Finland
10. Carter, T.R., Jylhä, K., Perrels, A., Fronzek, S. and Kankaanpää, S. 2005. FINADAPT scenarios for the 21st century: alternative futures for considering adaptation to climate change in Finland. FINADAPT Working Paper 2, Finnish Environment Institute Mimeographs 332, Helsinki, 42 pp.
11. Molarius, R., Keränen, J., Jylhä, K., Sarlin, T. & Laitila, A., 2010. "Suomen elintarviketuotannon turvallisuuden haasteita muuttuvissa ilmasto-olosuhteissa", VTT Tutkimusraportti, http://www.vtt.fi/inf/julkaisut/muut/2010/VTT-R-2672-10.pdf, [Online: 23/01/2012]
12. Berghäll, J. and Pesu, M. (2008) "Climate Change and the Cultural Environment - Recognized Impacts and Challenges in Finland" The Finnish Environment 44e - 2008, Ministry of the Environment Department for the Built Environment
13. Jóhannesson, T., Aðalgeirsdóttir, G., Björnsson, H., Pálsson, F. and Sigurðsson, O. (2004) "Response of Glaciers in Iceland to Climate Change." ACIA International Symposium on Climate Change in the Arctic Reykjavik, Iceland, 9-12 November 2004
14. Björnsson, H., Aðalgeirsdóttir, G., Guðmundsson, S., Jóhannesson, T., Pálsson, F. and Sigurðsson, O. (2006) "Climate change response of Vatnajökull, Hofsjökull and Langjökull ice caps, Iceland"
15. Björnsson, H."Climate change and coastal issues". http://hsvest.is/skraarsafn/skra/130/ [Online: 27/07/2010]
16. Ray, D. (2008) "Impacts of climate change on forestry in Scotland – a synopsis of spatial modeling research.", Research Note

17. Scotland's climate change adaptation framework (2009), The Scottish Government, www.scotland.gov.uk/climatechangeadaptation [Online: 27/07/2010]

18. Mc Grath, R., Nishimura, E., Nolan, P., Semmler, T., Sweeney, C. and Wang, S. (2005). “Climate Change: Regional Climate Model Predictions for Ireland Environmental.”, RTDI Programme 2000–2006

19. Dunne, S., Hanafin, J., Lynch, P., McGrath, R., Nishimura, E., Nolan, E., Ratnam, J. V., Semmler, T.,Sweeney, C., Varghese, S. and Wang, S. (2008) “Ireland in a Warmer World - Scientific Predictions of the Irish Climate in the Twenty-First Century.” Community Climate Change Consortium for Ireland (C4I)

20. “Impacts of a warming Arctic - ACIA Highlights. (2004)” Arctic Climate Impact Assessment

21. “Supported evidence for the key findings. (2004)” Impacts of a Warming Arctic: Arctic Climate Impact Assessment. ACIA Overview report

22. Saarelainen, S. “Climate Change and Road Management”. NORDIC. Roads and Transport Research. http://nordicroads.com/website/index.asp?pageID=148 [Online: 01.07.2010]

23. American Concrete Pavement Association. http://www.pavement.com/Concrete_Pavement/Technical/Fundamentals/Frost.asp [Online: 01.07.2010]

24. Aursand, P. O. and Horvli, I. (2009) “Effect of a Changed Climate on Gravel Roads”. Norwegian Public Roads Administration, Norway

25. Galbraith, R. M., Price, D. J., Easteal, R., Shackman, L., Motion, A. and Barnett, C. (2005). “Scottish Road Network, Climate Change Study. Summary Report”. The Scottish Executive 2005

26. Thordarson, S. (2010). “Real-Time Frost Depth Forecast Model for Thaw-Induced Axle Load Limitation Management”. XIII International Winter Roads Congress, Quebec, 8-11 February, 2010

27. Aho, S. and Saarenketo, T. (2006) “Design and Repair of Roads Spring Thaw Weakening”, Northern Periphery, ROADEX III.

28. Morton, J. O., Tremper, B., Stokstad, O. L. and Casagrande, L. (1938). “Prevention of Detrimental Frost Heave”. Highway Research Board Proceedings, Transportation Research Board (TRB), Vol 18, ParT II, pp. 356-365

29. Doré, G. and Zubeck, H. K. (2009). “Cold Regions Pavement Engineering. Chapter 3.” 1st ed. McGraw-Hill, 2008 - 416 pages

30. UNEP Environmental Knowledge for Climate (2007). “Global Outlook for Ice and Snow. Highlights”. http://www.grida.no/publications/ [Online: 26/07/2010]

31. Vetenskapsrådet (The Swedish Research Council) (2009). “Permafrost Is Thawing In Northern Sweden. ScienceDaily”. http://www.sciencedaily.com /releases/2009/02/090218081629.htm [Online: 26/07/2010]

32. Johansson, M. and Christensen, T. R. (2009). “Permafrost - To Be Or Not To Be”. Sustainability journal, Formas, Sweden

33. CICERO- Center for International Climate and Environmental Research – Oslo. “The Permafrost on Svalbard and in Norway Is Thawing”. http://www.cicero.uio.no/fulltext/index_e.aspx?id=2059 [Online: 26/07/2010]

34. Northwest Territories (2010). “NWT State of the Environment Report.” Chapter 13. Permafrost. http://www.enr.gov.nt.ca/_live/pages/wpPages/soe_permafrost.aspx [Online: 26/07/2010]

35. Dore, M. H. I. and Burton, I. (2001). “The Costs of Adaptation to Climate Change in Canada: A Stratified Estimate by Sectors and Regions. Social Infrastructure”. http://adaptation.nrcan.gc.ca/projdb/pdf/79b_e.pdf [Online: 01/12/2010]

36. McMaster University (2007, September 17). Peat and Forests Save Permafrost From Melting. ScienceDaily. Retrieved July 26, 2010, from http://www.sciencedaily.com /releases/2007/09/070913132927.htm

37. “Flood Management in Changing Climate. A Tool for Integrated Flood Management” (2009). WMO/GWP Associated Programme on Flood Management

38. Petkovic, G. and Larsen, J. O. (2009) “Climate Change – A Challenge for Norwegian Roads”. Transportation Research Board, 88th Annual Meeting, 11-15 January, 2009, Washington D.C.

39. Sumer, B.M. and Fredsøe, J. (2002). “The Mechanics of Scour in the Marine Environment”. World Scientific Publishing Co. Pte. Ltd.

40. Whitehouse,R. (1998). “Scour at Marine Structures. ASCE”. Thomas Telford Ltd.

41. Keller, G. and Sherar, J. (2003) “Low-Volume Roads Engineering. Best Management Practices. Field Guide ” US Agency for International Development (USAID)

42. Akkerman, G.J. (with contributions of: Knoeff, H., Koehorst, B., Hoffmans, G., Lindenberg, J., and Frans Barends) (2004)” Determination of Socio-Economic Impact of Natural Disasters. Living with flooding in Europe”. GeoTechNet Work Package 6.

43. Patel, D. (2004) “Determination of Socio-Economic Impact of Natural Disasters. Overview of Landslide Hazards in Europe”. GeoTechNet Work Package 6.

44. “Flood Management in Changing Climate. A Tool for Integrated Flood Management” (2009). WMO/GWP Associated Programme on Flood Management

45. Lacassee, S. and Nadim, F. (2009). “Landslides. Disaster Risk Reduction. Ch. 3 Landslide Risk Assessment and Mitigation Strategy.”

46. Ministry of the Environment, http://www.regjeringen.no/ (Online: 11/06/2010), also in English

47. Bjordal, H. and Larsen, O. (2009). “Avalanches Risk in a Changing Climate. Development of a Landslide and Avalanche Risk Model”. International Snow Science Workshop, Davos, 2009

48. Winter, M. G., Macgregor, F. and Shackman, L. (2005). “The Scottish Road Network. Landslides Study Summary Report”. The Scottish Executive 2005.

49. Petkovic, G., Humstad, T., Bjordal, H., Larsen, J. O., Aursand, P. O. (2010). “Climate and Transport – R&D Programme for Adaptation of Norwegian Roads to Climate Change”. Transport Research Arena Europe 2010, Brussels

50. Ter-Stepanian. G. (1999). “Quick Clay Landslides: Their Enigmatic Features and Mechanism”. Bulletin of Engineering Geology and the Environment

51. Aursand, P. O. and Horvli, I. (2009) “Effect of a Changed Climate on Gravel Roads”. Norwegian Public Roads Administration, Norway

52. Berntsen, G. and Saarenketo, T. (2005). “Drainage on Low Traffic Volume Roads”. Nordic Periphery, ROADEX II.

53. Prutsch, A., Grothmann, T., Schauser, I., Otto, S., McCallum, S. (2010). “Guiding Principles for Adaptation to Climate Change in Europe.” ETC/ACC Technical Paper 2010/6. European Topic Centre on Air and Climate Change.

54. Taivainen, O. A., Jumikis, A. R. and Gray, H. (1963). “Preventive Measures to Reduce Frost Action on Highways in Finland – and Discussion”. Highway Research Record, TRB, No. 33, pp 202-216

55. Hellman, F., Pihl, K. A., Hansson, K. (2010). ”SWAMP Report 4 – Inspection and Maintenance. Guide for Reducing Vulnerability due to Flooding of Roads”. ERA-NET ROAD Joint Research Activities. SRO3 Road Owners getting to Grips with Climate Change

56. ROADEX I. (2000). “Road Condition Management of Low Traffic Volume Roads in the Northern Periphery”. State-of-Art Study Report. Nordic Periphery ROADEX I.

57. PIARC, (2011). “How to deal with Effects of Climate Change on Road Pavements”, (consultation copy to author)

58. Finnish Road Administration (2009). “The effect of climate change on the routine and periodic maintenance of roads”. Finnish Road Administration, Central Administration. Finnra reports 8/2009, 66 p. + app. 8 p.

59. Natural Resources Canada (2007). “From Impacts to Adaptation: Canada in a Changing Climate” Chapter 4 and 5. http://adaptation.nrcan.gc.ca/assess/2007/index_e.php [Online: 01/12/2010]

60. Titus, J. (2002). “Does Sea Level Rise Matter to Transportation Along the Atlantic Coast?” The Potential Impacts of Climate Change on Transportation Federal Research Partnership Workshop October 1-2, 2002

61. Vägverket (2008). “VVMB 310. Hydraulisk Dimensionering”. 2008:61.

62. Larsen, M. and Pihl, K. A. (2010). ”SWAMP Report 3 – The Blue Spot Model. Development of a Screening Method to Assess Flood Risk on National Roads and Highway Systems”. ERA-NET ROAD Joint Research Activities. SRO3 Road Owners getting to Grips with Climate Change

63. Aho, S. and Saarenketo, T. (2006). “Managing Drainage on Low Volume Roads”, Executive Summary

64. National Roads Authority (NRA) (2009). “NRA Design Manual for Roads and Bridges”. http://www.nra.ie/RepositoryforPublicationsInfo/file,16152,en.pdf [Online: 08/07/2010]

65. Saarenketo, T. (2007). “Developing Drainage Guidelines for Maintenance Contracts”, Results of a ROADEX III pilot project in the Rovaniemi Maintenance Area in Finland

66. Vuorimies, N. and Kolisoja, P. (2006). ”Treatment of Moisture Susceptible Aggregates”, Executive Summary

67. Volkwein, A., Melis, L., Haller, B., Pfeifer R. (2006). “Protection from Landslides and High Speed Rock fall Events”. http://www.geobruggnz.co.nz/files/Chapmans%20Peak%20Drive_CI.pdf [Online: 01/12/2010]

68. Scottish Road Network Climate Change Study: UKCP09 update, October 2010

69. Aho, S. and Saarenketo, T. (2005) “Managing Spring Thaw Weakening on Low Volume Roads”, Northern Periphery, ROADEX II.

70. Dawson, A. and Carrera, A. (2010). P2R2C2 Report 11 “Overall Advice & Summary”, Pavement Performance & Remediation Requirements following Climate Change, ERA-NET ROAD Joint Research Activities. SRO3 Road Owners getting to Grips with Climate Change

71. Petkovic, G, et al, (2010) “Climate and Transport” – R&D Programme for Adaptation of Norwegian Roads to Climate Change, Transport Research Arena Europe, Brussels

72. Saarikivi, P., Gustavsson, T. and Rayner, D. (2009). IRWIN, “Improved local winter index to assess maintenance needs and adaptation costs in climate change scenarios”, ERA-NET ROAD Joint Research Activities. SRO3 Road Owners getting to Grips with Climate Change

73. “Durban conference delivers breakthrough in international community's response to climate change”, http://www.cop17-cmp7durban.com/en/news-centre/media-releases/breakthrough-response-to-climate-change-20111211.html [Online: 16/12/2010]

8. APPENDICES

Appendix 8.1 The ROADEX questionnaire

Appendix 8.2 National strategies on climate change of the ROADEX partner countries

Appendix 8.3 Summary of Good Practice and Adaptation Measures

Appendix 8.4 Drainage summary from ROADEX III

8.1 THE ROADEX QUESTIONNAIRE

Information sheet

Thank you for agreeing to participate in this study which is a part of the ROADEX RESEARCH TASK RE3 "Climate Change". Its aim is to produce a practical guidance document for engineers to help them manage any effects of climate change on their road networks.

The questionnaire that follows is the first part of the study and aims to find out from engineers and decision-makers how they see the effects of climate change being managed. It is accepted that climate change effects are uncertain at this time but the ROADEX Partners think that sharing strategies can help.

A number of possible adverse effects are predicted for climate change. Increased rainfall is possible which could cause higher groundwater levels, flooding incidents, landslides and erosion. Temperatures could rise and have an effect on bituminous pavements. Seasonal changes may occur that could result in changing winters with more freeze-thaw cycles. More storm events could happen with heavier rains and storms and heat waves.

There may even be some potential local benefits of climate change on road networks. The decrease of cumulative frost hours due to milder and shorter winters could reduce the number of sub-grade frost heave problems experienced on northern roads and facilitate winter maintenance.
This questionnaire however will focus on strategies to overcome the possible problems. The information collected will be used to prepare a guidance report to help engineers understand the possible effects and what can be done to adapt to them. All information which is collected during the study will be kept strictly confidential so that only the researchers carrying out the research will have access. Your name need not be recorded.

The study is being carried out by the Arctic Technology Center of the Denmark Technical University. If you would like more information about the research please contact:

Adriana Hudecz

Thank you for your help!

Questionnaire

1.You are invited to provide some basic information. These details will be kept strictly confidential.

Name: (optional)
Country:
Company:
Job title:

2.In the following, there are a number of photos of road related problems that are predicted to occur more frequently in the future. Please, indicate with an X your view of the likely effects of climate change on the problem shown.

A. Stability problems with road embankments		
Might significantly increase		Additional comments:
Might slightly increase		
No change		
Might slightly decrease		
To significantly decrease		

Are you aware of any documentation, guidelines or strategy was produced to help engineers to deal with this problems?

B. Freeze-thaw cycles problem with paved roads		
Might significantly increase		Additional comments:
Might slightly increase		
No change		
Might slightly decrease		
Might significantly decrease		

Are you aware of any documentation, guidelines or strategy was produced to help engineers to deal with this problems?

C. Freeze-thaw cycles problem with unpaved roads		
Might significantly increase		Additional comments:
Might slightly increase		
No change		
Might slightly decrease		
Might significantly decrease		

Are you aware of any documentation, guidelines or strategy was produced to help engineers to deal with this problems?

D. Rutting due to spring thaw weakening of paved roads		
Might significantly increase		Additional comments:
Might slightly increase		
No change		
Might slightly decrease		
Might significantly decrease		

Are you aware of any documentation, guidelines or strategy was produced to help engineers to deal with this problems?

E. Rutting due to spring thaw weakening of unpaved roads		
Might significantly increase		Additional comments:
Might slightly increase		
No change		
Might slightly decrease		
Might significantly decrease		

Are you aware of any documentation, guidelines or strategy was produced to help engineers to deal with this problems?

F. Differential frost heave		
Might significantly increase		Additional comments:
Might slightly increase		
No change		
Might slightly decrease		
Might significantly decrease		

Are you aware of any documentation, guidelines or strategy was produced to help engineers to deal with this problems?

G. Settlement due to permafrost		
Might significantly increase		Additional comments:
Might slightly increase		
No change		
Might slightly decrease		
Might significantly decrease		

Are you aware of any documentation, guidelines or strategy was produced to help engineers to deal with this problems?

H. Sheet ice problems		
Might significantly increase		Additional comments:
Might slightly increase		
No change		
Might slightly decrease		
Might significantly decrease		

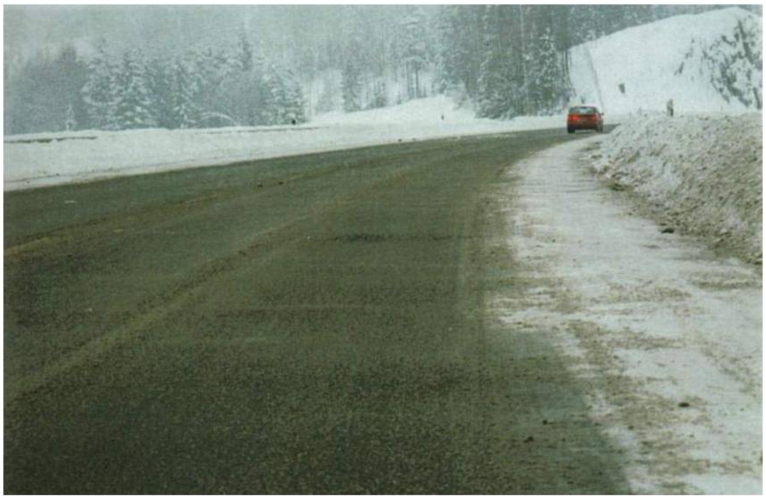
Are you aware of any documentation, guidelines or strategy was produced to help engineers to deal with this problems?

I. Winter maintenance problems due to drifting snow		
Might significantly increase		Additional comments:
Might slightly increase		
No change		
Might slightly decrease		
Might significantly decrease		

Are you aware of any documentation, guidelines or strategy was produced to help engineers to deal with this problems?

J. Winter maintenance problems due to icing		
Might significantly increase		Additional comments:
Might slightly increase		
No change		
Might slightly decrease		
Might significantly decrease		

Are you aware of any documentation, guidelines or strategy was produced to help engineers to deal with this problems?



K. Winter maintenance problems due to salt		
Might significantly increase		Additional comments:
Might slightly increase		
No change		
Might slightly decrease		
Might significantly decrease		

Are you aware of any documentation, guidelines or strategy was produced to help engineers to deal with this problems?

L. Avalanches		
Might significantly increase		Additional comments:
Might slightly increase		
No change		
Might slightly decrease		
Might significantly decrease		

Are you aware of any documentation, guidelines or strategy was produced to help engineers to deal with this problems?


M. Erosion of paved roads due to heavy rains		
Might significantly increase		Additional comments:
Might slightly increase		
No change		
Might slightly decrease		
Might significantly decrease		

Are you aware of any documentation, guidelines or strategy was produced to help engineers to deal with this problems?

N. Erosion of unpaved roads due to heavy rains		
Might significantly increase		Additional comments:
Might slightly increase		
No change		
Might slightly decrease		
Might significantly decrease		

Are you aware of any documentation, guidelines or strategy was produced to help engineers to deal with this problems?

O. Flooding		
Might significantly increase		Additional comments:
Might slightly increase		
No change		
Might slightly decrease		
Might significantly decrease		

Are you aware of any documentation, guidelines or strategy was produced to help engineers to deal with this problems?

P. Landslides		
Might significantly increase		Additional comments:
Might slightly increase		
No change		
Might slightly decrease		
Might significantly decrease		

Are you aware of any documentation, guidelines or strategy was produced to help engineers to deal with this problems?

Q. Rise of sea level		
Might significantly increase		Additional comments:
Might slightly increase		
No change		
Might slightly decrease		
Might significantly decrease		

Are you aware of any documentation, guidelines or strategy was produced to help engineers to deal with this problems?

3. Do you think it is necessary to produce a new and/or better version of guideline to prepare for the expected consequences of climate change on road networks?
4. Does your organization have a published strategy on impact of climate change on infrastructure or any materials? If yes, where can we find it?
5. Does your organization have a working group or contact person for climate change issues? If yes, could you give us the contact information?
6. Are you aware of any carried out any work on the carbon management of road operations or carbon footprint?
7. Are you aware of any guidance on climate change adaptation in your country?

Thank you very much for your time. We will come back to you with the results of this questionnaire.

8.2 NATIONAL STRATEGIES/POLICIES

8.2.1 FINLAND – National strategies for climate change

Finland´s National Strategy for Adaptation to Climate Change, www.mmm.fi/sopeutumisstrategia, was adopted in 2005. The aim of the Strategy was to reinforce and increase the capacity to adapt to climate change and to mitigate the costs to the society. The Strategy describes measures by 15 different sectors up until 2080. Each ministry is responsible for implementing the Strategy in its administrative sector.

National Climate and Energy Strategy section displays the strategies for 2001, 2005 and 2008. The latest strategy, which was accepted by the Government in 2008, covers climate and energy policy measures in great detail up to 2020, and in brief thereafter, up to 2050.

Evaluation of the Implementation of Finland´s National Strategy for Adaptation to Climate Change 2009 was conducted by a survey of whether and how the measures presented in the Strategy had been launched in different sectors.

An Action Plan to Implement the national Strategy for Adaptation to Climate Change has been prepared in the Ministry of the Environment in cooperation with the Ministry of Agriculture and Forestry, YMrep20en /2008 Adaptation to climate Change in the Administrative Sector of the Ministry of the Environment .pdf .

Climate Policy Programme for the Ministry of Transport and Communications´ administrative sector for 2009-2020 aims to substantially reduce emissions from business, industry, administration and people´s everyday lives by means of transport and communications policies. Besides the use of biofuels, emissions from transport will be cut by 2,8 million tonnes compared to the estimated emissions level of 2020.

Climate Change Adaptation Research Programme ISTO, www.mmm.fi/ISTO/eng, aims to produce information for the planning of the practical adaptation measures and promote the application of this information.

The changing climate in Finland: estimates for adaptation studies, ACCLIM project report 2009 contains climate information. The main outcomes are: return periods of storm events based on observations at twelve weather stations, climate scenarios and probabilistic estimates of changes in climate over Finland based on an analysis of global and regional climate model simulations, guidance in the use of climate information in climate change impacts and adaptation research.

Assessing the adaptive capacity of the Finnish environment and society under a changing climate aim was to study adaptation to the potential impacts of climate change in Finland, www.environment.fi/syke/finadapt.

The Finnish Road Administration conducted a survey on climate change adaptation in 2007, **Rail Administration** in 2008 and **Maritime Administration** in spring 2009. The Finnish Road Administration published in 2009 two reports: **The effect of climate change on the routine and periodic maintenance of roads** and **Strengthening of climate policy in road maintenance.**

The Finnish Meteorological Institute, www.fmi.fi/ilmastonmuutos, gives climate information to help people and organisations adapt to a climate change.

8.2.2 GREENLAND – National policies for GHG emission reduction

Greenland has not produced any policies or strategies regarding the impacts of climate change on roads yet. However, they have policies for GHG emission reduction and goals:

- Reduction of emissions of GHG from civil society by 5 % from 2013-2020 compared to GHG emissions in 2007
- Up to 60 % share of electricity production for civil society will be renewable by 2020.
- Development of renewable energy production
- Introduction of both information on energy consumption and economic incentives to influence the behaviour of the population
- Climate-friendly development and re-development of housing
- Focus on mitigation in the fisheries industry
- Improved utilisation of excess heating from incineration plants in district heating

8.2.3 ICELAND – National policies for GHG emission reduction and CC mitigation & adaptation

The Icelandic government is developing an implementation plan towards reduced GHG emission by 2020. A draft action plan prioritising eight steps was introduced in December 2009:

- Adoption of European emissions trading system.
- New taxation system on automobiles and fuel and raising public awareness on sustainable mobility.
- Increased competitiveness for travelling by foot, bicycles and public transport
- Shifting to bio-fuels in fishing vessels,
- Electrification in fishmeal plants.
- Increased forestry and land reclamation
- Wet-land reclamation
- Increased R&D and innovation in CC mitigation

No national policies are yet developed on CC adaptation. However the road- and maritime authorities are working on this issue.

8.2.4 IRELAND – National approach to the integration of environmental issues

To support the Environmental Impact Assessment (EIA) legal framework and the National Roads Project Management Guidelines (NRPMG), the Irish National Roads Authority (NRA) adopted a four-stage Environmental Integration Model (EIM) to facilitate the incorporation of environmental issues not only into national road planning but their construction and operation. The EIM incorporates all legislative requirements and, where feasible, national and international policy.
The first stage of the EIM involved the development of a series of best practice planning assessment guidelines covering a range of environmental issues. These documents underpin the planning approach outlined in the NRPMG for national road scheme development.

- **A Guide to Landscape Treatments for National Road Schemes in Ireland** (National Roads Authority, 2006);
- **Best Practice Guidelines for the Conservation of Bats in the Planning of National Road Schemes** (National Roads Authority, 2005);
- **Ecological Surveying Techniques for Protected Flora and Fauna during the Planning of National Road Schemes** (National Roads Authority, 2008);

- **Environmental Impact Assessment of National Road Schemes – A Practical Guide** (Rev. 1, National Roads Authority, 2008);
- **Guidelines for Assessment of Ecological Impacts of National Road Schemes** (Rev 2, National Roads Authority, 2009);
- **Guidelines for the Treatment of Air Quality During the Planning and Construction of National Road Schemes** (National Roads Authority, 2006);
- **Guidelines for the Treatment of Noise and Vibration in National Road Schemes** (Revision 1, National Roads Authority, October 2004);
- **Guidelines on Procedures for Assessment and Treatment of Geology, Hydrology and Hydrogeology for National Road Schemes** (National Roads Authority, 2008);
- **Guidelines for the Assessment of Architectural Heritage Impacts of National Road Schemes** (National Roads Authority, 2005);
- **Guidelines for the Assessment of Archaeological Heritage Impacts of National Road Schemes** (National Roads Authority, 2005);
- **Guidelines for the Management of Waste from National Road Construction Projects** (National Roads Authority, 2008);
- **Guidelines for the Creation, Implementation and Maintenance of an Environmental Operating Plan** (National Roads Authority, 2007);
- **Guidelines on the Management of Noxious Weeds and Non-Native Invasive Plant Species** (National Road Authority, 2008).

The second stage of the strategy involved the development of best practice construction guidelines.

- **Guidelines for the Crossing of Watercourses During the Construction of National Road Schemes** (National Roads Authority, 2005);
- **Guidelines for the Protection and Preservation of Trees, Hedgerows and Scrub, Post, Prior and During the Construction of National Road Schemes** (National Roads Authority, 2006);
- **Guidelines for the Treatment of Badgers prior to the Construction of National Road Schemes** (National Roads Authority, 2005);
- **Guidelines for the Testing and Mitigation of Wetland Archaeological Heritage for National Road Schemes** (National Roads Authority, 2005);
- **Guidelines of the Treatment of Bats During the Construction of National Road Schemes** (National Roads Authority, 2005);
- **Guidelines for the Treatment of Otters prior to the Construction of National Road Schemes** (National Roads Authority, 2006);
- **Guidelines on the Management of Noxious Weeds and Non-Native Invasive Plant Species** (In Prep., Rev. 1, National Road Authority, 2010);

In the third stage of the EIM the NRA prepared a guidance document to assist contractors working on national roads schemes to prepare and implement an Environmental Operating Plan. In the final stage of the EIM, the NRA is undertaking post-EIA research evaluation studies to assess actual impacts of national road schemes on different ecosystems and to validate and revise prediction methodologies used in the EIS to further reduce such impacts.

8.2.5 NORWAY – Climate Change in Norway

Norwegian Climate Change Adaptation Programme

Climate adaptation Norway is a climate change committee in the Ministry of the Environment Committee to examine society's vulnerability and need for adaptation to the impacts of climate change. Was established in May 2007 and is part of the Government's commitment to climate change. It will carry out an official report on Norway's vulnerability and adaptation needs arising from climate change. The committee's work culminated in a NOU-report (Norway's official reports) 15/11/2010. There has been launched an online guide to climate change. The guide is intended to provide an overview of how municipalities and counties can work with climate change. http://www.regjeringen.no/en/dep/md/kampanjer/engelsk-forside-forklimatilpasning.html?id=539980

Cicero's report on climate change strategies In 2004, Cicero wrote a feasibility study on adaptation to climate change strategies in Norway on behalf of the Ministry of Environment. The report considers the need to get an overview of knowledge about the impacts of climate change in Norway across social sectors, and outlines the main themes for a comprehensive national strategy for adaptation to climate change.

RegClim - research on climate change in Norway RegClim is the short name of a coordinated research project for the development of scenarios of climate development in the Nordic region, surrounding waters and parts of the Arctic by global warming.

Transnova “Transnova” is a project in the Ministry of Transport within environmental measures for the reduction of CO2 emissions from transport and it is operated by NPRA. Transnova promotes sustainable transportation by focusing on new technology, increased use of environmentally friendly modes of transport and reduction of transport volumes. Climate and transport **"Climate and transport"** is a four-year research and development in the NPRA. The purpose of this project is to improve the procedures and regulations for planning, design, construction and operation of roads in response to changing climate conditions. It is also recommending measures for climate change adaptation for the road sector. The project started in January 2007 and expected to be completed May 2011. **NVE (Norwegian Water Resources and Energy Directorate**) with a new strategy for climate change adaptation The strategy aims to ensure that NVE takes into account climate change in the management of water resources and energy sector. Published 2010.

The Government's Climate and Forest Initiative One of the key objectives of the project is to contribute to include the reduction of greenhouse gas emissions from deforestation and forest degradation in developing countries in a new global climate agreement.

8.2.6 SCOTLAND – National strategies for climate change

The Climate Change (Scotland) Act 2009 creates the statutory framework for greenhouse gas emissions reductions and places climate change duties on Scottish public bodies, such as Councils and roads administrations. It also includes other provisions on adaptation, forestry, energy efficiency and waste reduction.

Scotland’s Climate Change Adaptation Framework (2010) presents the national, co-ordinated approach to ensure that Scotland understands the risks and opportunities these changes present and is adapting in a sustainable way.

Scottish Climate Change Impacts Partnership (SCCIP), www.sccip.org.uk – is a free information and resource hub to help individuals and organisations adapt to the likely impacts of climate change. **Scotland & Northern Ireland Forum for Environmental Research (SNIFFER)**, has produced a handbook of climate trends across Scotland, 2006.

Scotland's Climate Change Declaration, 2007. Scotland's 32 local authorities have signed up to a Scottish Climate Change Declaration that commits them to action. As part of this Councils are required to take part in the **Carbon Trust Local Authority Carbon Management Programme**. A main output of this is a **Carbon Management Plan (CMP**) that outlines what the Councils propose to do to reduce carbon emissions from their activities.

The Highland Council is in the process of developing a **Climate Change Strategy** for their area which will include the actions to be taken at a regional level to tackle climate change. The timescale for completion is 2011. A key component of this will be to develop an **Adaptation Strategy**, outlining the actions that will enable the Council to prepare for, and adapt to, the anticipated effects of climate change.

8.2.7 SWEDEN – Climate Change in Sweden

The Swedish Energy and Climate Policy (2009), http://www.sweden.gov.se/sb/d/108/a/132242, aims to phase out fossil-based energy sources and substantial reductions of greenhouse gases. By 2020, greenhouse gas emissions from sectors such as transport, agriculture, forestry and housing will have decreased by 40 percent compared to 1990 level. Other targets are 50 % renewable energy, 10 % renewable energy in the transport sector, 20 % more efficient energy use. By 2050, Sweden will have a sustainable and resource-efficient supply and zero net emissions of greenhouse gases into the atmosphere.

The final report from the Swedish Commission on Climate and Vulnerability '**Sweden Facing Climate Change – Threats and Opportunities**' (SOU 2007:60), http://www.sweden.gov.se/sb/d/108/a/94595, pointed out specific problems to prepare for. The risk of flooding and landslides is increasing due to more plentiful and more violent precipitation. Sea level rise will affect part of the coast line. Higher winter temperatures causes losses of frozen soil and subsequent loss of bearing capacity on roads built on former frozen ground. The biggest challenges will be to maintain good drainage systems.

In the current situation there is no strategy or organization to adapt to climate change at the central level. The county administrative boards have the responsibility for regional climate adaptation efforts. A '**knowledge portal**' gathers information from a number of authorities as a support to those working on adaptation and impacts of climate change (http://www.smhi.se/klimatanpassningsportalen).

The Swedish Transport Administration has not yet a strategy for climate change adaption. Risk assessments are carried out according to a specific method.

8.3 SUMMARY OF GOOD PRACTICE AND ADAPTATION MEASURES

This Appendix summarises the good practice and adaptation measures listed in the boxes at the end of each subsection and chapter in the report.

<table>
<tr><th>Effect</th><th>Impact</th><th>Good practice and adaptation measures</th></tr>
<tr><td rowspan="2">Temperature</td><td>Higher summer Temperatures</td><td><u>Good practice measures</u>
• keeping the road drainage in good condition by Implementing the ROADEX drainage maintenance strategies and guidelines [63]
• sealing of cracked and distressed areas
• removal of roadside vegetation
• Increase frequency of grass cutting, etc

<u>Adaptation measures</u>
• reviewing pavement material compositions at the next rehabilitation/reconstruction event
• building on well-working practices from areas with warmer temperatures
• using more rut-resistant and/or stripping-resistant resurfacings
• surface dressing and microsurfacings, especially with chippings with high reflectivity
• pervious wearing course
• improving surface and sub-surface drainage systems
• stabilisation of unsealed pavements</td></tr>
<tr><td>Increased freeze-thaw cycles, frost heaves and frost damage</td><td><u>Good practice measures</u>
• keeping the road drainage in good condition by implementing the ROADEX drainage maintenance strategies and guidelines [63]
• Keeping ditches and culverts free of snow and ice by means of good winter maintenance practices
• Managing the vehicle numbers using the road
• Applying axle load restrictions where necessary
• Surfacing and/or regrading gravel roads to provide good crossfalls</td></tr>
</table>

Effect	Impact	Good practice and adaptation measures
Temperature	Increased freeze-thaw cycles, frost heaves and frost damage (continued)	*Adaptation measures* • Designing and repairing frost damaged roads in accordance with **ROADEX guidelines for roads suffering from spring thaw weakening [69]** • Lowering the groundwater table within the road embankment with deeper drainage • Sealing pavement cracks immediately after the winter period • Strengthening and rehabilitating weak road sections • Increasing the thickness of structural layers • Replacing any frost susceptible materials in the road structure with non-frost susceptible materials • Installing steel grids in the road structure • Providing frost insulation • Soil stabilisation / homogenisation • Raising the carriageway out of the snow field *Paved roads* • Improving the asphalt specification to increase its failure strain • Converting the paved road back to a gravel road
	Effects on permafrost areas	*Good practice measures* • Increasing vegetation/forest cover to protect the permafrost • Good drainage, similar to those recommended for drainage related problems • Increasing the thickness of the road embankment • Keeping records for establishing trends and needs • Monitoring, and risk evaluation over time *Adaptation measures* • Mapping of the permafrost areas, and understanding and managing the risk • Excavating the frozen icy material and replacing it with thaw-stable fill • Using open graded rockfill in embankments • Installing insulation into the embankment • Increasing the reflectivity of dark surfaces • Artificial cooling and/or extracting heat from the embankment *New roads* • Avoiding permafrost areas

Effect	Impact	Good practice and adaptation measures

Temperature	Milder winters	*Good practice measures*
		• Preventative pavement maintenance
		  – Sealing pavement cracks and joints to prevent ingress of water
		  – Using surface dressings and micro-surfacings to provide an impermeable surface layer
		  – Keeping surface and sub-surface drainage systems effective
		• Reviewing winter maintenance operational practices in to meet prevailing circumstances
		• Removing snow promptly from road surfaces, shoulders and roadside ditches
		• Keeping culverts free of ice
		• Removing snow walls and snow banks close to the road
		• Erecting snow fences where necessary to influence snow drifting
		• Keeping records for establishing trends and needs
		• In the case of existing ice roads, identifying alternative crossings

	Increase in sea level	*Good practice measures* • Mapping likely threatened areas • Installing warning signs • Upgrading coastal drainage systems to meet threats *Adaptation measures* • Edge-strengthening of road embankments • Physical reinforcement of the coast line to protect against wave action • Raising the level of roads and causeways to meet the threat • Use of submergible pavements *New roads* • numerical models to predict the extent of future flooding and potential erosion • new sea-defences, especially in places where they were not necessary before • new construction to take account of predicted sea level changes, especially in low lying areas • in extreme cases, provide alternative route away from the hazardous area *Causeways*: construction of all year bridge

Effect	Impact	Good practice and adaptation measures
Precipitation	Flooding	*Good practice measures* • Inspecting watercourses regularly • Cleaning out debris from clogged ditches and culverts • Cleaning out watercourses and structures in flood prone areas ahead of predicted heavy rainfall • Keeping records of flooding events and locations • Preparing contingency/emergency plans *Adaptation measures* • Reviewing storm water drainage requirements • More frequent clearing of ditches and culverts • Resizing drainage systems to meet threat • Paving ditches to reduce erosion • Drawing up maps of flood prone areas, considering increasing precipitation and sea-level (Blue Spot Model) • Keeping in-house Geographical Information Systems (GIS) up to date • Reviewing design storm return periods in the light of new weather information • Extreme case: rerouting
	Surface water drainage	*Good practice measures* (see summary of typical drainage problems and solutions in Appendix 8.4) • keeping the road drainage in good condition by Implementing the **ROADEX drainage maintenance strategies and guidelines [63]** – carry out drainage surveys and evaluations; – identify the areas requiring special drainage measures; – instruct work and monitoring the performance of contractors; – keep records of problem areas. • Inspecting watercourses regularly • Cleaning out debris from clogged ditches and culverts • Cleaning out watercourses and structures in flood prone areas ahead of predicted heavy rainfall • Keeping records of flooding events and locations • Checking outfalls of sub-surface drainage systems • Cutting grass and vegetation adjacent to roads/ ditches/ culverts

Effect	Impact	Good practice and adaptation measures
Precipitation	Surface water drainage (continued)	*Adaptation measures* • Increasing the frequency of cleaning culverts and ditches • Providing deeper and greater volume drainage where necessary • Cutting grass and vegetation more frequently in the vicinity of roads/ ditches/ culverts • Good winter maintenance practices as listed in "*Milder winters*" • Sealing pavement cracks immediately after the end of winter conditions • Reviewing the return periods of storm events in the light of new weather information • Revising design parameters/recommendations. ROADEX Partners are generally increasing waterway areas by 20%. • Improving sub-surface drainage systems and roadside drainage measures (These may require additional land to be acquired alongside the existing road for some Partners)

	Erosion of roads	*Good practice measures*
		• *Gravel roads*:
		  – stabilisation in accordance with ROADEX material treatment guidelines [66]
		  – improved compaction and drainage
		• *Paved roads*:
		  – improved drainage
		• *Side slopes*:
		  – installing interception drains
		  – terracing
		  – vegetation/rock blanket
		  – providing a retaining wall at the toe
		• Provision of armour protection to embankments on exposed coasts

	Erosion of bridges	*Good practice measures* • Inspecting before and after flooding events • Providing scour protection around piers and abutments • Underwater inspections with qualified divers where necessary • Providing armour protection against wave action where necessary

Effect	Impact	Good practice and adaptation measures
Precipitation	Slope failures, landslides and avalanches	*Good practice measures* • cutting back the slope to a shallower angle • terracing or benching the slope • vegetating the slope to provide an organic reinforcement of the surface layers • covering the slope with a rock blanket • supporting the slope with a retaining structure *Adaptation measures* • Implementing a system of geotechnical risk management • Mapping landslide and avalanche prone areas, including underlying geology • Carrying out risk assessment of identified areas determination • Structural and non-structural mitigation, e.g. catch fences *New construction* • avoiding landslide risk areas

8.4 DRAINAGE SUMMARY FROM ROADEX III

Drainage problems on low volume roads were investigated in the ROADEX II & III projects and a number of reports were published. Good practice in drainage maintenance operations was considered the ROADEX III report "*Managing Drainage on Low Volume Roads*" by Aho and Saarenketo [63]. The following table summarises the recommended maintenance practices for remedying defects associated with poor drainage from their ROADEX III report.

Defect	Possible causes	Good practice measures
Potholes	*Extensive potholes* Major underlying problem(s) *Occasional potholes* Frost susceptible soil *Gravel roads* Not enough crown/crossfall	• Patch the holes as soon as possible to avoid further damage • Whole reconstruction • Improve road crown/crossfall • More frequent grading on gravel roads
Scoured gravel shoulders	• False ditch left by grader • Blockage below guardrail	• Re-grade and slope shoulders • Cut/remove turf and false ditches • Clean below guardrail
Erosion and surface slides in road cut slopes	• Steep sideslopes • High ground water table / ground water flow • Erosion susceptible materials in the slope	• Install surface water drains • Lower the ground water table with ditches above the road cut slope • Cover with vegetation, geotextile • Cover with coarse graded gravel or macadam • Lessen slope and install retaining walls
Washouts along edge of road	• Substandard shoulder maintenance • Poor materials	• Grade out false ditches • Bring low shoulders up to pavement level • Replace poor materials with good material, well compacted
Unstable roadways	• Excess water in the subgrade from ditches, shoulders or cracks on surface • Water saturation of road structures during spring thawing periods and freeze-thaw cycle periods in mild winters	• Clean out ditches and deepen where necessary • Install interceptor drains • Install a geotextile and gravel surface on the crowned and ditched roadway • Deep drainage • Replace frost susceptible materials/ install frost insulation • Base course stabilisation • Provide good crossfall

Defect	Possible causes	Good practice measures
Culvert defects (e.g. washouts due to overtopping or reduced inlet / outlet flow)	• Culvert too small • Settlements • Clogged pipe • Broken joints • Improper construction of culvert and/or inlet/outlet • Both culvert and road low point at same location • Blocking of inlet/outlet with rubbish, branches, mud etc.	• Provide adequate size culvert(s) • Provide armour to upstream and downstream slopes • Re-grade ditch so low point not coincide with road low point. • Inspect culvert and clean out more often • Repair or replace as necessary
Ditch defects (e.g. erosion of slopes, inlets, ditches clogged)	• Too much water in concentrated form • Flow too fast for channel lining • Lack of erosion protection • Too steep slopes	• Clean out the ditches more often • Use berm ditches to intercept surface water on high slopes. • Reshape ditches • Install check dams in steep ditches • Re-vegetate ditches or line with erosion control materials/ pave
Alligator cracking	• The subbase/subgrade is soaked • The road is not strong enough for the traffic loadings	• Deepen and clean out ditches • Install interceptor drains • Keep passable with minimum maintenance and schedule reconstruction.
Rutting, longitudinal cracking	• The earlier stage of the above, with similar causes to alligator cracking	• In the case of saturated soils, the possible solutions might be the ones for alligator cracking • For occasionally damp road structures – recycle surface and build-up road thickness • Resurface
Edge cracking	• The road is too narrow • Shoulder is poorly drained • No edge support	• Keep the shoulders well graded • Provide shoulder support to the pavement edge

ROADEX
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ROADEX PROJECT REPORTS (1998–2012)

This report is one of a suite of reports and case studies on the management of low volume roads produced by the ROADEX project over the period 1998-2012. These reports cover a wide range of topics as below.

- Climate change adaptation
- Cost savings and benefits accruing to ROADEX technologies
- Dealing with bearing capacity problems on low volume roads constructed on peat
- Design and repair of roads suffering from spring thaw weakening
- Drainage guidelines
- Environmental guidelines & checklist
- Forest road policies
- Generation of 'snow smoke' behind heavy vehicles
- Health issues raised by poorly maintained road networks
- Managing drainage on low volume roads
- Managing peat related problems on low volume roads
- Managing permanent deformation in low volume roads
- Managing spring thaw weakening on low volume roads
- Monitoring low volume roads
- New survey techniques in drainage evaluation
- Permanent deformation, from theory to practice
- Risk analyses on low volume roads
- Road condition management of low volume roads
- Road friendly vehicles & tyre pressure control
- Road widening guidelines
- Socio-economic impacts of road conditions on low volume roads
- Structural innovations for low volume roads
- Treatment of moisture susceptible materials
- Tyre pressure control on timber haulage vehicles
- Understanding low volume pavement response to heavy traffic loading
- User perspectives on the road service level in ROADEX areas
- Vehicle and human vibration due to road condition
- Winter maintenance practice in the Northern Periphery

All of these reports, and others, are available for download free of charge from the ROADEX website at www.ROADEX.org.