Winter Maintenance Practice in the Northern Periphery

ROADEX

ROADEX SUB PROJECT B PHASE I
STATE-OF-THE-ART STUDY REPORT

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WINTER MAINTENANCE PRACTICE IN THE NORTHERN PERIPHERY

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PREFACE

The main goal of the Roadex project is to exchange information on experiences and practices on the maintenance of low traffic volume road network in the sparsely populated northern regions of Europe. The fields of the sub project B “Winter Maintenance” concentrated on winter maintenance of remote roads in harsh winter climates, and the need for information to the maintenance crew and the traffic users.

The Roadex Steering Committee nominated Professor Harald Norem at the Norwegian University of Science (NTNU) Trondheim, Norway to be the sub project B (SPB) work group chairman. The other nominated work group members, representing each partner district were:

Jukka Jääsko, Finnra, Lapland region, Finland

Lars Bergdahl, PRA, Northern region, Sweden

Arve Hegseth, PRA, Troms, Norway

Daniel Arnason, PRA, Iceland

Neil Gillies, PRA, The Highlands, Scotland

Ian Dyce, PRA, The Highlands, Scotland

This report, which completes phase 1 of the project, is based on answers of questionnaires, interviews of supervisors, and field trips in each partner district and literature review. Written reports, maps, drawings and photos give the presented information. The present report is thus a concentrate of the information assembled.

The theme of the questionnaires and the answers were discussed at project meetings. In total there have been five meetings for the phase 1 of the project. The meetings have concentrated on exchange of ideas, understanding of the differences in local conditions that may explain different practices of the winter maintenance and finally to define best practices.

The conclusions of the work of the group are presented at international conferences, in Lahti January 2000 and at the 4th International Conference of Snow Engineering, Trondheim June 2000. The project will also be presented at PIARC Winter Road Congress in Sapporo, January 2002.

The sub-project B on winter maintenance partly finances the doctor degree studies by Skuli Thordarson, on numerical analysis for the design of roads exposed to drifting snow.

This report is written by Harald Norem and Skuli Thordarson, and the report is mainly based on the answers of the questionnaires and the discussions during the project meetings. Even K. Sund, SINTEF, and Ron Munroe and Richard Evans from the Highland Council have made proofread to amend the language.

Special thanks are expressed to all people involved in the project and for valuable comments during the process of making the report. Roadex Project Steering Committee and its chairman Tapani Pöyry have provided encouragement and valuable guidance for the work.

Trondheim, 16. July 2001

Harald Norem, chairman

WINTER MAINTENANCE PRACTICE IN THE NORTHERN PERIPHERY

1. INTRODUCTION

1.1 Roadex Project

The road districts of Lapland in Finland, Norr Region in Sweden, Troms County in Norway, and The Highland Council in Scotland have initiated a technical, international collaboration. The aim of this collaboration is, through the exchange of experience, to identify best practice strategies and to develop procedures in order to deal with common challenges associated with the maintenance of low traffic volume road networks in the sparsely populated northern regions.

The Roadex project is partly financed by the EU (ERDF, Article 10) funded Northern Periphery Programme, which is a co-operation between the northernmost regions of Finland, Scotland, Norway and Sweden (Figure 1.1.1).

The project was started in 1998 as a pilot project between the four road administration bodies. The work has been divided into two sub-projects: Sub-project A which deals with road condition management issues while sub-project B studies winter maintenance problems common to the co-operating partner road districts. Both sub projects aim at technical exchange through studies, discussions and trials, and at identifying the most effective strategies within the studied issues, which could be applied in other Northern Periphery road districts. During the project period Iceland decided to participate in this sub-project.

The present report presents the results of the sub-project B on winter maintenance of roads.

The Roadex project will be completed by the end of 2001, but it is hoped that the technical partnerships between the partner road districts will continue via the professional networks established during this pilot project.

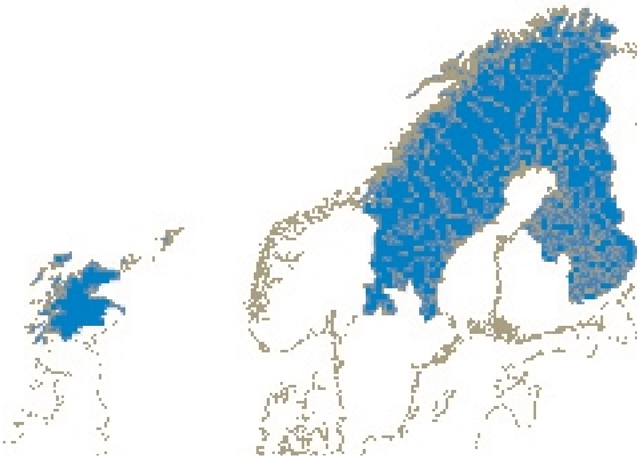


Figure 1.1.1. The Northern Periphery area.

1.2 Effects of harsh winter climates on mobility and accessibility

The Northern Periphery of Europe is characterised by harsh winter climates resulting in difficult driving conditions during the winter season. The difficult driving conditions may be a result of slippery roads, snow on the road, poor visibility during snowstorms and in some cases even closed roads during periods with extremely bad weather.

The difficult driving conditions in the winter affects both traffic safety and traffic speed and in periods of unexpected snow on the carriageway the risk of accidents is especially high. High risks are also found in the autumn and in the spring in areas with stable cold winters. During midwinter the general risk of accidents is twice the respective rate on bare roads. The highest risk, however, is found anytime when there is snow or ice on carriageways in areas with less stable winter conditions (Nilsson 1976).

Traffic speed should be considerably reduced on days with slippery roads or roads with a loose snow covering. A major task for winter maintenance is to secure the removal of snow and ice from the road and introduce an effective friction control. In some areas this removal of snow and friction control represents up to 40% of the total maintenance costs.

The worst driving conditions are found in areas with strong winds where there are no trees to provide shelter. In such areas the roads may be closed due to bad visibility or snowdrifts across on the roads. Road closures may also result when there are heavy and unexpected snow falls. Other kinds of extreme driving conditions are snow avalanches across the roads and high winds capable of blowing cars off the roads

The Northern Periphery is characterised by sparse population, remote settlements difficult terrain and climate. A major income source for the area is the exploitation of natural resources like timber, agricultural products, fisheries, and mining, and in recent years oil and gas. The traffic generated by these industries is usually long distance traffic, with a high percentage of heavy trucks transporting products to domestic hubs and to more central parts of Europe. Products such as fish and agricultural products have a limited shelf life and are sensitive to any delays on route to their markets. The need for reliable roads therefore is very high in the Northern Periphery area. These arteries also play an essential role in providing an improved quality of life and strong economy. They also greatly contribute to a more sustainable environment and cohesive society.

1.3 Goals and working methods

The climatic and topographical conditions in the participating districts differ substantially across the Northern Periphery area. These differences cause a wide variation in the challenges presented to the winter maintenance of roads. The districts also share many common problems and challenges of which the most common are:

- Harsh winter climate with difficult driving conditions, e.g. drifting snow, poor accessibility and low friction
- Remote roads with low traffic volumes, where the main part of the traffic is long distance traffic.
- Remote areas facing the danger of reduced economic activity.
- Substantial local experience with a variety of engineering solutions, some of which are not known outside the local area.

The main goals of sub-project B are:

- The identification of the state-of-the-art maintenance techniques, traffic information systems, snow drift and friction control measures.
- The identification of best practice procedures for the various topographical and climatic conditions in order to improve accessibility and safety during difficult driving conditions

In its early stages the Working Group defined the main themes of the sub-project and decided to start by gathering information on the local experiences using questionnaires. These questionnaires were answered in co-operation with local winter maintenance supervisors and engineers and replies included written text, drawings, photos and sometimes videos to show the use of different types of maintenance equipment.

The workload in the sub-project has concentrated on the special problems posed by the Northern Periphery in the management and maintenance of roads in remote areas exposed to harsh winter climates. As a result the project has mainly focused on:

Road Design
- Cross-section profiles
- Use of guard-rails
- Use of snow fences
- Interaction between road design and winter maintenance techniques

Winter Maintenance
- Comparisons of winter maintenance equipment
- Snow removal techniques
- Costs of winter maintenance

Operational Procedures
- Co-operation with the meteorological services
- Safety during severe driving conditions
- Authority to close the road during extreme weather situations
- Service standards for friction and snow removal

Information Systems
- Driving conditions
- Weather information

2. GEOGRAPHICAL AND CLIMATIC CONDITIONS

2.1 Characteristics of the climate in the Northern Periphery

The northern part of Europe belongs to the temperate climatic zone which approximately covers the area between 35° and 65° northern latitude below the polar zone.

The studied area for the present project lies almost totally within the temperate zone but some localised areas, in the mountains of Norway and Northern Finland, have a climate very close to the characteristics of the polar climate zone.

The temperate zone within Europe is usually subdivided into four different climatic areas as shown on Figure A1:

- Northwest Europe, having mainly cool summers and mild winters
- Central Europe, characterised by warm summers and relatively cold winters
- Eastern Europe, with warm summers and cold winters
- The Mediterranean area, with hot and dry summers and mild winters

Figure A1shows that Scotland, Iceland and coastal areas of Norway belong to the northwest European area whereas the northern region of Sweden and most of Lapland, Finland belong to the Central European climate zone.

The climate in the northern part of the temperate zone is strongly influenced by the polar front, which is formed where the tropical and polar air masses meet. These fronts are usually generated west of Iceland and move in an easterly direction towards Europe. The main wind direction at higher altitudes is thus westerly. The meeting of these air masses, which have substantial temperature differences, often generates high wind speeds, particularly in the winter when rapid changes in temperatures and wind speeds often occur.

The climate in the Northern Periphery is also strongly affected by the high-pressure systems in Siberia and the Azores causing periods with dry and stable air masses. When high pressures dominate in the winter there may be long periods with very low temperatures. The influence of the high-pressure zones is most distinct in the eastern parts of the studied area but they may sometimes cover the whole northern part of Scandinavia.

The transition between the north-western European zone and the Central European zone is found where the dominating effect of the westerly winds is reduced and the influence of the high pressures is progressively increased. Within the studied area this transition is close to the border between Norway and Finland.

The Northern Periphery of Europe thus shows a dramatic diversity of climate conditions being close to the transition zone between the temperate and polar climatic zones and covering both the north-western and central European climate zones. The types of climates found in the area vary from the arid continental climate in the central part of Scandinavia to the pure maritime climate in the coastal areas of the northern Atlantic region. The transition from one climate zone to another may be quite distinct and often follows the watershed.

The continental climate regions are characterised by cold winters, limited snowfalls and few days with wind speeds above gale (12 m/s). There are therefore few days with extremely difficult driving conditions in these regions.

In extreme opposite to the continental climate is the mild maritime climate found in Scotland, the islands off northern Norway and close to the shore in Iceland. These areas are characterised by high precipitation rates and strong winds. The average mid-winter temperature is generally close to 0° C with the precipitation either falling as snow or rain. Another characteristic of the mild maritime climate is the high frequency of days with temperatures below and above 0° C in nights and days respectively.

The transition between these two climate systems is what we may call the “cold maritime” climate zone, which is mainly found in most of Iceland and along the coast and sea facing mountains of mainland northern Norway. These climatic areas are extremely windy compared to other areas within Europe and the main part of winter precipitation is snow. These features present the very worst conditions for keeping roads open for free traffic in the wintertime.

2.2 Climate maps for the Nordic countries

2.2.1 General

Information regarding the climate of a region is generally issued by the national meteorological services in the form of tables and maps and in addition to this valuable information on national climates is also issued on the Internet.

The way of presenting weather data may differ from country to country. It is therefore difficult to present easy comparisons of climatic differences between districts in the Northern Periphery in this report.

In recent years there has been a Nordic co-operation to present common maps for all five Nordic countries. The maps are derived by applying an objective interpolation technique, combined with the utilisation of a geographical information system (GIS). The project has so far presented common maps for temperatures and precipitation. Unfortunately the climatic conditions for Iceland are only partly presented and at present these maps do not cover Scotland.

The following discussion on climatic conditions is based on the Nordic co-operation
on climate maps, national atlases on climates and information presented on Internet
by the respective national meteorological services.

2.2.2 Precipitation

The annual precipitation within the Nordic countries is presented in Figure A2. The highest precipitation rates are mainly found along the western coast of Norway up to Troms County and on the southern coast of Iceland. The highest recorded annual precipitation in Troms is above 1500mm whilst Iceland can record as much as 3000mm in the south-western mountains.

A similar map showing the average annual precipitation in Scotland is shown on Figure A3. As in the Nordic countries most precipitation is found in the mountains facing to west, with a maximum of 3200mm.

The most arid areas in the Northern Periphery are found in central part of northern Finland and Sweden with an annual precipitation close to 350mm. The same low precipitation is also found in the north-eastern region of Iceland. The most arid areas of Scotland are also found in the north-east at approximately 600mm a year.

Of special interest to the Roadex Sub-project B is the average precipitation over the winter season, which is shown on Figure A4. This varies from 400mm to less than 50mm from the coast of Northern Norway to the border between Finland and Sweden. This variation is shown graphically in Figure A5, which details a transect along the 69 degree north latitude showing the altitude, winter precipitation and average January temperature. The figure clearly shows that the highest precipitation is found close to the coastal mountains. On the lee side of the watershed between Norway and Sweden/Finland there is a dramatic drop in the precipitation rates. A similar diagram may also be made for Iceland and Scotland by making a profile from south-west to north-east.

The difference in precipitation rates between the maritime coastal zones and the continental climates is shown in the maps in Figure A6. These maps show the seasonal precipitation as a proportion of the annual precipitation for the four different seasons. An average 25% of the annual precipitation is recorded along the coast of northern Norway during the winter season. This percentage is reduced to 10-15% in the arid areas of northern Finland/Sweden. The continental climate is therefore not only characterised by low temperatures during the winter season, but also by extremely small winter precipitation rates.

Yet another parameter which is important in analysing the magnitude and cost of winter maintenance of roads is the number of days with snowfall. Figure A7 presents a map made for the National Atlas of Norway and shows the distribution of days with snowfall exceeding 3mm a day. Fortunately this map covers both maritime and continental climates and shows that the highest numbers of days with snowfall is found in the coastal mountains with more than 70 days. The respective number in the dry continental areas is less than 10 days in a winter.

The corresponding map for Scotland is shown on Figure A8. This map indicates that there is an average of approximately 20-30 days with snowfalls along the coast, and more than 100 days in the mountains. The number of days with snow lying on the ground is, however, lower in Scotland than in northern Norway. 15-20 days with snow are recorded along the coast of Scotland compared to 150-200 days along the coast of Norway. The equivalent number for the continental areas is approximately 200 days. Unfortunately the comparable numbers for Iceland, Sweden and Finland are not available.

2.2.3 Temperatures

The distribution of the mean temperature in January for the Nordic countries is presented in Figure A9. This map clearly shows the characteristics of the climatic types in the areas studied. Along the south-western coast of Iceland and some islands in northern Norway the mean January temperatures are close to 0° C. On the other hand, the areas with the lowest January temperatures are found in central parts of northern Sweden and Lapland, where the mean temperature may be down to –20° C. These two extremes are typical examples of what has been called mild maritime and continental climates.

The variation of the average temperatures in January from the coast of Norway to the Russian border is also presented graphically in Figure A5. This shows that there is a distinct fall in the temperatures both on the lee sides of the coastal mountains and of the mountain ridge to Sweden/Lapland. The increase in the temperatures toward the Finnish/Russian border is probably due to the influence of the Baltic Sea.

The mean temperature in January in Scotland is above 0oC in those areas where there are public roads. Along the coast the mean temperature is 2-4° C, and close to 0° along some of the mountain passes. This shows that Scotland has the highest winter temperatures in the areas studied.

2.2.4 Wind

The wind speeds and the wind directions close to the surface are highly influenced by the local topographic features, like mountains, valleys, forests etc. Therefore, it is not possible to make an overview map with isolines, either for wind directions or wind speeds.

As an example of the variations from coastal to continental climates, the wind map for January presented in the National Atlas of Norway is attached in Figure A10. This shows that at the lighthouse stations in northern Norway the prevailing wind direction is from south to west. This is also the wind that brings most of the precipitation during the winter season. Wind speeds along the coast are usually high with 15% to 30% of winds being gales or above (i.e. ≥10,8 m/s). The wind conditions of the coastal mountains are often similar to what is found at the lighthouse stations, as in both of these areas the winds are less affected by the topography than those at the meteorological stations found in valleys.

The wind conditions in winter in the outer ends of valleys and along the fjords are mainly influenced by the drainage of cold air from the mountains. The most frequent winds in these areas blow out of the valleys and generally have an easterly direction. These winds can sometimes be strong but generally they are less than those in the coastal areas.

Along the border between Sweden and Norway, close to the watershed, the climate is more similar to continental climates. By looking at the recordings from Sihccajavri one can see that the dominant wind direction is south, and that the frequency of gales is very low. The continental climates can therefore be characterised by low wind speeds during winter.

Figure A11 presents two wind roses from Sweden, one from Katterjåkk close to the Norwegian border and one from Luleå, at the coast to the Baltic Sea. The wind conditions in January at Katterjåkk are dominated by westerly winds, because both the gradient and topographic winds usually are westerly in this area. Approximately 5% of winds are gale or stronger (i.e. 11,5 m/s).

The equivalent wind rose from Luleå is less dominated by a single wind direction as there are two prevailing wind directions, SSE-SW and WNW-NNE. The frequency of gales is only 1-2%.

A wind map for Finland is found in Figure A12.

2.3 Winter maintenance due to climatic and topographic features

The winter maintenance of roads is strongly influenced by climatic conditions and topography. In addition to these natural considerations road managers also need to take into account the general preparedness of traffic users to deal with difficult weather driving conditions when drawing up their winter plans. Investigations made for the present project show substantial differences across the districts on how drivers are prepared and equipped to meet winter conditions as well as their different expectations for the standards of winter maintenance.

Frequent night frosts and subsequent slippery roads in the morning characterise the mild maritime climates. The number of days with snow lying on roads is limited. As a result of this drivers are usually poorly equipped with winter tyres and are inexperienced in driving on slippery roads. Similarly in these areas roads authorities need not be geared up to meet the heavy snowfalls found in cold maritime climates.

The need for friction control is thus higher in mild maritime climates than in areas where drivers are well equipped and have experience of driving on snowy and icy roads.

Coastal areas, especially the mild maritime climatic areas, may experience days with extremely heavy snowfalls, half a meter in a day and more. In such days, with heavy snowfalls and inexperienced drivers, local road networks may be closed with no access in any direction. It is possible that the number of road closures can be higher in such areas than in the colder areas of the Northern Periphery which have longer winters.

The continental climate areas represent the extreme opposite to the mild, maritime climates from the point of view of management of winter maintenance. Drivers are more prepared for the long winter conditions and the climate is usually cold and stable. During midwinter there are few variations of temperatures around 0° C, and there are few dramatic variations in the weather conditions from one day to another.

This preparedness of drivers is reflected in the frequency of traffic accidents. The risk of accidents on snowy/icy roads in northern Sweden is 2-3 times higher than that of driving on bare roads in winter, and the equivalent numbers for central and southern Sweden are 4-7 and 9-11 respectively (Nilsson 1976).

The main demand for winter maintenance in the continental areas is to keep the roads free of loose snow and to ensure that friction is within required standards. In these areas snow and ice may be acceptable on the roads. On windy days, however, snow may be eroded and transported by the wind. This drifting snow can reduce visibility for road users and may cause difficulties in keeping roads passable.

On major roads with high traffic speeds vortices at the rear of heavy vehicles often generate clouds of snow particles. Such kind of "snow smoke" causes very difficult driving conditions for following and passing traffic which has resulted in serious accidents during vehicle passes.

The most difficult driving conditions are to be found in the cold maritime climates. These areas are characterised by long winters, frequent snowfalls and strong winds. The frequency of snow ploughing is therefore much higher in these areas and the heavy snowfalls make it necessary to use graders more often to remove hard packed snow and ice. The removal of snow from junctions, ditches and signposts to improve the sight distances is an operation not generally necessary in other districts.

Mountainous road sections in cold maritime climates can be very difficult to keep passable during snowstorms due to bad visibility and heavy snowdrifts. Convoy driving is introduced in some areas to get traffic through critical sections safely.

A special winter problem found in steep mountainous areas is snow avalanches which can cross and block roads. These avalanches are only found in Norway, Iceland and part of Sweden within the studied area, and are not included in the present report.

An increasing amount of inexperienced drivers are moving around the Northern Periphery as a result of modern mobility. These drivers seldom have experience of handling snow conditions and driving on slippery roads. Their cars are often badly equipped without winter tyres and they seldom carry chains. In all districts such inexperienced drivers have caused serious accidents and frequent road closures. In future the standards and the demands for winter maintenance of roads may have to be redefined to meet the accident risks caused by these inexperienced road users coming from the outside areas.

2.4 Characteristics of the different districts

The following is a summary of the main topographical and climatic features, and the resulting winter maintenance problems for the participating districts. Summaries are presented separately for each district and hopefully this will give a background to better understand the experiences and practices presented later in this report. A topographical map of the Northern Periphery is presented in Figure A13.

Lapland, Finland

Topography

- The coastal areas in the south of Lapland are flat (<100m a.s.l.).
- South Lapland has a hilly landscape covered with forests, lakes and wetlands.
- Mid-Lapland has a mountainous terrain with variable coverage of forests. The mountains are not forested.
- North Lapland has a mountainous terrain with little forest and one large lake (Inari).

Winter climate

- The coastal areas have slightly higher average winter temperatures than the rest of Lapland due to the influence of the sea.
- The rest of southern Lapland has a continental climate and the highest rate of precipitation.
- Mid-Lapland has a cold and windy continental climate. The average winter temperature is in the range of -14 to -16 °C.
- In the northern part of Lapland the presence of the Arctic Ocean and Lake Inari makes the climate a little milder. The precipitation rate is the lowest in Lapland.

Winter maintenance problems

- Slippery roads due to snow, ice and frozen drizzle.
- Rapid changes in temperature which can cause problems with slippery roads and the removal of wet snow. Dry, loose snow can also cause visibility problems when driving behind heavy vehicles. Drifting snow can be a problem close to open areas like fields, lakes and wetlands.
- Heavy snowfalls combined with strong winds can cause problems with drifting snow in the mountains.
- Icing in roadside drainage system

Northern Region, Sweden

Topography

- Hilly and relatively flat landscape
- Mountainous terrain close to the Norwegian border
- Areas above 400m-600m a.s.l. have no forest vegetation
- Most remote areas covered with forests, but a substantial part is covered by lakes and wetlands

Winter climate

- Low winter temperatures. Temperatures above 0°C are seldom in mid-winter.
- Low precipitation rates in the winter. Most of the precipitation falls as dry snow
- Wind speeds are generally low. Gales or stronger winds are rare.
- Highest wind speeds and precipitation rates are found close to the Norwegian border.
- The climate along the border to Norway is a transition between the cold maritime and the continental type
- Heavy snowfalls can occur at the coast in pre-winter before the Botnian Gulf freezes.

Winter maintenance problems

- Uneven road surfaces, often due to uneven pavement and damage caused by frost heave.
- Removal of ice and snow from the roads.
- Slippery roads due to snow and ice. Occasionally severe problems due to freezing rain.
- Dry, loose snow on the roads can cause visibility problems when driving behind heavy vehicles.
- Drifting snow is only a problem close to open areas like lakes, wetlands and in the mountains.
- Major problem with drifting snow at the mountain passes into Norway.
- Icing in roadside drainage systems can in some years cause severe problems.

Troms County, Norway

Topography

- Troms County can be divided into three groups: the islands, the fjord districts and the mountains near the borders with Lapland and the Norr Region.
- The islands have mostly open birch forests with the tree line found at 200-300m a.s.l. The major islands are mountainous with steep sides
- The fjord districts are characterised by distinct open valleys covered with coniferous trees. Usually there are areas with relatively flat landscape between the fjords or the rivers and the steeper mountainsides.
- The mountain areas are all above the tree line, and may consist of both rounded landscapes and alpine-like topography.

Winter climate

- All three climatic types are represented in the district.
- Areas near sea level on the islands and outer parts of the fjords have a mild maritime climate, characterised by January temperatures varying around 0° C with high precipitation rates and strong winds. Precipitation falls either as snow or rain.
- The fjords, valleys and coastal mountains usually have a stable snow cover during the winter, but temperatures above 0° C may occur even during the midwinter period. Wind speeds are moderate in the fjords and in the valleys.
- The mountains close to the Finnish border are in the transition zone to the continental climate.

Winter maintenance problems

- Removal of snow and ice from the roads.
- Removal of snow from the ditches to create storage capacity for the next snowfall.
- Dry, loose snow on the roads can cause visibility problems when driving behind heavy vehicles.
- Strong winds along the cost and in the mountains cause severe drifting snow problems
- Temperatures varying around 0° C make the roads very slippery
- Icing in the roadside drainage systems in cold areas.
- Snow avalanches and falling ice blocks in steep terrain

Iceland

Topography

- Almost all roads kept open during winter are found relatively close to the coast
- The landscape is generally mountainous and there are only few areas where trees shelter the roads
- Steep mountainous terrain is found along the fjords in the north-western and eastern parts.

Winter climate

- All three climatic types are represented in the district.
- A mild maritime climate is found close to sea level in the south. This climate is characterised by January temperatures varying around 0° C, high precipitation rates, and strong winds. The precipitation falls either as snow or rain.
- A cold maritime climate is found along the coastal areas facing east and west. There is usually a stable snow cover during the winter, but temperatures above 0° C can occur even in the midwinter period. The frequency of strong winds is high.
- The continental climate is found in the fjord districts and the mountains in the north. Temperatures are usually around 0° C in January, and the precipitation rates are

low. The wind speeds are much higher than found in other areas with continental climate

Winter maintenance problems

- Strong winds along the cost and in the mountains can cause severe drifting snow problems.
- Removal of snow and ice from the roads.
- Removal of snow from roadside ditches to create storing capacity for the next snow fall
- Temperatures varying around 0° C make the roads very slippery
- Snow avalanches cause problems along the fjords in the western, eastern and northern parts

The Highlands, Scotland

Topography

- The Highland area may be divided in three groups: the coastal areas, the valley districts and the mountains.
- The offshore islands have mostly rounded terrain features with only sparse forest vegetation.
- The coastal areas on the mainland at lower altitudes are dominated by open landscapes partly covered by forests and partly by farmland and areas for grazing.
- The mountain areas are found in the central part of the mainland, and are usually intersected by distinct valleys, where the roads are located.

Winter climate

- The whole district is within the mild maritime climate zone
- Compared to the similar climate zones in Norway and Iceland the winter temperatures in the Highlands are higher. Stable snow cover is seldom found below 500m a.s.l. At lower altitudes most of the winter precipitation falls as rain, but heavy snowfalls can sometimes occur down to sea level.
- Strong winds are more frequent along the western coast and in the mountains.

Winter maintenance problems

- Heavy snowfalls can make it difficult to keep roads open even in calm periods.
- Snowfalls cause more trouble in the Highlands than in the Nordic districts as road users are less prepared for snow.
- Strong winds in the mountains can cause severe drifting snow problems when combined with falling snow.
- Temperatures varying around 0° C make the roads very slippery.
- Removal of snow and ice from roads.

3. COST OF WINTER MAINTENANCE

3.1 Data for the different districts

The returns to the questionnaires on lengths of roads, roads subject to temporary road closures and the cost of the winter maintenance are compiled in Table 3.1.

The replies for the length of roads subject to road closures have had to be defined differently from district to district. In Troms and Norr Region the figures given indicate the total length of road sections where road closures may occur due to poor visibility and/or where convoy driving may be organised. In Iceland, where there is no regular convoy driving, the figures given indicate the length of roads that may be non-passable during storm periods. The figures from Highland reflect those road sections that may be closed due to deep snow on the carriageway.

Road-users in Scotland are usually not prepared for driving on snow-covered roads. The climatic conditions in Highland that cause problems to driving are therefore less severe than in the Nordic districts.

The cost of the winter maintenance and the cost of the total winter maintenance within the different districts have been investigated and are presented in Table 3.1. The figures presented comprise an average of the years 1997-99:

The cost of the winter maintenance includes:

- Snow ploughing
- Use of snow blowers and graders
- Removing snow from crossings to improve the visibility
- Cleaning of traffic signs
- Temporary poles where necessary
- Friction control
- Removal of ice and melting ice from drainage systems
- Levelling of roads due to frost action
- Maintenance of snow fences

For the total road maintenance costs all maintenance costs are included except:

- Ferry costs
- Repavement
- Reconstruction
- Any other kind of investments

Table 3.1. Road maintenance cost in the NP area.

		Districts				
		Lapland	**Norr Sweden**	**Troms**	**Iceland**	**Highland**
Total road network in NP	km	9 052	18 008	3 523	8 207	7 790
Roads subject to temporary closures	km		90	245	4 300	335
Total road maintenance cost	Million EUR	16.1	42.1	26.6	46.6	52.2
Total road maintenance cost / km	**EUR / km**	**1 779**	**2 336**	**7 553**	**5 676**	**6 697**
Winter maintenance cost	Million EUR	9.4	25.3	14.4	9.7	15.7
Winter / total costs		59%	45%	54%	21%	30%
Winter maintenance cost / km	EUR / km	1 041	1 406	4 104	1 177	2 009

The cost figures presented in Table 3.1 and graphically in Figure 3.1.1 and Figure 3.1.2 indicate large variances in the cost of winter maintenance from district to district. This variance is obvious when looking at the total costs, the costs per km treated road section and when looking at the percentage of the cost of the winter maintenance relative to the total maintenance costs. These differences are likely to be the result of:

- Climatic conditions
- Topography
- Traffic volume and density of population
- Design and standard of the road network (note this includes expensive road elements like tunnels and bridges which can have high maintenance costs)
- Service standards for winter maintenance, mainly due to accepted levels of snow on the road and levels of friction
- Operation and safety procedures
- Winter maintenance organisations

The least expensive winter maintenance per km road is found in Lapland, Finland, with Iceland and the Norr Region of Sweden as number two and three. Highland records expenditures approximately twice as high as Lapland (although this is under review for winter 2001-2002) and Troms County, Norway has winter maintenance costs four times higher than Lapland.

The relatively low costs for Lapland and Norr may be surprising, since these districts have the longest winters. However they also have a continental climate with few days with falling snow and few days with temperatures varying around 0°C. The standard of the roads is in addition generally high in both areas. Another factor that might influence their low costs is that the drivers in these districts are generally well prepared for driving on winter conditions, and as a consequence require lower service standards on secondary roads.

The winter maintenance costs per km in Iceland is comparable to Lapland and north Sweden. This might be surprising when knowing the very harsh climate found along all roads of Iceland. The reason for the low cost is primarily due to the lower service standard on the secondary roads, where some roads may be closed, and some are only cleared of snow a certain number of days per month. The presented cost per kilometer is the total winter cost divided by the length of the public road. In the case of Iceland this probably is unrepresentative and it might have been better to use the actual road lengths treated in winter rather than the road network length.

The Highland area records the second highest cost for winter maintenance. This result may also be surprising since Highland has ‘less winter’ than the other investigated districts. These high costs may be explained by the following factors:

- The majority of the Scottish road users do not change their tyres in winter. Highland drivers are generally inexperienced in driving on snow and icy surfaces. This results in a high demand for friction on all carriageways and the complete removal of snow even on secondary roads.
- Highland has a high frequency of days and nights with temperatures varying around 0°C.
- The number of days with falling snow is actually higher in Highland than in Lapland/north Sweden, 30-100 versus 10-20.
- The high service level is a consequence of the demands of the local economy. Fish products transported via the road network to Central Europe represent the major commercial product. The low durability of these products requires a high regularity of carriageway surface even on secondary roads.

Highland is currently (ie summer 2001) carried out a review of its winter maintenace operations for winter 2001-2002 with a view to cutting costs by 30%.

Troms County has by far the highest cost of winter maintenance compared to any other districts. This may not be surprising when considering the climate and the topography, but the great differences need to be investigated. The main reasons for the high figures shown may be explained by the following factors:

- The number of days with falling snow is the highest of the investigated areas.
- The amount of snow on the ground is high, 1-2m in most areas. This requires an intensive removal of snow to improve the visibility in junctions, the removal of snow around traffic signs, and the clearing of snow from the ditches to create storing capacity for new snow.
- The frequency of days with temperatures varying around 0°C is relatively high.
- The service level is probably high, especially during difficult driving conditions with drifting snow and reduced visibility. In such situations convoy driving is offered regularly.
- The high service level is a consequence of the local economy. Fish products transported on road to Central Europe represent a major commercial product. The low durability of these products requires a high regularity even on the secondary roads.

The relative cost of winter maintenance compared to the total cost of road maintenance is an interesting factor to understand the different experiences and practices developed among the partner districts. The highest ratios are found for Lapland and Troms with a ratio of 59% and 54% respectively. Also north Sweden records a high ratio of 45%. The northern Scandinavian districts with cold maritime or continental climate thus use approximately half of the total maintenance budget to remove snow and provide friction control.

The ratios for Iceland and Highland are 21% and 30% respectively. The low ratio for Iceland is probably a result of lower service standards on the secondary roads, and for Highland the figure probably reflects the short winters encountered there.

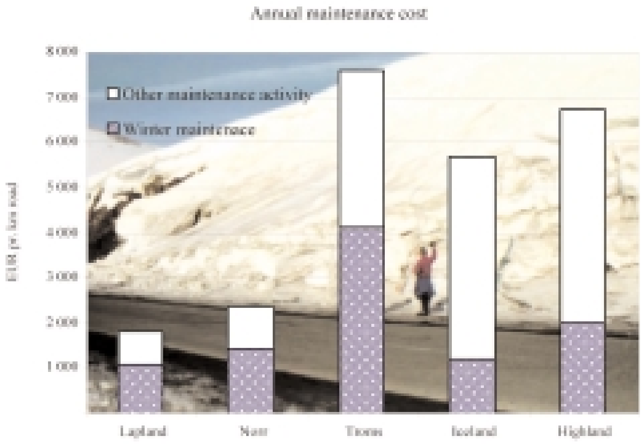


Figure 3.1.1. Average annual maintenance and winter maintenance costs per km road network for the partner districts 1997-1999.

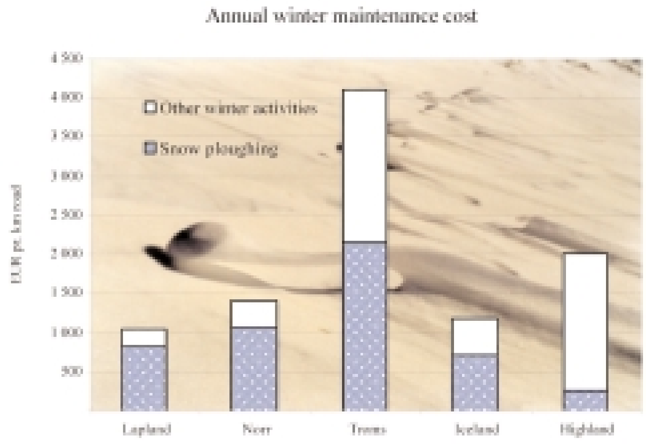


Figure 3.1.2. Average annual winter maintenance and snow ploughing costs divided by road network length for each partner district 1997-1999

3.2 Cost of snow removal

The differences in climate and topography across the Northern Periphery results in great differences in the cost for snow ploughing (Table 3.2 and Figure 3.1.2). The most expensive district, Troms, pays nine times more than the least expensive district, Highland, 2135 EUR/km versus 241 EUR/km. Between these two extremes is Iceland, Lapland and north Sweden, who pay from 704 to 1059 EUR/km respectively.

Table 3.2. Snow ploughing costs across the partner districts

		Districts				
		Lapland	**Norr**	**Troms**	**Iceland**	**Highland**
Total road network in NP	km	9 052	18 008	3 523	8 207	7 790
Ploughing	km	1 674 620	2 845 264	1 882 797		
Ploughing frequency	km/km	185	158	534		
Cost per ploughing km	EUR/km	4.4	6.7	4.0		
Snow ploughing cost	**Million EUR**	**7.3**	**19.1**	**7.5**	**5.8**	**1.9**
Snow ploughing cost / total km	EUR / km	806	1 059	2 135	704	241
Snow ploughing cost / winter cost		77%	80%	52%	60%	12%

These differences are mainly a result of the length of the winter, total amount of snow, numbers of days with snowfall and effects of wind. To have a better understanding of the cost of the snow ploughing the parameter “Ploughing frequency” has been introduced. The parameter is defined as the number of passes on a road section of a snowplough per winter, and has the unit km/km. One ploughing back and fourth thus represents a ploughing frequency of 2. The numbers for the three northern Scandinavian districts is 534, 185 and 158 for Troms, Lapland and north Sweden respectively. The ploughing frequency for Troms is therefore approximately three times higher than for the neighbouring districts.

Even with the very high ploughing frequency for Troms, their cost of snow ploughing represents only 52% of the total winter maintenance, compared to 80 and 77% for north Sweden and Lapland. The cost of other winter activities like snow removal from junctions and ditches, organising convoy driving and friction control is clearly more expensive in the cold maritime climates with high snow depths and windy conditions.

In Highland the cost of snow ploughing is only 12% of the winter maintenance. This low figure is a result of snow seldom remaining on the road, despite Scotland having a fairly high number of days with falling snow.

3.3 Cost of friction control

All districts spread either sand or salt on the road to improve the friction on roads covered by ice or snow. The type of salt for all districts is ordinary rock-salt or sea-salt (NaCl). Salt may work effectively down to temperatures –6 to –80 C to prevent icing on the roads.

Scandinavian districts use sand to a greater extent than the other two districts, Table 3.3 and Figure 3.3.1. The magnitude of sand spread varies between 5.9 and 8.2 t/km in Northern Scandinavia and only 0.8 t/km in Iceland and 1.1 t/km in Highland.

Table 3.3. Friction control across the partner districts

		Lapland	Norr	Troms	Iceland	Highland
Total road network in NP	km	9 052	18 008	3 523	8 207	7 790
Total use of sand	t	46 000	147 995	20 800	6 800	8 500
Sand per km	t/km	5.1	8.2	5.9	0.8	1.1
Total use of salt	t	1 000	5 048	365	5 300	90 000
Road treated with salt	km	260	639	250	351	7 790
Treated road / total road		2.9%	3.5%	7.1%	4.3%	100%
Salt per km	t/km	3.8	7.9	1.5	15.1	11.6

There are also substantial differences in the use of salt within the Northern Periphery. Highland uses salt on all public roads to avoid any ice forming on the carriageways, and partially to melt snow. The use of salt is thus very high, 90000 tons a year in Highland alone, which equals 11,6 t/km treated with salt.

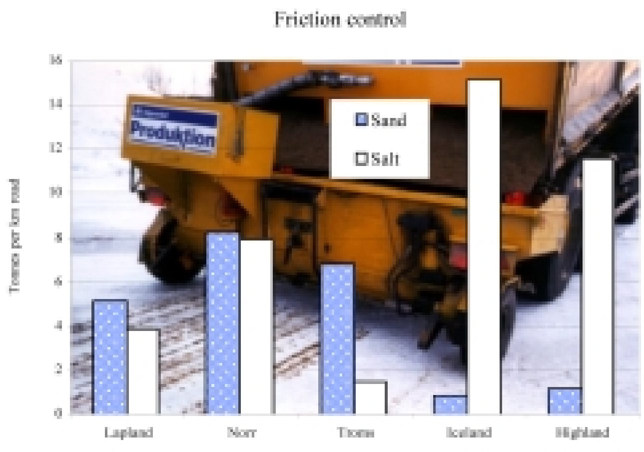
Iceland too makes extensive use of salt on the few roads treated by salt. In total only 4.3% of their roads are treated with salt, but the use of salt per kilometre is the highest among these districts, 15.1 t/km.

The northern districts of Scandinavia have less extensive use of salt. The Norr Region of Sweden treats only the major roads with salt. Only 3.5% of their roads are regularly salted each winter. The average use of salt is 7.9 t/km. This relatively low number reflects the high number of days with very low temperatures and few days with precipitation and high moisture.

In Troms County in Norway no roads are treated with salt regularly. Salt is used only on the major roads and only in the critical periods in the autumn and spring. The consumption of salt is thus very low, only 365 tons, i.e. 1.5 t/km.

In Lappland region, Finland, salt is used only on the major roads and only in the critical periods in the autumn and in the spring. Only 62 km of roads is bare most of the time or it may contain low, thin strips of packed snow between the lanes and ruts. The road may be slightly slippery during changes in the weather. Problem situations caused by expected slipperiness are reduced by using preventative anti-slipping procedures. Rest of main roads are maintained at high level, but mainly without using salt. The total consumption of salt is thus low, only 1000 tons, not including the salt mixed in the sand.

Figure 3.3.1 Average annual use of sand and salt for friction control in the respective districts 1997-1999.



4. RESEARCH AND REPORTS ON DRIFTING SNOW AND WINTER MAINTENANCE

4.1 Historical background and literature sources on drifting snow

Knowledge of how to design and operate roads and railways exposed to drifting snow has developed gradually as the need for winter access by wheel-carriages increased from the middle of the nineteenth century. To date this knowledge has usually been very practical and there are therefore few recorded contributions on the theme. Fortunately, some of these are still known, and the present section brings a brief overview of the Nordic experiences presented in publications.

The first written publication, known to the authors, on the design of roads exposed to drifting snow is the small book of G.D.B.Johnson issued in Oslo in 1852. The book has drawings on how snow collects behind road cut sections, other kind of terrain details and snow fences. Even today we still may learn from the author's precise observations.

The next major developments were as a result of the construction and operation of railways in mountainous areas in the beginning of the twentieth century. During the planning of the Oslo-Bergen railway extensive snow measurements were made and their system of snow sheds and snow fences is well documented.

Finney (1934) from Michigan made the first known scientific model experiments on the design of roads for drifting snow. He used balsa wood sawdust in a wind tunnel to model the flow of drifting snow. The pioneers in Scandinavia of model tests with snow fences were Nøkkentvedt (1940) from Denmark who studied the lee effect of such fences and Hallberg (1943) from Sweden who made extensive full-scale tests of the snow collecting capacity. In recent years, the thesis of Norem (1974) is the most extensive treatise in the location and design of roads in snow drifting areas. The conclusions of this thesis form the basis for the Norwegian national codes and Norwegian textbooks written on the subject since then (Norem 1994).

Extensive studies on drifting snow and roads have been carried out in United States for several years by Tabler. He first studied the use of snow fences for protection of roads in Wyoming, and later on he made more general studies for the design of roads exposed to drifting snow. His work is most easily found in the SHRP-report on drifting snow (Tabler 1994).

The subject of friction control has been studied both practically and theoretically for many years and various papers exist on the subject. For easy access to this literature readers are recommended to refer to papers presented at international conferences or the databases listed below.

4.2 Literature sources on winter maintenance

Literature on winter maintenance of roads is available both as textbooks, reports from national research institutes, national public road administrations and proceedings from conferences. In addition, national guidelines set standards for the maximum amount of snow and friction levels to assure acceptable driving conditions during winter events.

The best access to scientific literature is through international databases on published literature or through papers presented at relevant international conferences. Below is a list of conferences specialising in winter maintenance of roads and databases covering the same topic:

4.2.1 Conferences

Probably the most relevant source for papers dealing with winter maintenance of roads is the proceedings from the PIARC Winter Road Congresses. In total there have been ten conferences, and they are held every fourth year. The most recent are:

- 1990 Tromsø
- 1994 Seefeld
- 1998 Luleå

The Website of the World Road Association, PIARC, is http://www.piarc.lcpc.fr

The Transportation Research Board in United States, which is a sub-division of National Research Council, has for several years arranged conferences on winter maintenance of roads. The papers from these conferences are either presented as Special Reports or in a special series of conference proceedings. The Transportation Research Board issues both series as well as individual journals. The Website of TRB is: http://www.nationalacademies.org/trb

The National Research Council of US has in addition financed the SHRP program on highway research. This program has delivered reports on drifting snow, friction control and road weather information systems.

Literature on the same topic may also be found in the proceedings of the International Conferences on Snow Engineering. In total there have been four conferences and the last was held in Trondheim 2000. These proceedings cover a wider aspect of snow engineering than the PIARC conferences, and are probably more scientific. The web-address of the conference in Trondheim is:
http://www.bygg.ntnu.no/ktek/snow2000/index.htm,
and generally for the conferences:
http://www.ta.chiba-u.ac.jp/ICSE/

4.2.2 Databases

The main source today to find literature is databases. Such databases generally have thousands of references and very powerful search engines. Very good databases on Cold Regions Engineering, including winter maintenance of roads, can be found at:

- The Library of Congress:
  http://lcweb.loc.gov/rr/scitech/coldregions/access.html
- Cold Regions Science and Technology. Journal index from 1990, with abstracts,

at: http://www.elsevier.com/homepage/sad/coltec/fp.sht
In addition to these databases that have free access for all, there are several other databases where either the national public road administrations or university libraries have access. One of the latter is the database assembled by International Transportation Research Documentation, which is an OECD financed database.

5. ROAD DESIGN

5.1 Introduction

The aim of the questionnaire on road design was to identify any special procedures for the design of roads in drifting snow areas and on any interaction between the road design and the use of winter maintenance equipment. Included in the questionnaire were questions on practices and experiences with the use of guardrails in snowy areas and the use of snow fences and tree planting to prevent snowdrifts on roads.

National guidelines on road design generally only take minor account of the influence of winter conditions on the location of roads, cross section profiles, or the design of the right-of way areas. Norway had a separate chapter on the design of roads in snow drifting areas in the 1978 edition of the guidelines but this has been removed from the new editions of 1992 and 1999.

Textbooks or recommendations for the design of roads in areas with snowdrifts or heavy snow exist in most countries. Norway has a textbook on "Snow Engineering for Roads", including the protection and operation of roads exposed to snow avalanches and drifting snow (Norem 1994). Finland has a textbook on Arctic Road Design, which in addition to snowdrifts also includes consideration of construction of roads in cold climates. (Saarelainen 1993). Finland has also made a small textbook on "Reducing drifting snow" (Finnra 1982).

Textbooks on snow, roads and winter maintenance have for many years been published in Sweden. A comprehensive work on snow fences was issued by Hallberg (1943). Examples of more recent papers are "Snödrev" (Drifting snow) written by Lindquist and Äkermann (1980) and "Vinterväghållning (Winter Maintenance) from the PRA of Sweden (Statens Vägverk 1987).

Norem (1974) set up various requirements for a well-designed road exposed to snowdrifts:

- Limited formation of snow on the road
- Limited transport of snow by the wind across the road
- Best possible visibility during snow storm conditions
- Reasonable construction costs
- Simple and cost-effective maintenance of the selected profile

Roads are recommended to be located in areas less exposed to strong winds and in areas with snow depths less than average to achieve these requirements. Through this approach visibility should be improved and less snow accumulate on the road if the roads are aligned parallel to the prevailing wind direction.

For optimum results in snow conditions roads should be designed with fills as high as the local snow depths and any cut sections should have gentle slopes. The slopes should have gradients of not greater than 1:6 in flat terrain where the slopes are found at the windward side of the roads. Where roads are not well located or designed, conditions may be improved by redesign of the roads or by protection by snow fences or by tree planting.

5.2 Design procedures

5.2.1 Lapland, Finland

No special procedures are reported on the interaction between road design and the use of winter maintenance equipment in Lapland. Generally the area supervisor will assist the project team in pointing out locations where special snow drifting problems can occur and take part in the discussions on the location and design of the road. It is usually recommended to design the road with continuous fills and cut sections with gentle slopes

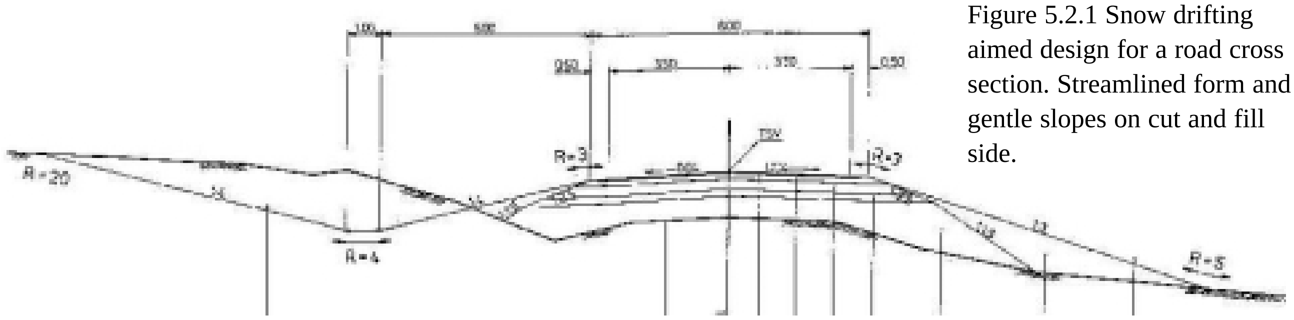


Figure 5.2.1 Snow drifting aimed design for a road cross section. Streamlined form and gentle slopes on cut and fill side.

Figure 5.2.2 Mainroad 21, Kilpisjärvi. Arctic road construction. The road has been designed with a continuous embankment with gentle slopes.

5.2.2 Norr Region, Sweden

To date Sweden has not issued guidelines on the planning or design of roads in areas with snow drifting problems but these have been taken into consideration when roads E10 and 95 were built.

Procedures for planning roads E10 and 95:

- During the planning stages of road 95 wind directions were checked and taken into consideration but no snow depths were measured. The road was built with high road embankments.
- During the planning stages of road E10 wind directions were checked and snow depths were measured. Areas with snow drifting problems were more accurately determined on road E10 than on road 95.

There is no interaction yet between the road design and the use of winter maintenance equipment. Experience has shown however that it is usually necessary to adjust the maintenance equipment over time to fit the final road design.

The design for roads with modest snowdrift problems to date has concentrated on:

- Fill in slopes to avoid the use of guardrails
- Deeper ditches in order to store snow
- High and flat embankment so that snow blows off
- Wider cross sections in cuttings to store snow

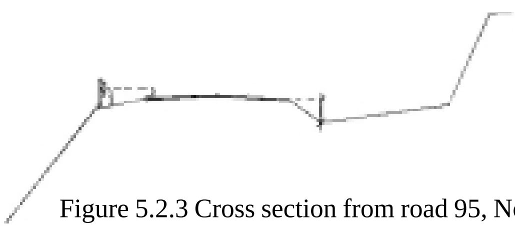


Figure 5.2.3 Cross section from road 95, Norr Region.

5.2.3 Troms County, Norway

Special design procedures exist only for roads in very harsh climates where roads frequently have to be closed due to poor visibility and heavy snow drifts. Common measures in the designing of new or improvement of existing roads include:

- elevating road embankments
- reducing ditch and embankments sideslopes
- removing steep cuts and terrain features which may cause snow drifting problems
- increasing ditch widths for snow storage capacity (Figure 5.2.4)

Roads subject to convoy driving during storm periods are sometimes designed with extra space for lining up cars in front of the snowgates. In recent years these critical road sections have been constructed with an extended shoulder or special “blower lanes” on the outside of the road (Figure 5.2.5), where rotary blowers can operate to remove the snow side-cast by snow plough operations. These ”blower lanes” offer added snow storage capacity and can improve visibility during snowstorm periods. In addition these lanes make it possible to use the snow blowers to prepare for the next snowfall.

Figure 5.2.4. Mountain road designed with gentle slopes and wide ditches, Troms County.

Figure 5.2.5. Blower lane along a mountain pass in Norway.

5.2.4 Iceland

When roads are designed or redesigned in Iceland, the new road alignment and design generally take local snow and weather conditions into cosideration. Embankment heights and slopes are always designed with due consideration of the expected snowdrift and winter maintenance conditions.

Figure 5.2.6 ”Vetrarvegur”, a special bypass along a difficult section.

In some cases, special short distance winter-roads ”vetrarvegur” are aligned to the side of the main roads. These winter-roads are used in places where the main road is subject to closure due to snow drifting problems and are located where snow seldom collects. The length of winter-roads vary in length from a few hundred meters up to one kilometer. In all cases they are gravel roads of low standard and are only used when the adjacent main road is closed by snow.

5.2.5 The Highland Council, Scotland

Scotland has not issued guidelines on the planning and design of roads in areas subject to winter conditions. Designers in the Highland area would however attempt to minimize cuttings where drifting snow can accumulate and cause the road to be blocked.

A recent public road to the ”Anoch Mor” ski area north of Fort William in the Highland area was designed to deal with winter snow conditions. Here embankment heights and sideslopes were laid out to ensure that the road was kept open for skiers to access the slopes during snowfalls.

5.3 Snow fences and tree sheltering

5.3.1 General information

Snow fences have been used extensively in all northern regions over the last 50 years to influence snow drifting on roads. The use of these fences has been a natural development as the demand for mobility in winter conditions on the existing road networks increased.

The aim of snow fences is to deposit the snow from the wind before the snow-saturated wind reaches the road. To achieve this fences have to be located at an optimum distance from the road to maximise their effect. Snow fences are sensitive to the topography adjacent to the road. In suitable areas snow fences collect a substantial quantity of snow and reduce the amount of snow reaching the road as well as increasing visibility for drivers.

The height of snow fences is dependent on the frequency of the prevailing winds and local snow depths. In areas with modest snow depths and only a few snow-drifting events per winter, fence heights are usually 2-2,5 m. In more harsh climates, heights of up to 3,5-4,5m are commonly used, with 5,0m as a maximum. In most cases these fences have been made of wood, but other materials as aluminum, plastic and fabrics have been tested.

The last two decades the use of snow fences has reduced considerably. The main reasons probably being:

- Snow fences are costly to construct and not least, they require very expensive maintenance
- Developments in wider roads and ditches have made roads less vulnerable to snow deposits
- The development of more powerful snow removal equipment makes it easier to remove even thick snow deposits on roads.

5.3.2 Lapland, Finland

There are 52 km of snow fences in the Lapland district, of which 4 km are temporary. fences. Despite their general condition these fences are still considered to be an important method for reducing problems caused by drifting snow although it is agreed that their maintenance should be carried out in a better way than it is presently being done. Snow fences in Lapland vary between 1.8-5m high and are mainly made from timber, but some are made from plastic.

Wooden snow fences are built for permanent use and plastic fences have been used as temporary measures in the southern part of Lapland. Plastic fences have not proven to be durable to date but are much cheaper and faster to build. Wooden fences can last up to 40 years.

Figure 5.3.1. Plastic snow fence in Saariselkä, Vt4 Ivalo-Inari, 21.7.1999.

Planting trees has not generally been used in Lapland. The method has only been tested along a one-kilometer road section. Snow banks are used instead of snow fences in some places. Snow is collected about 10-40m from the road thereby forming a wall of snow. The height of the snow wall is about 2 meters and snow accumulates behind it.

Figure 5.3.2 Main road 21 Kilpisjärvi, Lapland. Wooden snow fence, 4.3.2000

Figure 5.3.3. Road 1057 at Blaikfjäll. Example of poor maintenace of snow fences.

In some places with drifting snow problems a wall of snow is collected at a distance of 10-40m from the road. The height of the wall is about 1-2 m. The drifting snow gathers behind the wall on the lee side and reduces the problems on the road. This method is used on 2-4 different places in the region.

Figure 5.3.4. Example of making a snow wall on the side of the road. Hukanmaa (at the photo the amount of snow is less than usual).

5.3.3 Norr Region, Sweden

The building of snow fences in Sweden started as early as the thirties when snow removal began to be carried out mechanically. Fences were built as a result of inadequate maintenance equipment and later on also as an activity to increase employment. Most of the existing snow fences in the Norr Region were built during the sixties and seventies. Only a few have been built since 1990 and during the nineties the maintenance of snow fences has been at a minimum. Several snow fences have been torn down due to poor maintenance and many others are in need of maintenance (Figure 5.3.3).

Tree sheltering has not been used in the Norr Region but both trees and bushes are used in in the southern part of Sweden.

5.3.4 Troms County, Norway

Troms County alone has 14.000m of snow fences. They are mainly made from wood but other materials have been tested as well; aluminum, plastic fabrics and fishnet style fences. Experience has shown that wooden fences are the most economical over longer periods and that shows that snow fences can be a good solution where a stable prevailing wind direction is present and the fence can be optimally placed with respect to the road.

Tree planting has not been strategically applied, but natural forests have shown a good effect on snow drifting conditions. Fences have even been removed where trees have been established and provide sufficient sheltering.

Figure 5.3.5. Norwegian standard wooden snow fence.

Approximate empirical costs of wooden snow fences in Troms are:

- Building costs: 180-250 Euro per meter
- Maintenance costs: 6-12 Euro per meter per year

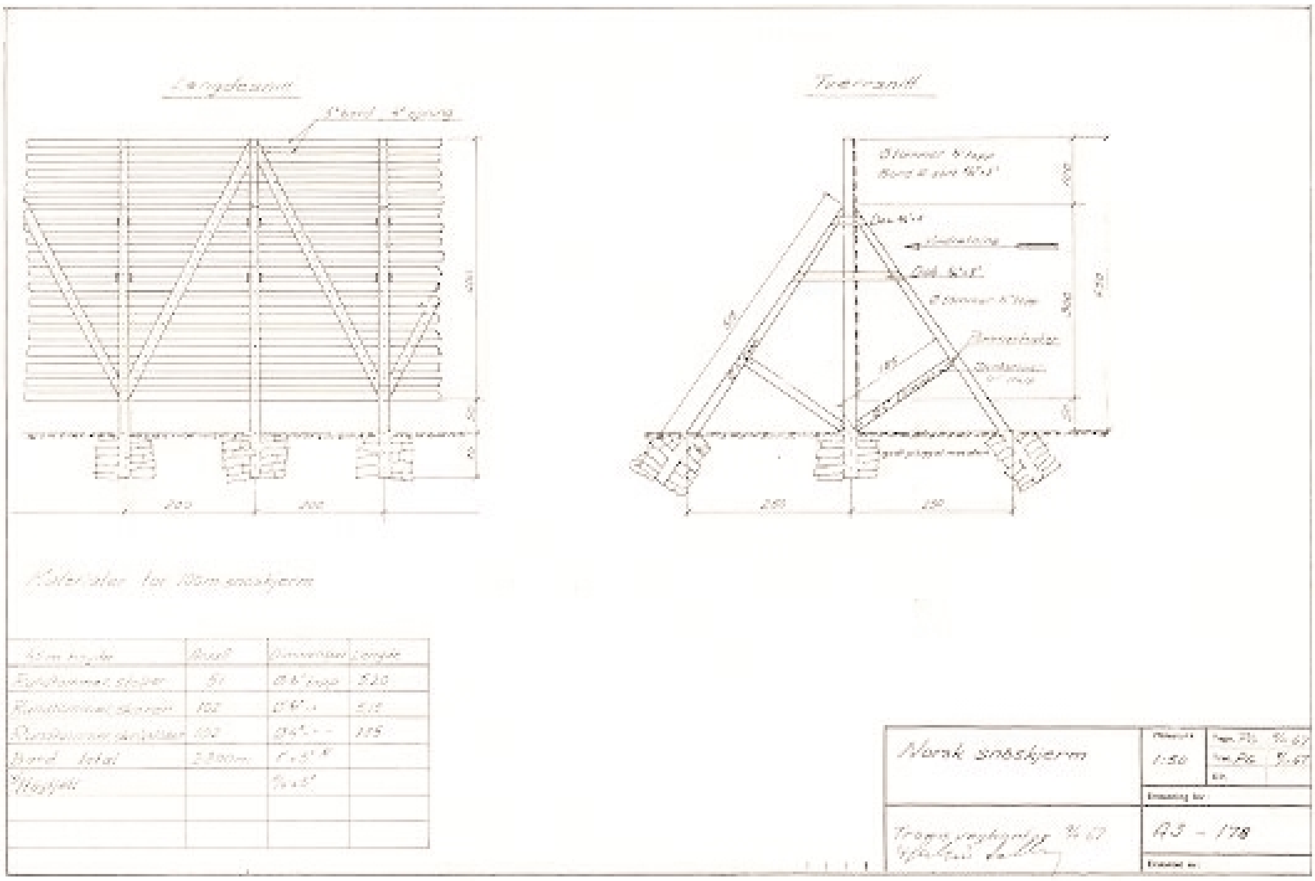


Figure 5.3.6 Typical wooden snow fence. Old drawing, but still the most common type used in Troms

Figure 5.3.7 Accumulation effect of a snow fence clearly shown. Main wind direction from left

5.3.5 Iceland

Snow fences are used in certain places in Iceland. They are made of timber with a height of 1.50m and varying lengths. Last year some experimental snow fences were made of recycled plastic. Their height was up to 4 m. They are still used on an experimental basis and the early results look promising.

Figure 5.3.8. Icelandic snow fence made of recycled plastic and standard signpost material.

Tree planting has been tried in Iceland but proven to be inpracticable because of the poor growing conditions. In some cases snow fences have been used as a shelter to make the trees to grow faster. In these cases a combination of fences and trees has stopped snowdrifting.

5.3.6 The Highland Council, Scotland

Snow fences have been extensively used throughout the the Highland area although there is little recorded evidence of their effectiveness. Opinions from local Area Engineers are mixed. Some think they are effective and others have found them to be ineffective.

Figure 5.3.9. Snow fence from Highland.

Highland snow fences have been constructed from a variety of materials including cleft chestnut fencing, railway sleepers and more recently plastic mesh webbing.

Snow fences are normally 1.5 to 2 meters in height and are set back approximately 35 metres from the road edge. The type of fencing used tends to have a low capital cost but requires regular maintenance as a result of damage suffered over the winter period. Fences are set in known exposed locations with snowdrifting and are subject to wind damage as well as damage from drifting snow.

Some success has been recorded in tree shelter belts in Sutherland and more are planned. These belts were planted in the 1970's and 1980's in peatland in known snowdrift locations and are now beginning to have a beneficial effect. To date they have been planted in strips 70m wide and consist of Lodgepole pine and Sitka spruce, approximately 10km are in place.

5.4 Use of guardrails

5.4.1 General information

Although very useful for vehicle containment at dangerous locations, the use of roadside guardrails is generally a hindrance for cost-effective winter maintenance operations. The main disadvantages being:

- Guardrails can cause heavy snow deposits on the road during periods of snow drifting. These snow deposits can result in a need for increased frequencies of snow ploughing, and in very bad situations may even make the roads impassable.
- Guardrails tend to lift the height of the drifting snow and thus reduce visibility to drivers considerably in snowstorm periods.
- Guardrails can make it difficult to remove the snow from the shoulders of the road. One consequence of this is that melting water from snowbanks can flow onto the road and freeze during the nights. Several bad accidents have occurred due to such unexpected local slippery roads.
- Guardrails can be exposed to high vertical and horizontal forces in snowy areas. These forces can be caused by snow plough trucks during maintenance operations and by the weight of the snow in snowbanks forming around the guardrails. Guardrails generally therefore need greater maintenance in areas subject to snow and have a

shorter durability there compared to areas with a milder climate.

The effect of guardrails to cause poor visibility has been visualized in model experiments by Norem (1974). Thordarson (2000) did numerical simulations to show that the tendency of guardrails to deposit snow on the road and to reduce the visibility depends on the size and shape of the guardrails. Generally a guardrail should be streamlined and narrow to minimise these effects.

The main type of guardrail in use in all districts is the W-type. This type is designed to take care for cars driving off the road. As a result there has been only minor consideration to the forces caused by snow and and winter maintenance vehicles. Some northern regions have found it necessary to develop other types of guardrails to make a better compromise between safety and maintenance.

The following comprises a list of guardrails in use within the Northern Periphery together with the main experiences recorded. Further descriptions of the practices and experiences of guardrails in winter are given separately below for each partner
district.

Type	**Width Mm**	**Cost per meter EUR/m**	**Post distance m**	**Experiences**
W-type	230-320	38	2/4	Collects drifting snow Damage by snowploughs, graders and blowers. Ploughs scratching the surface of the rail Some damage due to the weight of snow. Maintenance costs: 2-3 EUR/year/m
Kohlswa	160		2/4	Collects less snow than the W-type No damage recorded due to weight of snow The type with 4m post interval is more easily damaged during ploughing. No damage reported due to ploughing on the type with 2m post interval Easier to clear the road edges
Pipe-type	2x70	48	2/4	Collects little snow 4m post interval is more easily damaged during ploughing. No damage reported due to ploughing on the type with 2m post interval
Wire			3,2	Collects little snow Can be easily damaged during ploughing
Open Box Beam	***			

5.4.2 Lapland, Finland

Guardrails have caused snow to accumulate on roads and it is considered important to avoid their use as far as possible. Where embankments are so high that guardrails are required the slope of the embankment is decreased wherever possible to avoid the use of guardrail. If roads are located near open water, it is sometimes possible to avoid guardrails altogether by building a wider embankment on the water side.

Generally the Ty3/51 type guardrail (W-type) is used in Lapland. The depth of the rail is 230mm.

The Lapland district has specialized in using a pipe-type guardrail which results in a lower accumulation of snow on the road. Experiences from the “pipe-type”guard rail are very good. Traffic safety has increased and maintenance costs have decreased (Figure 5.4.1). The distance between posts is usually 4m. All guardrails are hot zinc dipped and do not corrode due to road salting. Damage due to snow weight has not been a problem in Lapland.

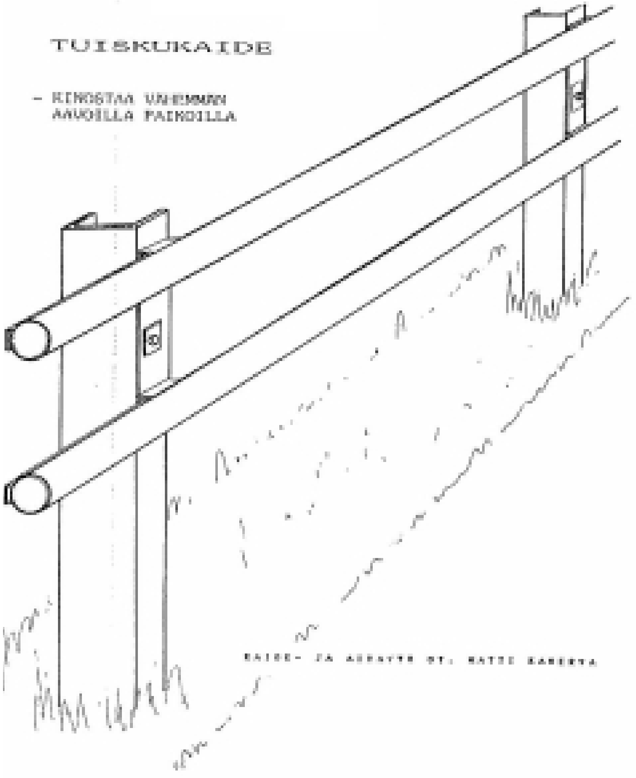


Figure 5.4.1. Guardrail, pipe design. Finland.

Figure 5.4.2 Mainroad Vt 21 Kilpisjärvi 5.3.2000 Open area where drifting snow has caused problems with extra maintenance activities and costs. This has been reduced by using the ”pipe-type guard rail”.

5.4.3 Norr Region, Sweden

Four types of guardrail are used in Norr Region; Kohlswa, W-profile, Pipe and Wire. Most guardrail installations are Kohlswa or W-profile and there are only a few pipe and wire examples.

The Kohlswa has been used since the sixties and is mainly used in the Norr district because of its low depth of 160mm and its robust construction. This low beam depth allows sufficient distance between the beam and the road surface, which makes it easier to clear the road of snow and there have been few problems with drifting snow on roads where Kohlswa has been used.

The W-profile was imported from Germany in the eighties but has not been popular in the Norr district because of its depth of 320mm which causes problems with snowdrift and snow removal. The W-profile has a weaker construction than the Kohlswa and is more easily damaged by ploughs.

Figure 5.4.3. Road E4 North of Båtskärsnäs. Notice how the snow is gathered to the guard-rail (Kohlswa). The steepness of the slope behind the guard-rail is 1:3 but notice that the snow behind is almost flat.

In the past the guardrail posts were made of concrete with a width of 30 cm. Today posts have a width of 5 cm. The difference in width makes snow removal easier and decreases the problems with drifting snow .

The pipe-type guardrail is used in a few places in the region where there are severe snow drifting problems. This type of guardrail is very effective in reducing snowdrift but snow removal machines can easily damage it. Investment costs are about 30% to 50 % higher than Kohlswa and W-profile.

A new type of road design with a cross-section called “2+1” is under construction south of Umeå. The section of road alternates between 1 and 2 lanes in each direction for every 2 or 3 kilometers. This road type has a wire guardrail separating meeting traffic and also when needed on the roadside. The guardrail is known to cause very little snowdrift and snow removal problems.

Road length with guardrails:

- Kohlswa 489,4 km
- W-profile 62,5 km
- Other 4,5 km
- Total 557,4 km

5.4.4 Troms County, Norway

The use of guardrails is avoided whenever possible in Troms County. Reducing the embankment slope in order to be able to remove the safety barrier is not regularly carried out on existing roads but is nevertheless scheduled when the budget allows for it. Such measures are often expensive because of the steep terrain.

W-profile

Guardrails of regular W-type (h=300mm) predominate in Troms County. The post distance is normally 4 m, but this is reduced to 2m at the ends of the guardrail sections for proper anchoring to the ground. On road sections with speed limit of 90 km/h, the post distance is 2 m. W-profile guardrails cause problems for winter maintenance as they collect considerable amounts of drifting snow on the road and are not designed for the forces caused by the winter maintenance equipment.

There has been considerable damage to steel guardrails by snow clearing equipment, mostly ploughs, but to a lesser extent graders and blowers also. Most of the damage occurs during winters with heavy snowfalls when guardrails are buried in snow, and on narrow roads where guardrails are close to the traffic lane. Some damage has also been recorded due to the weight of snow in areas with high winter precipitation.

On road sections where salt is used, there has been some corrosion on steel guardrails. This is mostly a cosmetic problem and so far there has been little experience of salt damaging the structure of the guardrail probably because the use of salt in Troms is very limited.

The maintenance costs for steel guardrail to approximately 1,23 EUR/m, including writing off the investment cost. The annual maintenance cost for repair and replacement of damaged guardrail alone is calculated to be about 0,31 EUR/m. Maintenance costs for concrete guardrails are negligible.

The Kohlswa-profile

Along the E6, Kvænangsfjellet, a narrower guardrail profile, h=160mm, is used. The effect of this design is not fully documented, but is believed to cause less snow to accumulate on the road. Since this type collects less snow around the rail the damage due to the weight of snow would also seem to be less for the Kohlswa-type than the W-type.

Concrete types

There are still some remaining concrete guardrails of older types. These types were constructed on site and generally installed too low to give sufficient traffic safety. These collect some snow, but generally the snowdrifts are smaller due to the reduced height. The main disadvantage of these concrete types is the damming effect of melted snow during snowfalls which creates hazardous ponds on the road.

Figure 5.4.4. The effect of the wind blowing under the guardrail. The drifting snow follows the road surface, and creates much less visibility problems, compared to drifting snow from the top of snow walls.

Length of guardrails

The length of guardrails in Troms is:

Steel, W-type and Kohlswa:	872 km
Concrete, New Jersey	1 km
Concrete, old type	41 km
Total	914 km

5.4.5 Iceland

Guardrail design itself does not take into account snowdrift and snow removal problems. The guardrails do however have a great effect on snow accumulation and removal problems on the roads and are therefore not popular in places where these problems exist. Some experiments have been carried out with narrow guardrails.

5.4.6 The Highland Council, Scotland

There are 4 types of guardrail in use in Highland. Conventional guardrail consist of three main types:

- Open Box Beam (Figure 5.4.7)
- Tensioned corrugated Beam (Figure 5.4.6)
- Untensioned corrugated Beam (Figure 5.4.6)
- Wire Rope (Figure 5.4.5)

The type of guardrail adopted is dependent upon location. The first three types have a solid beam construction and can cause a build up of snow in drifting conditions.

Figure 5.4.5. Wire rope guardrail placed on the safety margin between driving directions. Highland.

Figure 5.4.6 Tensioned corrugated beam, (untensioned corrugated beam has a similar profile)

There are no special designs for guardrail in areas subject to heavy or drifting snow. In some areas however, a wire rope safety fence has been erected to replace a guardrail with a post and solid beam construction. e.g. an untensioned or tensioned corrugated beam safety fence. Wire rope safety fence is used in many locations but has not been specifically developed for use in areas of drifting snow, although it has proved to be effective in these conditions.

Figure 5.4.7 Open Box Beam.

There are no locations recorded where the design of the road has been changed to avoid the requirement for guardrail as a result of drifting snow. In Highland the main hazard in winter is ice and the guardrail is required to prevent vehicles from skidding off the road in icy conditions. It would not be considered good practice to remove a guardrail as a method of dealing with drifting snow.

6. WINTER MAINTENANCE

6.1 Maintenance equipment

6.1.1 Overview

The main aims of the questionnaire on winter maintenance equipment and techniques were to collect information on the maintenance equipment in use, to identify any locally developed equipment and finally to investigate any special procedures and practices in winter maintenance that could have an application in partner districts.

The information collected has been analyzed with regard to differences in climate and topography in the partner areas. Generally the dominant reason for the differences in the reported winter maintenance practices relates to local climates.

Maintenance equipment dedicated to winter maintenance can be summarised as:

- Snow ploughs
- Rotary blowers
- Graders and underbody blades
- Sand and salt spreaders

In recent years there has been an increase in the use of "underbody blades", which are grader blades mounted under the mid-section of snow plough trucks (Figure 6.1.3). These blades work as a "light version" of graders and are usually less effective in removing and levelling hard snow and soft ice from the road surface than graders. The operation of the underbody blades is normally done simultaneously with snow removal but may also be done together with spreading of sand and salt, or as a separate operation. In the first type of operation the speed of the snow plough truck has to be reduced when using the blade but the use of dedicated graders is reduced. The introduction of "underbody blades" has for some districts resulted in summer maintenance needs being the critical factor in defining the numbers of graders, rather than previously, when the winter maintenance requirement was the critical factor. The numbers of dedicated winter maintenance units are presented in Table 6.1:

Table 6.1. Available equipment for winter maintenance in the different districts.

District	Lapland	Norr	Troms	Iceland	Highland
Snow ploughing units	116	414	200	52	234*)
Rotary blowers	0	5	15	32	14
Graders	18	51	12	34	0
Underbody blades	102	110	12	9	0
Sand and salt spreaders	116			46	234*)

*) Each unit is equipped with a plough and a salt spreader.

When the figures listed in Table 6.1 are divided by the total lengths of the roads from Table 3.1, comparative data on units/1000km can be calculated. These are presented in Figures 6.1 and 6.2. From this it is obvious that great differences exist across the districts for all types of equipment.

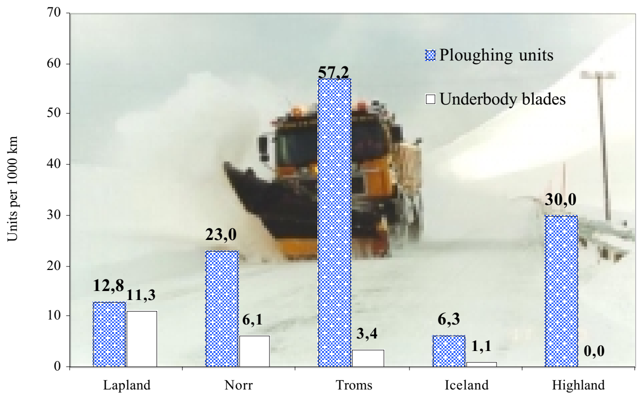


Figure 6.1.1 Snow ploughing units and underbody blades per 1000 km road across partner districts 1997-1999.

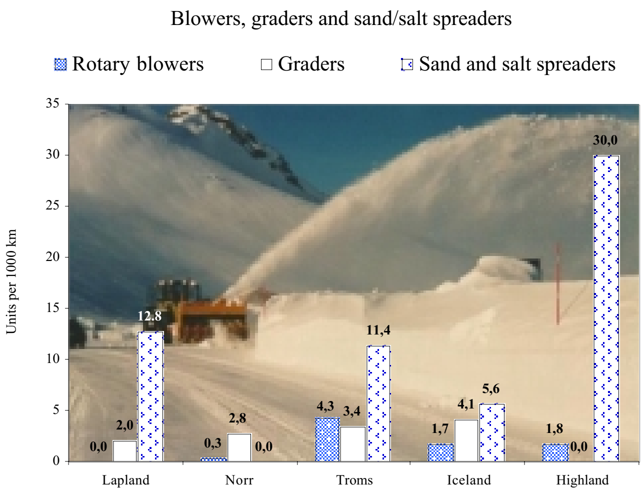


Figure 6.1.2 Rotary blowers, graders and sand/salt spreaders per 1000 km road across partner districts 1997-1999.


Figure 6.1.3. Underbody blade on a plough truck.

The highest useage of snow ploughing units is found in Troms County at 57 units per 1000 km road, compared to 13 and 23 for Lapland and Norr respectively. These high number reflects the large amounts of snow in Troms County but may also be a result of lower road standard. A low standard of road demands lower vehicle speeds, and thus a longer time for one unit to clear a certain road length.


Figure 6.1.4 Conventional snow ploughing. Truck with a diagonal plough.

The use of underbody blades is more developed in the eastern districts with continental climate than in the three maritime districts. There is no obvious reason for this, but it might be that underbody blades are more effective on roads with a high standard. The figures show that Lapland and Norr Sweden have equipped 88 % and 26 % of their snow removal trucks with underbody blades. The respective percentages for Iceland and Troms are 17 % and 6 %

The holdings of rotary blowers are mainly a result of the numbers of road sections exposed to strong winds and heavy snowfalls within each Area. The highest numbers are thus found in Troms and Iceland. The most powerful rotary blowers are also in use in these districts. Rotary blowers are not used in Lapland.

Graders are used for both for summer and winter maintenance. The highest numbers are found in Iceland and Troms, with 4.1 and 3.4 per 1000 km road respectively. Probably the numbers of graders in these areas is goverened by the local winter maintenance need rather than in north Sweden and Lapland which have a high ratio of gravel roads in their secondary roads.

6.1.2 Lapland, Finland

Winter maintenance vehicles in Lapland are equipped with various tyres of snow ploughs. The most common plough is the normal diagonal plough mounted on the front of the unit but all trucks also have an “underbody blade” mounted under the truck. “Side ploughs” are also used in Lapland.

Trucks and graders are equipped with flashing lights, diameter 180-250mm, placed on the rear of the units for improving the visibility in storm periods and dark time.

The underbody blade has become very common and this has decreased the need for normal graders. Underbody blading permits the levelling and grading of packed snow at the same time as ploughing and sanding.

Graders

The number of graders used in Troms is a compromise between the demand for summer maintenance operations and winter work. Overall the number of graders is reducing year on year because of increasing use of underbody blades. Almost all truck units have an underbody blade and operate the underbody blade 80% of the ploughing time. About 85-90 % of all leveling work is done with underbody blades instead of graders. Nowadays all winter maintenance subcontractors are required to equip their trucks with underbody blades.

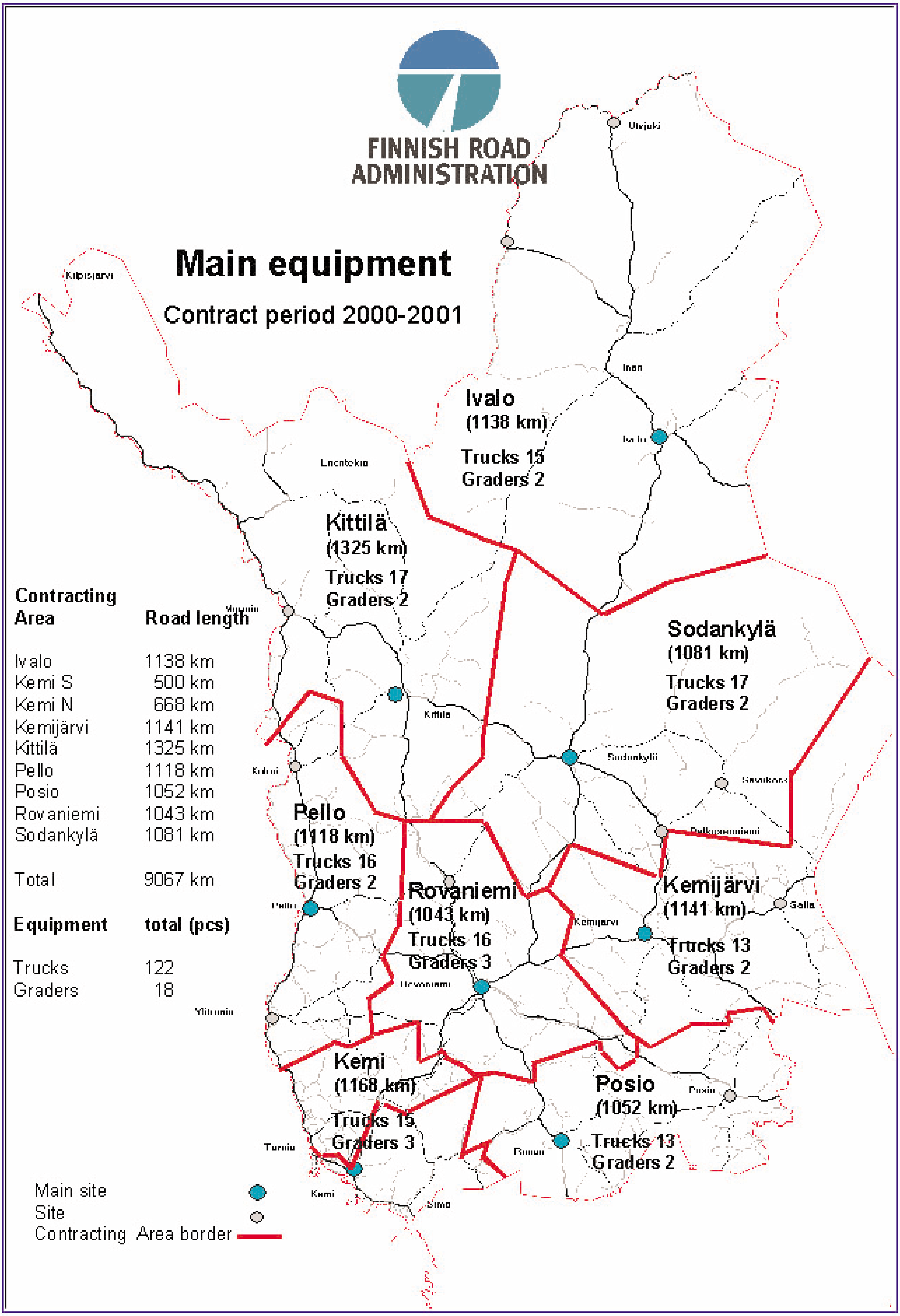


Figure 6.1.5 Location of main equipment in Lapland.

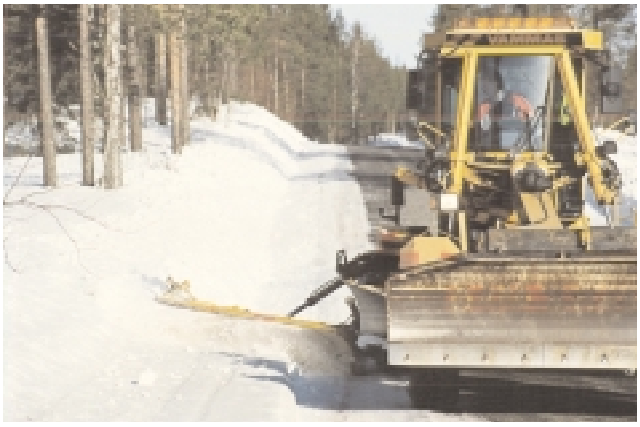


Figure 6.1.6 Removing snowbanks from road shoulder and embankment slope. Grader operating a side mounted blade

Snow ploughs

The most common snow plough in Lapland is the normal diagonal plough mounted on the front of the truck unit. Only a few V-ploughs are still held and these are located in the northern part of Lapland. These ploughs serve in emergency cases during severe snow storms when diagonal ploughs are not sufficient.

Side ploughs

Side ploughs are used at the same time as the diagonal plough primarily on the main roads when the width of the road is sufficient. In addition side ploughs are used to remove snow banks from the road shoulders.

Figure 6.1.7 Removing snow banks from road shoulder and embankment slope. Truck operating a side mounted blade.

6.1.3 Norr Region, Sweden

Ploughs

All ploughs are the diagonal type except for a few V-ploughs which are used to break through heavy snow and open closed roads.

There are two types of diagonal plough; the ordinary plough and a "heavy plough" which has several edges that are restrained with springs. These edges have a length of about 60cm and can work individually with different angles toward the surface. The "heavy plough" is heavier than the standard diagonal plough and the combination of weight and restrained edges makes snow clearance easier.

All trucks and graders used for snow clearance have a side-mounted plough. During the last four years it has been common practice to mount an underbody blade on trucks dedicated to snow removal. This has resulted in a reduced need for graders in winter maintenance.

When salt is used during snowfalls a slush-plough with rubber blades is used. This type of plough is also used on gravel roads to prevent filling the ditches with gravel when the surface are unfrozen.

Four and six wheel drive trucks are used to open temporarily closed roads..

Blowers

On roads E10, 95 and 1057 (AC) rotary blowers are used for snow clearance after storm periods. Blowers have a capacity of 600 – 800m_/minutes. Normally a sharp snow edge remains after using a blower and this can lead to later snow drifting problems. These edges are cut off by snow blowers or tractors.

Figure 6.1.8 The blower used on road 95 at Merkenäs. In the background is snowplough truck with V-plough.

Graders

Graders are used for many purposes in winter maintenance in the Norr Region. These include snow clearance, reducing unevenness, reducing the height of snow walls and removing snow from ditches.

6.1.4 Troms County, Norway

Ploughs

The most common snow plough in use in Troms County is the diagonal type. V-ploughs are additionally used during severe weather conditions when the road has become very narrow with high snow banks or when opening roads which have become totally blocked with snow. Also on a few very low standard roads, V- ploughs may be used instead of diagonal ploughs.

Figure 6.1.9 Diagonal plough, close-up

Figure 6.1.10 V-style plough (modern type to the right)

Blowers

On severely exposed road sections snow blowers are used. These are carried by loaders and are of differring sizes, mostly Øveraasen blowers (Norwegian made)

Figure 6.1.11 Snow blower, unit type. The carrying machine is a wheeled loader, approx. 20 tons.

Graders

Graders are used in levelling packed snow and ice on carriageways and for leveling side banks. For the latter purpose they are equipped with a special snow wing. Graders are not used for snow clearing of loose snow in Troms County.

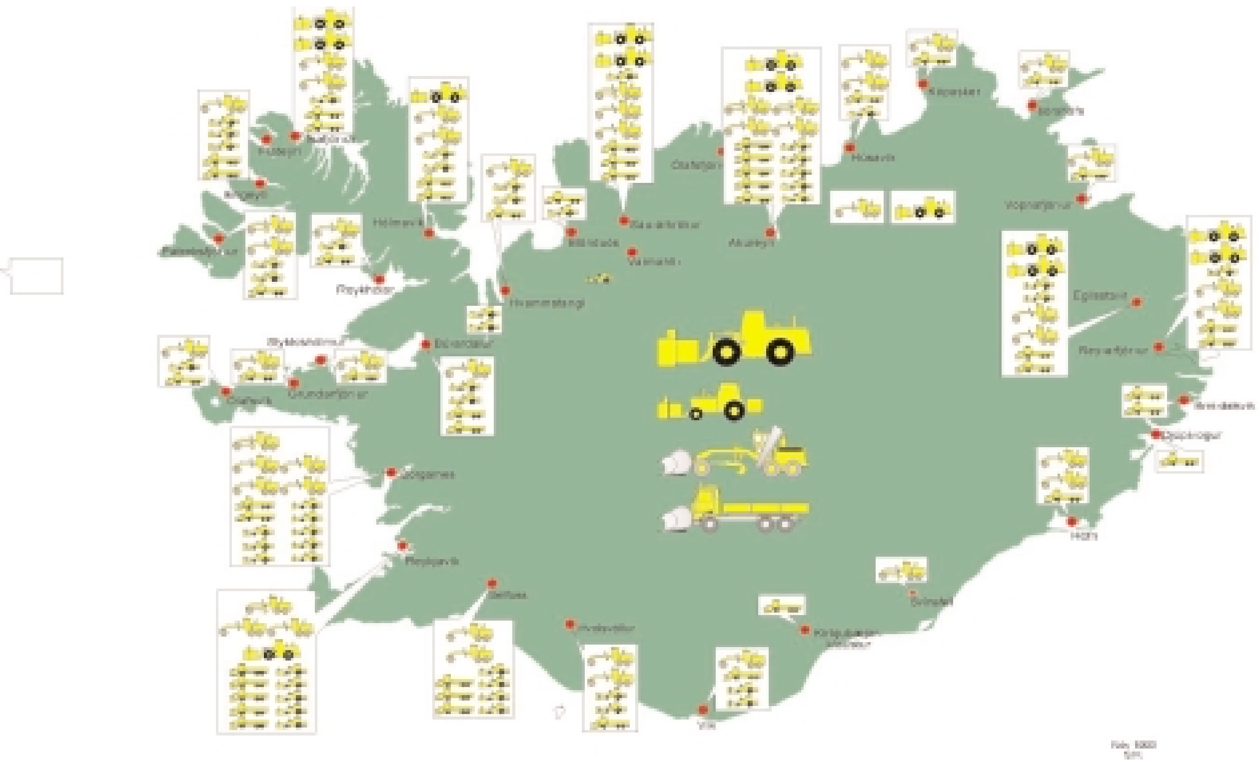


Figure 6.1.12 Location of winter maintenance equipment in Iceland.

Other machines
On the E6 Kvænangsfjellet, and some other road sections with difficult conditions, 4WD plough trucks are used. Loaders are frequently used for removing snow from totally buried roads, for levelling side-banks and for digging out extra space around roads. Under extreme conditions, backhoe machines are used for taking down side-banks.

6.1.5 Iceland

Lorries with snow ploughs, payloaders or graders comprise the most typical snow removal equipment in Iceland. Rotary blowers are very important in winter service on mountain roads and primary roads.

6.1.6 The Highland Council, Scotland

Snow Ploughs
A mixed fleet of snow ploughs are employed in the Highland area in winter maintenance operations. These range from normal haulage vehicles, temporarily converted to winter maintenance vehicles by fitting demountable gritting boxes and snow plough blades, to 6 wheel drive vehicles purpose built for winter maintenance.

Figure 6.1.13 Snow plough – V-blade

Dual Purpose Snowplough/Haulage Vehicles
Dual purpose vehicles are normal haulage vehicles which can be temporarily converted to winter maintenance vehicles by mounting a grittier box and snow plough. The equipment can be mounted and removed fairly quickly, usually in about 15 to 20minutes, to make the vehicle ready for winter maintenance. This provides flexibility and releases the vehicle quickly for other work when not required for winter maintenance.

Dedicated SnowploughVehicles
Dedicated snowplough vehicles are purpose built AWD vehicles which have been specially designed for winter maintenance work. These vehicles are not been used for any other purposes. These dedicated vehicles are generally deployed on the more exposed routes where steep gradients or deep snow may cause problems.

Types of Snow Plough
There are three basic types of snow plough used depending on the conditions and type of road. These are:

1. Slush Blade
2. Straight Blade (Figure 6.1.14)
3. "V" Blade (Figure 6.1.13)

The slush blade has a conical profile and is designed for the removal of slush and light snow up to 10mm on faster roads where it can be used at higher speeds to cast the snow further from the road.

The straight blade varies from a light polycarbonate blade to a heavy duty steel blade. These blades are designed to cast the snow to one side and the depth and condition of the snow will determine the size of blade to be used.

The "V" blade is used in heavy snow conditions in conjunction with powerful AWD vehicles. Smaller versions of the "V" blade are also used on single track roads which allows the snow be pushed to both sides of the road.

Figure 6.1.14 Truck operating a straight blade. Highland.

Snow Blowers and Graders
Snow blowers are located close to known problem areas where deep snow can cause roads to be blocked.

Graders are not used in Highland but sub-contracted excavators are called in during periods of very heavy snowfall.

6.2 Snow removal techniques

6.2.1 Overview

From the above summaries it can be seen that there are substantial differences in techniques for snow removal across the Partner Districts, especially on the removal of snow from road shoulders and ditches. These differences go back mainly to differences in climate and road standards.

Snow banks on road shoulders cause problems for traffic during the winter by:

- Reducing available sight distances in curves and at intersections
- Decreasing visibility during periods of drifting snow across the road
- Limiting space for snow storage
- Increasing the hazard due to wild-life crossing the road
- Thawing snow banks in spring can cause water flows across the road which can then freeze during the nights
- Damming of water in depressions on the roads

Surprisingly there is a benefit to have snow cover in roadside ditches as this can prevent water flowing on to the road and forming ice.

Figure 6.2.1 Ice building up in ditches. The ditch is full of ice, the water flows onto the road creating slush and ice, with a traffic danger point as result.

All districts, except Highland, report that removing or lowering roadside snow-banks is necessary. In addition to the benefits described above the process also improves the thaw characteristics of the embankment and this in turn permits the road construction layers to dry out faster.

6.2.2 Lapland, Finland

High snow banks in Lapland limit the visibility at intersections and interchanges. They also cause more severe drifting problems. If the banks are very high they can present difficulties for winter maintenance crews to cast snow over them when ploughing.

The maximum allowed snowbank height in Lapland is 0.80m generally and 0.5m at junctions. Lowering work must be done carefully so as not to damage buried snow stakes and guide posts. In snow drifting areas it is considered important to keep the snow walls as low as possible and on some road sections snow is removed far from the shoulders and ditches to provide sufficient space for accumulated snow.

The most common technique to remove snow banks is by trucks with side wings, graders with side wings, although excavators with a blade may also be used.

In spring snow banks are pushed off the road shoulder onto the slope to prevent melting snow draining onto the roadway causing localised wet and icy stretches. Special attention is given to areas where melting snow ponds on the carriageway before the banks can be pushed back. In these cases drainage is provided through the snow bank.

Figure 6.2.2 Removing snowbanks from road shoulder and embankment slope. Truck operating a side mounted blade.

6.2.3 Norr Region, Sweden

Reducing snow wall height

Snow wall height reduction is mainly carried out with graders and trucks with a plough mounted on the side. Some contractors use a wheeled loader with a smaller plough mounted on the back hoe. With this method it is easier to avoid damage to road markers and work around signs. The combination of loader and plough is also useful in snow removal in crossings, behind guardrails and narrow places because of the greater backhoe range.

Snow walls are also reduced to improve sight conditions in curves and crossings. The improvement of sightlines at junctions and crossings is often carried out with tractors. A lower snow wall makes it easier to spot reindeers, elks and wild life on the side of the road.

The winter service standards for sight distances at road junctions and crossings are:
Max height of the snow bank= 0,9m (roadside)
Eye point at 3m from the edge of the main road on the connecting road

Speed(kn/hr)	**Required sight distance (m)**
<= 50	80
70	130
>=90	190

Sight distance is measured at a height of 1,1 m, where a driver shall be able to see the headlights of an approaching car. In practice this leads to a permissable snow wall height of 0,6m on traffic separators and in crossings.

Figure 6.2.3 Road 616 North of Luleå. Example of sight improvement in crossings. Notice that a tractor has shovelled out the snow in the crossing.

Figure 6.2.4 Result of cutting snow wall with a side wing

Removing snow from ditches

Snow ditching is carried out on all roads when spring arrives in the Norr Region. The removal of snow from ditches is carried out with graders to depth of about 20 cm. Snow removal from ditches is carried out for two reasons:

- at the edge of the road the action prevents melting water flowing out onto the road. In spring the nights are often cold enough to freeze this melt water which can produce very slippery condition on roads.
- from the inside slope of the ditch to make the road thaw faster . This action helps water drain faster from the road structure. To date however, no equipment has been found which can do snow ditching where there are guardrails.

On roads with buildings close to roads, snow walls have to be removed several times during the winter. This is done with tractors or snow blowers in combination with lorries. This practice is also carried out on some roads with narrow cross sections.

6.2.4 Troms County, Norway

Leveling snow-banks and removing snow from ditches

Troms County uses a standard procedure using a grader fitted with a snow-wing to lower snow banks into the road, from where the snow can be removed by a following blower. Occasionally a loader is used instead of the blower in this arrangement. When the snow amount is moderate a plough can be used to remove snow left by the grader.

When side-banks are fairly low and storage capacity on the outside of the side-bank is sufficient a grader with a snow-wing can level the side-bank directly without further assistance.

Figure 6.2.5 The procedure of taking down high snow banks to make room for new snowfalls. In front, a grader tears down the snow bank with a snow wing, and behind a blower is clearing the road.

Preventing icing in ditches, sub-drains and rock cuts

The formation of ice in ditches, sub-drains and rock cuts can be a considerable problem in the Troms area especially in cold winters with little snow cover. Ditches and sub-drains can get clogged, and ice can build up on the road surface.

To prevent this icing problem it can be effective to divert ditches away from the road and heating cables are sometimes used in sub-drains. Double sub-drains have also been tried, with one overflow sub-drain placed above the normal drain. When the lower drain is clogged by ice, the overflow sub-drain takes care of the water until the normal sub-drain is opened. Excavators are often used to remove ice from the ditches. Steam cleaning is also used to open frozen sub-drains.

Icing on steep rock cuts may lead to traffic hazards when the interface between the rock cut and heavy ice blocks starts to melt and the ice blocks slide down onto the road. Fortunately, this is only a problem on road sections with very narrow ditches.

Figure 6.2.6 Ice formation in a rock cut. In the spring thaw the ice may fall down on the road.

To prevent this type of hazardous ice building up on rock cuttings surface water can be diverted by ditches on the top of the cut. The rockface may also be equipped with netting to prevent ice from falling down on the road during the spring thaw. Removal of dangerous ice with excavators or other machines in the spring is also carried out.

Opening ditches in the spring

Ditches usually are filled with snow during winter in Troms and when the snow starts to melt in Spring this snow has to be removed.. This has two purposes (a) to prevent melting water flowing onto or over the road. When this water freezes at night, it creates a traffic danger and (b) to lead the water away from the pavement structure to prevent reductions in bearing capacity.

Small blowers or graders are used to remove snow from the ditches in spring. Graders can often do the job on their own but snowploughs or other machines can assist when required to clear the road.

6.2.5 Iceland

Snow blowers and special snowploughs are used to remove snow walls along road shoulders in Iceland to prevent snow drifting onto roads and to improve visibility. Guardrails, signs and in some cases, abandoned cars can make this work less effective.

Removing snow from ditches at roadsides is often necessary because of flooding due to melting snow and to create storing capacity for the next storm. In northern Iceland a new road at Bolstadahlid has been designed with wide snow ditches to collect snowdrifts from the mountain and to facilitate the removal of snow.

6.2.6 The Highland Council, Scotland

Reducing Snow Wall Heights

No special techniques are used in the Highland area to reduce snow wall heights. Snow normally thaws within days of falling and there are not the same problems as in the Scandinavian districts where temperatures remain below freezing for the entire winter period.

On rare occasions during prolonged periods of freezing without thaw, snow blowers or excavators are used to remove snow walls from the edge of the road.

Figure 6.2.7 Snow blower in action, removing a snow wall in the Highland area.

Removing Snow from Ditches

This is not a problem in the Highland area.

7. OPERATIONAL PROCEDURES

7.1 Introduction

The main aims of the questionnaire on operational procedures were to identify local operational practices on roads during difficult and hazardous driving conditions and to investigate the procedures that are in use in the partner districts to improve winter traffic safety.

The climatic conditions in the Northern Periphery can cause very difficult and hazardous driving conditions. Sometimes these conditions reach such critical levels that roads should not be left open to free traffic. The most common actions implemented by Roads Authorities during severe driving conditions include; road closures, convoy driving reduced allowable speeds and surveillance of the traffic.

Some of these actions reduce free access to the road network and they are only implemented after thorough considerations. The main questions to be addressed in such situations are:

- What are the limiting conditions before special precautions need to be introduced to take care of the safety of road users and maintenance crews?
- What are the most appropriate actions?
- Who has the responsibility to enforce the appropriate actions?

The present study showed that there are great variations across the participating districts concerning these three questions. The differences may be explained in part by the differences in climates and road standards but they are also reflected by different views on maintenance policies and safety. The harmonization of these issues would be advantageous to long distance and international traffic.

The risk of accidents during difficult driving conditions can be reduced if roads authorities are prepared for the situations that may occur. The most common preparation is winter road signing and, to a very small degree, artificial road lighting.

Service standards for friction and maximum snow depths on carriageway surfaces need to be defined to ensure that roads are both trafficable and safe. This is especially important for long-distance vehicles that pass through several maintenance districts to ensure that they meet consistent standards along their journey.

Figure.7.1.1. Convoy driving at mountain road Haukeli in Norway.

7.2 Safety procedures

7.2.1 Lapland, Finland

Winter speed limits are used in Finland during the winter period. The speed limit is lowered from 100km/hr to 80km/hr on high traffic volume roads but is not generally enforced on low traffic volume roads.

Climatic conditions are not normally so bad that roads need to be closed and to date there are no established procedures for convoy driving. Sometimes however, under severe climatic conditions, road users have to wait for a short time on higher roads for the maintenance unit to pass through critical sections. The Traffic Information Center (TIC) is informed immediately when a road is impassable. There are no night closures procedures or special preparedness for helping cars stuck in the snow. Roads are generally kept open with normal maintenance procedures.

7.2.2 Norr Region, Sweden

Winter speed limits

Speed limits are lowered from 110km/hr to 90km/hr in winter in the SNRA Norr Region, in some places from 90km/hr to 70km/hr. These speed restrictions are normally made on longer road sections with high traffic volumes.

Surveillance

Personnel from winter maintenance contractors carry out the surveillance of the road network. When the weather forecast indicates that severe weather is expected this surveillance is intensified.

Roads with temporary closures

The Norr Region operates temporary road closures on sections of the E10 and 95 at the Norwegian border. When these roads are closed, or convoy driving is being carried out, illuminated signs are activated in Kiruna for road E10 and Arjeplog for road 95 to inform road-users. Roads are closed by means of maintenance personnel lowering a bar, equipped with lights and an illuminated information sign, across the road. After closure of the road the maintenance personnel make sure that there are no cars in the closed section. Cars remaining in the closed section are towed away by winter maintenance vehicles.

Maintenance personnel decide how many vehicles are allowed in a convoy. During convoy driving a maintenance vehicle is positioned in front of the convoy and one at the end. These machines have radio connection with each other. All contracting operations in this procedure are carried out under the "Policy for convoy driving".

Figure 7.2.1. Sign on road E10 just out side Kiruna with a fixed message; "Snow obstacle, road E10 closed Björkliden-Riksgränsen, for information call 020-227766".

Avalanche warning system

There is an avalanche warning system on road E10. The system is activated when an avalanche starts and an automatic process commences to close the road with red lights and bars. This section of road has a lower speed limit at 70km/hr.

7.2.3 Troms County, Norway

Temporary road closures

Troms County uses road closures and/or convoy driving whenever visibility is reduced or when there is high risk of cars getting stuck in the snow. Road closures are enforced by locked gates and information on closures is given by means of signs about possible diversionary routes and where to get further information. The foreman of the maintenance crew has the authority to introduce such measures and his decision is usually based on recommendation from his machine operators. All road closures and convoy driving operations are notified to the TIC. There are no particular criteria for closing roads at specific wind speeds.

Figure 7.2.2. Gate closed, convoy driving is taking place. The road is so narrow that two vehicles cannot pass.

In Troms the amount of snow on roads will rarely cause closures in itself as visibility will normally be the critical criteria long before the snowplough has problems with clearing the snow. In exceptional cases roads can be closed by vehicles becoming stuck in the snow. These stuck vehicles block the road and prevent the snowplough from passing. Convoy driving is usually introduced in response to bad visibility. However, in some cases convoy driving is ordered because the road is so narrow that two vehicles cannot pass.

Figure 7.2.3. A quite common problem on some roads after periods with heavy snowfall. The road is so narrow that larger vehicles hardly can meet.

Convoy driving

Convoy driving is carried out in accordance with Troms County procedures and regulations. A snowplough truck leads the convoy and a pickup truck drives at the rear, ending the convoy. A suitable private vehicle can also be used as the last car. The lead snowplough and the last vehicle have radio connection. The maximum number of cars in a convoy depends on the weather conditions, but usually no more than 10 or 20 vehicles are allowed in one convoy.

Before the convoy starts the lead snowplough truck driver inspects the participating cars and drivers to decide if they are adequately equipped. The driver has the authority to reject whoever he considers unsuitable to take part in the convoy, for instance if the vehicle's tires are not good enough, or if the driver or passengers are not fitted out with warm clothes etc.

A leaflet containing the general instructions for convoy driving is distributed to the drivers before passing into the affected. This instruction is described in detail in Appendix B

Surveillance of the traffic

Under severe weather conditions winter maintenance trucks drive back and forth along the exposed sections removing snow from the road and looking after the traffic. No special surveillance routines are carried out in addition to this regular patrolling.

Avalanche warning

In January 2000 a bad snow avalanche accident in Troms caused the death of 5 people. As a result the PRA initiated a project on forecasting the probability of avalanches and developing new procedures on how to operate roads exposed to avalanches.

7.2.4 Iceland

Temporary road closures

Only the Police have authority to force road closures in Iceland. In recent years it has become very popular to drive powerful 4x4 on big tires in winter. These cars have caused problems with closing roads because of their ability to drive on snow in very bad conditions.

Figure 7.2.4. An example of modified 4x4 vehicle (often called Super-Jeeps). This particular vehicle belongs to a rescue team unit

7.2.5 The Highland Council, Scotland

Road Closures

Only the Police have the responsibility to close roads in Scotland but this decision is usually taken after consultation with the Roads Authority who carry out the winter maintenance operation. Once the decision to close the road is made, road closed signs are erected. In some cases the Police will man the site of the closure to ensure that motorists do not attempt to use the road.

Roads are closed when the depth of snow makes the road impassable or when drifting snow reduces visibility to a dangerous level.

Snow Gates

Snow gates have been erected on strategic routes in the Highland area and these allow the Police to physically close the road to traffic.

Figure 7.2.5. Snow gate for closing road under severe conditions.

Monitoring Conditions

Winter road conditions are monitored on a regular basis to determine when road closures can be removed. The public is kept informed through the local radio network and a dedicated telephone information line. Variable message signs are also used on strategic routes to advise motorists of road closures.

During periods of adverse weather the most vulnerable routes are patrolled by winter maintenance crews and the Police.

Convoy Driving

When a road is considered to be safe for re-opening the Police will normally arrange for a convoy system, led by a snowplough to take the traffic through under controlled conditions. The convoy system is kept in place until it is considered that it is safe to resume normal driving.

7.3 Winter marking

7.3.1 Lapland, Finland

Lapland uses signs and posts as an optical guide for winter maintenance crews. These winter markings delineate the road alignment and the edge of the road when visibility is poor. Normally wooden (birch) sticks or fiberglass poles are used but where drifting snow causes visibility problems these poles can be equipped with reflectorised stickers. The road markers are erected at sufficiently small intervals to meet the weather conditions. The maximum distance is 90m, while at difficult sites this is reduced to 20m. Normally the distance between poles is between 40m up to 90m depending on the road width and alignment. Markers are placed on the shoulder of the road offset from the edge of the asphalt by 25-30cm

Figure 7.3.1. Plastic poles with reflective stickers in Finland

Fixed poles have been erected on road No. E75 as this does not have as many drifting snow problems. On this route the poles are used to improve traffic safety during the hours of darkness by increasing visibility. These poles are sited 1m off the edge off the asphalt to minimize damage to the poles during lowering of side snow-banks.

Temporary poles	8873 road-km
Fixed poles	179 road-km

7.3.2 Norr Region, Sweden

All the roads in north Sweden have markers to improve edge definition. 3 types of markers are used: reflectorised fixed markers, reflectorised temporary markers and birch sticks.

On roads with traffic volume of > 500 vehicles per day reflectorised permanent and temporary road markers are used. Reflectorised fixed markers are used on national road E4 and sections of road E12, 97 and 372 that have high traffic volumes. On roads with traffic volumes < 500 temporary markers of birch sticks are used.

All three types of road markers are used as guides for winter maintenance snowplough drivers to indicate where the edge of the road is. Road users especially appreciate reflectorised road markers during the autumn darkness.

Edge markers are placed at 60m centres, shorter in curves, and those with reflectorised strips are required to be visible from 120m when using half lights. Temporary winter markers are put up the 1st of September and taken down in April. Longer temporary road markers are used on roads with snow drifting problems and the pole to pole distance is decreased from 60m to 20m.

Figure 7.3.2. Fluorescent temporary pole. The pole has a very good visibility in heavy snowfall and drifting snow. The pole is used by some contractors to mark out guardrails, bridges and crossing. On road E10 and 95

Trials have been carried out in winter season 1999-2000 with fluorescent temporary markers on road E10. These markers were found to produce a big improvement in visibility for snowplough drivers. Fluorescent markers cost about 3 times more than ordinary road makers. Another test of the marker is being carried out on road 95 on the interaction with lorry headlights with UV-light to further improve the visibility. The results so far are good and the tests will continue.

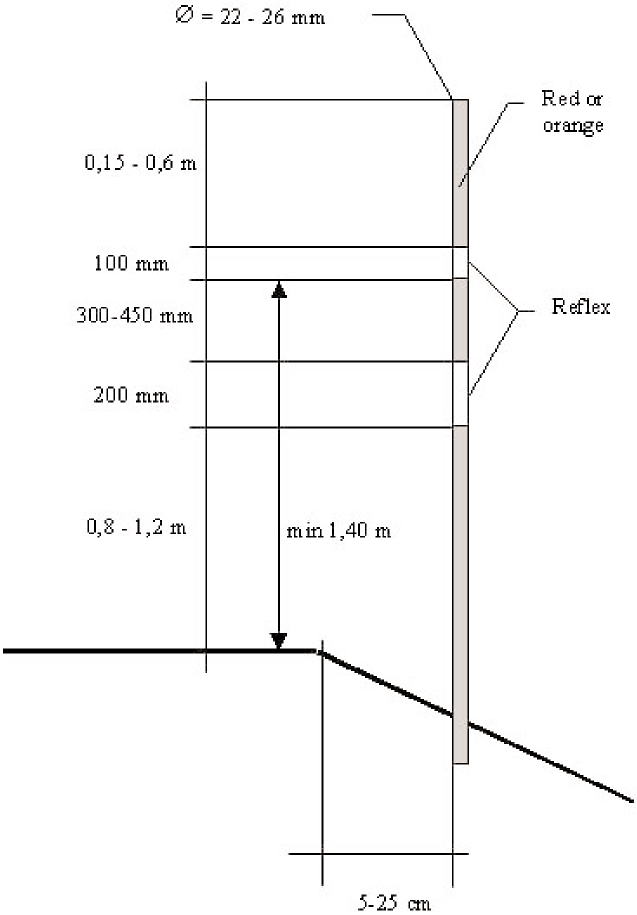


Figure 7.3.3. A sketch of a temporary snow pole, dimensions and placement

7.3.3 Troms County, Norway

Temporary poles

The most common type of snow pole in Troms is made from red plastic. On low traffic roads, poles made of bamboo or birch wood are occasionally used. Poles are equipped with a 10cm wide reflectorised tape 1m above the ground. Besides being an optical guide for motorists during snowstorms, these reflectors are also practical during the hours of darkness.

Figure 7.3.4. The effect of reflector tape on temporary poles at night

Plastic poles are generally 25mm diameter and 210cm long but on difficult road sections may be 350cm high poles. Pole spacing is normally 25-40m between poles depending on the road geometry and visual conditions. Extremely difficult locations can have a 10m pole spacing. Plastic poles have been found to be very flexible even during very cold weather. Durability is found to be good, 60-70% of the material is reused depending on climatic factors.

Permanent poles

On road sections with low or moderate drifting snow problems all-season poles of 1 m height are normally used.

Figure 7.3.5. Permanent marking pole which is lengthened with a temporary snow pole for winter purpose

Distance from the edge of the road and special procedures

The distance of the pole from the edge of the road varies with the alignment and width of the road. Normally the poles are placed 10 - 30 cm outside the pavement edge. On primary roads with wide paved shoulders the poles can be placed 0 - 50 cm outside the edge line into the pavement.

Green plastic poles are being trialed in some districts of Troms for marking the drainage system, drum inlets and gullies. On some road sections the ends of guardrails are also marked with two standard poles (Double poles)

7.3.4 Iceland

Special snow poles are used on mountain roads in Iceland in deep snow. These poles are extendable. In summertime the snow poles are exchanged for ordinary road poles.

The height of standard road poles is 1m whereas snow poles are 2m long and extendable. Road posts are placed 0,5m from road site at 50m intervals. In curves this spacing is reduced to 25m.

Figure 7.3.6. Permanent marking poles of plastic, usual spacing is 50 m.

7.3.5 The Highland Council, Scotland

Temporary poles

Temporary snow poles are not commonly used in the Highland area. Fixed snow poles are left in place for the entire year.

Fixed Poles

Fixed poles tend to be made of aluminium with a 50mm diameter. The aluminium is more durable than plastic and gives a longer life. The poles are fitted with reflectors on both sides to indicate which side of the road they are on. Motorists will see red reflectors on the left-hand verge and white reflectors on the right-hand verge. The poles are generally 2 meters in height and offset from the road edge by 0.5metres. Poles are spaced at 25 to 100 metres depending on road alignment and exposure to drifting.

Plastic poles have been tried but aluminium poles have been found to be more robust

Other

In many locations the road edge is marked with plastic verge marker posts. Their primary function is to mark bends for night time driving but they are also useful in snow conditions when the edge of the road may not be visible.

Figure 7.3.7. Verge markers. Highland.

Artificial Lighting

Is not used in the Highland area except at major junctions.

7.4 Service standards for friction and ploughing

7.4.1 Overview

The most common climatic effects that cause difficult driving conditions in the winter are snowfalls on the road surface and slippery roads due to snow and ice. All districts, except Highland, which has a “black road” policy, have defined critical levels for maximum snow depths and minimum friction. These levels are defined by national standards for winter maintenance. These standards also include permissible depths of ice on roads, times to improve sight distances at junctions, clear traffic signs etc. These last parameters are not included in the present report.

The critical levels for snow depths and friction are either dependent on (a) the traffic volumes and the importance of roads or (b) the traffic volume alone. National standards set requirements for an acceptable level for snow and friction together with a reaction time to improve the conditions to this level.

As a consequence of this it is difficult to easily compare the different standards across the partner districts as there are both critical levels and reaction times involved.

Figure 7.4.1. Here the snow and ice layer is removed with a grader, and the conditions are well within the limitations of the standard. Troms County

To explain this difficulty in comparing districts an example for snow on the carriageway is presented in Figure 7.4.2. The figure summarises the maximum snow accepted and the reaction time for the highest maintenance class. The vertical axis shows is the snow depth and the horizontal axis the reaction time. There are obviously no districts that have exactly similar standards and there appears to be a wide variety of acceptable conditions at first glance However, by assuming that a heavy snowfall has a snow fall intensity of 1cm an hour, as shown by the snowfall line in the figure, the difference in the standards is comparatively small.

The corresponding winter standards for friction similarly differ across road districts and it is not possible to present the various requirements in a simple graph. The standards are thus presented separately for each partner district.

On friction control, a comparison indicates that Lapland has wider requirements for friction as a function of traffic volume compared to the other Nordic districts. On the other hand, the Norr Region has no specific requirements for their secondary roads with very little traffic.

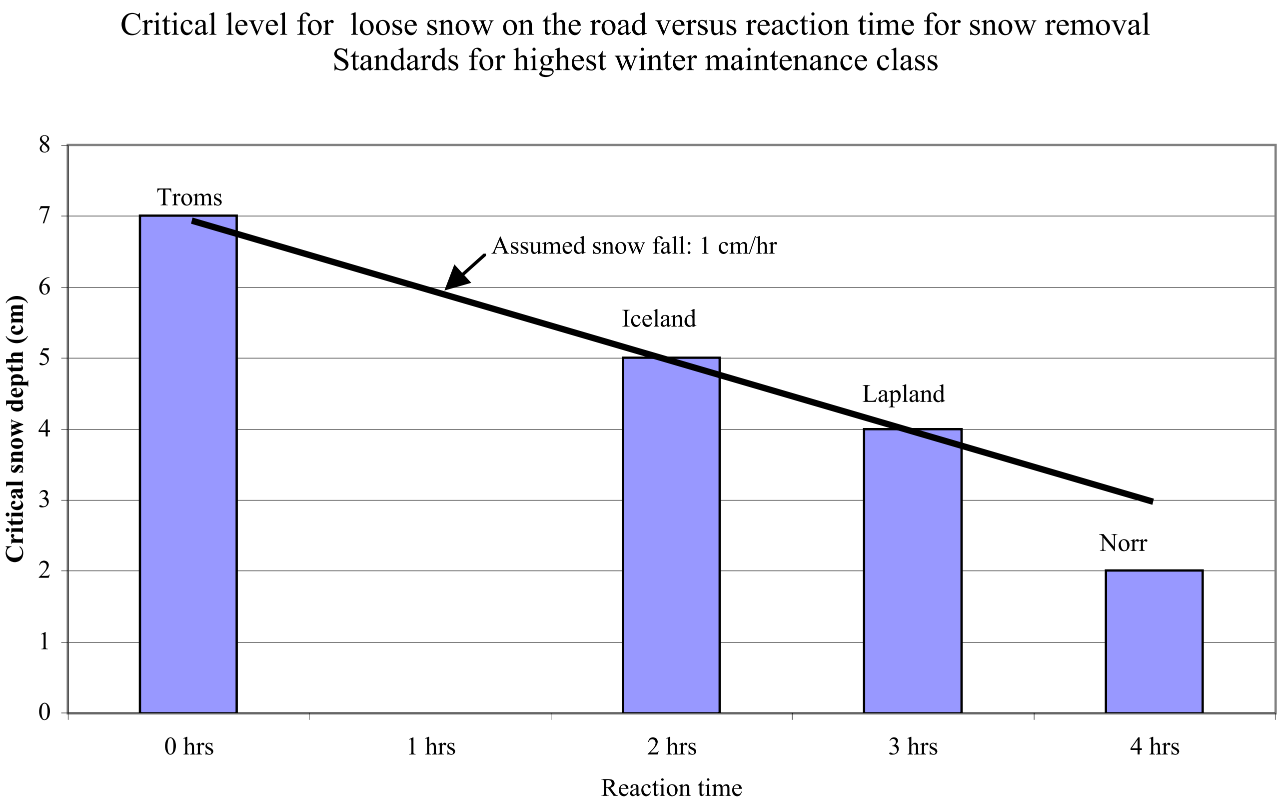


Figure 7.4.2. Critical level for loose snow on the road versus reaction time for snow removal. Standards for the Nordic districts and highest winter maintenance class

7.4.2 Lapland

The road network is divided into five maintenance classes (Is, I, Ib, II, III) for the purpose of planning the level of service and implementing winter maintenance operations. The roads in each class are maintained according to the quality standards described in detail below. The road network is divided into classes based on traffic volume and functional class. The division of the road network in the different classes is given in Figure 7.4.3. Note that classes ‘Is’ and ‘I’ are not used in Lapland.

Factors such as level of service, speed limit, local conditions and traffic needs are taken into account when deciding which class of road a specific road should belong to. If the traffic needs of a road changes temporarily (such as during temporary use by heavy traffic) the winter maintenance practices are usually improved without necessarily changing the winter classification of the road. The purpose behind this is to maintain the sections of roadway in such a way that road users do not meet with unexpected situations. Special attention is made to avoid jumps in maintenance standards at the border between two maintenance contract areas.

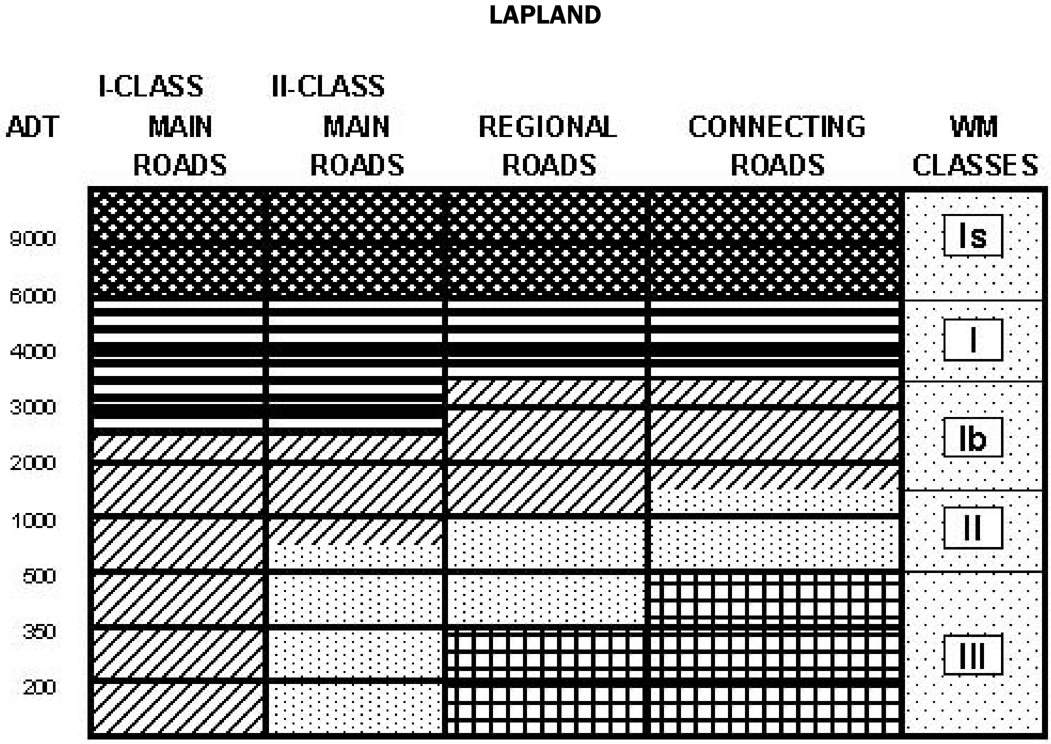


Figure 7.4.3. Lapland Distribution of Roads into Different Winter Maintenance Classes

The goals for the levels of service of winter maintenance classes depict the level of standards required in normal conditions. It is accepted that these may not be achieved during periods of severe weather conditions.

The Winter Maintenance Policy defines the recommended wintertime level of service on different parts of the road network. This policy also includes general quality standards together with detailed requirements and instructions.

The publication ”Winter Road Maintenance Methods in Finland” outlines the winter maintenance methods used in Finland. This maintenance manual includes instructions how to operate on the road and what kind of equipment combination is the most efficient for snow removal.

In winter, trafficability is ensured in both normal conditions and when the weather changes. Excess snow is ploughed off the road and slippery road surfaces are treated with sand or de-icing salt depending on the circumstances. The surface of the road is leveled and any grooves in packed snow are removed.

For the most of the winter in Lapland the main roads remain either partly or completely free from snow and cause no problems to traffic. However driving styles still need to be adapted to local conditions. There may temporarily be 2-4cm of snow on the road and this should be removed within three (3) hours after the snowfall stops.

Main roads that have less traffic, and busy regional roads, can be partly or completely covered with snow and their surface relatively even. Usually, traffic continues to run smoothly. These slippery conditions require speeds to be moderated. Occasionally there can be 4-8cm of snow, which has to be removed within four (4) hours after the snowfall. When necessary, crossroads, curves and slopes are sanded to reduce their slipperiness, and if need be, whole sections are sanded.

Less busy roads are trafficable at all hours in the winter. These roads can remain covered with snow and may be slippery after snowfall or when the weather becomes warmer. A maximum of 10 cm of snow is permitted on these roads, to be removed within six (6) hours after the snowfall. Crossroads and hills sections are sanded when necessary, including the whole of the road in difficult conditions within 10 hours.

Pedestrian and bicycle ways are kept in such a condition that pedestrians, bicycles and prams can move with ease. No more than 3cm of powdery snow is permitted on pedestrian ways.

The two following tables present the main critical parameters set by the standard.

Quality standards in Lapland for normal winter conditions:

Winter Maintenace Class	**Friction**	**Evenness (mm)**	**Temperature Threshold (°C)**	**Period of Validity [1)] (time)**
Is	0.3	-	-6	always
1	0.28	10	-4	5-22
Ib	0.25(0.20)	15	-	5-22
H	rough, compacted snow	30		6-22
M	rough, compacted snow	30		6-22

[1)] unless local traffic needs require otherwise

Quality standards of winter maintenance in Lapland for changing weather conditions:

Winter Maintenance Class	**Max. Snow Depth (loose Snow / slush) (cm)**	**Cycle Time**		
		Snow/Slush Removal (hr)	**Skid Prevention (hr)**	**Surface Evenness (day)**
Is	4/2	2	2	1
1	4/2	3	2	1
Ib	4/2	3	3 (salt) 4 (sand)	
11	8	4	6	3
	10	6	10	3

7.4.3 Norr Region, Sweden

The standard for the winter maintenance in Sweden is divided in four winter maintenance classes: B1A, B1B, B1C and B2A.

Standard class	**Critical snow-depth for initiating snow removal**	**Finished within**	**Friction[2]**
B1A	2 cm	4 hours	m ≥ 0,25
B1B	Day: 2cm Night[1]: 5 cm	4 hours	μ ≥ 0,25
B1C	Day: 3 cm Night*: 5 cm	5 hours	μ ≥ 0,25
B2A	Day: 4cm Night*: 6cm	6 hours	μ ≥ 0,17

[(1)] Night: Between 20.00 and 03.00 hour (2) In temperature below –10°C μ ≥ 0,23 for standard class B1x is required

7.4.4 Troms County, Norway

The Norwegian standard for winter maintenance defines two strategies for snow removal and friction control; a) "winter road" and b) "clean road". Only the "winter road" strategy applies in Troms. The "Clean road" strategy, which is based on salt treatment, is only practised on high traffic volume roads in southern Norway.

a) Strategy "winter road"

Snow removal

Under snowfall: The maximum snow-depth on the road surface shall not exceed:

AADT	Remove snow before depth exceeds Dry snow (cm)	Wet snow (cm)
0-500	15	12
501-1500	12	8
1501- 3000	10	7
> 3000	7	6

With drifting snow: The maximum snow-depth on the center of driving lane shall not exceed:

AADT < 1500	15 cm
1500 < AADT< 5000	10 cm
AADT > 5000	8 cm

Friction control

De-icing methods: Sand or salt/sand mixtures.
Measures shall be initiated when following criteria are exceeded:

AADT	Measure and time criteria Friction < 0.15	Friction < 0.25
0-500	Complete coverage within 4 hours	Partial coverage within 4 hours
501-1500		Complete coverage within 4 hours
> 1500		Complete coverage within 2 hours

Partial coverage means treatment in curves, slopes, intersections and other hazardous spots.

b) Strategy "clean road" – not applied in Troms

Strategy "clean road" means that the road surface should be free of snow and ice for most of the winter. This strategy requires an extensive winter maintenance service and it is only applied on some well defined main roads that have a traffic volume exceeding 1500 vehicles a day. All other roads are maintained in accordance with the "winter road" strategy.

Snow removal

Under snowfall: The maximum snow-depth on the road surface shall not exceed:

AADT	Remove snow before depth exceeds Dry snow (cm)	Wet snow (cm)
1501- 3000	10	7
> 3000	7	6

With drifting snow: The maximum snow-depth on the center of driving lane shall not exceed:

1500 < AADT < 5000	10 cm
AADT > 5000	8 cm

Friction control

De-icing methods: Salt or saline solution. Other chemicals can also be used. The strategy demands air or road surface temperatures higher than -5°C:

Measure	Measure and time criteria according to AADT 1501 - 3000	3001 - 5000	> 5000
Preventive treatment initiated if:	Expected friction < 0.4		
After snowfall: clean road within	6 hours	4 hours	2 hours

Requirements in the service standard which are difficult to fulfill

The standard for ploughing and maximum snow depth is normally achieved except under extreme weather conditions. This is the case also for the thickness of ice layer and rut depth.

The service standard for snow clearing in crossings (to improve visibility), and clearing snow in front of, and on signs, is more difficult to attain. After heavy snowfalls this is an extensive task, and in some cases Troms do not have the necessary capacity to do the job within the time limits given in the service standards, or before new snowfalls.

Figure 7.4.4. Clearing snow in front of traffic signs is often a neglected issue in hectic periods

The standard for friction control is generally met but is difficult occasionally. The maritime climate, which dominates large parts of Troms, produces rapid changes in temperature. In a few hours the weather can change from stable temperatures well below 0∞C, to several degrees above 0∞C with rain, and in large areas. In the stable cold periods the roads often have a hard snow layer covering the traffic lane, which changes to very slippery ice under the action of rain. Under these circumstances the limited capacity of the Troms fleet i.e. the number of sanding units, cannot cover all affected roads within the time limits given in the service standard.

The standards for pedestrian and bicycle ways demand that the conditions should be no worse than on the road, to ensure that the “soft” trafficants continue to travel on the pedestrian way.

7.4.5 Iceland

Icelandic service standards define five different classes, and the roads are classified based on both the traffic volume and the importance of the roads, see Figure 7.4.5

These service standards not only set levels for maximum snow depths on the road, but also specify how often snow removal services are offered. The frequency may vary from 7 days a week to once a week. Figure 7.4.6 presents the map issued every autumn by the Roads Authority to inform the public.

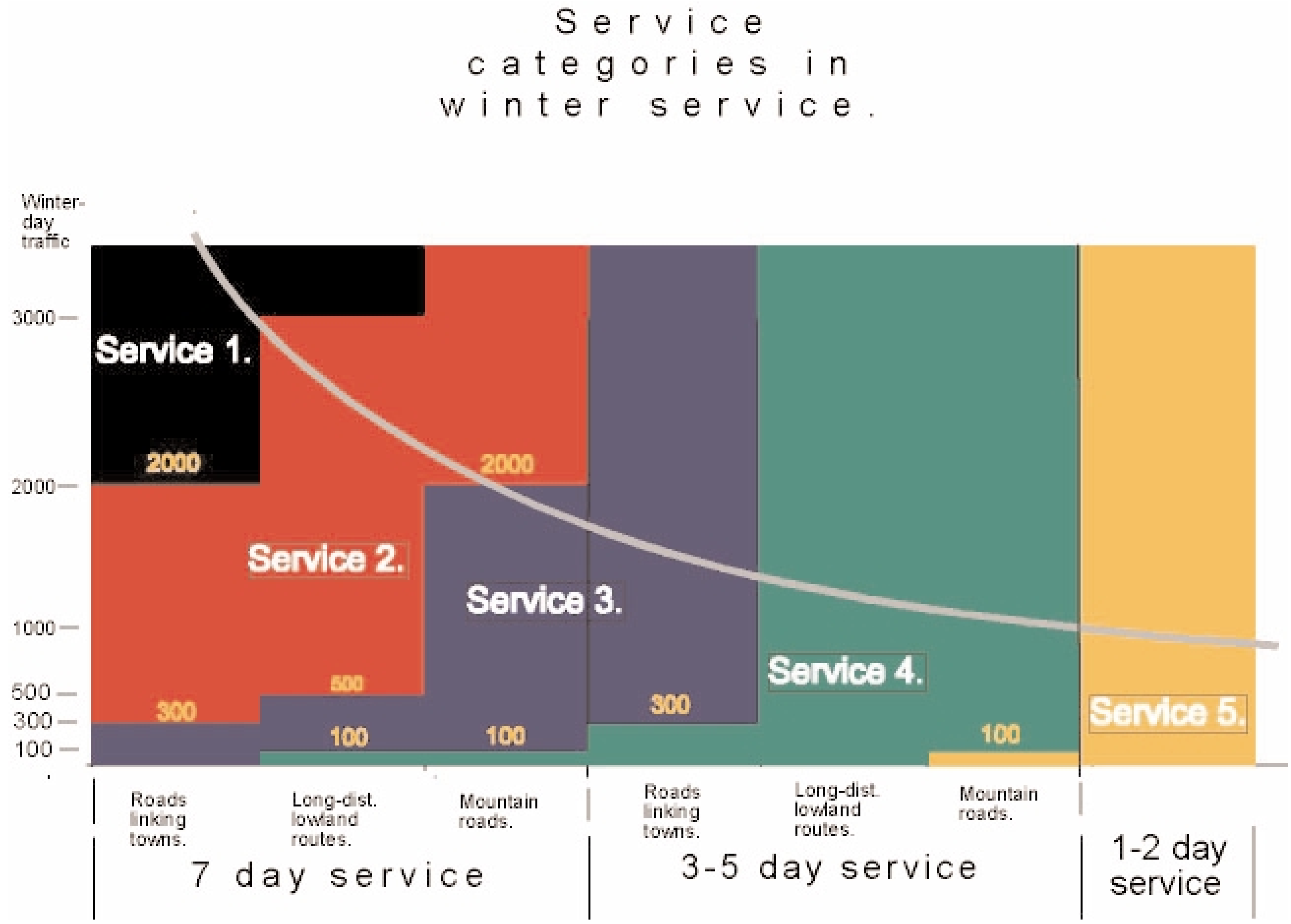


Figure 7.4.5. Service categories in winter service

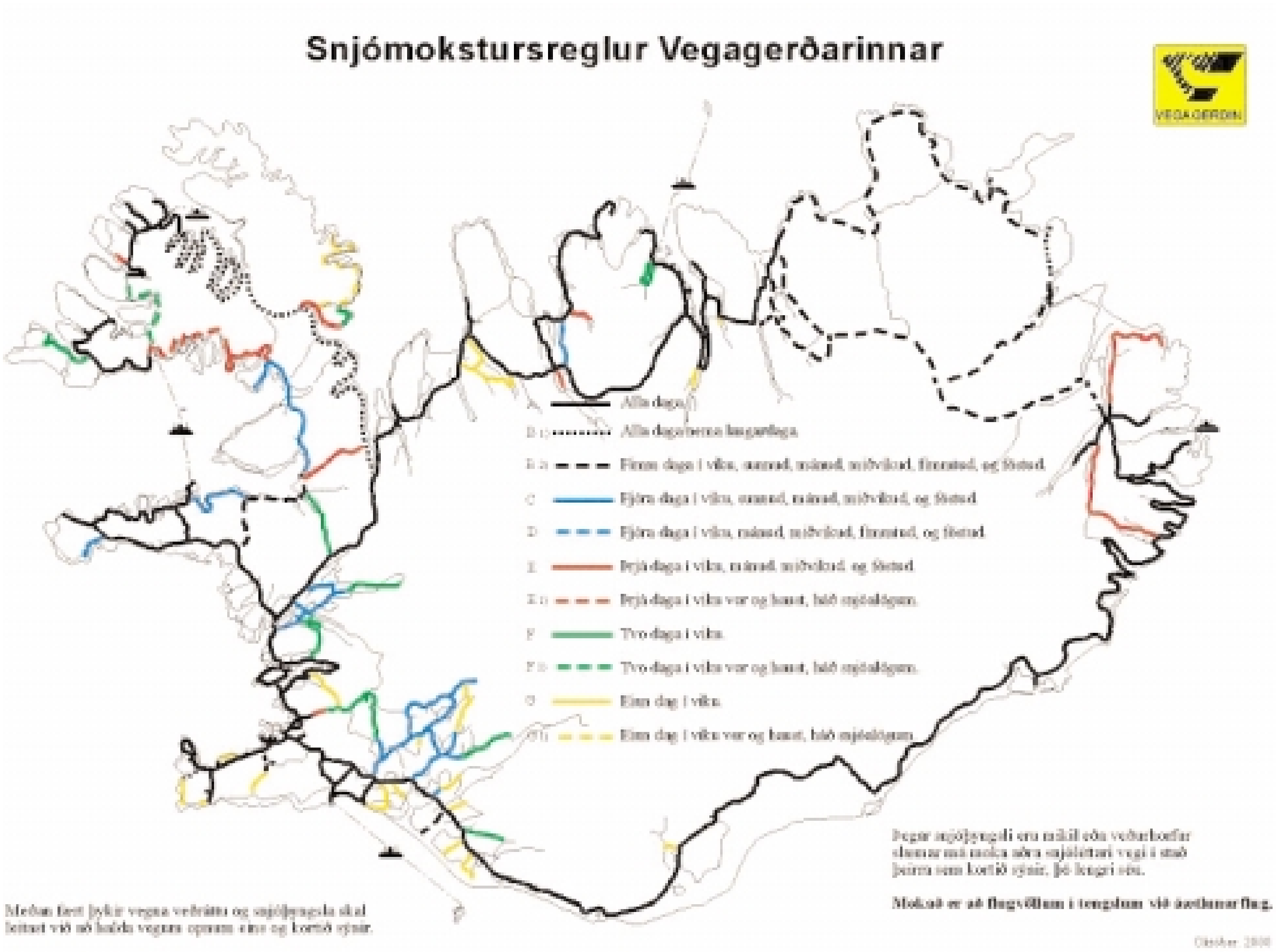


Figure 7.4.6. Winter service days on the road network

Friction coefficients and snow depths on the road have critical values defined by the service categories. These values are given at the next page:

Service Category 1

Service aim	Road surface clear on a 24-hour basis Service routes < 50 km/service vehicle
Service level	Snow depth < 2 cm In snowfall <5 cm Clearing completed within 2 hours Friction >0,25

Service Category 2 – see Figure 7.4.7

Service aim	Road surface clear on a service time basis Service routes < 50 km/service vehicle
Service level	Snow depth < 4 cm In snowfall <12 cm Clearing completed within 3 hours Friction > 0,15 On dangerous roads/district > 0,25

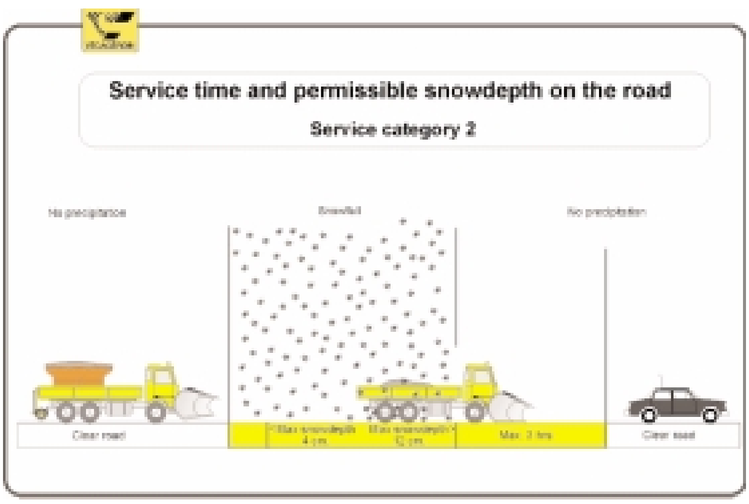


Figure 7.4.7. Service Category 2

Service Category 3

Service aim — Road surface serviced on workdays and special service days
Service routes < 60 - 120 km/service vehicle

Service level — Snow depth < 6 cm
In snowfall <16 cm
Clearing completed within 3 hours
Impassable roads cleared within 4 hours
Friction > on dangerous roads/district >0,15
On extreme dangerous roads/district > 0,25

Service Category 4

Service aim — Road surface serviced where snow or ice has insignificant effect on traffic or safety.
Service routes < 80 - 120 km/service vehicle

Service level — Snow depth < 8 cm
In snowfall <18 cm
Clearing completed within 4 hours
Impassable roads opened within 6 hours
Friction > on dangerous roads/district >0,15

Service Category 5

Service aim — Road surface serviced on special service days
Service routes not specified

Service level — Snow depth < No limit
In snowfall <No limit
Clearing completed within 4 hours
Impassable roads cleared within 6 hours
Friction: No limit, except in special reason on very dangerous places under highly adverse conditions and when extreme skid conditions have arisen.

7.4.6 The Highland Council, Scotland

National Perspective

Section 34 of the Roads (Scotland) Act 1984 sets out the responsibilities of the Regional Roads Authority in relation to the clearance of Ice and snow. This states:-

"A roads authority shall take such steps as they consider reasonable to prevent snow and ice endangering the safe passage of pedestrians and vehicles"

Each Roads Authority is required to develop a winter maintenance policy based on Section 34 of the Act. The policy of each authority will take into account issues such as, the local climate, road priorities, volumes of traffic and available budget. From the policy each authority then develops an operational plan which will be designed to implement the standards set out in the policy.

THE HIGHLAND COUNCIL POLICY

Treatment Priorities

Main National Routes (Trunk Roads) - 24hr response

Priority 1 'A' class main roads - Covered between the hours of 06.00 and 21.00

Priority 2 Other defined main roads including bus routes - Covered between the hours of 06.00 and 21.00

Priority 3 Lesser rural access routes - Covered between 06.00 and 18.00

Priority 4 All other routes - Subject to resources available between the hours of 06.00 and 18.00

Removing Snow

There are no national standards in Scotland which specify maximum snow depth on the road before ploughing is initiated. Guidance on ploughing advises that, for practical reasons, ploughing on main roads will start when the snow depth reaches 30mm. Ploughing and salting generally continues until the road is cleared.

Minor roads receive treatment when resources permit.

Removing Ice

Ice formation on the road surface is treated by the application of coarse rock salt to British Standard Specification. In the Highland area ice formation is the dominating problem throughout the winter period and salt usage can vary from 70,000 to 140,000 tonnes per annum depending on the severity of the winter. "Black Ice" is the most dangerous situation and forms on a wet road surface after a sudden drop in temperature. This is most common around daybreak when clearing skies can result in a small drop in temperature, which is sufficient to cause icing on the road surface. Very often the motorist is unaware of the situation as the road can still appear wet and there is often no other evidence of freezing, i.e. frozen windscreens or car locks.

Friction

The formation of hard-packed snow and ice is not common, except after heavy snowfalls before ploughs and gritters can be effective. When it does occur a mixture of salt and sharp 6mm single sized grit is applied to provide improved traction.

8. INFORMATION SYSTEMS

8.1 Introduction

Cost-effective operation and winter maintenance of roads is dependent on reliable systems for the assembly and distribution of information on weather and driving conditions on the road network. The purpose of this is:

- To assemble information for the operation of the roads.
- To distribute appropriate information to the road-users.

The operation of roads in winter requires reliable data on actual conditions at critical road sections and access to the very best weather forecasts. The Public Roads Authority thus needs to be able to assemble information from people on the road, from instrumented road stations and with the good co-operation of the meteorological services. The latter is extremely important, as the interpretation of modern weather forecasts need to be done by experienced professionals to give accurate forecasts.

This information is assembled through:

- Instrumented stations transmitting data of actual weather and road surface conditions
- Co-operation with the weather service
- Weather radars
- Operation of TV-cameras at critical road sections
- Information from the road-users
- Patrolling by the maintenance crew

Figure 8.1.1 shows an example of a "weather station" capable of collecting data on both weather and driving conditions.

Figure 8.1.1. Weather station

At all times there is a need for the roads-users to be informed about the driving conditions. This need is especially high during severe driving conditions when road-users need to be aware of any major deviations from the normal conditions so that they can select the best route and be able to ascertain the expected time for their trip.

This information is generally expressed in 2 forms: (a) that which the road-users need to have to make their journey and (b) other useful information. In the first group are road closures, expected closures, convoy driving and other kinds of extreme driving conditions. The latter group includes road surface conditions (ice, snow, bare), weather conditions and any other hindrances to free traffic. A primary task for the roads authority is to select the kind of information that should go into each of these groups.

The distribution of information in all partner districts is organized by national or regional Traffic Information Centers (TIC) by using:

- Traffic signs, temporary or variable
- TV and radio
- Telephones via Traffic Information Centers
- Internet

Road-users are in addition usually given information on winter maintenance policy and advice how to behave in case of difficult driving conditions by specially designed leaflets, Figure 8.1.2

Figure 8.1.2 Information leaflets on winter driving from different countries.

8.2 Lapland, Finland

The Traffic Information Center (TIC) in Rovaniemi is shared with the police and the regional emergency center. TIC receives weather forecasts from Finnish Meteorological Institute three times per day, and has in addition daily contact with:

- 7 radio stations
- 2 TV stations
- Contractors and maintenance organizations
- The National Information Center in Helsinki
- Local TIC:s in Finland

The Center also cooperates and exchanges information once a day with the Luleå TIC in Sweden and Oslo / Mosjöen / Skaidi TICs in Norway and into Russia when needed. The police, regional emergency center and newspapers also receive this information.

The TIC provides information on:

- road conditions
- road closures
- speed and weight limits
- traffic accidents
- road works
- maintenance activities
- ferry and ice road traffic
- local events
- wild animal warnings etc

Figure 8.2.1 presents a graphical description of the assembly and distribution of information for the Traffic Information Center in Rovaniemi.

In addition to the information issued by the Rovaniemi TIC, Finnish Television also presents a daily service called "The Road Weather" during the winter. This service has been developed in co-operation with The Finnish National Road Administration, The Finnish Meteorological Institute, The Central Organization for Traffic Safety, The Finnish Motor Insurers' Center and The Finnish Broadcasting Company. The information is based on road conditions and weather forecasts.

There are three categories in Road Weather Information to describe the driving conditions on roads:

- 1 normal
- 2 poor
- 3 hazardous

Today this information is sent and received electronically via telephone, telefax, e-mail and Internet.

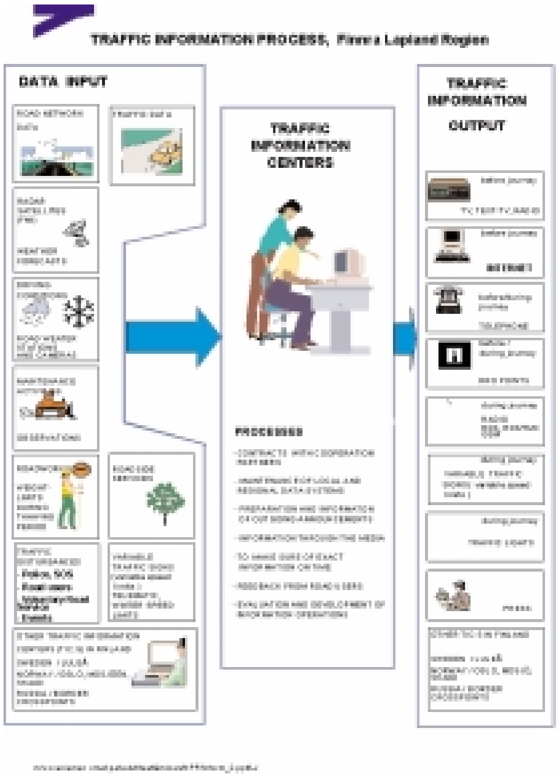


Figure 8.2.1. Traffic information process.

Another service offered is a round-the-clock phone service for road users called "Finnra's Road User Telephone Service" which is available on Tel 0200 – 2100 (traffic hotline).

Information on road conditions is also available by weather stations run by Finnra. In total 19 stations and 17 cameras are connected to the Traffic Information Center and the data is presented on the Internet. It is thus possible for everyone to get up to date information on road weather conditions, traffic situations and roadworks on Finnish public roads 24 hours a day.

Figure 8.2.2 shows the distribution of weather stations and TV-cameras run by the PRA in Lapland.

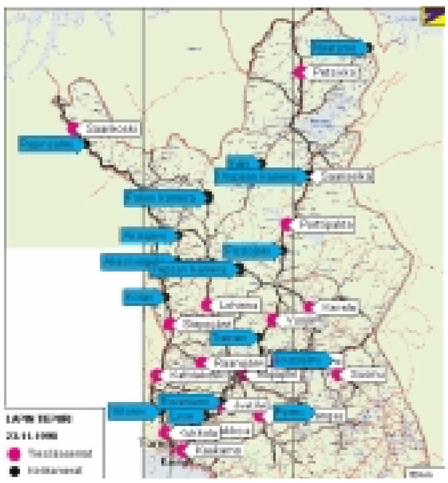


Figure 8.2.2. Loacation of weather stations and traffic cameras

8.3 Norr Region, Sweden

There are approximately 75 weather stations in the SNRA, Norr Region. This system is called the Road Weather Information System, or RWIS, and is supervised by the TIC in Luleå. There are 14 road weather cameras connected to the RWIS and this technical instrumention and data are monitored both day and night around the year. All the information is logged and can be used for later analysis.

Weather reports from the meteorological institute (SMHI) are provided every 12 hours, via the Internet, and through live forecasts from weather radar and satellite pictures. The Road Administration buys this information from the SMHI and the TIC and accesses the meteorological institute at any time for updates.

Figure 8.3.1. Weather station.

Winter maintenance contractors also use the RWIS and have contact with the TIC at least three times a day; in the morning, in the middle of the day and in the evening, and also whenever there is a change in conditions for road users. The TIC regularly updates its Internet page with changes as well as all other users who request the information.

The Luleå TIC co-operates with Norwegian and Finnish Traffic Information Centers under a project called BARTIC, (BARents Traffic Information Co-ordination). Under this agreement information is exchanged on everything concerning the accessibility of roads. The Internet is being used more and more for this aspect.

The TIC receives in average about 30 phone calls per day in summertime, and around 80 in winter but has the capacity to handle up to 350 to 400 calls in 24 hours. Their web page www.vv.se – “Läget på vägarna” has around 1500 visitors a day.

The information is delivered from the TIC to the road users through a system called TRISS which stands for TRaffic Information Support System. It is used in all the TIC’s in Sweden and the system delivers information nationwide through the Internet, e-mail and fax, and to the RDS/TMC-system. Information regarding closed roads in the mountains is given on interactive signposts at the roads, Figure 8.3.2. Radio, mail, fax, telephone and Internet are used for all kinds of traffic information.

Figure 8.3.2. Sign on road E10 just out side Kiruna. Fix message; “Snow obstacle, road E10 closed Björkliden-Riksgränsen, for information call 020-227766”.

8.4 Troms County, Norway

Weather stations

In January 2001 seven weather stations were in operation, but during the summer of 2001 a further five new stations will be installed so that by autumn 2001 there will be 12 stations in operation. These stations can be used for real time weather monitoring but the measurements are also recorded for statistical use. Some of the stations will be equipped with surveillance cameras in the near future. The purpose of these weather stations is to monitor driving conditions, support the maintenance activity, and collect statistical weather data for use in strategic planning etc.

Patrolling

Patrolling is not used on general basis but maintenance crews may have to inspect different road sections when climatic conditions vary spatially.

Weather forecasts

In addition to public forecasts on TV and radio, the PRA receives special detailed forecasts for chosen road sites (meteogram) from the Weather Bureau, Figure 8.4.1. This meteogram gives a detailed description of the weather expected to come and has been a valuable tool for winter maintenance. Especially useful has been the timing of coming storm-periods for planning maintenance strategies. The meteogram read-outs have already initiated broadcasting warnings to motorists about road closures due to strong winds and drifting snow.

There also is an agreement between the Weather Bureau and the PRA, that if there are expected rapid changes into extreme weather conditions, and this change has not been mentioned in the forecasts, the Weather Bureau will send a warning to the PRA. The actual weather conditions are:

- Rain freezing on the ground
- Major deviations from forecasted magnitudes or types of precipitation if the deviations are expected to affect the driving conditions.

Warnings are sent by telephone or fax from the Weather Bureau to the PRA's national traffic information centre in Oslo who pass the information on to the affected region.

Directly submitted information

A telephone-controlled signpost on road no. 86 at Silsand advises about closed roads on the island of Senja. Two manual signs on road E6 on either side of mountain-road Kvænangsfjellet at Storslett and Burfjord respectively advise on closures and convoy driving, Figure 8.4.2.

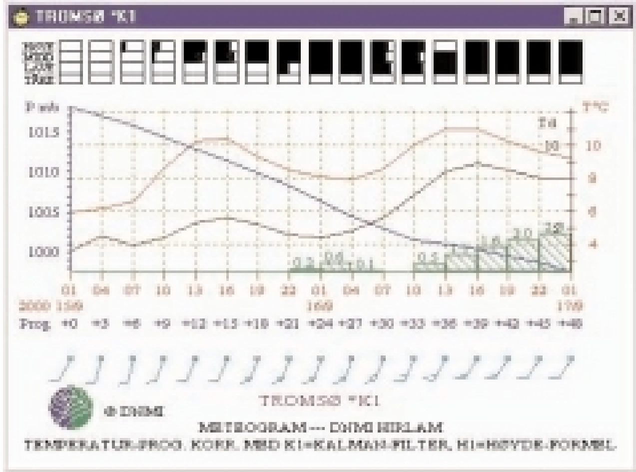


Figure 8.4.1 A 48 hour prognosis meteogram for the Tromsø area.

Figure 8.4.2. Manual sign showing the status on E6 at Kvænangsfjellet. "Stengt" in Norwegian for closed.

Radio and TV stations nationwide receive data on weather and driving conditions from the TIC. Additionally conditions on a defined network of main roads are reflected on a Radio Data System (RDS) by the National broadcasting organisation.

Active action information

The nationwide TIC telephone number, 175, directs all calls to the regional information center. Up-to-date information is available at the national web-site:
http://www.vegvesen.no. The same information is also presented on text-TV on the National Television.

8.5 Iceland

Computers at the Icelandic Roads Administration headquarters download information from weather stations and other roadside monitoring points at regular intervals. The data collected is immediately formatted for different user groups and then automatically distributed to the media and Internet. The system includes information on weather, road conditions, driving conditions, weight limits, road works and ferry schedules. The PRA has a good cooperation with The Icelandic Meteorological Office who also have access to weather radars, Figure 8.5.1.

The PRA information service is carried out by service telephones with the same number, (1777) for the whole state and offers a direct information service from 7:00 am to 20:00 pm. Daily. At other times recorded information is given on road conditions.

PRA´s home page, http://www.vegagerdin.is also gives online information on road and weather conditions as Figure 8.5.2. Variable weather message signs are additionally placed on some roads with histories of high winds dangerous for driving or other weather conditions which influence traffic, Figure 8.5.3.

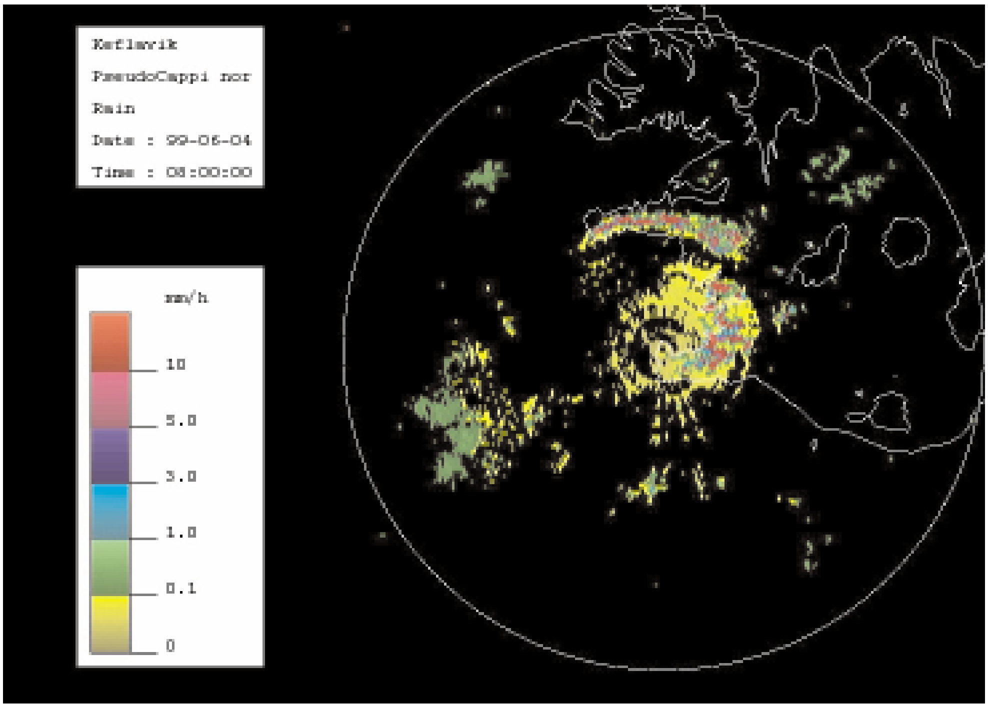


Figure 8.5.1.
Weather radar image, precipitation rate

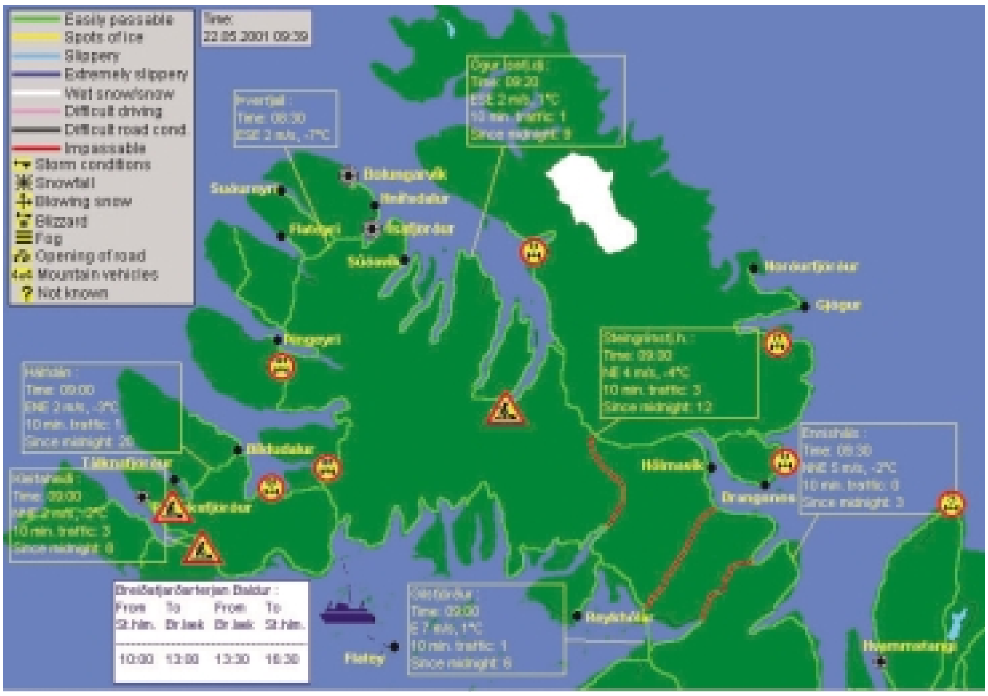


Figure 8.5.2. Information on weather, driving conditions and ferry schedules on the Internet.

Figure 8.5.3 Variable signpost monitoring weather station.

8.6 The Highland Council, Scotland

Weather Stations

Within the Highland Area there are 65 ice detection sites, which provide real time information on actual road conditions. The Roads Authority has access to the outstations within its area through a computer system and these outstation sites provide the following data:

- Road surface temperature
- Air temperature
- Road surface condition (dry or wet)
- Salt concentration
- Wind direction
- Wind speed

Figure 8.6.1 Ice detection sensor in the road surface.

Patrolling

Routine winter patrols are only carried out on the main A9 route between Perth and Ardullie, just to the north of Inverness. This route has some high passes and the road reaches its maximum elevation at the Drumochter Pass at 460 m above sea level. The A9 is the main road link into the Highlands of Scotland. Patrols are carried out throughout the winter period, from November to March.

Forecast Stations

Of the 65 ice detection stations, 20 are used as Forecast Sites, Figure 8.6.1. The Meteorological Office interrogates these sites on a regular basis to collect information to produce forecast information. The forecast graphs predict the temperature and precipitation profiles over the next 24-hour period. This information allows Engineers make operational decisions with regard to the treatment of roads in their area, Figure 8.6.2.

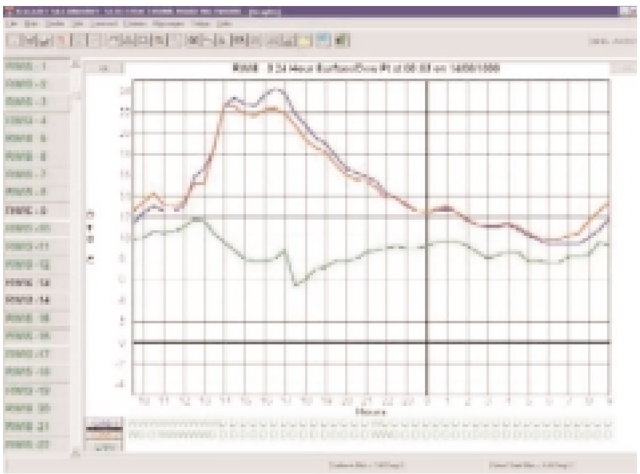


Figure 8.6.2. Example of computer output.

Weather Forecasts
The Meteorological Office provides daily forecasts to the Roads Authority on a daily basis. These forecasts, pro-duced as part of the “Open Road” service, provide the following data.

24 Hour Forecast – predicts weather patterns over the following 24 hours

- Temperature profile
- Precipitation profile
- Wind strength and direction
- Advice on potential hazards

2 to 5 Day Forecast - a summary of the forecast over the following 2 to 5 days

In addition to these forecasts each operational area has direct telephone access to The Meteorological Office forecasters to get advice on specific issues.

Other
Reports from supervisory staff on road conditions.

The Police will also advise the Roads Authority of any problems that develop on the road network.

Special Signposts
NADICS – the National Driver Information Control System controls a series of strategically based variable message signs throughout Scotland. NADICS was established by the Scottish Executive, with the aim of providing drivers with information about conditions on the road network on a Scotland-wide basis. NADICS operates from a single control point located in Glasgow.

There are 4 variable message signs in the Highland Area and one of the main purposes is to provide drivers with up to date information on road conditions during the winter period, Figure 8.6.3.

Figure 8.6.3. Variable Message Sign.

In addition to the variable message signs there are a further 16 fixed message signs, which are used specifically to advise motorists of road closures.

Local Radio
Local radio is used on a regular basis to provide the public with up to date information on road conditions during the winter, especially during periods of severe weather when roads may be closed due to snow.

Other
Information leaflets are issued to the public each winter, which gives information about the level of service to be provided on both their local and main roads. The Scottish Executive issues a similar leaflet in respect of the trunk road network.

Telephones
A telephone information service is available throughout the winter. This allows the public to access up to date information on road conditions. The message is pre-recorded and updated on a regular basis as road conditions change. Small cards are issued through petrol stations and other outlets at the beginning of each winter that give general advice on winter driving together with the phone number for advice on road conditions.

Internet
To date there are no plans to use the Internet.

Text-TV
Text-TV gives general information on weather forecasts but to date has not been used to provide detailed information on road conditions at a local level.

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Rekkverk

APPENDIXES

Appendix A , Climatic maps

Figure A.1. Subdivision of Europe into four climatic zones due to temperature and precipitation. (Statens Kartverk. National Atlas of Norway, Climate)

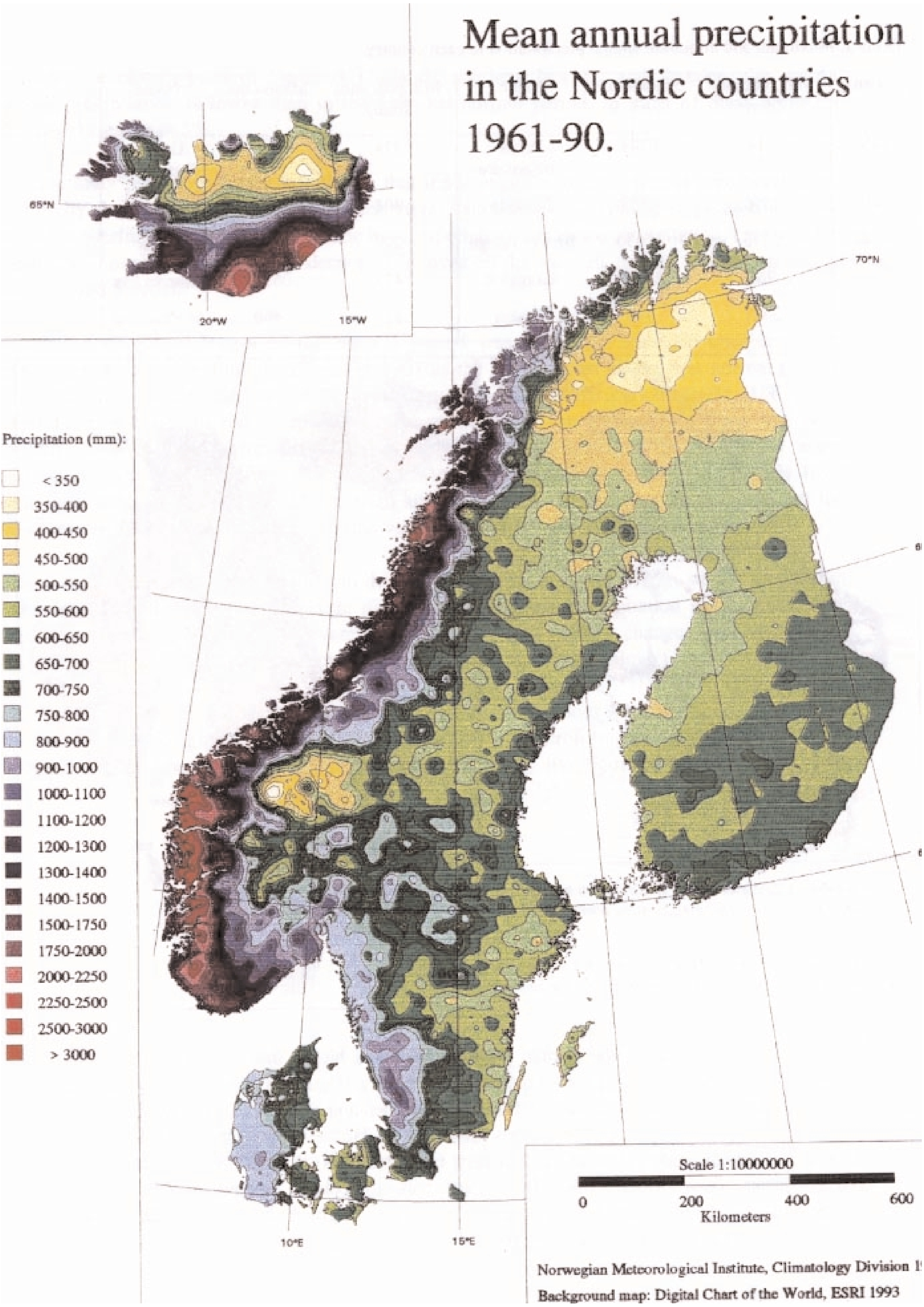

Figure A.2. Annual precipitation in the Nordic countries. (Norwegian Meteorological Institude. Nordic precipitation maps, report no. 22/97 KLIMA)

Figure A.3. Average annual precipitation, Scotland. (Met Office, Britain: www.metoffice.com).

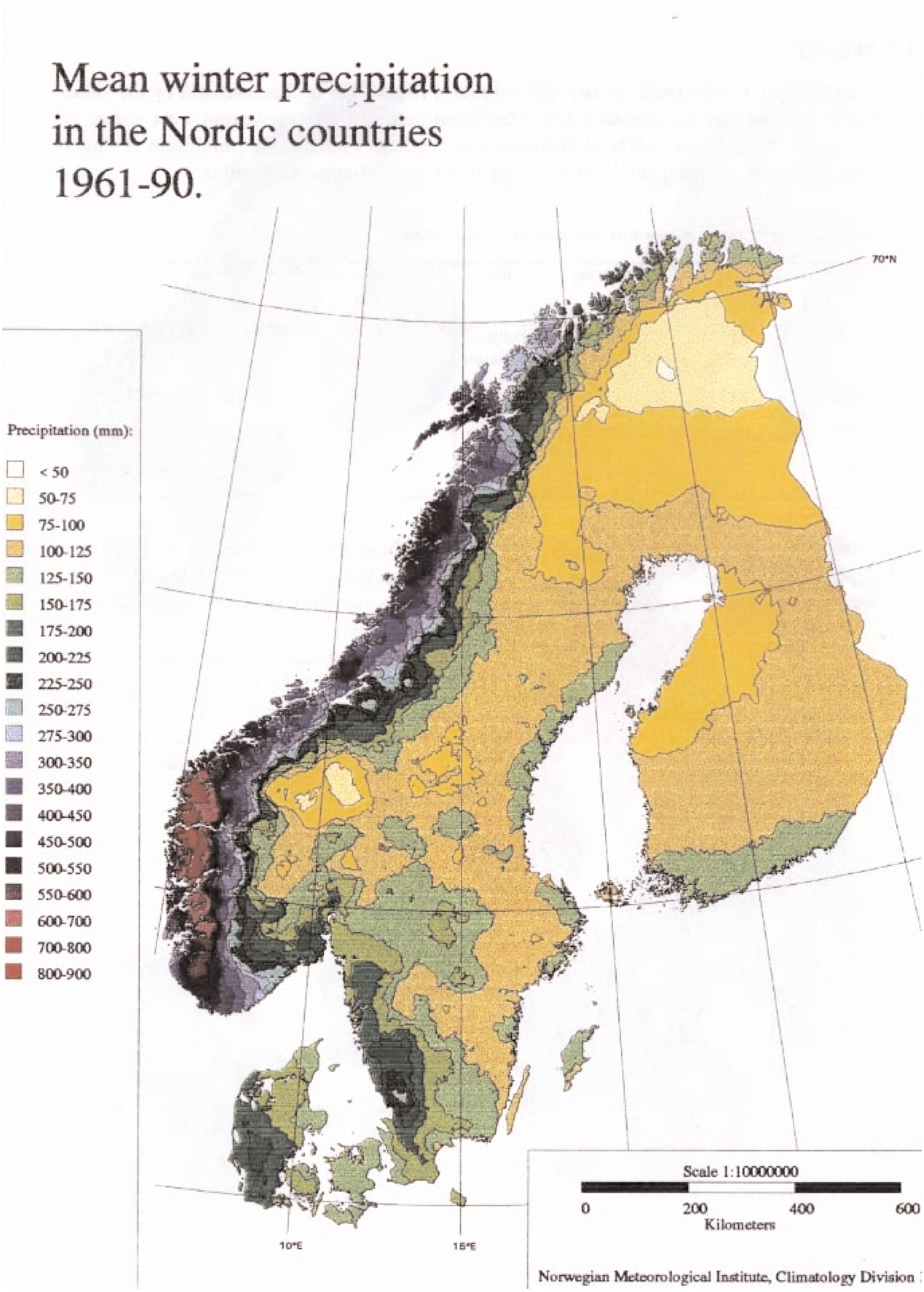

Figure A.4. Average precipitation in the winter season. (Norwegian Meteorological Institude. Nordic precipitation maps, report no. 22/97 KLIMA)

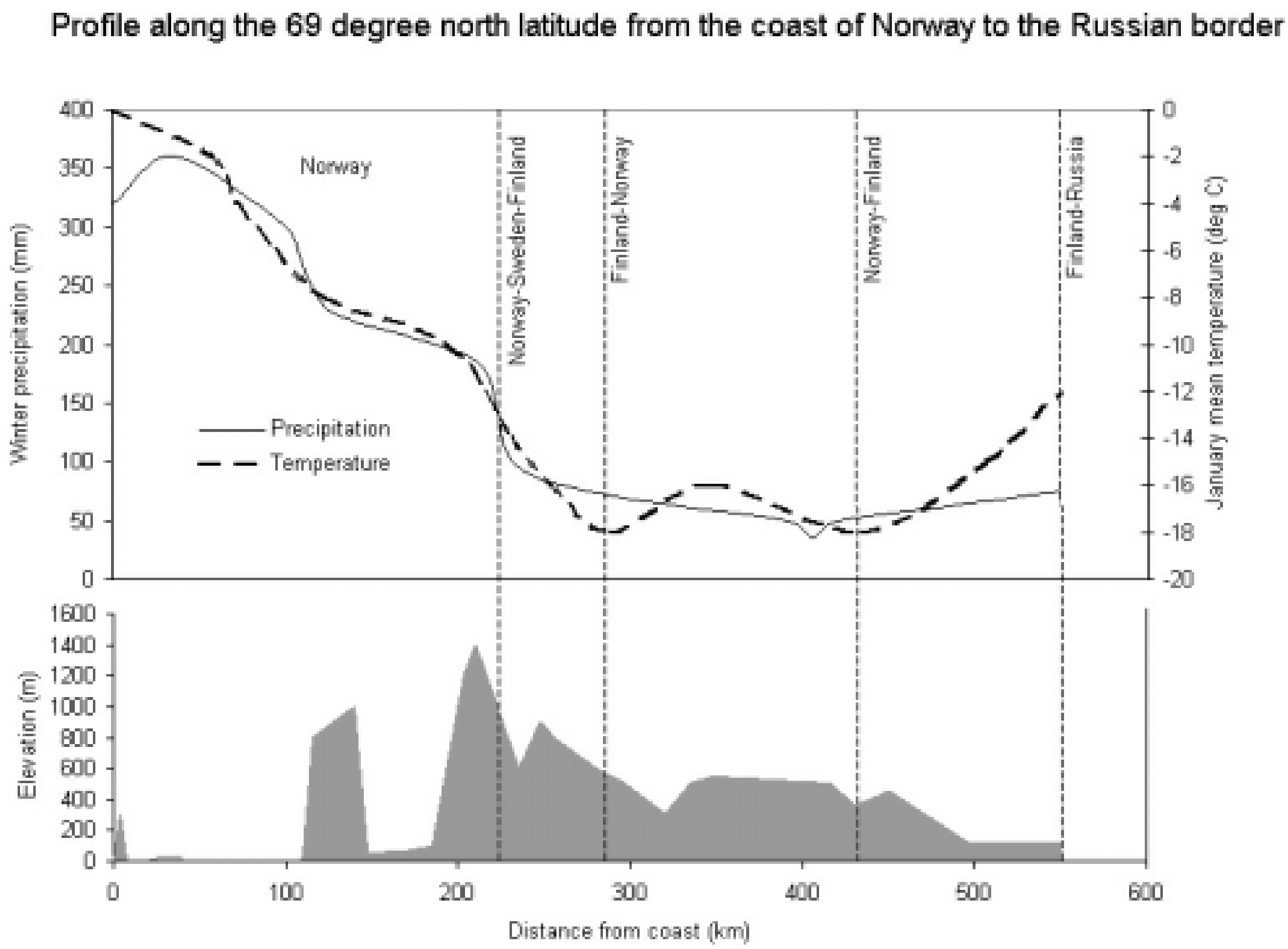

Figure A.5. Profile along the 69 degree north latitude. Climatic variations.

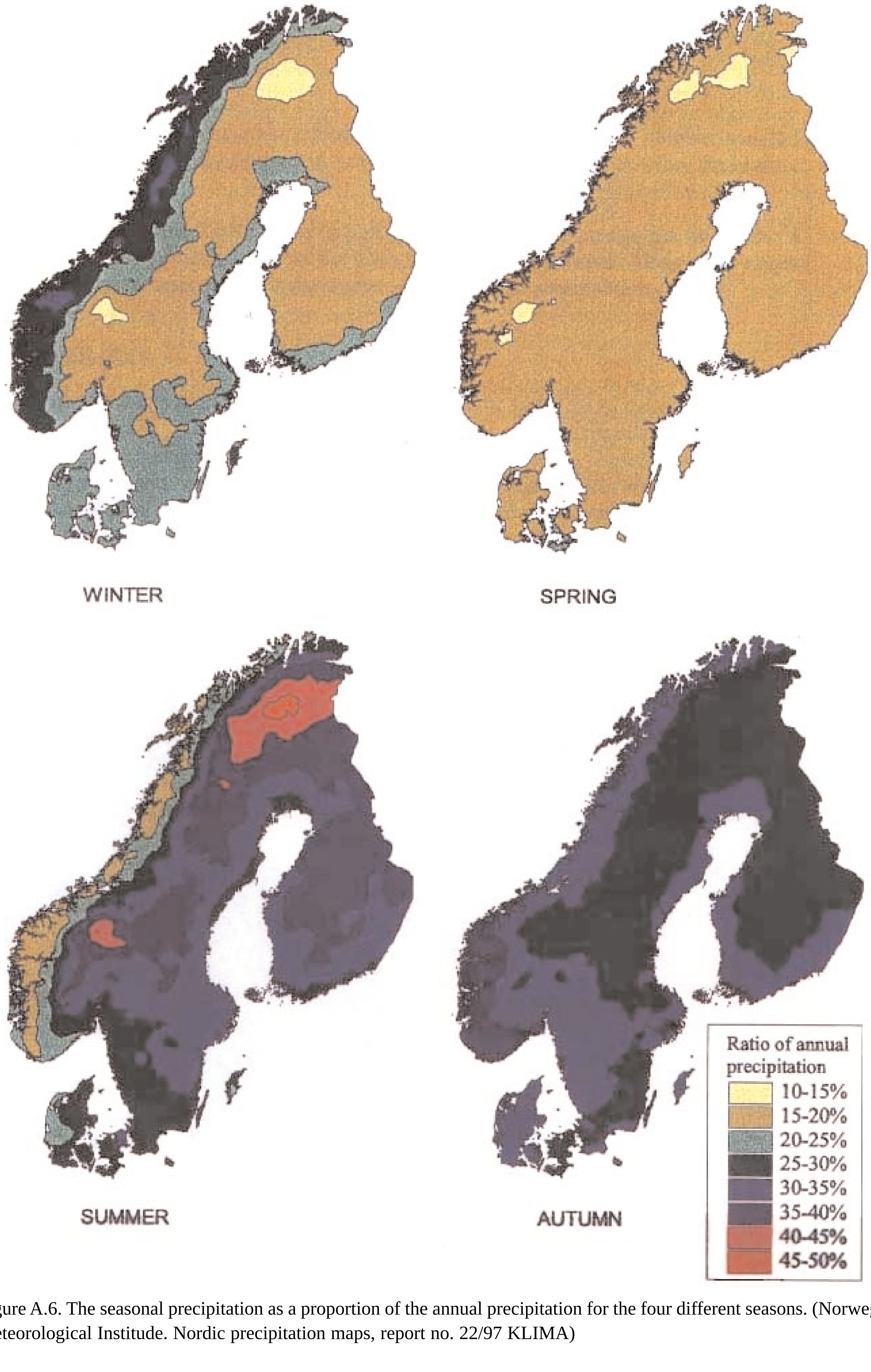

Figure A.6. The seasonal precipitation as a proportion of the annual precipitation for the four different seasons. (Norwegian Meteorological Institude. Nordic precipitation maps, report no. 22/97 KLIMA)

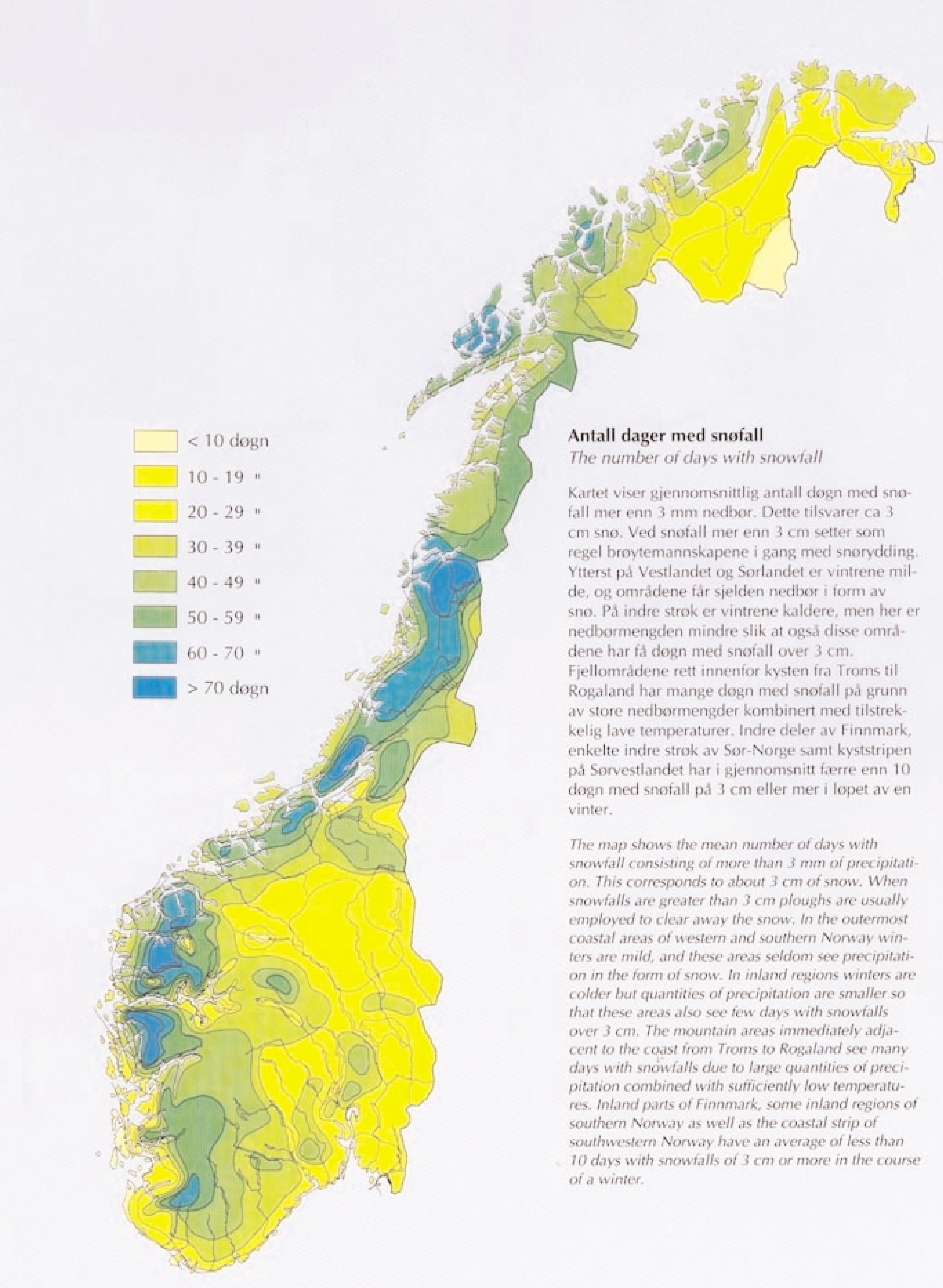

Figure A.7. Number of days with snow fall, Norway. (Statens Kartverk. National Atlas of Norway, Climate)

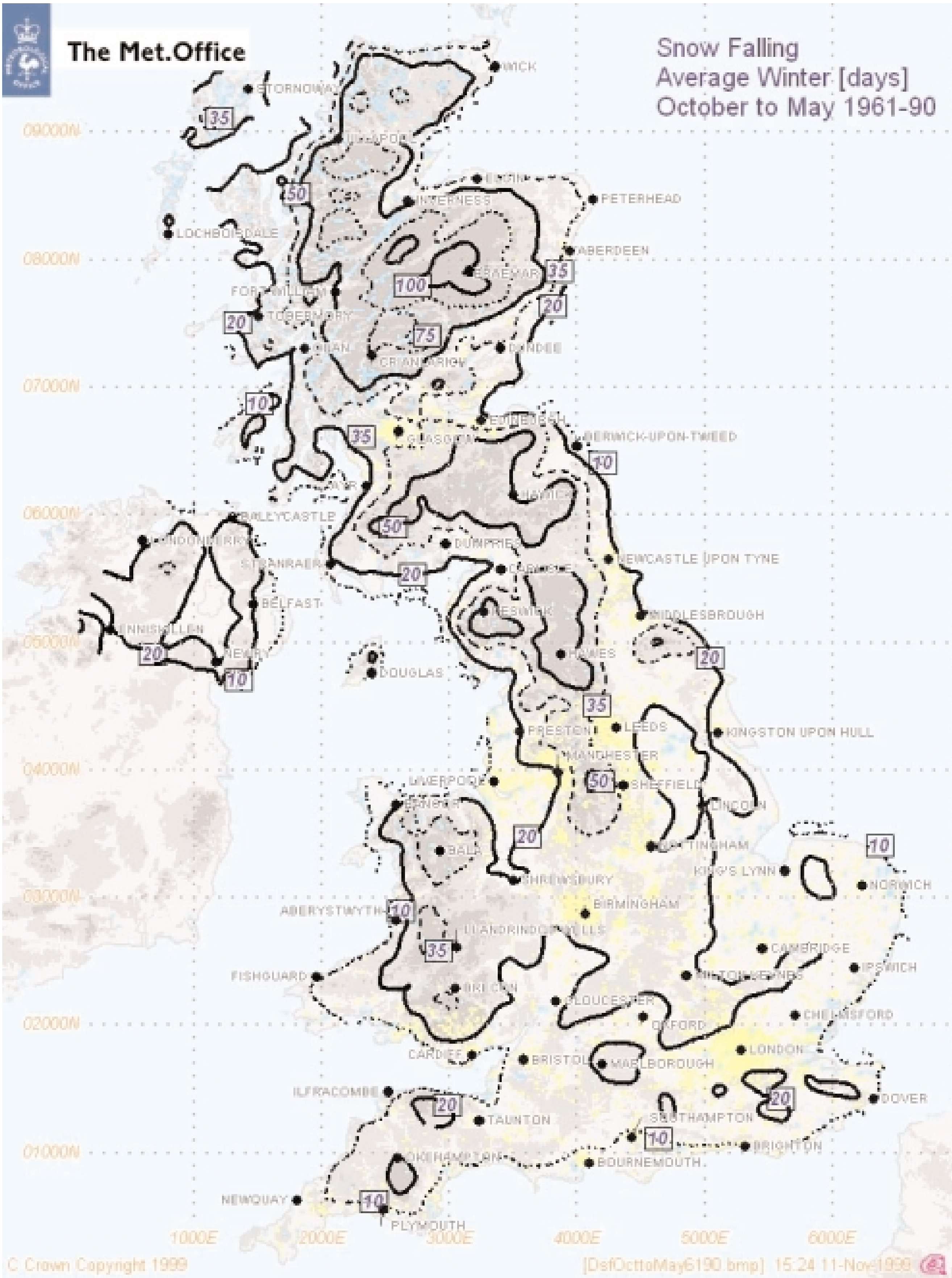

Figure A.8. Number of days with snow fall, Scotland. (Met Office, Britain: www.metoffice.com)

Mean January temperature 1961-90

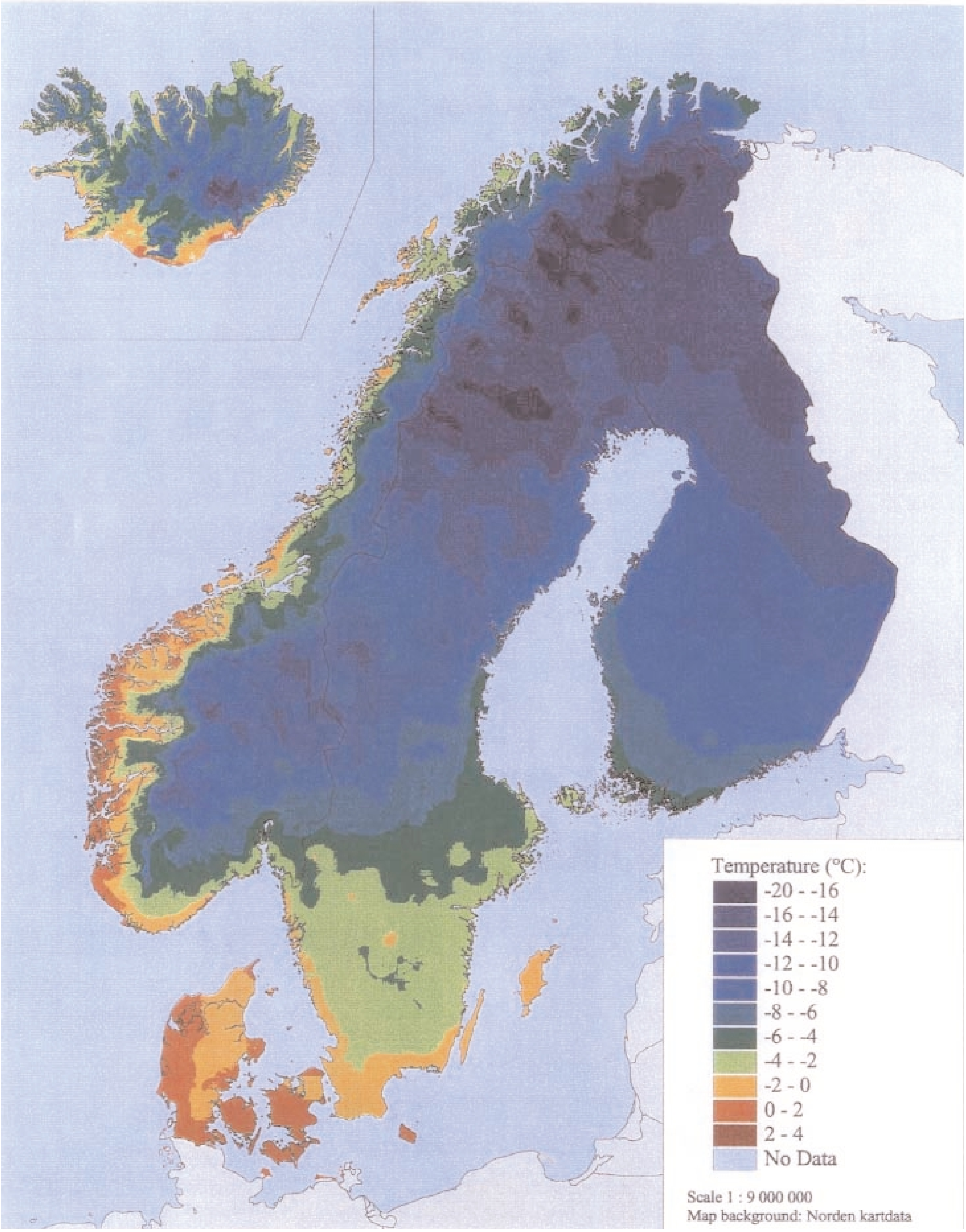

Figure A.9. Mean temperature in January for the Nordic countries. (Norwegian Meteorological Institude. Nordic temperature maps, report no. 09/00)

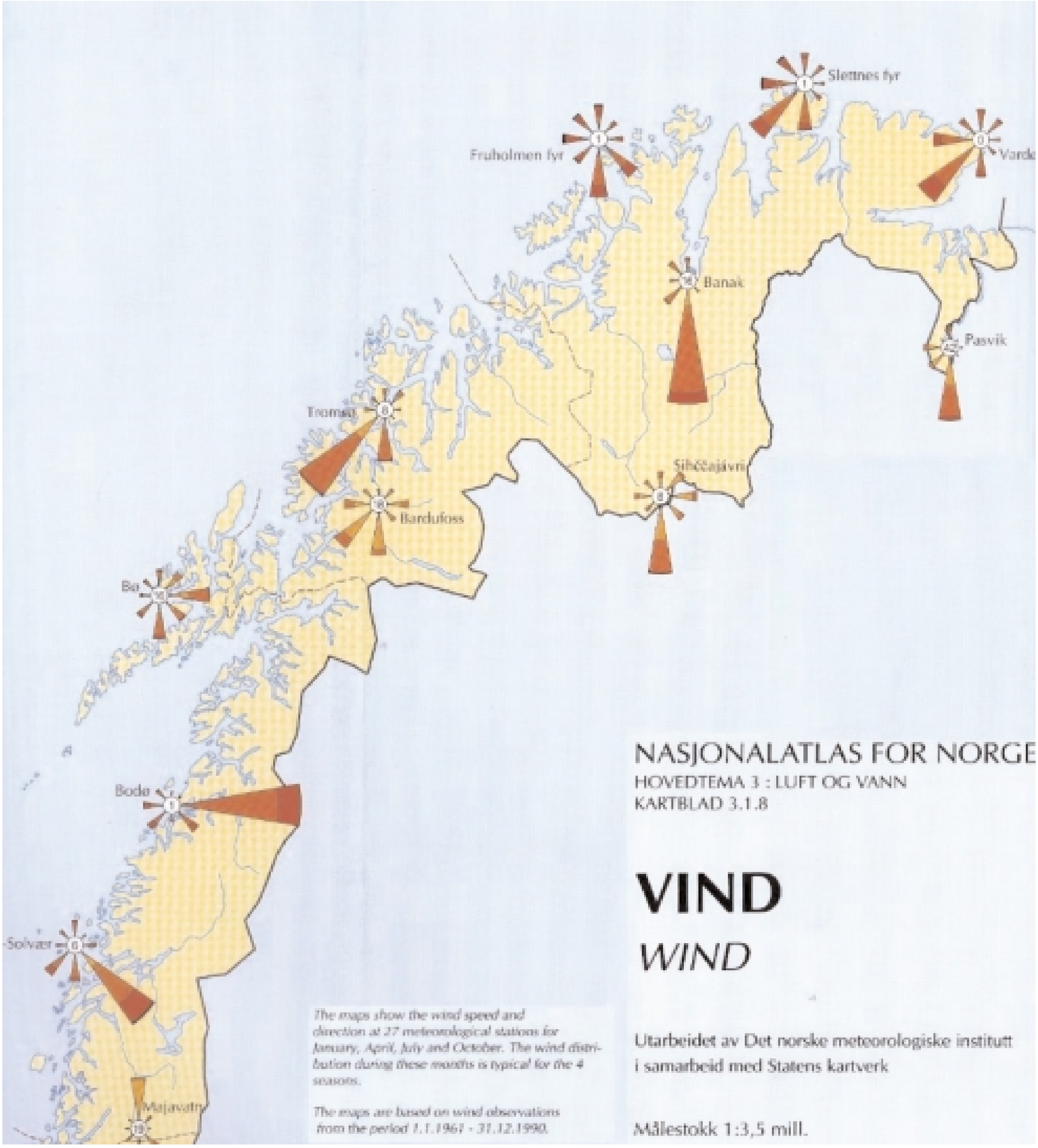

Figure A.10. Wind map for January, Norway. (Statens Kartverk. National Atlas of Norway, Climate)

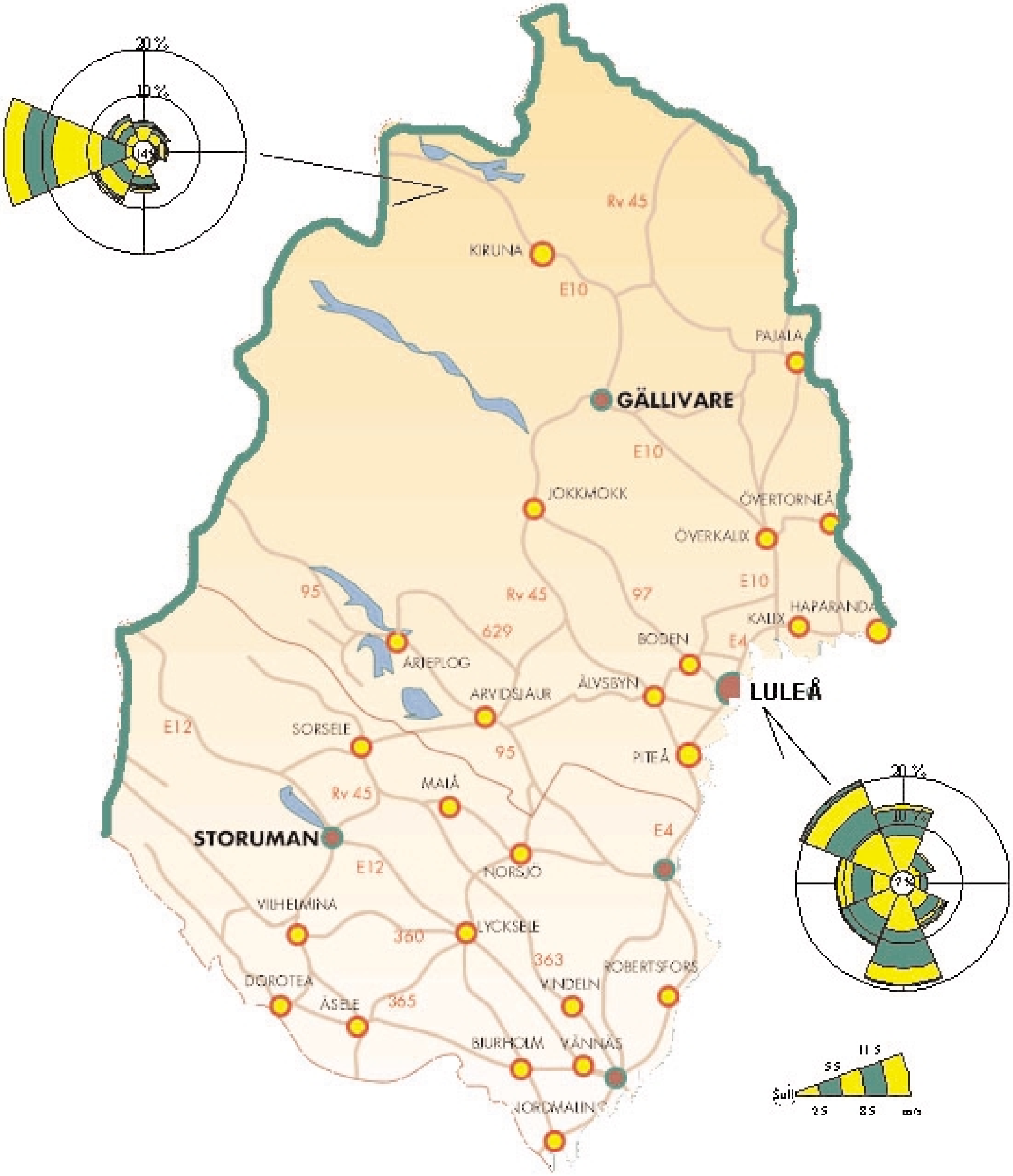

Figure A.11. Wind roses for January, Sweden (SMHI, Swedish Meteorological and Hydrological Institute)

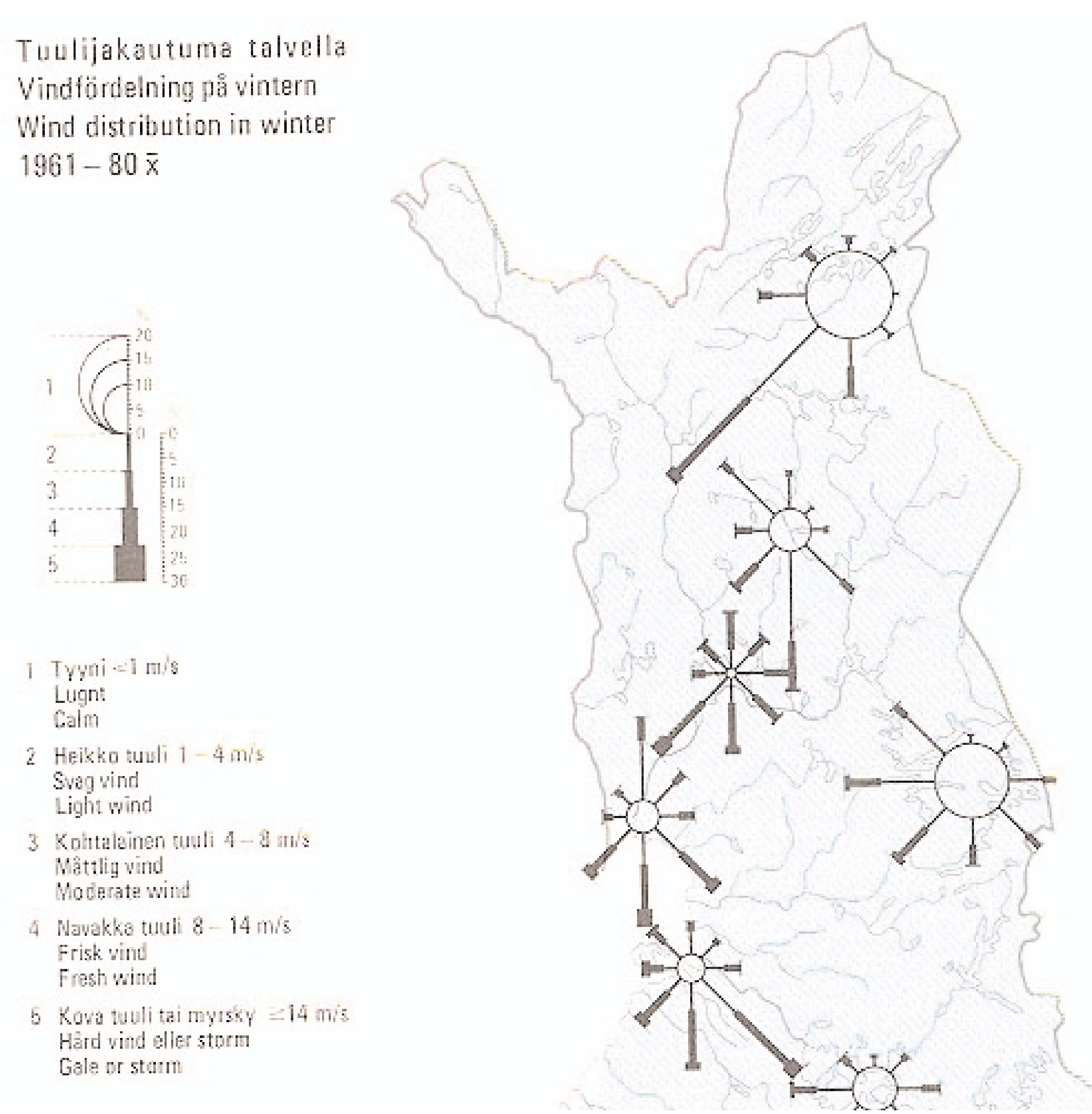

Figure A.12. Wind map for winter, Finland.

Figure A.13. Topographic map.

APPENDIX B CONVOY DRIVING POLICY

Swedish administartive guidelines

1. The decision of when convoy-driving starts is taken by the maintenance crew who is in charge at the actual road.
2. Convoy driving shall be initiate when the weather and road conditions are so severe that there are risks for the traffic to get stuck due to bad visibility or due to too narrow road caused by snowdrift.
3. When convoy driving not can be carried out due to traffic safety, the road shall be closed to traffic.
4. When initiating convoy driving, great attention shall be paid to conditions of wind and precipitation, weather reports and data from weather stations.
5. The maintenance crew in charge shall inform the Traffic Information Centre when convoy driving is initiated and cancelled. The crew shall note dates and times of when convoy driving is initiated and cancelled in a diary.
6. When convoy driving is initiated the road must be closed with a lockable gate. Warning lights and an information sign must be lightened. The maintenance crew in charge shall make sure that no road users are on the closed section. The gate shall be locked as long as convoy driving is carried out, or as long as the section is closed.
7. The road users should be kept informed as far as possible about the conditions on the road section and be informed of the regulations for convoy driving. Road users who cannot join a convoy shall be informed about how long they are expected to wait for the next convoy.
8. The maintenance crew in charge decides the composition of heavy trucks, cars and how many vehicles that will be included in the convoy. In normal cases should heavy trucks be at front of the convoy to avoid collision with cars.
9. In the front of the convoy shall always be plough truck. The convoy shall be kept together and be followed by a maintenance vehicle. The maintenance vehicles shall be able to communicate with each other by phone or communication radio.
10. Special criteria for the actual road section are given by the “Function- and standard description” in the tender document

Norwegian instructions for drivers

1. For your own safety, only a limited number of vehicles are allowed in a convoy.
2. Snowplough drivers have liberty and aythority to turn away any travellers they belive may have difficulty in managing the strenuous journey, e.g. persons who are not wearing winter clothes, persons in vehicles that are not technically up to standards.
3. Keep a torch, a tow rope and a snow shovel within easy reach.
4. While driving in a convoy, never loose sight of the car in front.
5. Maintain a steady speed as far as possible.
6. Adjust your ventilation system to supply cold air to your front windscreen.
7. Use your blinking emergency lighting and fog lamps, if possible.
8. Do not leave the convoy or try to turn.
9. If you have to stop, or if the convoy comes to a halt, it is important that you stay in your vehicle as leaving the vehicle can be extremely dangerous.
10. Due to limited transmission/line capacity please do not use your cellular phone when driving in convoy.

APPENDIX C ROADEX PUBLICATIONS

Following are references to presentations and publications from Roadex Subproject B, Winter maintenace.

1. Tapani Pöyry, presentation at the Winter Road Congress in Tampere, 2.-3.February 2000

2. Tapani Pöyry (in preparation) Technical Exchange in the European Northern Periphery to Identify Best Practices in Winter Maintenance. PIARC Winter Road Congress, 2002, Sapporo

3. Norem, Thordarson. Operation of roads exposed to drifting snow in Northern Europe. Proceedings of the 4th International Conference on Snow Engineering, Trondheim 2000.

4. A PhD. student at NTNU, Skuli Thordarson, has been partly financed by the Roadex project. His thesis on road enginneering in snow drifting areas is scheduled for defence in 2002. The method of the project is to use numerical simulations to find better criteria for the design of roads exposed to snowdrifts. By june 2001 the following material from the research is available:

   - Thordarson, Norem. Simulation of two-dimensional wind flow and snow drifting applications for roads, Part I & II. Proceedings of the 4th International Conference on Snow Engineering, Trondheim 2000.

   - Thordarson, 2000. Guard drails, evaluation of snow drifting properties by wind flow simulation. Internal note to the Icelandic Public Roads Administartion.

   - Thordarson, 2001. Road cuts, snow drifting evaluation. Internal note to the Icelandic Public Roads Administartion.

   - Thordarson, 2000. Climatic analysis for mountain road Kaperdalen. Internal report to the Troms county PRA.

   - Thordarson, 2000. Troms Suggested modification of the Kaperdalen Road. Internal report to the Troms county PRA.

   - Thordarson, 2001. Wind tunnel experiments and numerical simulation of snow drifting around avalanche dams. To be submitted to Environmental Fluid Mechanics, Kluwer Academic Publishers.