

“Climate and Transport” – R&D Programme for Adaptation of Norwegian Roads to Climate Change

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Abstract

The coming climate changes in Norway are expected to bring higher precipitation - more frequent and more intense rainfall, milder winters, warmer summers and an increase in wind speed and storm frequency. This will affect the road network in several ways. Higher groundwater levels will yield higher probability for floods and erosion. More rain will give a higher risk of slides, occurring at new locations and in changed forms, such as slush avalanches, debris slides and mud flows. Our present design specifications for the choice of structural solutions and physical protection may be incorrect given the new climate conditions and the existing protection measures may not be sufficient. Areas exposed to stable winter conditions may experience higher exposure to repeated freezing and thawing. Reduced accessibility and regularity on the road network should also be expected. All this requires improved emergency plans.

The paper presents the work currently being carried out by the Norwegian Public Roads Administration on adaptation to climate change. The work is organised as a 4-year R&D programme, “Climate and Transport”, with the main goal: adaptation of specifications for planning, design, operation and maintenance of roads under changed climate conditions.

The programme consists of seven projects, or work packages: “Programme conditions and demonstration projects”, “Data collection, processing and storage”, “Flood and erosion prevention”, “Avalanches and landslides”, “Bearing capacity of roads”, “Consequences for winter operation”, and “Susceptibility and emergency plans”.

The results will be formulated as amendments to Road Administration manuals and reports from field tests and observations on the road network demonstrating necessary action for adaptation to climate change.

1. Introduction

The purpose of this paper is to give an overview of ongoing work at the Norwegian Public Roads Administration (NPRA) on adaptation to climate change. At present, this work is organised as a research and development programme “Climate and Transport”. The programme started in 2007 and a major part of it is to be finalised in 2010. Some programme activities will continue through 2011. The main objectives of the programme are to investigate the effect of climate change on the road network and recommend remedial actions concerning planning, design, construction and maintenance. Remedial measures need to sustain both safety and accessibility in a changed climate. Proposals for revised guidelines shall also be formulated.

The programme is planned in close cooperation with the Norwegian National Rail Administration, and is carried out with the help of a large number of cooperating partners, such as the Norwegian Coastal Administration, Avinor (air traffic control and services), the Norwegian Water Resources and Energy Directorate, the Norwegian Geological Survey, Centre for International Climate and Environmental Research (CICERO), the Norwegian Meteorological Institute, the Directorate for Civil Protection and Emergency Planning, the Norwegian Geotechnical Institute, the Norwegian University of Science and Technology NTNU/SINTEF and the Norwegian Institute for Agricultural and Environmental Research.

2. Description of climate change – a starting point for adaptation

The first analysis of vulnerability of the road network to a more severe climate was performed in 2002, and followed up in 2007, in cooperation with other national transport authorities (National Transport Plan, 2010-2019, (2007)). The basis for the analysis was the description of climate changes as given by the Norwegian Meteorological Institute, based on the results of the RegClim project, www.regclim.met.no, a coordinated research project with the overall aim to produce scenarios for regional climate change in Northern Europe, bordering sea areas and major parts of the Arctic.

The work on improving predictions for regional climate change was continued and the Meteorological Institute and partners issued a new report in June 2009, with revised descriptions of the expected changes in temperature, precipitation etc. (Hanssen-Bauer et al., 2009)

The vulnerability analyses of 2007 pointed out the major challenges for roads: insufficient drainage capacity, landslide risk and its consequences on traffic safety, deterioration of roads and consequently higher demand for repair measures, environmental effects of precipitation increase, and generally more demanding conditions to be met by more effective emergency plans.

3. Main fields of work in “Climate and Transport”

3.1 Flood and Erosion Prevention

The topics included in the work are: drainage, erosion of slopes, bridge foundations, erosion from waves, ensuring flood proof road levels and pollution control under less predictable weather conditions.

3.1.1 Drainage structures and erosion protection

Both criteria for the choice of drainage method or system and procedures for calculating necessary capacity should be studied. An initial challenge is the lack of “new” design loads. Although higher and/or more frequent floods are to be expected, the projection of flood values

based on global climate change scenarios is an extremely difficult task. The outcome of such work would not necessarily improve the level of certainty for design loads to be applied in engineering projects. Even with no climate change coming, a general source of uncertainty is already present in the methods for calculation of run-off volumes. Calculation based on precipitation (the rational formula) is widely applied, although it includes a number of assumptions that may lead to underestimated run-off values, i.e. surface characteristics (infiltration). Calculations of drainage capacity are very much dependent on reliable series of precipitation measurements. Especially the effect of precipitation *intensity*, which is of major relevance for future climate conditions, highlights the need for more frequent precipitation measurement.

One way of taking into consideration higher precipitation and higher general uncertainty concerning climate change is introducing climate factors for calculation of run-off volumes and necessary drainage capacity. The function of climate factors is to increase the calculated run-off volumes in geographical areas where higher precipitation should be expected. A proposal for introducing climate factors in NPRA design guidelines is currently being discussed.

3.1.2 Demonstration of climate change impact through case studies

To demonstrate the effects of climate change and the shortcomings of traditional design methods, “Climate and transport” is performing several case studies. One of the goals is to look at residual capacity of existing drainage structures or erosion protection measures regarding what climate loads they are designed to withstand and how their relative capacity will be reduced by climate change. Another goal is to map the need for weather and flood data, and to demonstrate the discrepancies in the results coming from different approaches and calculations methods.

The road between Ålesund and Dombås in Norway (E134) was chosen as a demonstration road for the programme. During the summer of 2009 a survey regarding the condition of the culverts on this road was performed, with respect to effective capacity /performance, level of maintenance and adequacy of earlier repair work. This work is currently being reported. The findings were interesting and show the need for a closer look into NPRA’s routines for repair and formulation of requirements in maintenance contracts.

3.1.3 Pollution control

Storm water ponds have been included in road construction projects for the past ten years. They are made for the purpose of sedimentation of run-off water and pollution control. In “Climate and Transport” a study of the impact of climate change on the effects of storm water ponds is being performed. The focus is on higher precipitation values and more intensive rainstorms on the environmental performance of these ponds. The work will be reported in 2010.

The other function of storm water ponds is to retain excessive run-off water to prevent flooding. This function should be utilised to a higher degree. One should look for good engineering solutions that combine all drainage elements and control run-off water in a flexible way. This comes in addition to, or in some cases instead of, “waiting for” improved projections of future flood values.

3.1.4 Sea level and storm surge

Predictions for sea level rise (from 40 – 70 cm along the coast of Norway) indicate an expected increase in storm surge (Vasskog and Drange, 2009). This requires a closer look at erosion of coastal roads and criteria for safe height above sea level. On this topic, the NPRA is collaborating with the coastal authorities. It is also necessary to check the elevation of sub-sea tunnel openings and evaluate the risk of tunnels being filled by sea-water. This is not a safety

issue, since the tunnel would be closed for traffic before a critical high sea-level is reached. The costs of tunnel closure and subsequent repair are however, extremely high.

There are 25 sub-sea tunnels on the Norwegian road network. The R&D programme is currently focusing on four of them, which have already experienced threat from high sea levels during stormy weather. Embankments exposed to wave erosion are also a part of the study. A report from this work is expected to be completed during the summer of 2010.



Figure 1 Sea level rise and increases in storm surge may be challenging for operation of coastal roads (E10, Lofot Islands)

3.2 Data: collection, processing and storage

One of the goals of “Climate and transport” is to improve the accessibility of data related to weather situations and weather related hazards on the road and railway networks. A web portal for weather and terrain data is being developed for improving awareness of extreme weather situations and hazard mitigation.

The basis for this work is a web-based dynamic map, www.SeNorge.no, developed by the Norwegian Water Resources and Energy Directorate, the Norwegian Meteorological Institute and the Norwegian Mapping and Cadastre Authority. Norway’s weather situation is presented in 1x1 km² grid cells. For each cell, chosen weather parameters are generated based on interpolations from measurements of precipitation, temperature and snow depth data. In addition, data derived from hydrological models, such as data on ground water level, snowmelt and snow cover conditions, are appointed to each cell. All these data are presented as absolute values in the SeNorge.no web portal. Both observations (analysis tool) and prognosis (awareness tool) are presented in 1-day resolutions.

In “Climate and Transport”, the Norwegian Public Road Administration and the National Rail Administration, have specified how to use the data from the same platform, but with reference to *relative threshold values* instead of absolute values. The intention is to identify unfavourable and extreme weather conditions that are critical for maintaining operation of roads and railways. A beta version of this web portal, named “Føre var” is now available, <http://forevar.senorge.no>. The threshold values are calculated based on empirical data on weather conditions that have previously lead to avalanches landslides and rock falls, traffic chaos due to heavy snow fall, etc. A measure of how close an actual weather situation is to calculated threshold values is presented by a colour scale of yellow, orange and red, where red corresponds to the greatest hazard.

Defining models for calculating threshold values requires good data and a major amount of processing work. At present, six themes have been introduced in the web portal and are being tested. These are shown in the following table.

Table 1 Main themes introduced in the web portal “Føre var”

	Themes	Data sources	Possible hazard mitigation related to:
1	Water supply last day	Precipitation/rainfall, snowmelt and snow cover	Debris flows
2	Water supply last 3 days	Precipitation/rainfall, snowmelt and snow cover	Debris flows
3	Snowfall last day	Precipitation/snowfall	Snow disaster
4	Snowfall last 3 days	Precipitation/snowfall	Snow disaster and snow avalanches
5	Freezing and thawing last 10 days	Temperature variation, precipitation/rainfall, snowmelt and snow cover	Rockfalls and rockslides
6	Wetting of fresh snow cover last day	Snowfall last 3 days, precipitation/rainfall, snowmelt	Wet snow avalanches and winter floods

Experience so far shows that there are clear relations between some of the map themes and recorded problems on the roads and railways. Other themes are less clear. It has also been proved necessary to adjust the threshold values for the themes according to each other, so that the same colours represent more or less the same risk level in the different themes that are introduced.

Figure 2 gives an example of a map of landslide risks produced for the criterion “water supply last 3 days” on a day with several debris flows in the red and orange area.

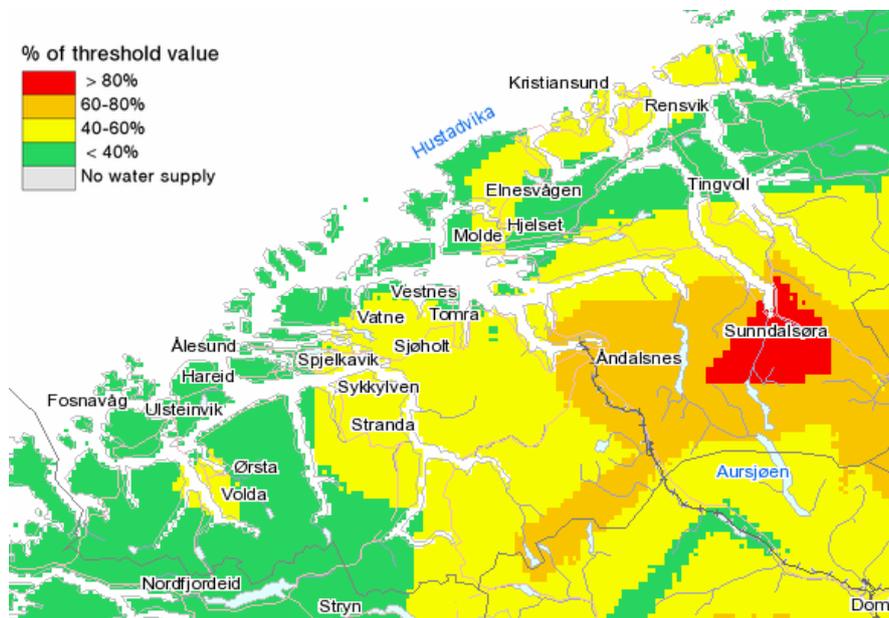


Figure 2 Map of landslide risks based on calculated threshold values

3.3 Avalanches and landslides

Approximately 2000 landslides and avalanches affect the Norwegian road network every year. The risk of landslides has always affected road projects in Norway, been a safety threat and

probability for more frequent landslides of the water-related type (debris slides and slushflows) is one of the most serious consequences of climate change.

'Climate and Transport' is attempting to study all types of landslides and avalanches and how their frequency and triggering factors can be influenced by climate change. The main topics are: risk assessment (methods for probability and risk description), and risk acceptance criteria, mitigation and protection plans and methods of physical protection. Special attention is given to types of landslides that are influenced by the presence of water, such as slushflows and debris slides.

The programme has chosen to focus on developing a better model for calculating the risk of landslides and reviewing the ways of how the need for landslide protection investments are assessed and prioritized. One goal is also to adapt and develop design guidelines for landslide and snow avalanches protection measures, and obtain more knowledge of and propose remedial actions concerning debris slides.



Figure 3 Higher landslide and avalanche risks constitute safety and mobility issues

In order to improve the basis for studying how changes in weather will affect landslide and avalanche risks, a new risk assessment model for landslides and avalanches is being developed (Bjordal and Larsen, 2009). The risk assessment of landslide hazards has traditionally been related to statistics, i.e. records of earlier landslides. One of the conditions for developing the new model was to disregard statistics and create a tool that can be used independently of where landslides, rock falls and avalanches have occurred up to now. This will presumably provide a model that is more robust in relation to climatic variations.

In the risk model, landslides and avalanches are described by factors affecting the probability of a landslide or an avalanche. The factors represent exposed terrain, geological conditions, weather conditions and others. Each of them is given a score and weight factor that contribute to the total risk value in a particular road section. Consequences are similarly described with factors representing the amount of traffic, importance of the road and consequences for road users.

The first use of the risk model will be to compare different road sections regarding risk level. The model will further on be used to develop a method for classification of probability and consequence. Finally, in order to evaluate climate change, the model can be used to consider changes in hazards due to climatic variations. For debris flow, extensive laboratory modelling has been performed in 2009 at NTNU in order to study how debris flows pass under bridges. The models will give a better idea of the criteria for triggering debris avalanches and their paths.

3.4 Bearing Capacity of Roads

Higher precipitation and an increase in freezing and thawing will affect the bearing capacity of roads. In 'Climate and Transport', the impact of climate factors on deterioration of roads is being studied with the aim of estimating the cost of maintaining the present road standard.

The deterioration of roads with asphalt pavement is being modelled by the help of AASTHO 2002, ME-PDG (Mechanistic-Empirical Pavement Design Guide). The model needed some calibration and adaptation to Norwegian conditions. For the calculation of day-by-day deterioration of a road section the model requires detailed climate data such as temperature, precipitation, wind, solar radiation and ground water table. Much effort was put in collecting these data. It was particularly difficult to develop future fictitious sets of weather data, based on today's measurements and projected climate change. Figure 4 shows results of deterioration modelling on the demonstration road E136.

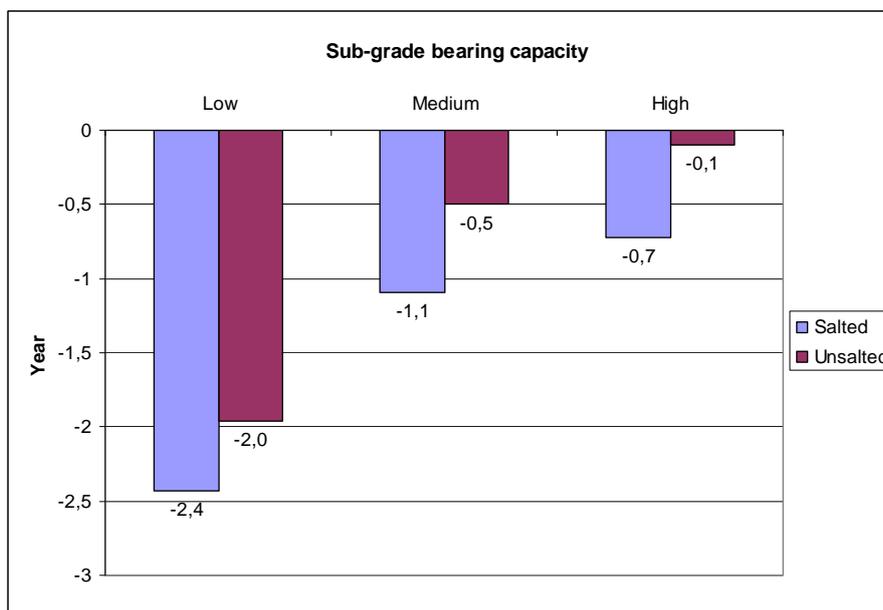


Figure 4 Change in pavement life for an assumed 20 % increase in precipitation

In addition to roads with asphalt pavements, gravel roads are included in the study, due to their importance for the county and forest road network and their susceptibility to climatic conditions. The condition of a gravel road is influenced by traffic, material properties, drainage conditions and climate (Aursand and Horvli, 2009).

A state-of-the-art study by Lerfald & Hoff (2007) shows that unbound materials are mostly affected by temperature changes around 0°C. An increase in the number of freeze-thaw cycles and mild periods during the winter season will increase the accumulated length of the thawing period leading to faster deterioration. Gravel surfaces are also sensitive to rainfall when the road is unfrozen. Heavy rainfall will lead to washing out of fines, implying development of potholes, corrugation and unevenness. Long-lasting rain will soak the surface, raise the ground water table and thus reduce the E-modulus. A change in climate will therefore influence the maintenance needs and costs. The main maintenance actions on a gravel road pavement are gravel surfacing, grading, dust control, ditch clearing and in some cases stabilization (e.g. bitumen).

The yearly maintenance costs for the county gravel road network within the period of 2070-2100 will, according to these calculations, increase by 31 mill NOK or 19 % compared to the present maintenance needs. LCC calculations in this study also indicate that it will be cost effective to

perform drainage and strengthening upgrading of the gravel road network in order to reduce the excessive maintenance costs due to climate change.

3.5 Consequences for Winter Operation

The project investigates necessary measures for maintaining traffic safety and regularity during extreme winter conditions concerning snow, wind, and temperature changes. The task is to adapt strategies for winter operation in zones with shifting climatic conditions and define a reasonable standard level of maintenance in operation and maintenance contracts.

3.6 Susceptibility and Emergency Plans

All effects of climate changes that cannot be avoided must be met with efficient emergency plans. In this programme, ways of performing risk and susceptibility analyses for climate impacts are considered. A survey of vulnerable assets is starting in 2010. The case studies being carried out in the programme will help define the criteria for vulnerability and the formulation of actions for achieving robustness with regard to climate change.

'Climate and Transport' is also working on improved application of weather data in emergency plans. The aim is to use weather maps in a proactive manner and adapt the level of preparedness to the actual risk.

4. Continuation of work

In order to obtain the desired benefits for the Norwegian Public Roads Administration, 'Climate and Transport' wishes to introduce the climate change perspective in all relevant types of work performed by the road administration. The case studies will hopefully demonstrate the effect of climate change and of proposed remedial actions, and these examples will be applicable to the rest of the road network. The programme also wishes to achieve more coordinated use of existing weather data bases and develop a web portal that can be used for improved preparedness for weather related events. Finally, the programme aims at proposing necessary revisions of existing guidelines for design and maintenance. 'Climate and Transport' issues yearly reports on recommended measures for adaptation to climate change. Developing a strategy for adaptation to climate change would be a good way to finish the programme in 2011.

5. References

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