Effect of a changed climate on gravel roads

Per Otto Aursand,
Norwegian Public Roads Administration (NPRA), Norway

Ivar Horvli,
ViaNova Plan and Traffic AS, Norway

ABSTRACT: In the Norwegian Public Roads Administrations (NPRA) R&D program “Climate and Transportation” the main goal is to improve planning, design, operation and maintenance of the road network in Norway in order to adapt to future climate changes. This implies to come up with recommendations and to develop revised guidelines to cope with a changed climate based on the Intergovernmental Panel on Climate Change (IPCC) reports and Norwegian climate research (RegClim). One of the tasks is to investigate the effect of a changed climate on gravel roads, which is described in this paper. This task will be dealing with analyses of pavement condition, estimation of changes in maintenance costs and proposal for actions to cope with negative consequences of a changed climate. There are limited data available on gravel roads in Norway; hence, a survey in all the NPRA regions was carried out. Pavement and drainage condition data, current maintenance methods, maintenance costs, and intervals where collected and analyzed. The results were used together with the estimated change in climate to do some preliminary estimation for rehabilitation and maintenance needs and the corresponding maintenance costs.

1 INTRODUCTION

In the Norwegian Public Roads Administrations (NPRA) R&D program “Climate and Transportation” the main goal is to improve planning, design, operation and maintenance of the road network in Norway in order to adapt to future climate changes. One of the tasks is to investigate the effect of a changed climate on gravel roads, which is described in this paper. This will make a basis for revised guidelines and maintenance routines to cope with a changing climate.

The gravel road network in Norway consists of 5 657 km of county roads (2007), 17 388 km municipal roads and 48 500 km of forest roads. The gravel road network is unevenly spread around the country with a concentration in the eastern and central regions. Traffic volume on the county roads are on average AADT= 1200. The standard for maintenance of gravel roads used by NPRA is described in the Handbook 111 (NPRA 2005). There are given requirements for evenness, crossfall and dust dependent on AADT. The condition of a gravel road will be influenced by climate, traffic, material properties and drainage conditions. The most important climatic factors for gravel roads are temperature (frost, freeze/ thaw-cycles/ spring thaw weakening) and precipitation (total rainfall, intensity). Other factors like wind and cloud cover will also have some influence. Today’s climate (mean yearly precipitation and temperature) in Norway is shown in Figure 1. The anticipated change in climate found by the Intergovernmental Panel on Climate Change (IPCC) (2007) and Norwegian climate research (RegClim) (National Transport Plan 2007-2019 (2007)) is shown in Figure 2. From the climate data over the last 30 years and the anticipated climate change, the present and future situation for the different regions in Norway is summarized in Table 1.

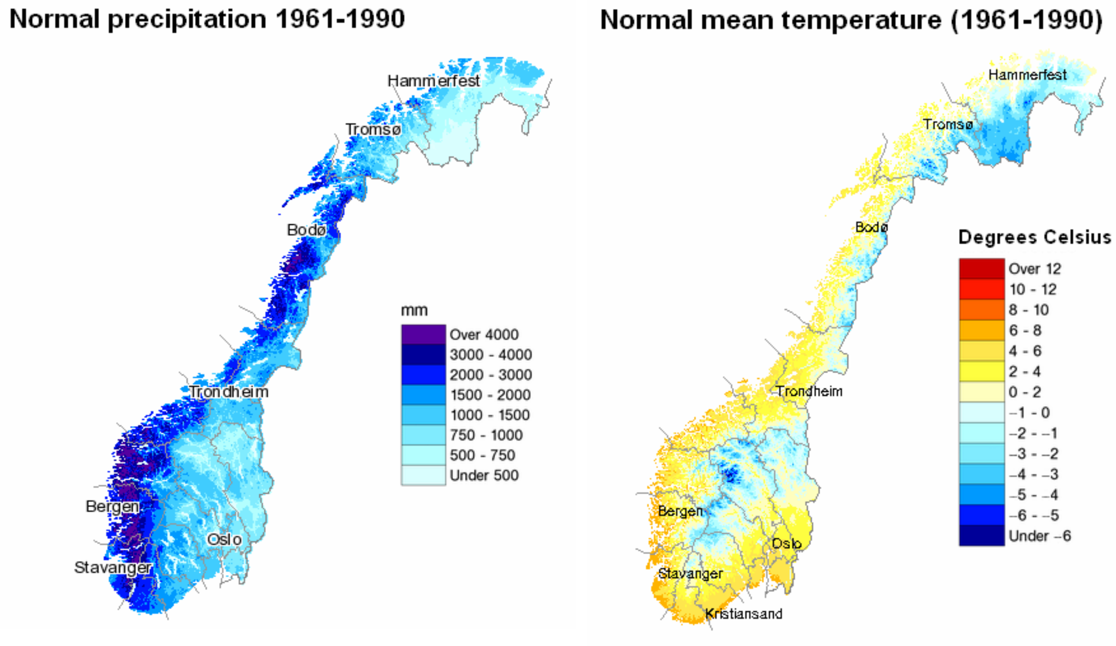

Figure 1: Normal mean year precipitation and temperature

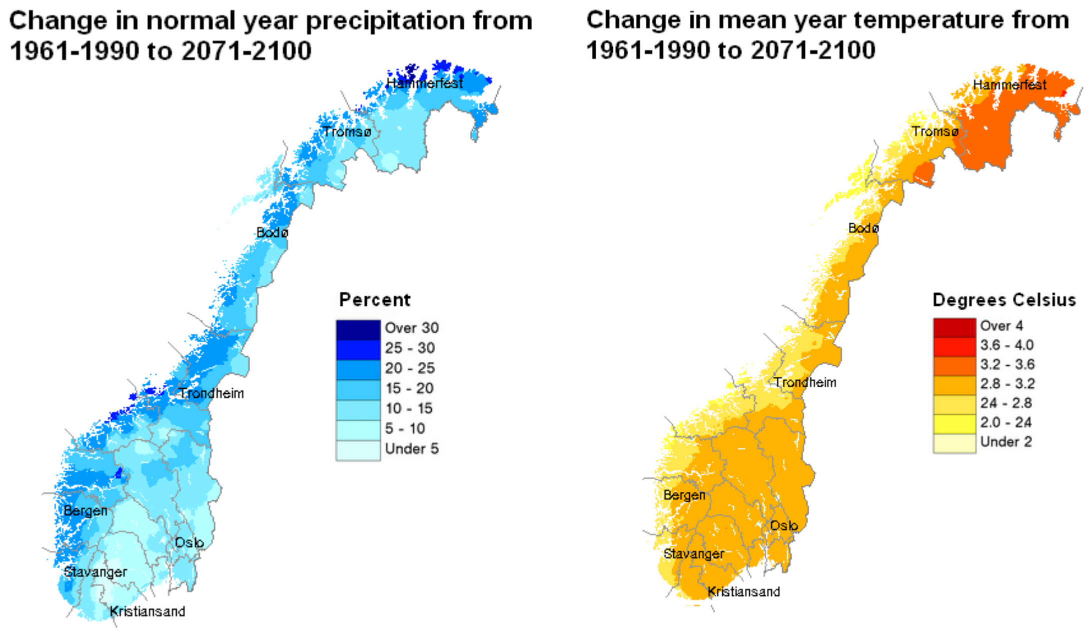

Figure 2: Anticipated change in mean yearly precipitation and temperature

Table 1: Average climate parameters in the different regions

Region	Precipitation			Change in number of freeze-thaw cycles (days)
	present (mm/year)	future (mm/year)	future (mm/summer)*)	
East	900	990	578	+55
South	1500	1605	936	-50
West	3000	3660	2135	-60
Mid	2000	2440	1423	0
North	1500	1800	1050	-30

*) Summer is defined as the bare ground season between April 01. – October 31.

2 CONDITION OF GRAVEL ROADS

Because there are limited data available on gravel roads in the Norwegian Road Data Bank (NRDB), a survey in all the NPRA regions was carried out in February 2008. The answers represent around 40 % of the county gravel road network. The main areas of interest were pavement and drainage condition, current maintenance methods, maintenance costs and intervals.

Figure 3 shows the answers from the respondents regarding pavement and drainage condition. Results show that over 50 % of the pavements are in a poor or very poor condition. This implies lack of bearing capacity, lack of cross fall, unevenness, wheel-tracks and potholes, edges preventing drainage and thin gravel surface layer making grading difficult or impossible. At the same time 40 % of the ditches has a poor condition, and in some locations totally missing. All these factors acting together will be an even bigger challenge in the future under a changed climate with increased precipitation. The main method of investigating the condition today is by video / photo documentation or visual inspection in situ. Use of FWD, DCP or GPR is not very common on gravel roads today. It is therefore a great lack of condition data in the NRDB on the gravel road network in Norway making the condition assessment difficult and not very accurate.

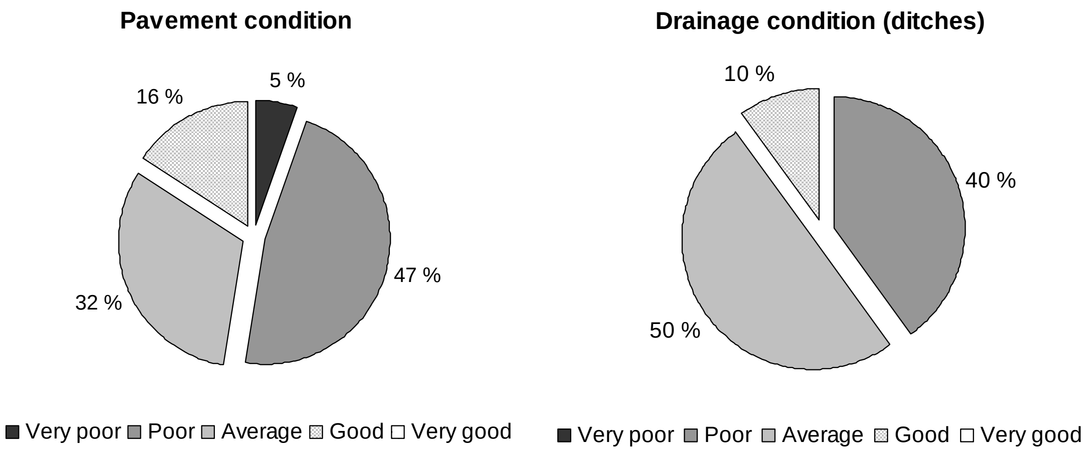

Figure 3: Pavement and drainage condition on Norwegian county gravel roads

2.1 *Backlog calculations / estimation*

Over the years there have been budget limitations leading to a significant backlog in required maintenance of gravel roads. A study made by Johansen et al. (2004) calculated the accumulated maintenance backlog to 906-954 mill NOK (129-136 mill USD) for the road pavement and approximately 200 mill NOK (28 mill USD) for the drainage system on the county gravel road network. The accumulated maintenance backlog for road pavement distributed on the different regions is shown in Table 2.

Table 2: Drainage system backlog on the gravel road fundament (base and subbase) (Price level and road lengths 2004)

Region	Gravel county road length (km) *)	Part of roads with strengthening need		Backlog		
		(%)*)	(km)	Base and subbase (mill NOK)	Gravel surface layer (mill NOK)	SUM (mill NOK)
East	1 831	68 %	1 239	340,8	24,1-34,0	365-375
South	779	23 %	182	50,2	3,8-12,6	54-63
West	56	52 %	29	7,9	0,5-0,9	8-10
Mid	2 135	52 %	1 102	303,0	15,1-34,4	318-337
North	1 207	45 %	548	150,6	10,1-18,2	161-169
Total	6 010	52 %	3 100	852,5	53,7-100,1	906-954

*) ref. Johansen Jonny, Evensen Ragnar, Holen Åsmund (2004)

The drainage system maintenance backlog was calculated to 928 mill NOK (132 mill USD) (2004) for the whole county road network in Norway. Estimation for the part linked to the gravel roads is shown in Table 3 giving 204 mill NOK (29 mill USD) for this part of the county roads. NRDB also shows that the relative part of gravel roads of the county road network differs quite a lot from region to region as shown in Table 3.

Table 3: Estimation of Maintenance backlog for the drainage system. (Price level and road lengths 2004)

Region	Accumulated drainage backlog, total (mill NOK)	Gravel roads, part of total (%)	Estimated drainage system backlog (mill NOK)
East	156,3	30,5	47,7
South	168,4	13,0	21,9
West	136,6	0,9	1,2
Mid	250,4	35,5	88,9
North	215,9	20,1	43,4
Total	927,5	22	204

The maintenance backlog for the county gravel road network in Norway linked to the road pavement and drainage is all together estimated to:

- Gravel surface layer 54 - 100 mill NOK (8 - 14 mill USD)
- Base course and subbase course 853 mill NOK (121 mill USD)
- Drainage 204 mill NOK (29 mill USD)

This gives totally 985 - 1039 mill NOK (140 - 148 mill USD) in accumulated maintenance backlog that also has to be taken into account when estimating the strengthening needs to meet more severe climatic loads caused by climate changes in the near future.

2.2 *Data from the Norwegian Road Data Bank (NRDB)*

There are limited data in the NRDB on gravel roads. Only data from the secondary roads / county roads are available. For the municipal gravel roads and forest roads, very few systematically collected data exist. These data are available in the NRDB for County gravel roads:

- Road length
- AADT
- Drainage condition (limited data on ditches, good data on culverts)
- Bearing capacity (Falling Weight Deflectometer (very limited data))
- Structural- and material data (scarce data)

3 MAINTENANCE ON GRAVEL ROADS TODAY

The main maintenance actions on a gravel road pavement are gravel surfacing, grading, dust control, ditch clearing and in some cases stabilization (e.g. bitumen). The frequency of maintenance actions is controlled by the roads condition and budgets. Often the need for maintenance is bigger than the budgets. Comparing the length of gravel road being maintained each year with the total length of gravel roads, gives an indication on how much maintenance is done each year with the combined effects of both budgets and needs. A questionnaire was sent to 21 contract districts to investigate the maintenance frequencies. The answers showed that with today's budgets and climatic situation, the county gravel roads are being graded approximately 2,5 times a year, approximately 40 % of the total length gets a new gravel surfacing and approximately 9 % of the ditches are being cleared each year. Figure 4 shows the timing of each maintenance action. Grading and ditch clearing is done all year round, while gravel surfacing is mainly done in spring but also to some extend in the autumn. Spring gravel surfacing can be trigged by spring thaw weakening. Table 4 summarizes the maintenance action frequencies from the questionnaire.

Table 4: Maintenance frequencies, result from questionnaire

Maintenance action	% per year	Maintenance frequency (pr. Year)	Period between maintenance action (Years)
Grading	230	2,3	0,4
Gravel surfacing	40	0,4	2,5
Ditch clearing	9	0,09	11

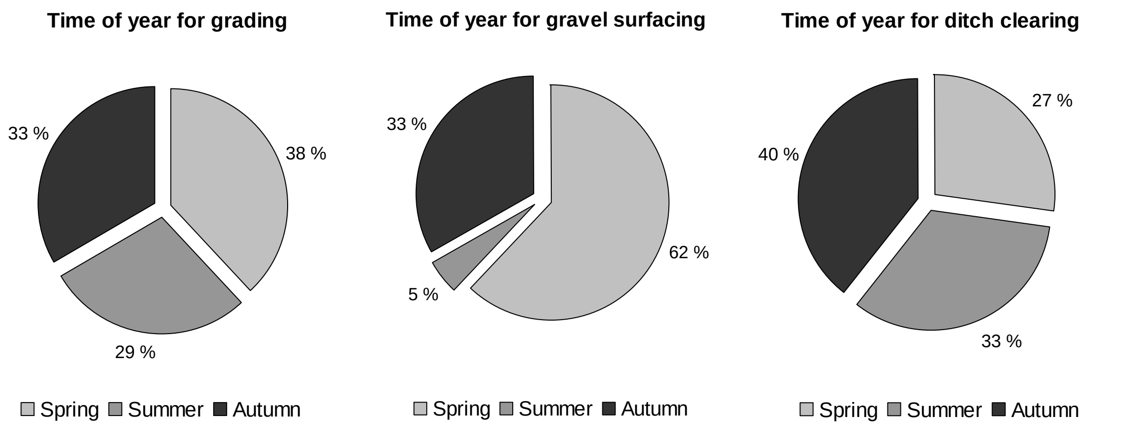

Figure 4: Timing of maintenance actions

One important factor in maintenance is the triggering factor for when a maintenance action is being preformed. Figure 5 shows the triggering factor/condition for gravel surfacing, grading and ditch clearing.

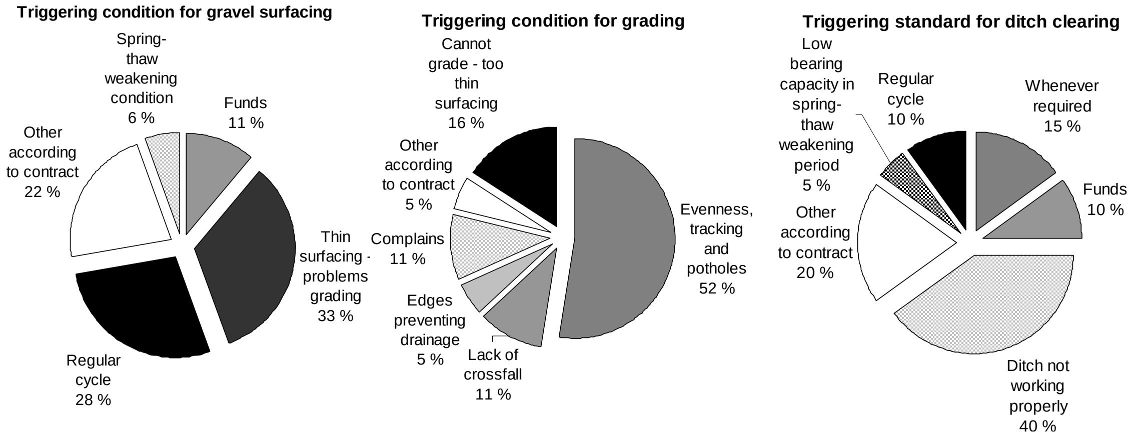

Figure 5: Triggering factors/condition for maintenance

4 FUTURE SITUATION; NEEDS AND CHALLENGES

4.1 *Future climates effect on gravel roads*

No studies indicate that a temperature increase will have a significant effect on unbound materials. According to Lerfald & Hoff (2007), a changing freezing condition is the main factor that will affect these materials; hence, unbound materials are not significantly affected by temperature change unless they go from a frozen state to a thawed state. This means that a change in temperature around 0 ^{o}C will affect the state of these materials the most. A freeze-thaw cycle is defined as a change in temperature around 0 ^{o}C with an amplitude of minimum ± 2 ^{o}C. This parameter was defined to describe the number of freeze-thaw cycles. The change in number of days with these freze-thaw cycles are shown in Figure 6 in addition to the localization of the county gravel roads. More freeze-thaw cycles and mild periods during the winter season will increase the accumulated length of the thawing period leading to increased deterioration. In particular this will be true for the gravel road network, as the sub-base and base course on these roads often consists of slightly frost susceptible materials. The freezing index will decrease in most areas, and the level at which the frost fronts stabilises during winter will be higher up, in some cases in the pavement structure in stead of in the subground as it is today. For gravel roads, this is critical because of the frequent presence of frost susceptible materials in the road structure.

The inland areas in the southern and eastern part of Norway will have a great increase in the amount of days with temperatures changing around 0 ^{o}C, and approximately 33 % of the county gravel road network is located in these areas. The present climate in these areas includes dry summers and cold stabile winters, which have resulted in the use of frost- and water-susceptible construction materials without any adverse consequences. With a changed climate as described, a decrease in the condition of these roads will be much likely. Stabilisation of the base course or the use of coarser material in maintenance will probably be important tasks for preparing these roads for the changed climate.

Gravel surfaces are sensitive to rainfall when the road is unfrozen. Heavy rainfall will then lead to washing of materials implying development of potholes, corrugation and unevenness. Long-lasting rain will soak the surface, and the E-modulus will be reduced. Increased rainfall in general leads to higher ground water table, infiltration of rainwater and more melt water in the subgrade and the drainage systems in springtime. This again leads to increased water content in the pavement and reduction in bearing capacity. Figure 6 shows the anticipated rise in ground water reservoir and; thereby, a rise in ground water level.

The greatest increase in precipitation will find place in the costal areas of western and northern Norway, but as indicated on Figure 6 there are few county gravel roads in the western part of the country; therefore, an increase in precipitation will have strongest effect on the gravel roads located in the north. These roads represent approximately 50 % of the county gravel road network in Norway. For these roads an upgrading of the drainage system is required. As shown in Table 2 a great amount of the gravel road network has poorly constructed drainage system, and this will be a critical factor. Intense rainfall could also be a reason to stabilise the surfacing.

The EU North Hemisphere Project ROADEX II has demonstrated a huge effect of improving the drainage system on the low volume road network in the north, Berntsen & Saareketo (2005). Calculations as well as field investigations showed increased service life on these roads in the range of 50-100% and more by improved drainage only. LCC calculations showed positive cost benefit values even with ditch clearing every second year, making drainage improvement to be the most cost-efficient strengthening method of all alternatives.

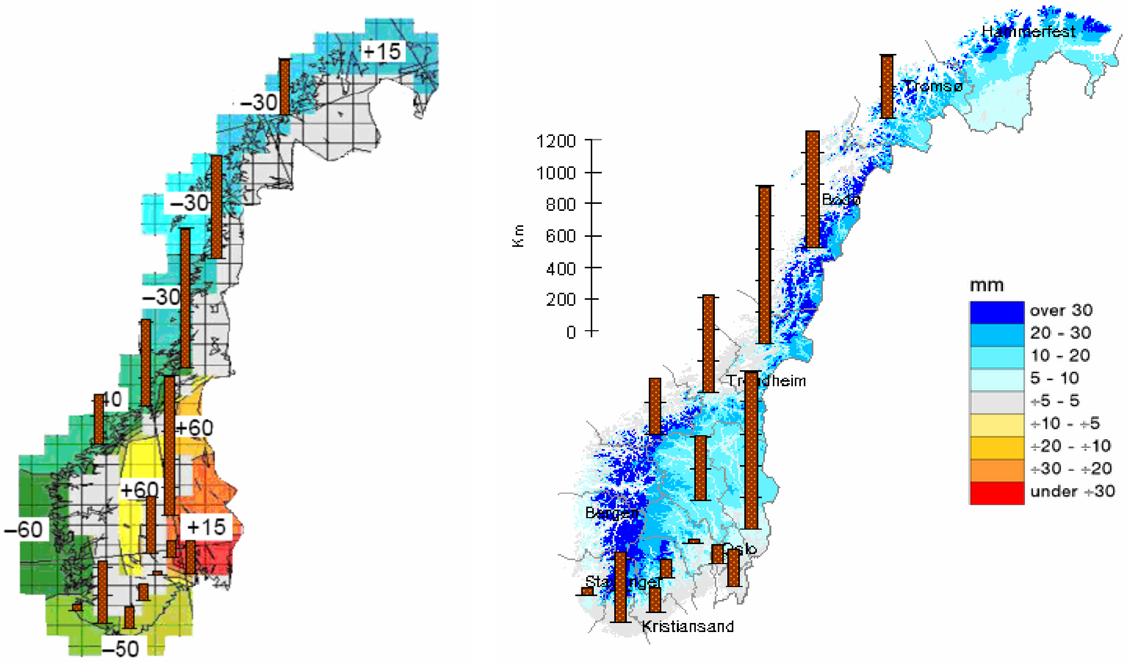

Figure 6: Localization of county gravel roads compared with change in number of freeze-thaw cycles (days) (left) and change in groundwater reservoir (right).

4.2 *Future standard and needs*

The standard for operation and maintenance (Handbook 111) for roads including gravel roads in Norway is under revision. In the new standard a better-defined quality assessment system will be given. This will make it easier for contractors as well as for road owners to follow up on the operation and maintenance contracts.

4.3 *Life Cycle Cost calculations*

Maintenance costs have been estimated for each region through the use of a revised model (MOTIV) used by the Norwegian Public Roads administration for budget estimations, Evensen & Holen (2008). In these models there is some trade-off between climate data and maintenance costs. These have been used in addition to other estimations of links between climate and maintenance frequencies. The results from these first preliminary calculations are summarized in Table 5. The calculated changes in maintenance costs are done with respect to the climate in the two norm periods of 1960-1990 and 2070-2100, representing todays and future climate, respectively. The yearly maintenance costs for the county gravel road network within the norm period of 2070-2100 will, according to these calculations, increase with 31 mill NOK (4,4 mill USD) or 19 % compared to the present maintenance needs.

A more proactive solution is to improve the quality of the gravel roads to reduce the expected increased maintenance costs caused by a changing climate. One strategy could be to fill the accumulated backlog gap in order to make a less vulnerable gravel road network. The effect of upgrading of drainage up to 30% of the calculated backlog and / or strengthening of the pavement (base and surface) at a level of 40 % at 5 years intervals over 20 years has been estimated as shown in Table 6. The calculations showed a reduction in the maintenance costs by about 30 % each year as a result of improving drainage and strengthening the pavement. The cost of the drainage was, however, far less than the cost of the strengthening; hence, the drainage was much more cost-efficient than the strengthening.

This preliminary study indicates that it will be cost efficient to do drainage and strengthening upgrading of the gravel road network to reduce the excessive costs due to the expected climate change.

Table 5: Maintenance needs per year and estimated effects on climate change

Region	Maintenance needs today (norm period 1960-1990) 1000 NOK			Effect of climate change on maintenance costs (norm period 2070-2100) Difference 1000 NOK			
	Graveling	Grading	Ditch clearing	Graveling		Grading	Ditch clearing
				from precipitation	from freeze/thaw	from precipitation	from precipitation
East	22 178	8 423	363	2 778	6 653	1 685	73
South	17 315	3 583	154	1 379	-5 195	502	22
West	2 661	258	11	623	-798	113	5
Mid	65 452	9 821	423	15 837	0	4 321	186
North	26 829	5 552	239	6 104	-5 366	2 221	96
Whole C	134 435	27 637	1 190	26 721	-4 705	8 842	381
SUM	163 261			31 238			
Acc. over 20 years	2 688 693	552 736	23 792	534 424	-94 103	176 833	7 612

Table 6: Maintenance costs and present value over 20 years life cycle at different investment rates (0 % and 5 %)

Strategy	Maintenance cost (mill NOK)			Drainage / Strengthening costs (mill NOK)		SUM Maint + Drain/strength (mill NOK)	
	per year	Present value		Present value		Present value	
	mill NOK/year	r= 0%	r= 5%	r= 0%	r= 5%	r= 0%	r= 5%
No improvement	194	3 890	2 423	0		3 890	2 423
Drainage	138	2 754	1 716	82	59	2 836	1 775
Strengthening	129	2 584	1 610	279	201	2 863	1 811
Drain+ Strength	72	1 448	902	361	259	1 809	1 162

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 *Conclusions*

This work indicates that the predicted climate change will affect the condition of gravel roads on the secondary road network in Norway significantly. The drainage system and the base and surface accumulated maintenance backlog are major limiting factors for a good riding quality and sufficient bearing capacity on the gravel road network in Norway. This preliminary study indicates that it will be cost efficient to do drainage and strengthening upgrading of the gravel road network to reduce the excessive maintenance costs due to climate change.

5.2 *Recommendations*

Following recommendations are given:

- Upgrading and more frequent maintenance of the drainage system is recommended.
- Review of rehabilitation and maintenance plans in an optimization process by the use of LCC and asset management calculations together with cost benefit analyses.
- More detailed studies on the effect of climate change on gravel roads should be made as a basis for plans to cope with a changing climate.
- The condition survey mapping system for gravel roads should be improved through the use of video, Ground Penetrating Radar (GPR) and Falling Weight Deflectometer (FWD).
- Simple maintenance actions as the removal of edges and surface reshaping should be made more frequently to allow water to drain more effectively from the surface.
- Removing ice and snow from the edges during spring should be done to increase spring-thaw bearing capacity by draining melt water.

6 ACKNOWLEDGEMENT

The Norwegian Public Roads Administration who has sponsored this work is highly acknowledged.

7 REFERENCES

Alzubaidi, Hossein (2002): *On Rating of Gravel Roads,* PhD thesis, KTH, Sweden

Alzubaidi, Hossein (2005): *Rating of Gravel Roads – Method Description* / Bedömning av grusväglag, Metodbeskrivning 106:2005, Vägverket publikasjon 2005:60, Sverige 2005-11-01, ISSN:1401-9612 (in Swedish)

Berntsen & Saareketo (2005): *Drainage On Low Traffic Volume Roads*- Problem description, improvement techniques and Life Cycle Costs, ROADEX II report April 2005

Evensen, Ragnar (2007): *Asessment of Computer System for Calculation of Road Deterioration /* Vurdering av EDB-system for beregning av nedbrytning av veg, ViaNova Plan og Trafikk AS, Desember 2007 (in Norwegian)

Evensen & Holen (2008): *Maintenance of gravel surface layers* / Arbeidsnotat for vedlikehold av grusdekker, Statens vegvesen, MOTIV-revisjon 2008 (in Norwegian)

Evensen & Holen (2008): *Maintenance of drainage systems* / Arbeidsnotat for drift og vedlikehold av drens- og avløpsanlegg, Statens vegvesen, MOTIV-revisjon 2008 (in Norwegian)

IPCC 2007: Climate change 2007: The physical Science Basis, summary for policymakers. (http://www.ipcc.ch/).

Johansen J, Evensen R, Holen Å (2004): *Secondary Roads. Maintenance Backlog* / Fylkesveger. Etterslep vedlikehold, Hp 4: Grøfter, kummer og rør. Hp 5/6: Vegfundament/Vegdekke – grusveg, November 2004, ViaNova Plan og Trafikk AS, del av Statens vegvesens etatsprosjekt Vegkapitalprosjektet 2000-2004 (in Norwegian)

Hansen M W, Stensvold B (2005): *Asessment of Maintenance Backlog for the Secondary Road Network* / Beregning av vedlikeholdsetterslep for fylkesvegnettet, Statens vegvesen, del av Statens vegvesens etats-prosjekt Vegkapitalprosjektet 2000-2004 (in Norwegian)

Lerfald B.O., Hoff I (2007): *Climate Influence of Road Material* / Klimapåvirkning av vegbyggingsmate-riale. State of the art studie, Statens vegvesen Etatsprosjekt Klima og transport, Sintef rapport nr SBF IN A07014, 2007-12-04 (in Norwegian)

National Transport Plan 2007-2019 (2007) / Nasjonal Transportplan 2007-2019. Arbeidsdokument: Virkninger av klimaendringer for transportsektoren (in Norwegian)

NPRA (2005). *Handbook 111 - Standard for operation and maintenance* / Håndbok 111 – Standard for drift og vedlikehold. Vegdirektoratet, 2003. (in Norwegian).