

**XXVIth WORLD ROAD CONGRESS  
ABU DHABI 2019**

**NORWAY - NATIONAL REPORT**

**STRATEGIC DIRECTION SESSION STE**

**NORWEGIAN ROADS AND CLIMATE CHANGE  
– AN ADAPTATION FRAMEWORK**

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## 1. INTRODUCTION

The purpose of the report is to summarise the work on adaptation to climate change in the Norwegian Public Roads Administration (NPRA). It is a review of invested efforts, a description of status and a look ahead at the expected benefits of ongoing projects. During the ten years of work on adaptation to climate change, a 'framework' for adaptation gradually emerged. This consists of the tools, documents, working routines, expertise, etc. involved in assessing vulnerability and risk, and implementing adaptation measures in a sustainable way.

This gradually developed framework is compared to PIARC's International Climate Change Adaptation Framework for Road Infrastructure [1]. The PIARC framework provides an overview of tasks to be carried out when preparing the road network for a future climate. The framework was published in 2015, and presented at the XXV World Road Congress in Seoul. PIARC TC E.1 in the cycle 2016-2019 has worked on proposals for the refinement of the PIARC framework. The proposals will be presented at the XXVI World Road Congress in Abu Dhabi in 2019.

The impact of climate change on buildings and infrastructure is one of the greatest threats within the building and infrastructure sector in Norway. In 2017 alone, there was natural damage amounting to around NOK 870 million [EUR 95 million] and more than half of the compensation from insurance companies relates to flooding (Finance Norway).

The Norwegian Public Roads Administration has always had to manage natural hazards on roads, especially ensure safety from landslides and keep the roads open in difficult winter conditions. However, the future climate requires even more awareness, caution and action. Firstly, there will be more of all the challenges known from before. Secondly, NPRA has to prepare to manage combinations of adverse weather and unexpected changes in weather conditions.

Some examples from 2018 can illustrate this. The spring and summer of 2018 were extremely hot and dry in large parts of Norway. The Meteorological Institute had considered 1947 as the driest summer that has been registered in Norway. However, the temperatures in 2018 exceeded the monthly records, one by one. The drought was a disaster for agriculture, showing that the future warmer climate may not lead to the anticipated prolonged growth season at all. The drought caused problems on the roads as well. In some areas, cutting the vegetation along the road was stopped because of the risk from fire. Forest fires are generally dangerous. However, forest fires can also, in their extreme consequence, cause instability of slopes, especially under heavy rain. Long dry periods decrease the permeability of the ground, which, if exposed to heavy rain, causes flooding.

Heavy rain came in October, in the same areas that were exposed to severe summer drought. In the mountain areas (Møre og Romsdal, Sogn og Fjordane and Jotunheimen) new snow had come at the usual time, at the beginning of October. However, the temperature suddenly rose to 10-15 degrees. Floods from heavy rain and snow melting closed roads, railways, and led to substantial damage in whole communities.

## 2. THE NATIONAL FRAMEWORK FOR ADAPTATION TO CLIMATE CHANGE

In Norway, meteorological and hydrological data is easily accessible to the public. The Norwegian Water Resources and Energy Directorate (NVE) and the Meteorological Institute operate the website [www.senorge.no](http://www.senorge.no), which provides free access to daily updated maps of snow, weather and water conditions and climate in Norway. Topics include water (run-off, soil saturation), weather (air temperature, precipitation), snow (depth, fresh snow, melting snow, newly even skiing conditions!) and climate (current and future). This web portal has been the basis for the development of a risk management tool, xgeo.no (see 6.2.1), and a national alert system for avalanches and floods (see 6.2.2).

The first **national survey of vulnerability to the impacts of climate change** was carried out and reported in 2010 [2]. The study covered all sectors in Norway and all levels of management. As part of the national vulnerability study, the report “**Climate in Norway 2100**” was issued in 2009 [3]. This gives a thorough overview of the climate in Norway - past, present, observed trends, and the results of the modelling of climate change towards the end of this century. Three levels of projections are described: low, middle and high. The projections of climate parameters are calculated for the whole country, and for each of six temperature regions and 13 precipitation regions. They are presented as annual average values and projections of seasonal changes. The report was updated in 2015, and provides the official basis for adaptation in Norway.

“Climate in Norway 2100” describes the future in Norway as such: more precipitation in most places and seasons, more heavy rain all over the country, shorter snow seasons, less snow in lower-lying areas and eventually also in mountain areas. There will also be more floods in general: larger rain floods, eventually less ‘spring floods’ from melted snow. Sea level rise will affect coastal Norway, with variations depending on the level of post-glacial rebound [4].

**The Norwegian Centre for Climate Service (NCCS)** was launched in 2014 [5] to address the need for climate data interpreted for practical use, as well as for a common decision base for adaptation to climate change, for all sectors in Norway. The centre facilitates and communicates climate and hydrological data for applications in adaptation work. Regional climate profiles, comprising overviews of climate change, impacts and anticipated risks, have been developed for each administrative region. New features are added continuously, such as the maps of monitored and modelled short-term precipitation, which were introduced in 2017.

In 2013, the “**Climate Adaptation in Norway**” white paper was published [6,]. The document emphasised the shared responsibility, from the individual to the organisational level, and the importance of knowledge and cooperation. In addition, it recommends that the society adapts to the *high* projection of climate parameters. See also [7].

Providing the political framework for climate adaptation is continuous work. In 2017, the Ministry of Climate and the Environment issued a document [8] stating the responsibilities of the municipalities, county offices, and the state to stimulate and contribute to the reduction of greenhouse gas emissions, as well as increased environmental-friendly energy conversion through planning and other government and business activities. In addition, a commission appointed by the government is studying the impacts of climate change, including necessary mitigation and adaptation measures, on the Norwegian economy. The report is due in December 2018, and is expected to be followed up by new political aims concerning climate change.

Norwegian Environment Agency coordinates climate change adaptation in Norway. Among other things, the directorate is responsible for the Norwegian Climate Change Adaptation Portal [9].

### **3. MAIN FEATURES OF THE ROAD NETWORK IN NORWAY AND ADMINISTRATIVE FRAMEWORK FOR ADAPTATION**

The Norwegian Public Roads Administration (NPRA) is the public construction authority responsible for the planning, construction and management of highways and county roads. The NPRA develops tenders for construction and operation projects, and develops rules and guidelines for design and practice. The NPRA consists of the Directorate of Public Roads and five regional units. The public road network consists of approximately 90,000 km of roads, 10,000 km of which are national roads.

**The National Transport Plan (NTP)** is the main strategic document in the transport sector in Norway [10]. It is a twelve-year-plan, revised every fourth year, under the direction of the Ministry of Transport and Communications. The NTP outlines how the government intends to prioritise resources within the transport sector, for all transport modes.

Climate change and the transport sector's need to adapt have been part of the preliminary studies for the NTP since 2002. Although the impact of climate change is recognised, there are no explicit investments in adaptation to climate change. Adaptation is supported indirectly, by prioritising investments in maintenance and renewal and in preparedness measures. Some investments will be made simply because changes to design rules will introduce more resilience.

**The Norwegian Road Database (NRDB)** is the NPRA's central database for the road network and associated technical data. For a continuous network, including all roads longer than 50 m, the NRDB collects more than 400 types of technical data: physical objects (e.g. culvert and railings), abstract objects (e.g. speed limits and traffic volumes) and incidents (e.g. traffic accidents and landslides). The NRDB is mostly used for operation and maintenance, but it is also a good source of information for adaptation to climate change.

**The NPRA's own manuals for design and practice** cover all fields of work: planning, design, operation, maintenance and management of the road network. They are based on standards, but contain additional requirements and adaptations for road structures.

**National and international networks for research and knowledge sharing** provide important support for adaptation to climate change. Established collaboration networks with knowledge centres, data providers, other state agencies (see 7), participation in national and international R&D projects, and the networks of CEDR and PIARC are important arenas for sharing, learning, and collaboration. The NPRA's own R&D programmes, focusing on practical solutions and improvements of our design rules or routines, are also valuable.

These are the four important pillars of all aspects of the NPRA's work, including adaptation to climate change. By making adjustments to include the aspect of climate change, these systems and routines become adaptation tools.



Figure 1 – National road 55 flooded from heavy rain, in October 2018, in Skjolden, Sogn og Fjordane. Photo Mari Vold, NVE.

#### **4. MAIN CHALLENGES RELATED TO CLIMATE CHANGE**

The main challenges for the Norwegian road network come from the expected increase in precipitation, especially from more frequent heavy precipitation. The main impact of the anticipated climate change on roads can be summarised as follows:

- Higher risk of flooding and erosion, from rivers and sea.
- Higher risk of flooding of the roads, due to insufficient or inadequate drainage.
- Risk of flooding from the sea - storm surges and waves, important for coastal roads and sub-sea tunnels.
- Higher risk of water-borne pollution, for example from sedimentation ponds.
- A change in the level and type of landslide risk. In many areas, a higher risk of landslides and rock fall, landslide risk in new locations and with increased frequency. More of the 'wet' landslide types, such as debris flows or flash floods.
- A change in avalanche risk. In lower altitude areas, avalanches might be more uncommon, while the expected increase in heavy precipitation can give more frequent avalanches in other areas. An increased frequency of slush avalanches is also expected.
- Deterioration of roads due to higher precipitation. Gravel roads will be particularly affected.
- Operational problems in the event of heavy rain or heavy snowfall. Drifting snow on mountain roads. In some areas, more temperatures fluctuating around zero degrees, with all the friction problems that causes.
- Reduced accessibility and regularity on the road network, placing higher demands on road operation and preparedness.

## 5. R&D PROGRAMMES IN NPRA

The awareness of the impact climate change may have on the road network came from the professionals dealing with landslide protection. This motivated the start of organised work to investigate the impact of climate change.

### 5.1. “Climate and Transport”

The “Climate and Transport” programme was carried out in 2007-2012, and the main objectives were to investigate the impact of climate change on the road network and to recommend remedial action concerning planning, design, construction and maintenance. The project budget was EUR 2.2 million, in addition to internal resources. The R&D programme focused on flood and erosion risk and protection, landslides and avalanches, the bearing capacity of roads, and winter operation. In addition, for all these fields of work, the programme investigated the adequacy and functionality of existing databases, together with preparedness systems and plans. “Climate and Transport” put effort into making use of and adapting existing systems and routines, in order to facilitate the implementation of proposed measures.

The results from the “Climate and transport” R&D programme have been published in a series of 40 reports and conference papers [11]. More importantly, the results were implemented in the NPRA’s manuals for design and practice, see Section 6.1.

### 5.2. “Natural Hazards – Infrastructure, Floods and Landslides” (NIFS)

In 2012, the 4-year Nature hazard programme (NIFS) was initiated, as a joint initiative of the Norwegian Public Roads Administration, the Norwegian National Rail Administration, and the Norwegian Water Resources and Energy Directorate (NVE). The budget was EUR 4.5 million, in addition to joint personell resources. The NIFS project explored issues of common interest, and worked on the clarification and understanding of roles, and coordinating the agencies’ contributions to the national management of hazards from floods and landslides.

The results from NIFS have been published in a series of 120 reports and several conference papers [12], and are being implemented by all three collaborating agencies. The collaboration established in NIFS was continued in the Natural Hazard Forum, see Section 7.

## 6. ADAPTATION MEASURES

Two important principles have been followed throughout the work. Firstly, we base our work on knowledge provided by agencies with the best competence in the field. Secondly, as far as possible, NPRA uses existing systems and routines, and adapts them in order to incorporate climate change.

### 6.1. Amendments to design rules

The NPRA publishes and maintains a series of manuals, which incorporate international and national standards and guidelines for best practice for Norwegian roads. One of the aims of “Climate and Transport” has been to provide proposals for revisions of and supplements to these manuals. The majority of these proposals have already been implemented or are on their way to be implemented. Revised design rules are the main way of ensuring the improved resilience of new roads.

## Natural hazards as a mandatory part of the planning procedure

The effects of climate change should be considered as an integrated part of the planning and development of a road project. The aim is to avoid excessive vulnerability by means of adequate planning and design.

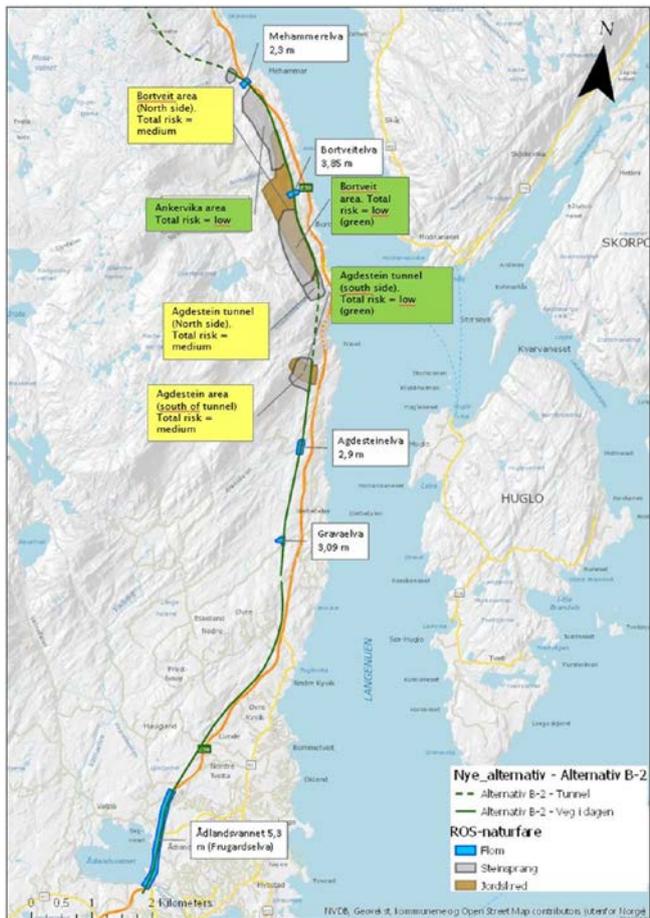


Figure 2 - Example of a vulnerability map for risk analyses of alternative routes of a planned section of E39, island of Stord, Norway (Knut Inge Orset, NPRA)

## Ensuring flood-proof elevation

The manual for road design of 2013 included a requirement for elevation of roads for the first time. The minimum elevation is determined from the 200-year flood level, increased by a safety margin recommended by NCCS\* and in collaboration with the NVE†.

The 2018 edition includes an additional requirement for alignment of coastal roads, calculated from:

- 200-year storm surge level,
- sea level rise by year 2100, magnified by a safety climate margin (recommended by the NCCS),
- and the calculated impact of waves (200-year return period) and local accumulation.

\* Norwegian Centre for Climate Services

† Norwegian Water Resources and Energy Directorate.

### Erosion protection, including wave erosion

The design load for the erosion protection of slopes is the 200-year return period of water flow. This rule is also included in the bridge manual.

Coastal roads need protection from wave erosion, where storm surge and sea level rise have to be included. The design high-water is calculated from: 200-year storm surge level, sea level rise by year 2100 and 200-year significant wave height. Requirements for the geometry of the erosion protection layers and stone size are provided.

### Ensuring adequate drainage and sufficient drainage capacity

The 2011 manual for road construction adopted new provisions for the design return period of precipitation used for calculating water flow. The range is from 50 years for drainage along the road and good redundancy, to 200 years, for transversal drainage and low redundancy. The 2011 edition introduced a climate factor,  $k_f$ , which was added to the rational formula for calculating water flow  $Q$  in small catchments.

The revised design guidelines of 2018 introduced a number of changes. The uncertainty is compensated for by two safety factors - a climate factor (incorporating projected changes) and a general safety factor (compensating for uncertainties in the calculation method and data quality):

$$Q_{\text{dim}} = Q \times F_k \times F_u$$

The climate factor follows recommendations from the NCCS, whereas the uncertainty factor is chosen for predefined safety classes. It is recommended that the design water flow,  $Q$ , is calculated by multiple methods, in order to reduce the uncertainty. Among other things, the choice of method is dependent on the catchment area and shape. Hydraulic calculations are to be adapted to the water management solution.

New road projects are required to establish a storm water management plan. Drainage should be planned to cover a larger area and include alternative flood ways, retention ponds and protective ditches on slopes and cuts.

### Bridges: free height, vulnerability analyses

Besides the requirement of 200-year water flow as the basis for erosions protection, the bridge design manual increases the requirement for free height over water, relating it to the 200-year water level, with an safety allowance of 0.5 m.

Risk analyses are not required to be performed on all bridges. However, inspections may result in a decision to perform a risk analysis. Moreover, the results of a risk analysis can influence the frequency of inspections. A proposal to perform a risk analysis with respect to 1,000-year flood conditions in order to avoid catastrophic consequences, such as loss of life or loss of the entire structure, has not been implemented.

### Maintenance, operation contracts

Changes have been introduced concerning the frequency of inspections – e.g. requiring annual inspections for culverts, with reports of irregularities. Preventive maintenance is required when adverse weather conditions are forecast. NPRA develops vulnerability maps for natural hazards for operation contract areas, see 6.2.3. Operation contracts need to take into consideration the observed trends and the uncertainty of the climate, such as unusual weather combinations (winter flooding, sudden temperature changes), more vegetation along the road, temperatures around freezing point, and drifting snow, etc. Contracts need to be formulated in a flexible way, in order to account for the unpredictable elements.

## 6.2. Amendments to established working processes

Some of the NPRA's tasks have evolved as a response to the effect of *today's* climate. However, these tasks can also be seen as climate adaptation measures. The resilience of the road network is dependent on maintaining the effort, knowledge and resources invested into these tasks. Adaptation measures will, in most cases, be relatively small, but important, adjustments to the original procedures.

### 6.2.1. Landslide and avalanche protection

Landslides and avalanches represent a well-known challenge to Norwegian roads. 2,000 to 3,000 such events are reported to hit the road network every year, the most usual being rock falls, snow avalanches and landslides.

All stretches of public road subject to the risk of landslide or avalanche should be mitigated so that the risk is reduced to an acceptable level. As part of the National Transport Plan (NTP), landslide and avalanche protection plans are made and revised every four years. The protection plans summarise the results of the landslide and avalanche risk evaluation, which is based on factors such as landslide frequency, the length of the stretch of road affected by the landslide, the traffic load on that particular road, and the number of events that have caused road closures in the past. Each factor is evaluated and scored systematically, and the result is a total score that either gives a low, medium or high risk for each particular event on a specific stretch of road. Stretches of road that get a high risk for landslides or avalanches are given priority in the upcoming 12-year NTP period. However, the final decision depends on more than the risk score, e.g. available investments or compatibility with other road plans.



Figure 3 – Andøya island, Nordland, Norway, county road 976, with protection fences for rock fall. Photo: Tomas Rolland, NPRA

Climate change aspects are taken into account in the calculation model by the use of updated landslide frequencies, hence implementing the knowledge of changes in the

probabilities for the different types of landslides and avalanches. Because of this, changes in frequency will have a significant impact on the total risk calculated for each location. All parameters in the model are evaluated regularly, ensuring that changes in climate are taken into account.

In order to address the impact of climate change, a manual for debris flows and slush avalanches was published in 2014. To ensure a more consistent and uniform management of all types of landslides and avalanches, manuals for rock fall, snow and slush avalanches, and debris flow are presently being revised into one major manual, to be published in 2020.

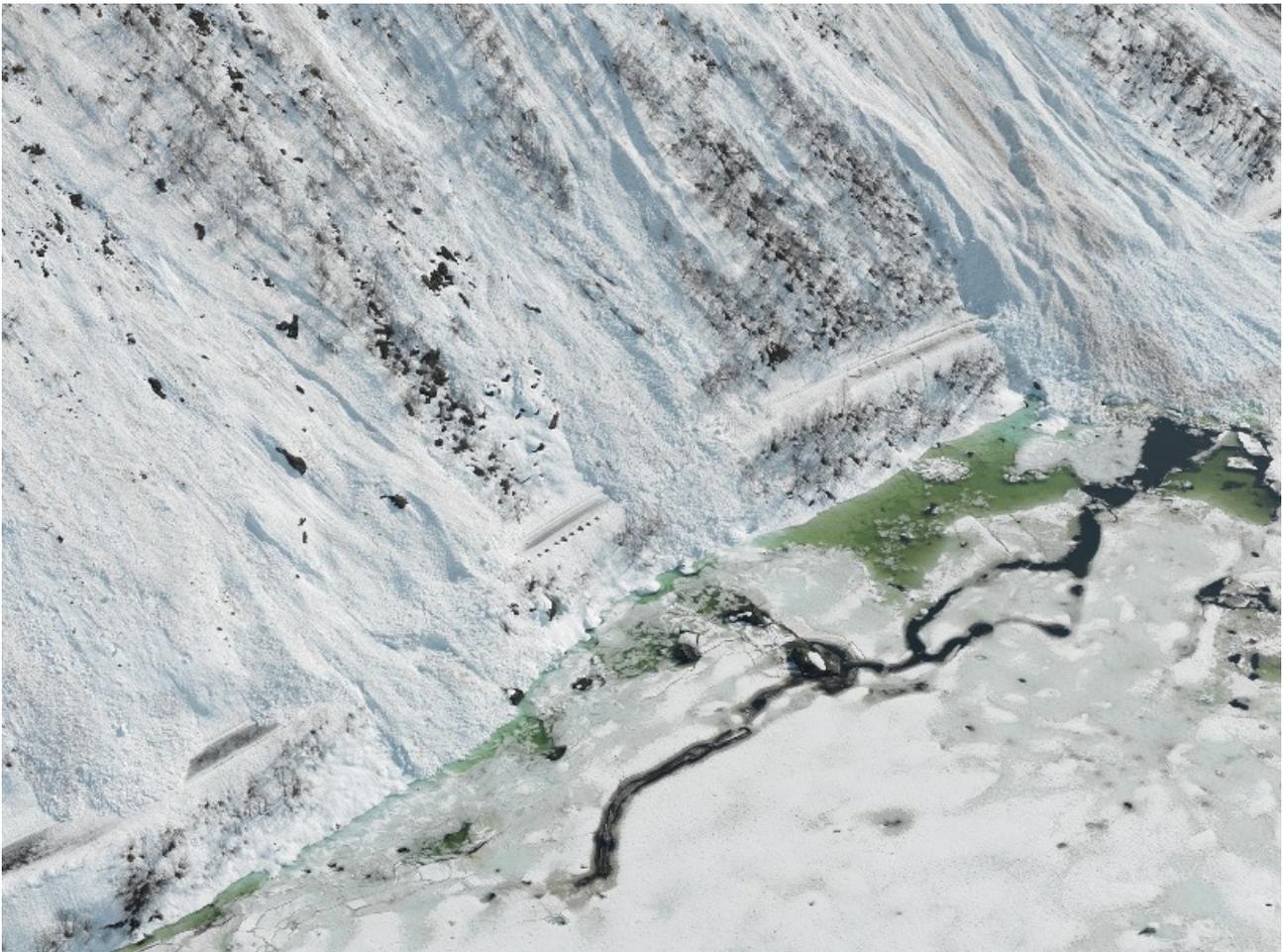


Figure 4 – A snow avalanche hits county road 655 in Norangsdalen, Møre og Romsdal, in April 2010, and closes the road for several weeks. Photo: Arild Solberg.

#### 6.2.2. Early warning services for floods, landslides and avalanches

Equally important as safety measures and protection plans is the early warning service for floods, landslides and snow avalanches in Norway. The warning service is a collaboration between the NVE\*, the Meteorological Institute, BaneNOR† and the NPRA. The NVE is responsible for the daily management of the centre, and for publishing avalanche bulletins and flood warnings on the [www.varsom.no](http://www.varsom.no) website.

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\* Norwegian Water Resources and Energy Directorate

† State-owned company responsible for the Norwegian national railway

Flood warnings were initiated as early as in 1989. Landslide and snow avalanche warnings were included in the service in 2013, after two years of trial warnings. The NPRA contributes to the early warning service with snow avalanche and landslide forecasters. In addition, 28 trained snow avalanche surveyors regularly report their local observations and hazard assessments from the field. Field observations and meteorological data are the main sources of information for the warning service. All professional surveyors, as well as the public, are encouraged to report observations of recent events or hazard indicators, such as flooding on roads or intense rainfall, on the [www.RegObs.no](http://www.RegObs.no) website.

The NPRA's contractors report their observations of natural hazards with the use of ELRAPP - an in-house communication system for contractors working for the NPRA. In 2015, a mobile phone app was launched to facilitate this communication, making it faster and easier for contractors to report to the NPRA about recent hazardous events and danger signs along the road. ELRAPP is a vital part of the NPRA's preparedness system for natural hazards.

[www.Xgeo.no](http://www.Xgeo.no) is a web portal where all the data from ELRAPP and RegObs is stored and managed in maps [16]. The information in Xgeo comprises historical observations, model simulations, forecasts and real-time data. The different maps show the current weather situation together with the results of empirical analyses of floods, landslides and snow avalanches throughout the country. The forecasters in the early warning service utilise this weather data, when assessing the natural hazards.

### 6.2.3. Natural hazard preparedness plans

Norwegian public roads are divided into 120 operation areas, each having an operation contract with associated local contractors. The operation contracts change every 5-7 years. To preserve the local knowledge on natural hazards, and ensure continuity between contracts, preparedness plans for natural hazards and maps of vulnerabilities along roads are produced for each contract area.

Each preparedness plan contains information about the contract area's terrain, and highlights areas with specific threats. Flood zones and hazard zones for landslides or avalanches are included for applicable areas. In addition, the preparedness plans contain information about the area's climate and weather situations that typically cause natural hazards. The vulnerability maps contain all known areas exposed to hazard from snow avalanches, landslides and rock falls, as well as road sections exposed to flooding, coastal flooding, erosion and snow drift. The maps may also include text boxes with details about the events, such as the location, the frequency of the event and other relevant information. Existing protection measures are located on the map. Figure 5 shows an example of such a map. Templates for preparedness plans are under continuous development, based on experiences in the use of the first editions. See also [17].

Operation contracts shall ensure the preventive operation and maintenance of the road network with regard to natural hazards, focusing especially on keeping waterways open and reporting through ELRAPP. Operation contracts shall be composed in such a way that climate change considerations are included in the description of all tasks in the contract area.

The early warning service, together with the natural hazards preparedness plans, make up the NPRA's system for preparedness against avalanches, floods and other natural hazards. In challenging weather situations, the conditions are followed closely and the level of preparedness elevated accordingly. Remedial measures are in place before

excessive damage occurs. The NPRA provides training for contractors, concerning preparedness measures, vulnerabilities, new knowledge about climate change and tools for better risk management.

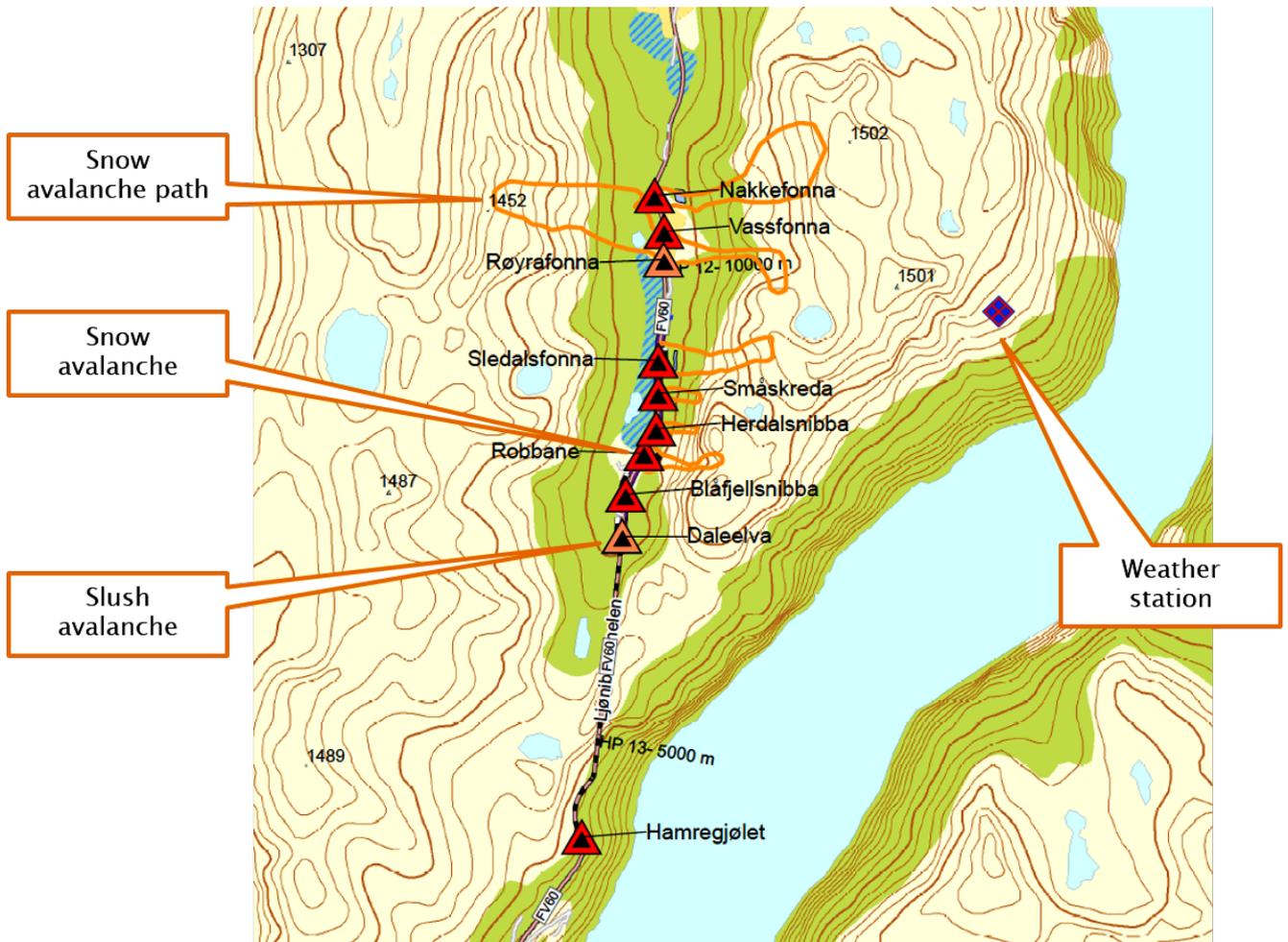


Figure 5 - Example of a vulnerability map in a contract area (Knut Inge Orset, NPRA)

#### 6.2.4. Regular risk assessment on the road network

A vulnerability assessment of the roads is performed annually on all national roads. In its original version, this work focused on road closures due to accidents and security issues. Adaptation to climate change required changes, and the risk presented by natural hazards is now included in the analyses. In order to incorporate trends in climate change, climate data for year 2050 is used as a basis for the analyses. The process teams include staff with knowledge of natural hazards and climate change impact. This means that the usual system for risk assessment is now also a system for mapping climate vulnerability.

In short, the risk score consists of three elements:

- the threat (a function of the probability of the event and the severity, expressed though the extent and duration of the disruption),
- the adaptive capacity (expressed though the agency's readiness to handle the particular disruption and the redundancy),
- the "importance" of the road.

Climate vulnerability enters the process through the choice of events for which the risk is assessed and by keeping in mind the future climate when estimating the probability of events.

The results of inventories of vulnerability provide the basis for the assignment of priorities. For assets identified as vulnerable, more detailed analysis is required, including the collection of improved meteorological and hydrological data, and more detailed calculations of capacity.

As part of the National Transport Plan preliminary work, the main routes in the national road network are subjected to a survey of functionality and standard. These surveys also contain a component of vulnerability to natural hazards, and should therefore always include the aspect of climate change.

The NPRA has recently started a project on a risk-based approach to asset management for maintenance, to ensure that the NPRA's own processes, systems and expertise have a comprehensive perspective on the maintenance management of the road network.



Figure 6 – Heavy local rain and flooding causes massive destruction in the small community of Utvik, July 2017. Photo: Silje Drevdal, NPRA.

### 6.3. Improving the knowledge base for adaptation

The more knowledge the road owners have about today's climate and its impact, the better the basis they will have for adaptation to the future climate. Uncertainty requires greater awareness among road owners, as well as cross-disciplinary dialogue. Improved monitoring of climate parameters (e.g. rain intensity and wind), better statistics, maps, data sharing and the combination of data from several owners into common databases, and availability through practical web portals, etc. will provide a better basis for adaptation to future challenges. In addition, it is important to have good documentation of events and implemented measures, especially the costs of preventive and /or remedial measures.

### 6.3.1. Maps and monitoring

A number of ongoing projects **improving monitoring techniques and maps** will also give a better basis for all kinds of analyses concerning natural hazards: floods, landslide, sea level rise, etc.

A new trend is the “crowd-sourcing” of data, which enables improved statistics for some observations. For example, the Meteorological Institute has made use of weather data from registered private suppliers, thereby increasing the basis for forecasts.

- The NVE has various flood and landslide risk maps available on its web site. <https://kartkatalog.nve.no>
- The NVE is improving its flood database, which will include better collections of data and observations through mobile apps.
- Elevation data obtained by laser scanning is available from the Norwegian Mapping Authority. <https://hoydedata.no/LaserInnsyn/>
- The Norwegian Mapping Authority recently published a practical interactive map showing sea level rise, where global sea level rise, post-glacial rebound and storm surge levels are superimposed. See <http://www.sehavniva.no>.
- Satellite monitoring has enabled maps of movements /subsidence, which can also be useful for resilience. See [www.insar.ngu.no](http://www.insar.ngu.no), a web portal with access to more than 2 billion points throughout the entire country, with measurements taken between 2014 and 2018.
- Ground based InSAR-radar both monitors and documents movement on the surface of the monitored area, with accuracy to 1 mm, and within a radius of 4 km.
- NPRA is developing the use of drones for improved local scanning and terrain mapping, e.g. inspections after flood or landslides, or collecting more detailed terrain data.

### 6.3.2. Ongoing R&D work

**Klima2050** is an 8-year (2015 to 2022) Centre for research-based innovation, for “risk reduction through climate adaptation of buildings and infrastructure”. The aim of Klima2050 is to reduce the societal risks associated with climate change, and enhanced precipitation and flood water exposure within the built environment. Both extreme weather and gradual changes in the climate are addressed. The centre is led by SINTEF, but is enabled by contributions from a large number of partners, as well as from the Research Council. Klima 2050 focuses on climate exposure and moisture-resilient buildings (wp1), stormwater management in small catchments (wp2), and landslides triggered by hydro-meteorological processes (wp3). A fourth work package called “Decision-making processes and impact”, brings together the first three topics of research and connects them to implementable and sustainable solutions, leading to innovation and added value for the building, construction and transportation sectors.

The **KlimaDigital** project has recently been established, by SINTEF. The aim is to conduct research on the use of digital solutions to mitigate societal risks due to geohazards in a changing climate. The four-year project is financed by the KLIMAFORSK section of the Research Council of Norway, which supports the development of research on topics crucial for the development of business and industry in Norway.

“**Vestlandet kompetansesenter**” is a new research centre for sustainable climate adaptation. It aims at providing research, consulting and educational services in adaptation to climate change. <https://klimatilpasningssenter.no/>

## 7. COOPERATION NETWORKS

The **Natural Hazard Forum** was established in 2016 as a collaboration forum for preventive work on natural hazards. Its purpose is to strengthen cooperation between national, regional and local actors in order to reduce society's vulnerability to natural hazards. It shall identify deficiencies or improvement potential in society's prevention and management of natural hazards and propose appropriate measures. The forum initiates and carries out projects in areas where there are particularly cross-sectoral challenges. It is also the national platform for the Global Disaster Prevention Framework (Sendai Framework), which Norway has committed to follow. The board consist of representatives of several other major public offices\*, in addition to the agencies collaborating in NIFS (5.2).

One of the ongoing projects, which is expected to facilitate work on natural hazards and climate change, is "**Kunnskapsbanken**" (The Knowledge Bank). The aim is to gather all relevant available data in a platform for sharing, comparison, and relation mapping. The Knowledge Bank will start with data related to natural hazards, but will be expanded with other available data. The project is led by the Directorate for Social Security and Emergency Planning (DSB). In addition to the partners of the Natural Hazard Forum, Finance Norway is another collaborator. The presence of Finance Norway adds insurance data to the scope, which is essential for obtaining the relationship between damage costs and protection measures. Collaboration on data sharing will contribute to the general efficiency of the public sector.

**Regional networks for adaptation to climate change /resilience** are active in several places in Norway. These are collaboration platforms for state agencies, municipalities, and all other stakeholders within a region, or area (i.e. watershed) for issues of common interest regarding land use, risk management, etc. The NPRA is an important partner in such networks.

Finally, although importantly, an internal network within the NPRA has been established for better the exchange of knowledge and experience, and the dissemination and implementation of results from research.

## 8. COMPARISON TO THE PIARC FRAMEWORK

The question is how Norwegian gradually evolved 'framework' for adaptation to climate change relates to the PIARC International Climate Change Adaptation Framework (2015). The PIARC framework guides road authorities through the process of increasing the resilience to climate change of their networks and assets through four stages: Identifying scope, variables, risks and data (Stage 1); Assessing and prioritising risks (Stage 2); Developing and selecting adaptation responses and strategies (Stage 3); Integrating findings into decision-making processes (Stage 4).

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\* The Directorate for Social Security and Emergency Planning (DSB), the Norwegian Water Resources and Energy Directorate (NVE), the Norwegian Public Roads Administration (NPRA), Bane NOR (state-owned company responsible for the Norwegian national railway), the Agriculture Directorate (LDir), the Local Government Organisation, the Environment Directorate (MDir), Meteorological Institute (MET), Kartverket (the Norwegian Mapping Authority) and County Governor Offices (FM).

<p><b>Stage 1 Identifying scope, variables, risks and data</b></p> <p><b>Establishing assessment scope, aims, tasks and a delivery plan; assessing vulnerability and adaptive capacity; and assessing climate change projections and scenarios.</b></p>
<p><b>Preparation phase</b></p> <p>The NPRA emphasises the importance of establishing early connections with experts /organisations working on meteorology, hydrology and climate. If climate change projections are not available, these expert groups will be best qualified to give a description of the future changes. Communication with experts and data providers outside the transport sector is important throughout, due to the cross-disciplinary nature of the tasks. The road owners' responsibility is to define the needs in a clear way.</p> <p><b>Vulnerability assessment</b></p> <p>The NPRA started this task by performing a vulnerability analysis on a <i>general</i> level, i.e. addressing <i>types</i> of structures, <i>types</i> of climate loading, etc. This was done in the "Climate and transport" R&amp;D programme. It was, for the most part, a desktop analysis, supplemented with pilot projects on chosen roads stretches and assets. The authors are of the opinion that this phase of work is very useful and important for the adaptation work as a whole.</p> <p>On the <i>road network level</i>, the NPRA carries out annual vulnerability mapping using the VegROS method for risk assessment (6.2.4).</p>
<p><b>Stage 2 - Assessing and prioritising risks</b></p> <p><b>Assessing impact probability, assessing impact severity, establishing risk scores and risk register.</b></p>
<p>Following the VegROS methodology, the NPRA carries out a scoring of elements of risks and calculates the overall risk scores. The algorithm is different from the PIARC framework, but yields the same type of information – a list of risk scores for all relevant points on the stretches of road studied. This provides a basis for prioritising measures. Some vulnerable points need a closer risk assessment, involving more data, other models, etc.</p>
<p><b>Stage 3 – Developing and selecting adaptation responses and strategies</b></p> <p><b>Identification, selection and prioritization of adaptation responses and strategies, and the development of an adaptation action plan or strategy.</b></p>
<p>Here the NPRA has done a lot of work, including for example amendments to guidelines for design and practice, vulnerability maps in planning and operation contracts, etc. On a <i>general</i> level, most of the tasks outlined in the PIARC framework are followed. However, NPRA decided that climate aspects should be included in the National Transport Plan and the NPRA's Action Programme (Section 3), and not in a dedicated adaptation strategy. There is more work to do on including climate issues in the NPRA's quality system, in the description of all relevant procedures.</p> <p>On the asset /road level, improvements are necessary to include economic analyses in decisions concerning the choice of adaptation measures. There are concrete plans of doing this, by adapting existing tools for cost–benefit analyses to account for the impact of climate change.</p>
<p><b>Stage 4 – Integrating findings into decision-making processes</b></p> <p><b>Incorporating recommendations into decision-making processes, education, awareness training, and effective communication, developing a business case and future planning and monitoring.</b></p>
<p>The recommendations of education, awareness, training and effective communication are also present in the NPRA framework. Assessment findings are gradually being incorporated into all decision-making processes. Including climate issues in the NPRA's quality system is ongoing work.</p> <p>However, developing a business case for adaptation is the most important task to address. It is of crucial importance to document the costs and benefits of climate adaptation measures. A lack of this type of documentation will lead to insufficient investments and the postponement of action.</p>

## **9. CONCLUSIONS**

Climate adaptation requires the addition of awareness, data, and knowledge on climate change to all our tasks, systems and routines. The adaptation measures for the Norwegian public road network make use of existing systems and processes, such as the National Road Database (NRDB), manuals of design and practice and existing risk assessment surveys of the road network.

Adaptation to a changing climate is significantly helped by good collaboration between research environments in Norway, free access to hydrological and meteorological data, publicly available regional projections of climate change, and clear political recommendations for adaptation.

Adaptation measures for roads include:

- introducing climate issues as early as possible - in the planning phase of a project
- revised rules for design and maintenance, revised procedures for protection measures – a continuous process of including new knowledge for maintaining resilience
- improving preparedness – especially risk management tools and improved preparedness plans
- improving the knowledge base for adaptation for better management of uncertainty – through research, improved monitoring, better maps etc.

The PIARC International Climate Change Adaptation Framework is a useful reference even for road administrations that have been working on adaptation to climate change. A comparison of Norway's gradually evolved framework and the stages of the PIARC framework show that the task most important to address now is developing a business case for adaptation. It is of crucial importance to document costs and benefits of climate adaptation measures. A lack of this type of documentation will lead to insufficient investments and the postponement of action.

On the other hand, some elements of the NPRA's adaptation work are proposed as amendments to the PIARC framework. This is especially valid for the early establishment of cross-disciplinary collaboration, and starting the work by carrying out an introductory general assessment of risks.

## **10. ACKNOWLEDGMENTS**

The authors wish to acknowledge the colleagues who participate in the work on adaptation to climate change, in their various fields of expertise: Roald Aabøe, Heidi Bjordal, Martine Frekhaug, Tore Humstad, Jan Husdal, and Joakim Sellevold.

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