Considerations of road condition in relation to ground conditions

Case study in Nedre Eiker municipality

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Preface

This thesis is written spring semester in 2016 at the Faculty of Technology, Economy and Management and represents the final part of the master program "Sustainable Manufacturing" at Norwegian University of Science and Technology in Gjøvik.

Throughout the thesis I have had good guidance of Professor Halvor Holtskog on design and method of work. Unfortunately, it has proven difficult to establish contact with some professionals in building and construction for support and guidance within the scientific for road structures, this in spite of several requests to NTNU and Norwegian Public Roads Administration. This may have had some effect in the insight of the scientific for road constructions.

On the other hand I want to thank Associate Professor Erling Onstein in Department of Civil Engineering, Geomatics and Science for invaluable help to find and understand geological maps, and he gave me a good training in the GIS tool QGIS. Moreover, I would like to thank Torill Finnerud in Sweco who have contributed with good professional explanations of how they registers and processes data from damage registration, as well as good models for operation and maintenance of Norwegian roads. Furthermore, I like to highlight Geir O. Evensen from my workplace in technical department in Municipality of Nedre Eiker. He has shown great interest in my work and has been a good interlocutor in many contexts.

Although I've been a part-time student at NTNU - Gjøvik, I've got to attend some workshops on campus and become familiar with many of the other students in the same study. This is a great bunch of people from all around the world who have contributed to a good work enjoyment through the master program "Sustainable Manufacturing". Therefore, I would lastly like to thank all my fellow students who helped to make this 3 good years in Gjøvik.

Hønefoss, juni 2016

Erik Josephson

Abstract

This study concludes that the municipal road network in Nedre Eiker has a large maintenance backlog. There are many critical damages on the roads that should be repaired immediately.

This study looked at the prevalence of damages in relation to ground conditions. Municipal roads in Nedre Eiker were used as a case in this work, and the study concludes that there are four prominent types of injuries that occur in 4 different soil conditions. The 4 damage types are cracks, crazing, desiccation and patching. The 4 different zones with soil conditions are zone 41 (Ocean and fjord deposition, continuous cover, often with large thickness), 50 (River and stream deposition), 72 (Weathering Material, incoherent or thin cover over the bedrock) and 120 (Filling material (anthropogenic material)) from the maps from Norges Geologiske Undersøkelse. Through literature search, data collection and analysis, and evaluating results against the literature, this study shows that the proven damage is related to the ground where the road is built. Using the available literature, the study proposes what measures will be most sustainable, efficient and economical for the roads. The measures are as follows:
Soil zone 41: The zone contains frost hazardous materials, and the best action would be to build up the road again with a new substructure. The costs can be kept down if some work can be performed in combination with water and sewer upgrade. An effective drainage can extend the life of the asphalt surface, but will not eliminate problems with frost.

Soil zone 50: The zone contains a lot of sand and gravel, which suggests that a good drainage will be able to extend the road life. In addition, it will be effective to lower the groundwater level whenever possible.

Soil zone 72: The zone contains a thin incoherent layer weathering material. An efficient drainage system could extend its lifetime. Construction of a new thick substructure will probably have a poor benefit / cost. Alternatively, it could pay off with a thin supporting layer under the asphalt surface if the road will be dug up for other reasons.

Soil zone 120: This is a zone which may contain many different soil qualities. This area must be carried out geological surveys to determine the best actions. But drainage is an action that always will provide an improvement, so this will give (small) gains if there is no economy to greater improvements and sampling.

This report concludes finally that there are effective solutions to road maintenance even though the road is built on a poor foundation. An extended study can find good solutions for several types of soils and ground conditions than is presented in this report.

The Norwegian road network represents great values that require continuous monitoring and maintenance to maintain the desired quality. Since municipalities as road owner often have limited resources, it is important to prioritize measures where these provide the greatest economic benefit. Many of the municipal roads in Norway is in poor condition, probably both because of the bad economy and lack of expertise at the time these roads were established. The results presented in this thesis is arrived at through an extensive registration of damage to municipal roads in Nedre Eiker, study of maps from Norges Geologiske Undersøkelse, Statens Kartverk, Statens Vegvesen and from PMS RoSy. All map data is compiled in the GIS tool QGIS where special features are used to extract relevant data from the maps in form of tables. Then all data recorded in the tables processed and analyzed using Excel.

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1 Introductory part

1.1 Introduction

1.1.1 Goal

The objective of this thesis is to look for relationships between the condition of the roads and the type of soil that the road is built on, and consider whether it is possible to plan maintenance of the road on the basis of soil conditions, especially in those cases where the road is missing base course and subbase.

Audit question

Are there links between the development of the condition of Norwegian roads and the geological ground conditions?

Reasearch question

1. **Is there a connection between soil conditions and the condition of Norwegian roads? Municipal roads in Nedre Eiker are used as case study.**
2. **Can maintenance of municipal roads be planned differently according to type of ground conditions?**
3. **Has the groundwater level some significance for the bearing capacity and the lifetime of the municipal roads?**

1.1.2 Structur

The thesis is divided into five main sections, where each section consists of subsections with related paragraphs.

The thesis 5 parts are shown below.

Part 1 - Introductory part

Part 2 - Literature and Theory

Part 3 - Fieldwork

Part 4 - Results

Part 5 - Discussion, recommendations and conclusions

Part 1 provides an overview of the task, and defines the overall framework and structure.

Part 2 describes the theory behind the technology and methodology for the collection, analysis and use of data from state registration of damages in the road surfaces. Further the chapter describes the collection of geological data and the localization of these in relation to the road network.

It is recommended to read the theory chapter first to ensure a good understanding of the following chapters.

Part 3 describes the practical execution of the fieldwork, including methods that are used in the processing of data.

Part 4 contains the results from the field work, presented as tables, charts and interpretations thereof.

Part 5 contains discussion, recommendations and conclusions which run from the literature search seen in conjunction with the results from the fieldwork.

1.1.3 Delimitations

To ensure that the task is held within the framework of the issue, some delimitations are chosen.

Description of Nedre Eiker: Nedre Eiker is used as a 'case' in this task. Nedre Eiker's geographical location, population, road network, financial situation and any other things that may affect the conclusions of the task will be described.

Description of state registration of roads: The technology behind state registration and mobile measuring system is very advanced, and includes use of a number of technical systems. In the thesis, it is emphasized to give a general presentation of the relevant technology and in some cases a more depth description where it is considered necessary for the understanding of the thesis' content. It is aimed at giving an overall presentation of analytical methods for use in identifying and classifying damages, supplemented with some examples of individual methods. Detailed descriptions of algorithms and all the various methods are considered to be outside the thesis' frames.

Description of the road network: The road network structure, geographic location, length and history may affect the analysis of the results and interpretation of findings, and will be described to the extent that is appropriate.

Description of standards, road standards and damage definitions: Pavement Management System (PMS) is a collective term for all systems used in roads administration; we can include a number of sub-systems depending on how detailed one wants to dive into the theoretical basis. It is in this task has been chosen to give a general description of the PMS since the objective is to form a general picture of the situation around the roads in Nedre Eiker.

Description of types of damage: The damage types that are represented on the roads is described only briefly. A deeper analysis and description of a variety of damages that proves to be affected by soil conditions will be provided.

Description of geology: The soil types found on the relevant roads in Nedre Eiker will be described with their properties so they can be seen in conjunction with condition of roads.

1.1.4 Definition of key concepts

To ensure a good understanding of the term that is used in this paper, some of these are defined here:

Condition analysis: The standard NS 3424 (Standard Norge 2012) provides a comprehensive definition of the term evaluation reports involving a pooled analysis of defining the task purpose, scope and reference level, scheduling, registration, evaluation and reporting of the condition as well as a description of measures. In this thesis the term state analysis is kept at a more limited level, and will include the collection of state data on a limited number of roads, sorting, categorization and assessment of these in order to form a basis for further analysis.

Road surfaces: This is the visible surface of the road, also called wear layer or surface. Road surfaces mentioned in this thesis consist of asphalt, although a road surfaces may also consist of concrete or gravel.

Damage: This is a generic term for deviations in road surfaces compared with the new state. A damage may for example be unevenness, a hole or crack.

Crack: A crack is an injury in road surfaces, and can be further divided into different categories, such as longitudinal, transverse, alligator cracks, etc.

Pothole: A pothole is a damage in the road surface which has a circular or oval shape in which all or part of the wear layer is gone.

Rutting: is a longitudinal lowered track in the road surface. These are caused by the load or wear of the wheels of cars and will therefore be localized to either side of the lane.

Surface damage: Surface damage is a generic term for injuries occurring on the pavement surface. Most of the damage is related to the wear layer or the performance of how it is produced. Examples of surface damage are uneven surface texture, open length joint, bleeding, stone drop or mechanical damage such as plant equipment.

Road images: Snapshots of the road taken by a predetermined distance, usually 20 meters, but others distances are used when needed.

PMS: PMS is short for Pavement Management System. PMS is used as a collective term for all components included in a road management system, from data collection to analysis and use.

Ground conditions / soil: Masses that is located above the bedrock and is composed of particles of different sizes, ranging from rock and coarse gravel to fine particles of clay and silt.

QGIS: (also known as Quantum GIS) is a free, crossplatform application for GIS (geographic information system). The program can display maps, edit and analyze geographic data and export in most common map file format. The program includes tools for both vector and raster maps.

SA 10: SA10 stands for Standard axle 10 tons. Norwegian main, collect- and access roads should normally be designed for 10 tonne axle load and 20-year design period, (Forskrift om anlegg av offentlig veg, 2014).

1.2 Methodology

The thesis must determine the choice of methods, and what information is needed and to respond to this. A literature study can be useful for obtaining an overview of previous work in the same field. Own experiments and surveys can provide deeper or other insight into that are not mentioned in the literature. Tests can be performed in many ways, such as laboratory experiments, surveys or fieldwork. Data from own or others attempts can form the basis for further analysis and discussion.

In this paper, the following three methods are selected:

1. Literature search
2. Search in map databases
3. Fieldwork
4. Processing

The literature search is conducted before the fieldwork. The purpose is to gather information about the chosen theme as a theoretical basis.

The fieldwork represents the practical part of the thesis. Theory of the literature search is used as a basis for planning and design of the fieldwork.

Processing involves preparation, assessment and discussion of results from the fieldwork. The preparation is to clarify data and perform analysis. Then the results are considered by comparing the analysis with existing theory. Finally the consequences of the results are discussed, as well as the opportunities and challenges these implies.

1.2.1 Execution of a literature search

Since the study is about to examine the ground conditions and the condition of municipal roads in Nedre Eiker it was natural to start literature search at the Geological Survey of Norway (Norges Geologiske Undersøkelse - NGU) and the Norwegian Public Roads Administration (Statens Vegvesen – SVV) publications. Google Scholar and Docplayer were also used in an attempt to find scientific literature that can substantiate SVV's literature, but this search gave very few results. It was found some American literature corresponding SVV's. In addition, several internal reports from Nedre Eiker commune was used, and it was conducted interviews with two professionals in the municipality to identify practices and history concerning the municipal roads.

1.2.2 Execution of fieldwork

State Registration of road network

The main part of the fieldwork in this task is carried out simultaneously with a comprehensive state registration of all municipal roads in connection with pavement management system RoSy was adopted in the municipality. RoSy stands for Road System and is as mentioned a Pavement Management System (PMS). The system calculates the economic optimum road maintenance and collects all road information in a database. Further RoSy calculates the optimal actions for all roads, for the current season and more than 10 years into the future. RoSy is a dynamic road database, both for the operation and maintenance of the road network. The database contains all types of roads, sidewalks and trails. It is Sweco who are supplier of this system. A system called CamSurvey is used for the actual registration of roads, both road characteristics and condition. A road technician has a screen in the car where the damages are manually registered. On this screen, he sees a drawing of the road, and then he has all damages icons where he "drags" the damages into the road and specifies the amount of damages. The system also has a trip odometer that are always in control the localization, ie where on the way the car are located in relation to a defined zero point. The system requires in other words a visual registration conducted by road technician. Widths and the like are measured manually using a measuring wheel.

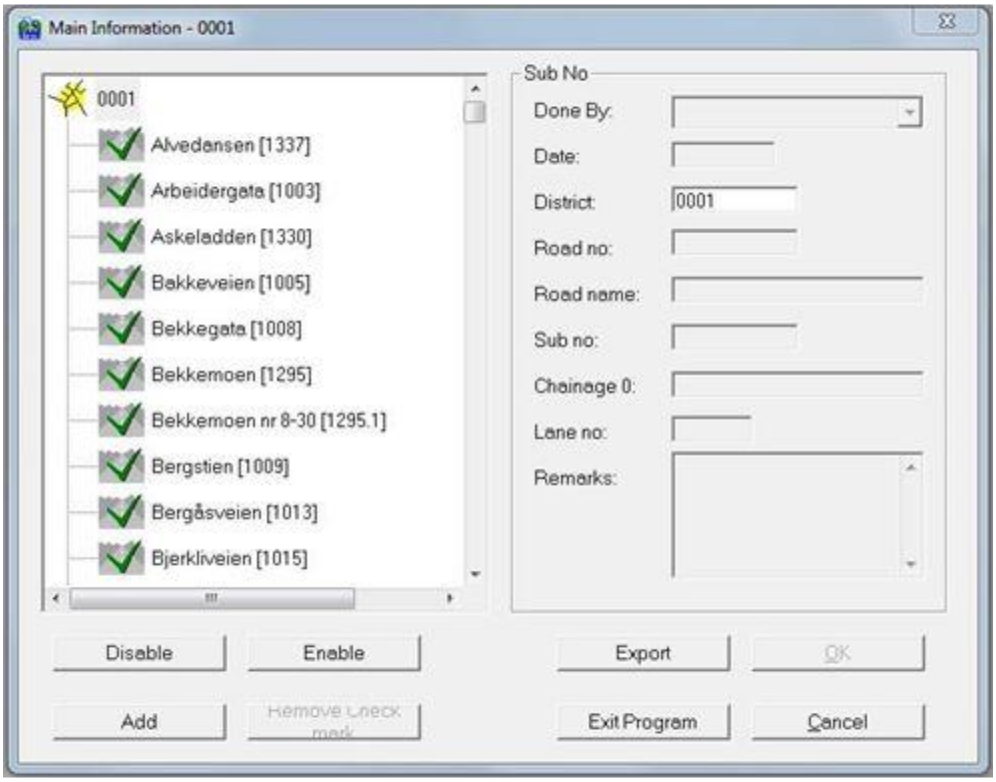


Figure 1:1 - CamSurvey contains a database for the municipality. Here the road technician choose the way he wants to work with.

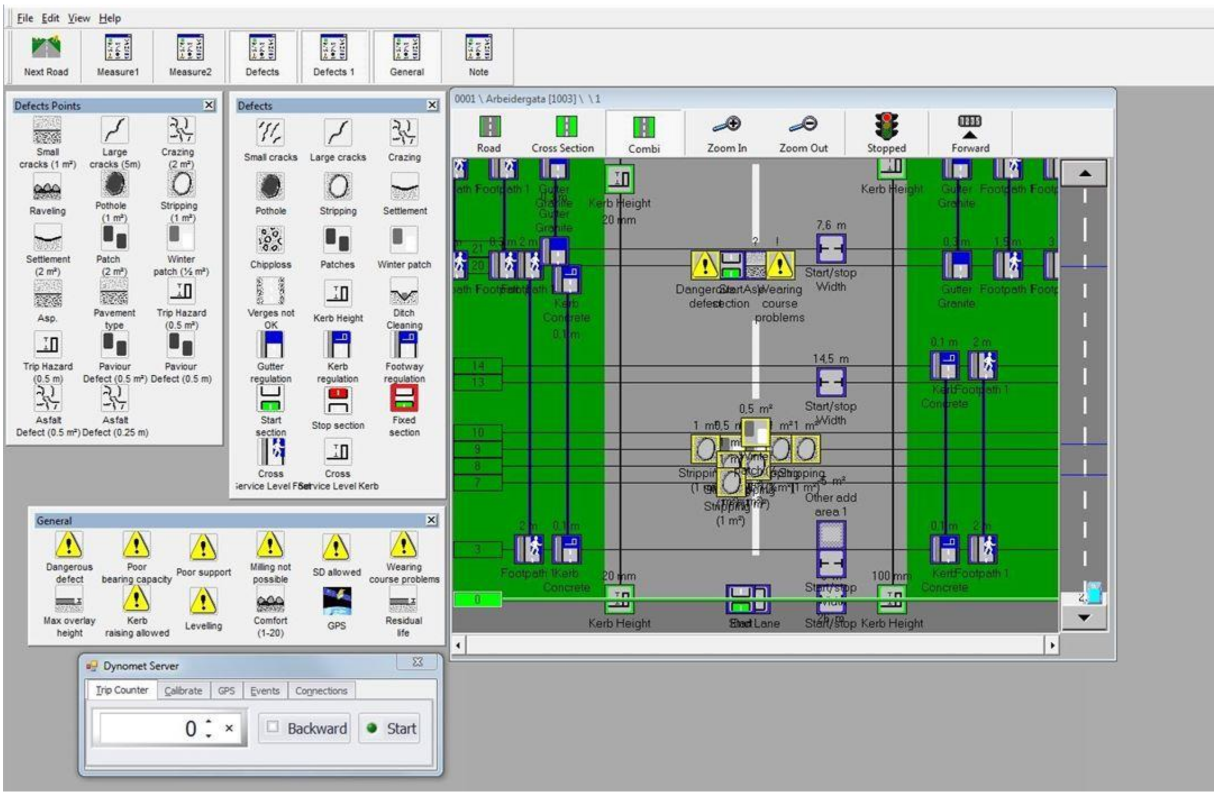


Figure 1:2 - Example of classification of damage stretches. Kerb height and other properties are also registered in this window.

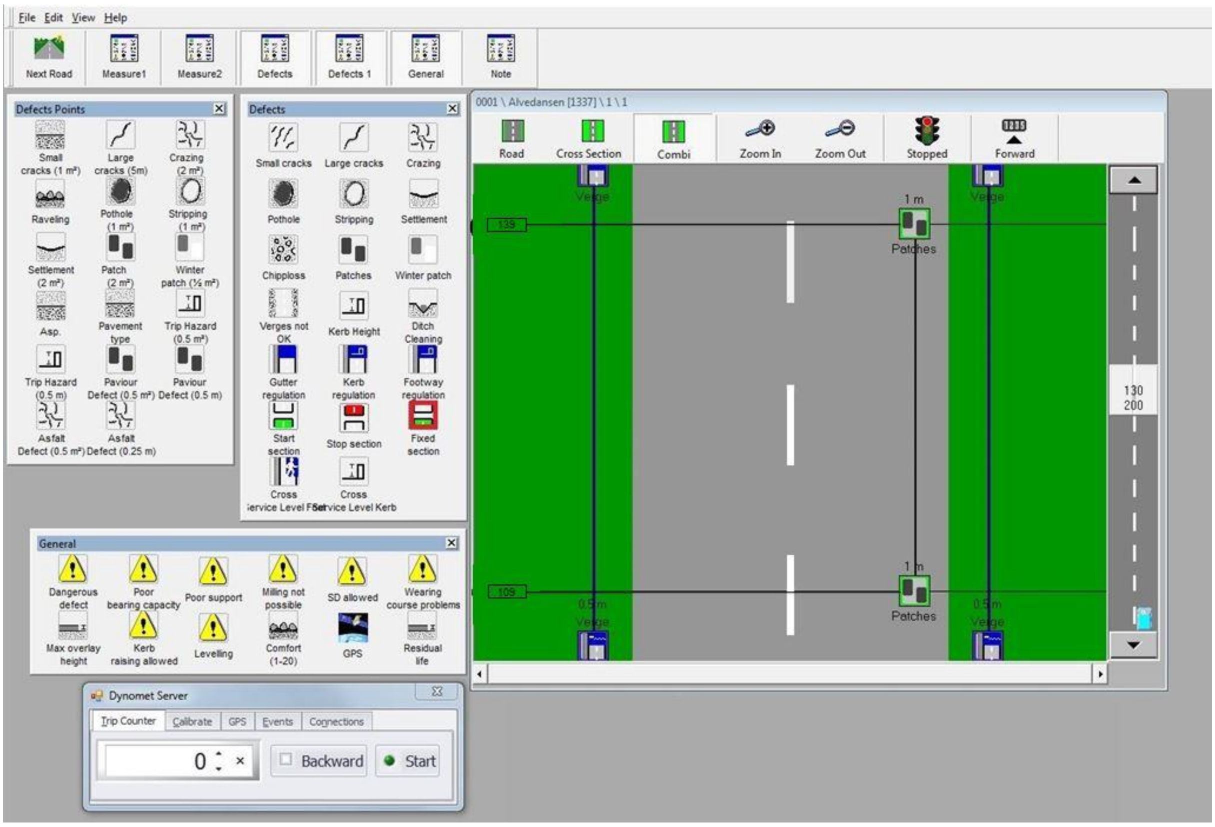


Figure 1:3 - An example of an injury registration of patches that start at station 109 and ends at station 139 (screen dump from CamSurvey)

Nedre Eiker has used this system before, but it has not been active since 2008. The plan is now to get this up and running again, and the start of this was a comprehensive state registration, which was also became a major part of the field work in connection with this thesis.

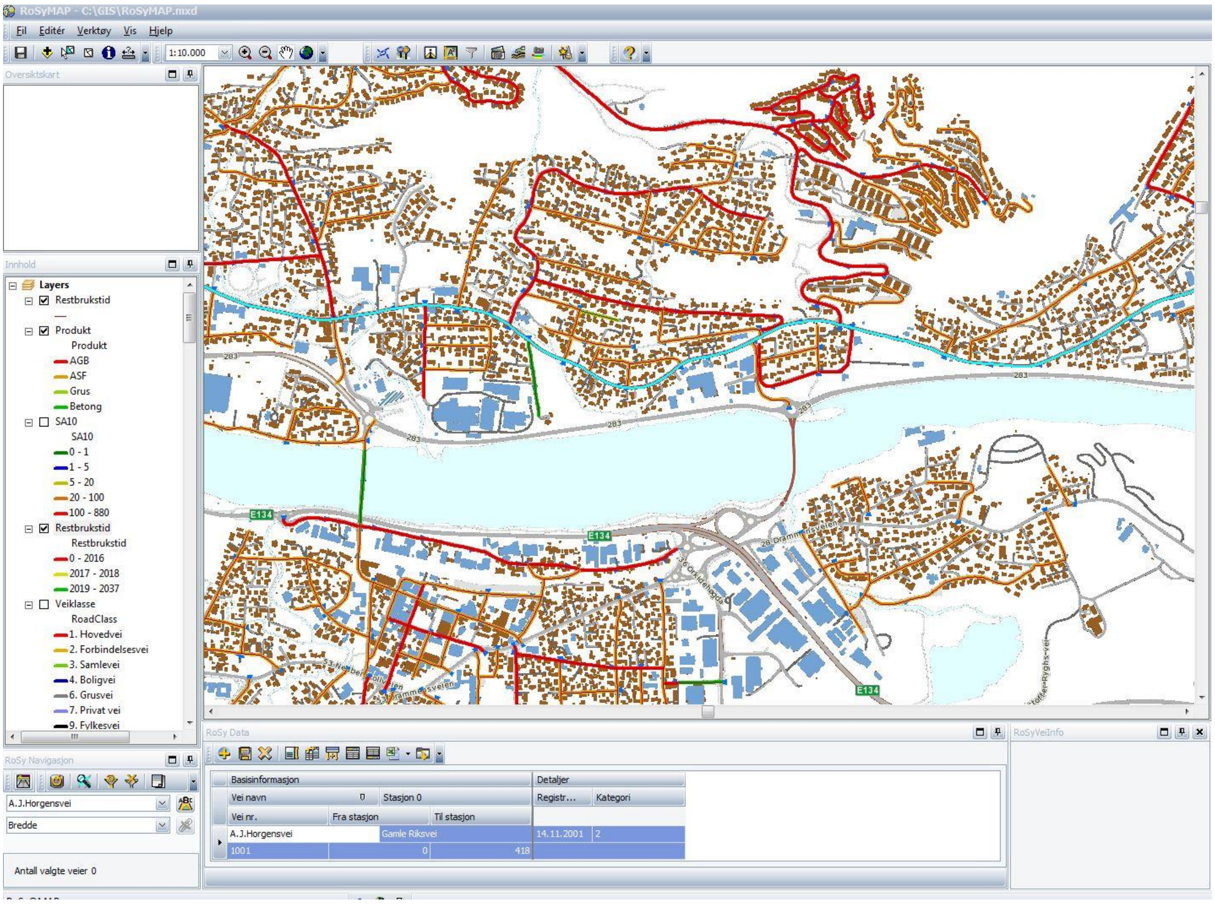


Figure 1:4 - User interface in RoSy MAP

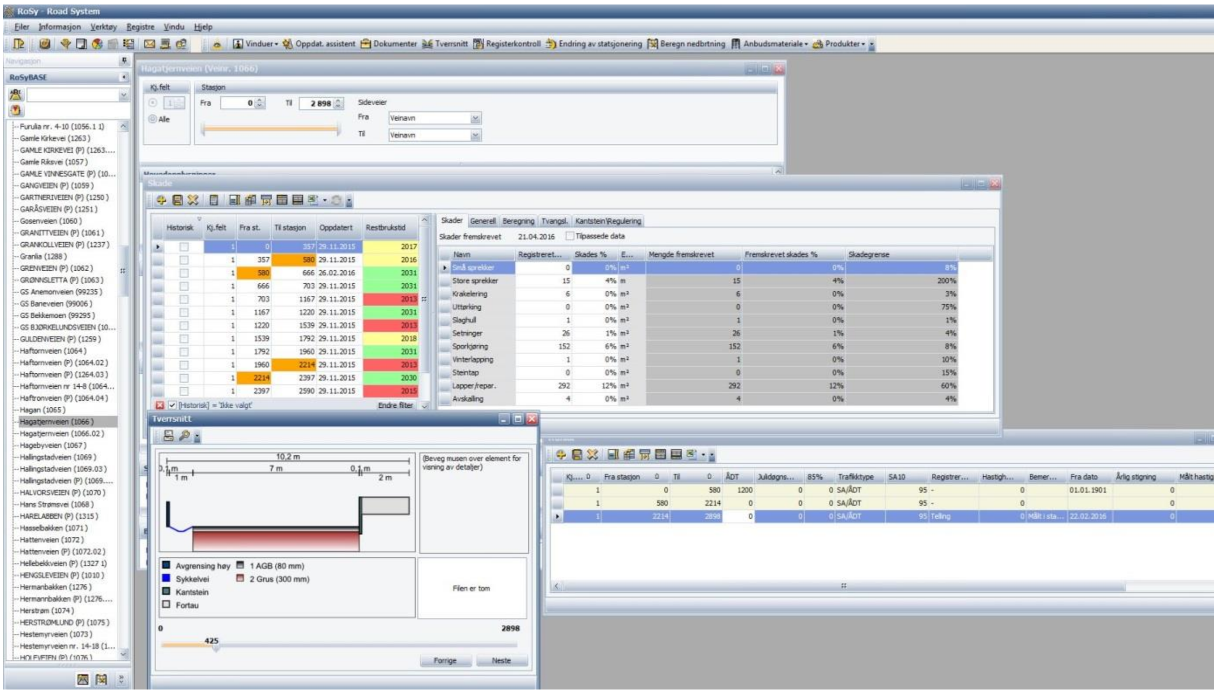


Figure 1:5 - User interface in RoSy BASE, shows only a few of functions available.

Traffic measurement

As a part of the fieldwork in this task it is registered traffic figures for many of the roads. These data are measured by a traffic meter called ViaCount (http://www.viatraffic.de/engl/viacount.html), see Figure 1:6. The data were then recorded into RoSy so that they could be considered when the load on the roads is calculated. It is possible to read out the total number of vehicles that have passed, and the number of heavy vehicles with SA10. Unfortunately, it has not been possible to obtain measurements on all the roads because the meter must be placed at least a week in each place, so it can record traffic numbers on weekdays and all hours. There is also a possibility that the data is not correctly if traffic has been measured in connection with holidays.

Figure 1:6 - Viacount traffic counter that are used for traffic measurements in this thesis

Evaluation time	11. mars 2016,09:00 - 18. mars 2016,11:00					
Speed limit	30 km/h		Count	Vd[km/h]	Vmax[km/h]	V85 [km/h]
Speed violations	68,28 %	Two-wheelers	539	28	63	39
Average gap time	41,31 s	Car	15242	33	62	39
Queue traffic	18,12 %	Vans	4352	34	62	39
ADT	3248	Trucks	2293	34	54	40
AYT	1185520	Semi-Truck	579	27	56	33
LGV traffic share	12,48 %					
Evaluation direction	Both directions	Total	23005	33	63	39
Adaptationer:						
Comment:						
Location:	Utenfor Hagatjernveien 117					
Arriving vehicles from:	Orkidéhøgda					
Departing vehicles to:						

Figure 1:7 - Example result from traffic measurement performed with Viacount II (Josephson, no date)

Geological exploration

The fieldwork is in many ways divided in two, the physical-state registration of all municipal roads and a geographical examination of how soil conditions appear in the municipality. For geographical and geological survey the map database of NGU was an important tool. In addition, the map "Elveg" from the Norwegian Mapping Authority (Statens kartverk) was used to add the road network over the zones showing soil conditions in soils maps from NGU. These maps are obtained through the website of Geonorge (https://www.geonorge.no/).

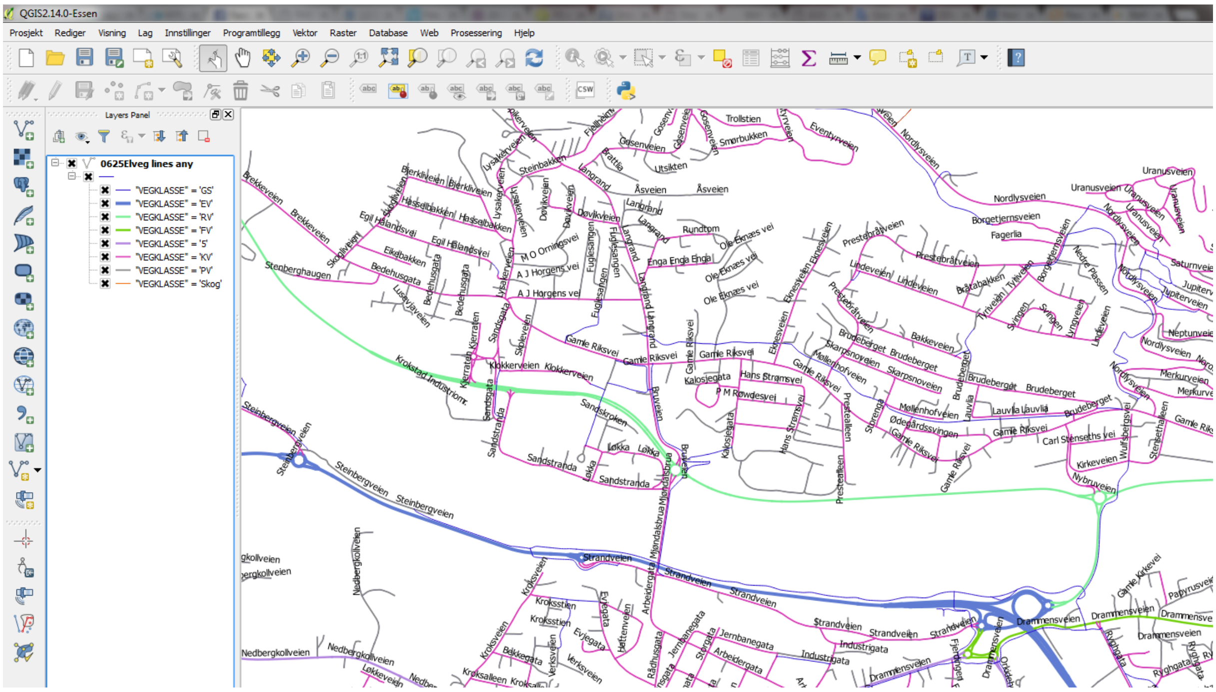


Figure 1:8 - Screenshot of sections of “Elveg” maps created from Statens kartverk (displayed in QGIS)

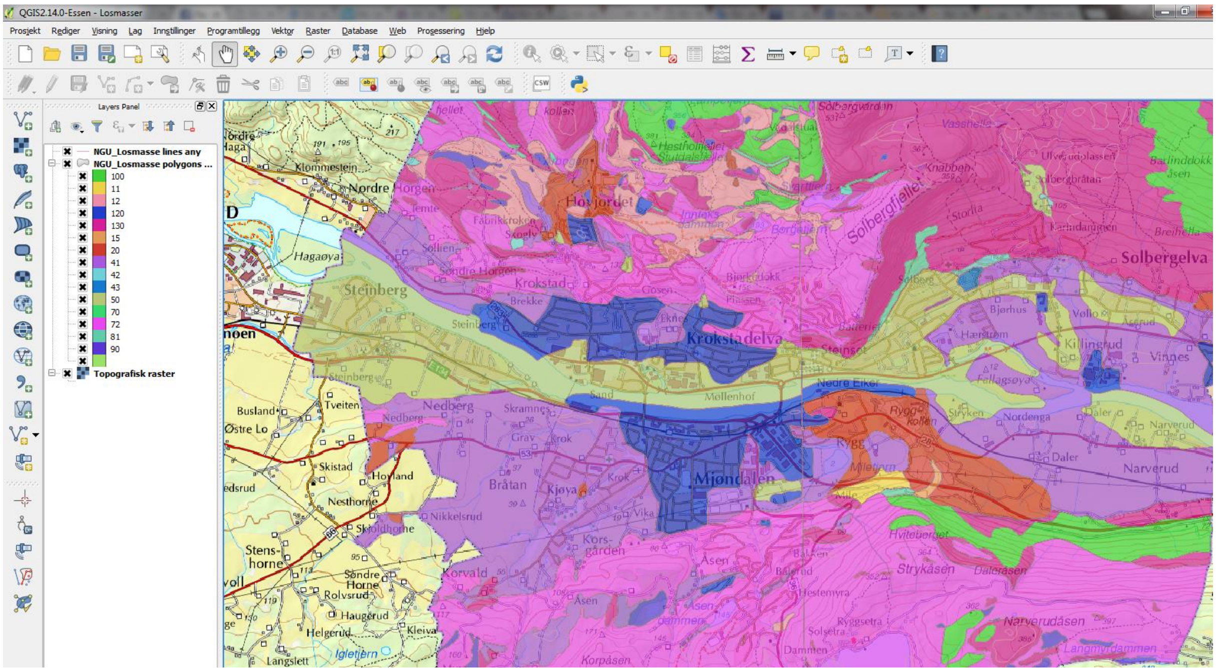


Figure 1:9 - Screenshot of soil zones in parts of Nedre Eiker (displayed in QGIS)

As a tool for extracting common data from different map layers, the geographic information system tool (GIS) QGIS was used. After state registration was completed, the results were placed in RoSy. RoSy also has a map section showing the condition of the road in a map layer. This map layer was also exported into QGIS allowing state data also be added together with the geological conditions.

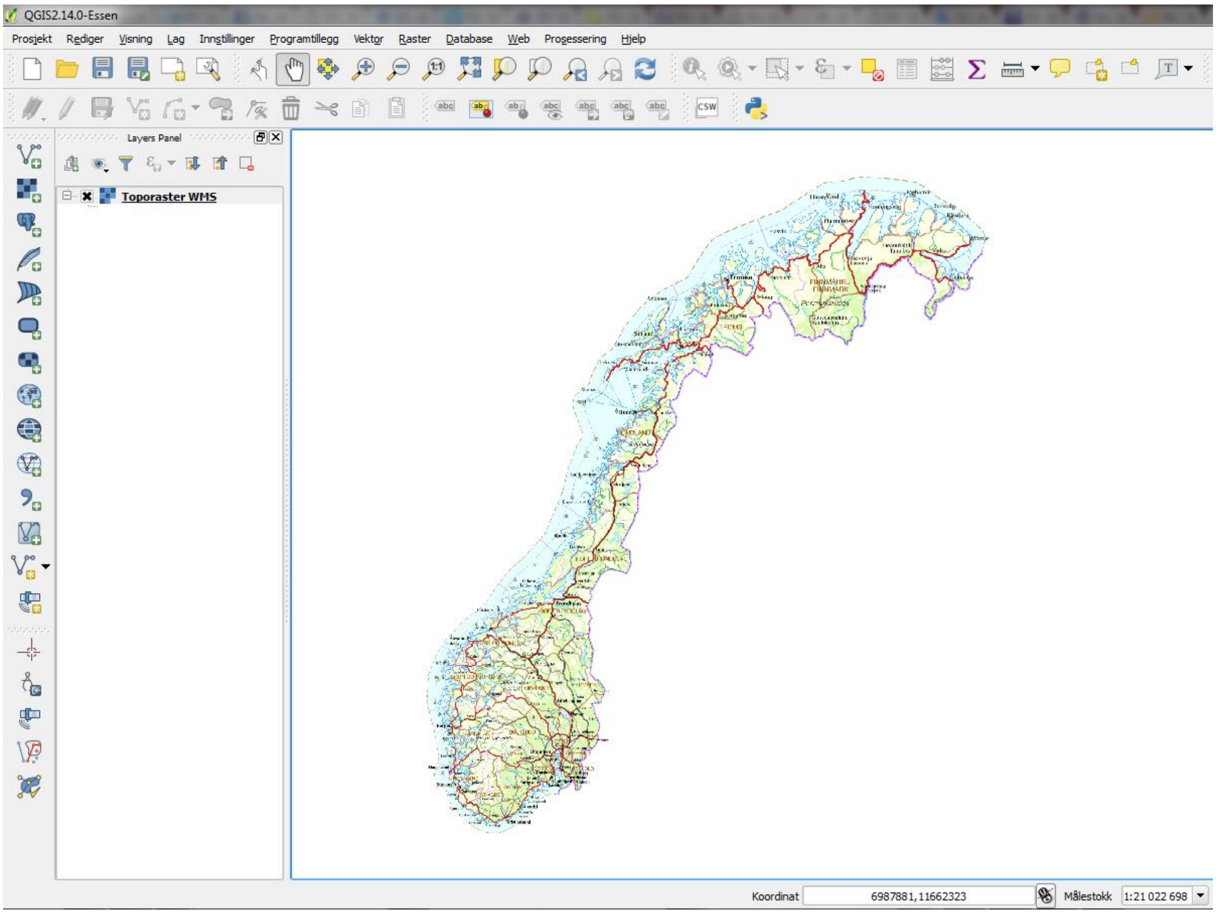


Figure 1:10 – User interface in QGIS

1.2.3 Execution of data processing and analysis

After the literature search and field work, treatment of data and analysis to be performed. Now data from the field is analyzed and evaluated in the light of the theory.

Data from state registration was registered both into an Excel spreadsheet and PMS RoSy. Thereafter, layers from NGU's soil maps, roadmaps from Norwegian Mapping Authority and roadmap with registered state from RoSy were exported to QGIS. Here the function "union" was was used to extract data from the individual roads within the various soil conditions zones.

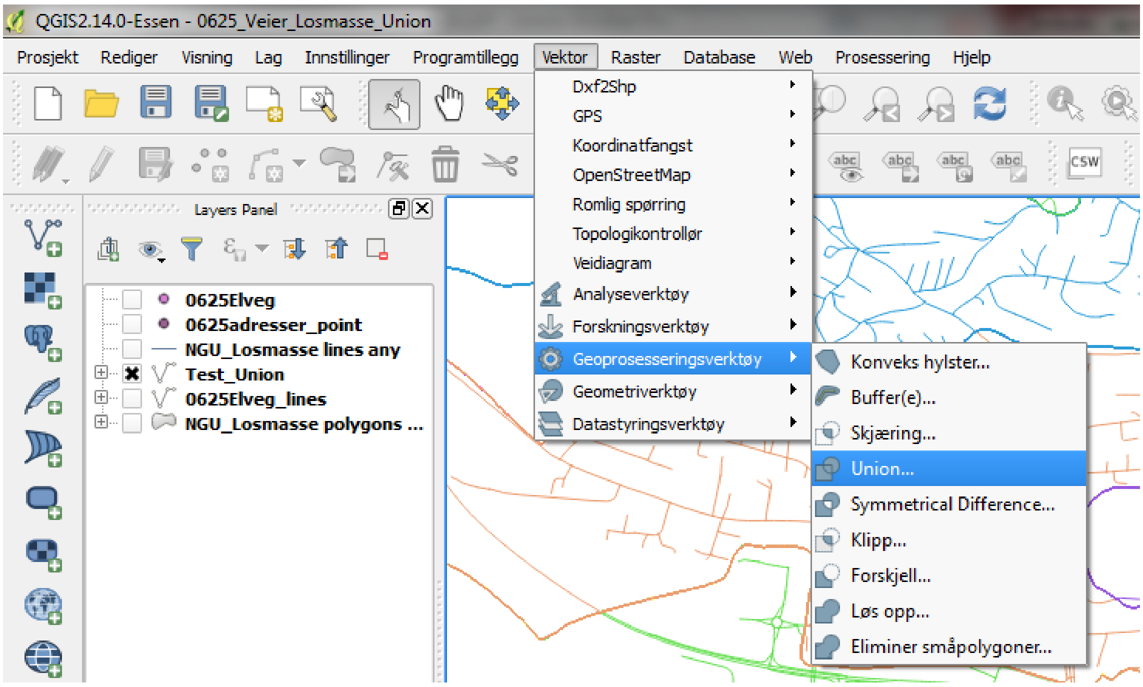


Figure 1:11 - Union function in QGIS

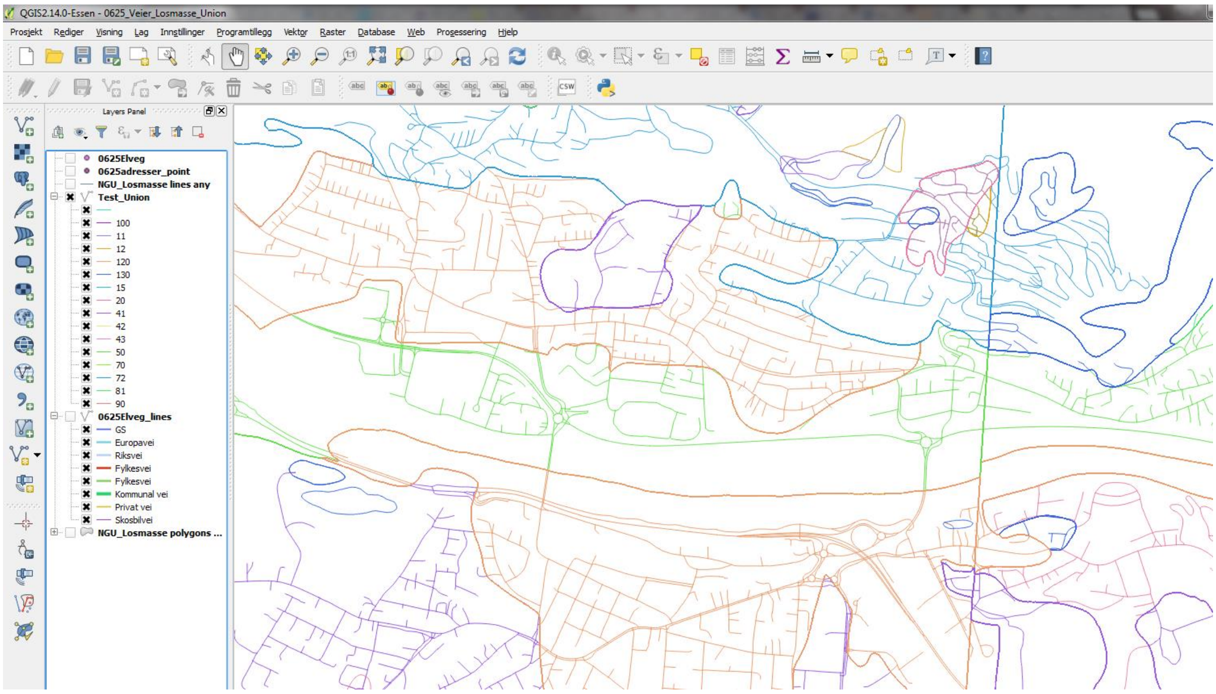
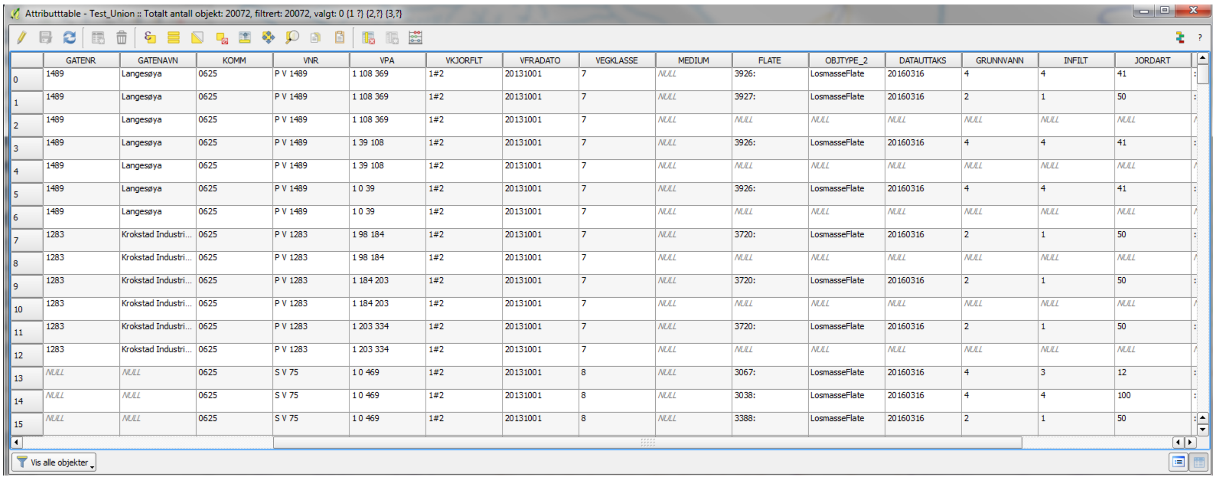


Figure 1:12 - Roads and soil zones merged in QGIS



	GATENR	GATENAVN	KOMM	VNR	VPA	VKJORFLT	VFRADATO	VEGKLASSE	MEDIUM	FLATE	OBJTYPE_2	DATAUTTAKS	GRUNNVANN	INFILT	JORDART
0	1489	Langesøya	0625	P V 1489	1 108 369	1#2	20131001	7	NULL	3926:	LosmasseFlate	20160316	4	4	41
1	1489	Langesøya	0625	P V 1489	1 108 369	1#2	20131001	7	NULL	3927:	LosmasseFlate	20160316	2	1	50
2	1489	Langesøya	0625	P V 1489	1 108 369	1#2	20131001	7	NULL	NULL	NULL	NULL	NULL	NULL	NULL
3	1489	Langesøya	0625	P V 1489	1 39 108	1#2	20131001	7	NULL	3926:	LosmasseFlate	20160316	4	4	41
4	1489	Langesøya	0625	P V 1489	1 39 108	1#2	20131001	7	NULL	NULL	NULL	NULL	NULL	NULL	NULL
5	1489	Langesøya	0625	P V 1489	1 0 39	1#2	20131001	7	NULL	3926:	LosmasseFlate	20160316	4	4	41
6	1489	Langesøya	0625	P V 1489	1 0 39	1#2	20131001	7	NULL	NULL	NULL	NULL	NULL	NULL	NULL
7	1283	Krokstad Industri...	0625	P V 1283	1 98 184	1#2	20131001	7	NULL	3720:	LosmasseFlate	20160316	2	1	50
8	1283	Krokstad Industri...	0625	P V 1283	1 98 184	1#2	20131001	7	NULL	NULL	NULL	NULL	NULL	NULL	NULL
9	1283	Krokstad Industri...	0625	P V 1283	1 184 203	1#2	20131001	7	NULL	3720:	LosmasseFlate	20160316	2	1	50
10	1283	Krokstad Industri...	0625	P V 1283	1 184 203	1#2	20131001	7	NULL	NULL	NULL	NULL	NULL	NULL	NULL
11	1283	Krokstad Industri...	0625	P V 1283	1 203 334	1#2	20131001	7	NULL	3720:	LosmasseFlate	20160316	2	1	50
12	1283	Krokstad Industri...	0625	P V 1283	1 203 334	1#2	20131001	7	NULL	NULL	NULL	NULL	NULL	NULL	NULL
13	NULL	NULL	0625	S V 75	1 0 469	1#2	20131001	8	NULL	3067:	LosmasseFlate	20160316	4	3	12
14	NULL	NULL	0625	S V 75	1 0 469	1#2	20131001	8	NULL	3038:	LosmasseFlate	20160316	4	4	100
15	NULL	NULL	0625	S V 75	1 0 469	1#2	20131001	8	NULL	3388:	LosmasseFlate	20160316	2	1	50

Figure 1:13 - Example of an attribute table of Union-map-layer with roads and soil, this was exported to Excel

2 Literature search and theory

2.1 Introduction and background

Municipality of Nedre Eiker is a small and compact municipality of in Buskerud county. It extends over an area of approximately 122 km^2 and has about 24,000 inhabitants (according to Statistisk Sentralbyrå, SSB). In other words, Nedre Eiker is a municipality that has many residents in a small area. The municipality has about 102 km municipal roads as well as some national and regional roads that are thoroughfares that run through the municipality. There are also about 50 km of pedestrian and cycle paths in the municipality. The municipality is responsible for building, operating and maintaining all of the municipal roads, including pedestrian and bicycle paths. This means that winter road snow removal, gritting, salting, cleaning signs and sweep the streets in the spring. This is a maintenance that the municipality will have to carry out, and is in most cases required by law because there are demands for accessibility. Therefore, the municipality is also obliged to spend money on this. But the municipality is also responsible for summer maintenance consists in repairing damage to roads, which can be anything from filling in small holes to total reconstruction of damaged roads. This is a maintenance that is not required by law to the same extent as winter maintenance, and is therefore a victim of savings. This results in a dilapidated road network that can be both uncomfortable to drive on, and may be the cause of decreased traffic safety. Municipality of Nedre Eiker has had a bad economy for several years, the municipality is on the so-called Robek list, which also probably has affected the summer maintenance of the municipal road network.

Robek means "Registry of conditional approval and control" which is a registry of local and regional authorities who are in financial imbalances. Municipalities and counties in Robek must have approval from the Ministry of Local Government and Regional Development to conduct valid decisions about borrowing or long-term leases, and that the legality of budget resolutions must be checked. Government Act § 60 (§ 59 a). 1 defines what economic imbalance means. (Kommunal- og moderniseringsdepartementet, 2016)

Ordering unit for municipal engineering Nedre Eiker is a division consisting of management and engineers who manage the planning and development of the technical services of the municipality. This includes roads, water, drainage and flood protection. It is this department that sets up the budget and planning the operation and maintenance of all municipal roads and pedestrian and cycle paths, as well as all associated equipment as streetlights, signs, railings, bridges etc. The reason why there is a separate specialist unit for flood control is that Nedre Eiker is a very flood prone municipality. It is located in a valley along the Drammen River with many large and small streams and rivers from the hills on either side of the valley. In addition, the municipality has a flat profile at the bottom of the valley, which in combination with Drammenselva provides a relatively high groundwater levels. High groundwater level and frequent floods also provides major challenges for roads in the area. Ordering unit for municipal engineering do also accept and executive officer complaints on roads from residents and users of the municipality. A large proportion of these complaints goes on poor and dilapidated roads. Many of the complaints also goes on traffic safety, and is largely about poor visibility at intersections, blind curves, and worn, missing or Covered traffic signs. In addition, many of the complaints are directed at high speed in densely populated areas. These complaints show that road and traffic system in the municipality is probably not adequately maintained, as well as population growth is probably larger than the road network has the capacity to cope.

Historically, the municipality had mostly gravel roads, at some point, most of the roads were paved directly on top of an old gravel surfaces. Geir O. Evensen has information about this stored in his archives, and he gave an interview about this historical events (Evensen, 2016). If it is the case that this was practiced, it then means that large parts of the municipal road network lack good superstructure and drainage. The extensive state registration is carried out now will hopefully provide concrete data on this.

2.1.1 Status road system in Nedre Eiker

Municipal roads registered in PMS RoSy:............ **103,8 km**
Estimated roads, asphalt:.................................. **101,9 km**
Low standard roads:... **24,7 km (24,2 %) (see 2.1.5,** Low standard roads (asphalt roads)**, page 28)**
Current road assets:... **401,8 mill. NOK (see 2.2.4,** Road assets, **page 35)**

(Finnerud and Sweco, no date)*

** (Finnerud and Sweco, no date) refers to a report made by Torill Finnerud, project manager for Sweco Pavement Consultants AS. This report is for internal use and is not published.*

Road class *	Low standard roads	Total length of road	Percentage
Main road	2,9 km	15,1 km	19,2 %
Connecting road	0,1 km	3,8 km	2,6 %
Collect road	2,4 km	5,1 km	47,1 %
Housing estate road	19,3 km	77,4 km	24,6 %
Total	24,7 km	101,4 km	24,2 %

* According to SVV Handbook N100 roads are defined as follows (Vegdirektoratet, 2014a):

- Main roads have as a primary task to cover the need for transportation between districts, regions, cities and city districts.
- Connection roads are connecting major roads together.
- Collect roads are connection roads between residential areas and are the link between access roads / residential roads and other main roads.
- Residential roads or access roads are providing access to the residential areas, recreational facilities, industrial areas or similar.

Table 2:1 - Distribution low standard roads in Nedre Eiker 2015/2016 (Finnerud and Sweco, no date)

Optimum level of operation and maintenance implies ideally the solutions that provide the lowest total cost to society over time. An accurate calculation of the optimal standard for operation and maintenance can be challenging. For example, both the quality of road construction, weather conditions, traffic volume and traffic composition will affect. It would therefore be lower operation and maintenance standard requirements related to a low-traffic road than high traffic road.

For the planning of optimal operation and maintenance of the road network, we need to use two key values. This is measured on the basis of road value and the amount of low standard roads. According to state registration 2015/16, we see that the amount of low standard roads in Nedre Eiker is 24.2% and road value is NOK 401.8 million. The maintenance backlog in road network of approximately NOK 18.7 million, which is the estimated cost of putting low standard roads repaired again. The definition of low standard roads is that the road's life has expired, or expires in the current year. This is controlled by how much of the road has any damage over a defined limit. This limit varies according to road class, for example, we can accept a greater degree of damage to a residential road than on a main road.

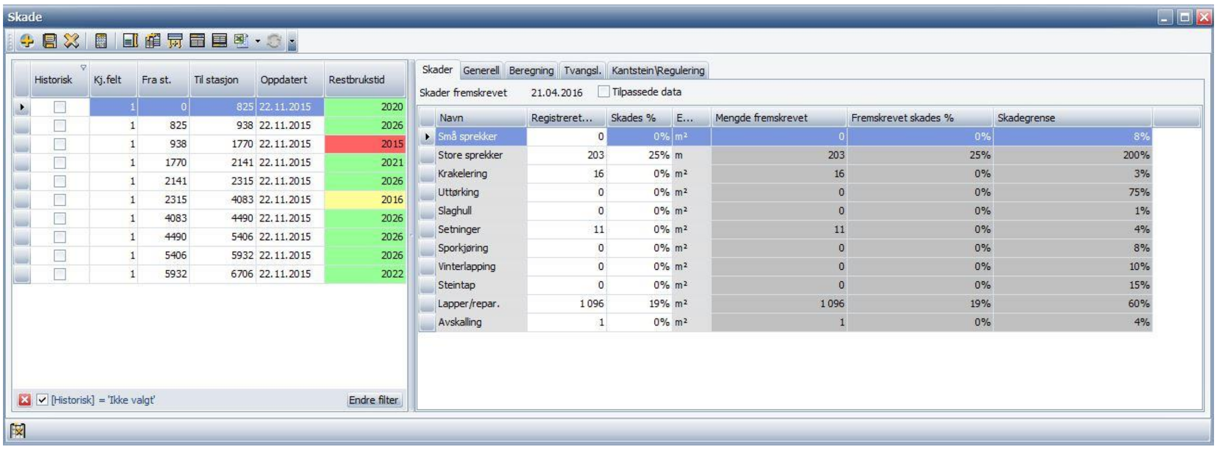


Figure 2:1 - Example of a damage image with damages residual life and damage limits for "Gamle Riksvei" (RoSy)

Previous state registration in Nedre Eiker was conducted in 2008, and it is not done any follow-up after this registration. Therefore, we cannot compare the numbers directly with previous calculation.

2.1.2 Road network in Municipality of Nedre Eiker

There are a total of 103.8 km municipal roads placed in the PMS RoSy, with an area of 535,031 m^2. The metered roads include 284 roads. Not all areas are included in this project. Road routes that are either gravel roads or roads with paving stones are included in the measurement, but not taken into account. Calculations are based on municipal roads that are paved.

Number of road sections which are included in the damage calculation:....473
Road length of all damage routes for these road classes:..............................101.9 km
Road areas at all damage routes for these road classes:................................528 199 m^2

Municipality of Nedre Eiker has invested both time and capital in building a road database of the municipal road network. In this database are the road network are measured and state are registered. This is a strategic and long-term way to gather information about the roads. All information is collected in RoSy database - where all the maintenance plans and budget estimates for the road network are stored.

It's in 2015/16 conducted an extensive registration work based on the old road database from 2008. Surveying and state registrations are done on large parts of the road network.

The following registrations are conducted in 2015/16 (Finnerud and Sweco, no date):

State Registration:.......................................61.7 km asphalt road
Measuring and state registration: ....29.2 km road including side facilities
Load capacity:...6.2 kilometers in 2 roads

In 2015 there was performed a bearing capacity measurement on 2 roads in Nedre Eiker. In addition to bearing capacity measurements and state records conducted 21015/16 it is today 55 roads that are registered with acute damage to all or parts of the road (only visual judgment). In case of damage registration of these roads we will be able to see trends over time, and will thus have a good track record on damage evolution and remaining lifetime.

As road manager, it is necessary to have an overview of the roads we are responsible for, state of the roads and not least the consequences of the measures we can implement. Using the PMS RoSy BASE municipality has a good tool to handle these tasks and schedule maintenance on the roads.

The database should be regularly updated with the changes that occur on the municipal road network, including new asphalt and repairs. This allows RoSy giving an accurate picture of reality. It is also important that the condition of the road network is continuously recorded and we should keep an eye on increasing traffic loads. When we have collected information in RoSy BASE will we be able to get a big win by using combinations of the information in the database to make analysis.

2.1.3 Damages

There may be so many damages on a road that the entire value of the wear layer, the upper asphalt layer is lost. Other times, parts of the reinforcement layer may be so damaged that it almost no longer has any value. The causes of the damages on a road can be numerous and complex. Load (traffic), water and structure of pavement are some criteria that affect the extent of damage. It is expected that a road going to get some damage development, but it is important that the development is not too fast, leading to need for frequent and costly maintenance.

Roads are complicated structures, and there may be several factors that lead to the same kind of damage. It is therefore not always easy to determine the reason behind a damage that can be observed on the surface. The properties of road construction materials depend on temperature, precipitation and groundwater level. Rapid climate shifts, shorter winters in addition to freezing and thawing processes is also important. It is primarily the change in deformation characteristics and material stiffness parameters that are of importance for any damage development of a road.

Maintenance itself can affect the damage progress greatly. If damages is not rectified, it will damage development accelerate. Water is one of the roads greatest enemies, and therefore it is important to prevent water penetration in the asphalt layer. Open cracks will cause water to enter the structure. It makes materials in the substructure loses some of its carrying capacity, which in turn causes the damages progresses even faster.

2.1.4 Traffic

The quantity and weight of traffic are also important factors when talking about the selection and prioritization of maintenance measures. On roads trafficked by heavy vehicles, wear layer should help reduce stress on the support layer to ensure the planned lifetime of the pavement.

- Traffic is in deciding which product is best on different roads.
- Traffic is involved in determining how quickly a road will be broken down.

It is therefore important to detect the correct traffic numbers so that construction, operation and maintenance of roads can be planned in the best way. As a part of the fieldwork in this thesis there are record traffic figures for many of the roads. These data are recorded in RoSy so they can be considered when the load on the roads is calculated. Unfortunately, it has not been possible to obtain measurements on all the roads when the meter must be out at least a week at each site so that it can record traffic numbers on weekdays to all hours. There is also a possibility that the data is not completely correct, if traffic has been measured in connection with holidays. See section Traffic measurement at page 18 for information about the traffic recorder.

The traffic load is a significant factor in the calculation of the benefit / cost value (B / C). Standard axle (SA) is the term for an axle load of 10 tones and describes the load on the pavement.

In addition to the normal frequency of heavy transport, the construction traffic on development projects poses a significant wear and tear on roads.

2.1.5 Low standard roads (asphalt roads)

Low standard roads are a phrase used to indicate that the roads have more damages than we can accept. As an example we can say that if a heavily trafficked the road (High city) has 6% crazing it is considered low standard the road, while on a residential road it may be 10% crazing before it becomes a low standard the road. Based on the road class, and in cooperation with the municipality, these limits are set.

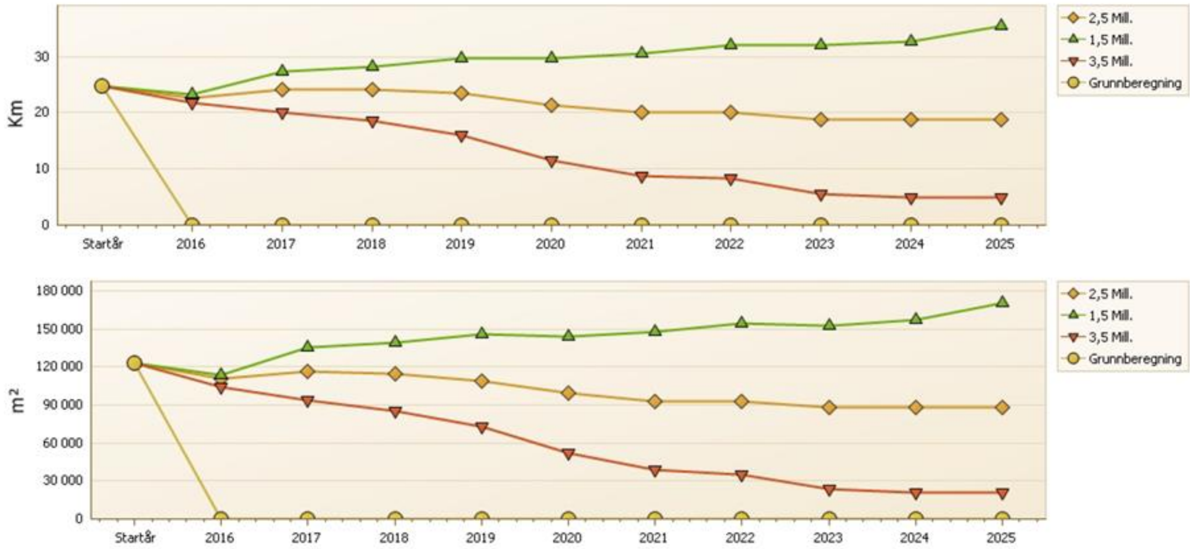
In 2015/2016 the amount of low standard roads was 24.7 km of the estimated road network. This represents 24.2% of the amount of municipal asphalt roads that are calculated. (Finnerud and Sweco, no date)

On the next page appear low standard roads in Nedre Eiker in a map. The roads are marked with red color are low standard roads in 2016. Here you get a good overview of the areas low standard roads are.

Figure 2:2 - Localization of low standard roads in Nedre Eiker (Finnerud and Sweco, no date)

The following graph shows how the amount of low standard roads will evolve on the basis of which measures the municipality follows for maintenance next year and in future years. It are shown consequences for all budget calculations. By applying the optimal solution all low standard roads will be repaired.

Optimal solution means basic calculation. Ie that we spend as much money as are necessary to obtain maintenance backlog, and then what it is necessary not to get new low standard roads in the subsequent years.



	Startår	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1,5 Mill.	24,7	23,3	27,3	28,2	29,8	29,7	30,6	32,0	32,0	32,7	35,5
2,5 Mill.	24,7	22,7	24,1	24,1	23,4	21,3	20,0	20,0	18,9	18,9	18,9
3,5 Mill.	24,7	21,7	20,0	18,6	16,1	11,5	8,8	8,3	5,5	4,9	4,9
Grunnberegning	24,7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Figure 2:3- Overview of how the length and area of low standard roads will evolve over 10 years with various maintenance budget. (Finnerud and Sweco, no date)

With a budget of NOK 1.5 million the low standard roads will increase to represent approximately 35% of the road network after 10 years. With a budget of NOK 3.5 million the low standard roads will represent approximately 5% of the road network after 10 years. Based on calculations, a budget of about NOK 2.0 million will be able to keep the current low standard level.

2.1.6 Rest Lifetime measured in area

The road network can be divided into condition classes that reflect the residual useful life. Rest usage time is an expression of how many years one section of road theoretically can be used at a certain level, which is better than the fixed damage values (thresholds). A section of road has residual life equal to 0 this year when the road section has reached the defined damage threshold.

The distribution of roads in these condition classes in relation to the residual life / condition are as follows in Municipality of Nedre Eiker:

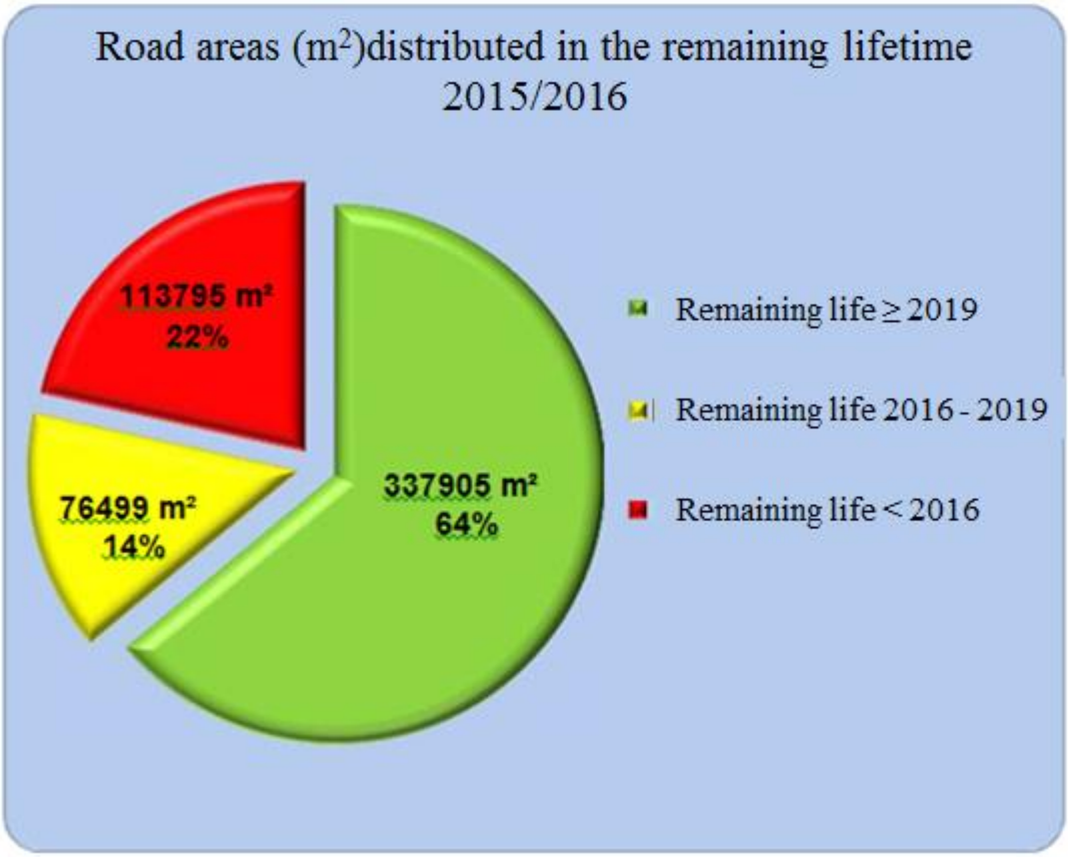


Figure 2:4 - Municipal roads remaining lifetime in Municipality of Nedre Eiker (Finnerud and Sweco, no date), (Josephson, no date)*

2.2 Socio-economic considerations

Based on the uncovering of the share low standard roads in Nedre Eiker it may be useful with some socio-economic considerations.

The calculations we perform using RoSy includes a basic calculation and budget of 1.5-2.5 and 3.5 million. In the chapter about Investment analysis at page 38 the different budgets are summarized over a 10 year period. A budget of approximately NOK 2.7 million will be enough to maintain the current road capital financial level on paved roads (Finnerud and Sweco, no date). Since this amount only applies to repairs and re-asphalting of the paved roads, the need will be higher, as the maintenance of road elements (signs, speed bumps, manhole and drain etc) and roads with gravel / paving stones are not included in the budget. The need for funding for operation and maintenance of gravel covering, as planing, add more gravel and reduce dust, must be taken into consideration in addition to the paved roads.

The state registration in 2015/16 shows that Municipality of Nedre Eiker has a road network with a moderate percentage low standard roads. Anyway, one must take into account that in the period 2018, 2022 and 2025 there is a need for additional funds since several roads going over to become a low standard road. The decay of the roads that already have bad qualities accelerates rapidly, and the roads value decreases rapidly. It is thus important to make sure that we get enough funding to maintain the road network similar to the current level as a minimum. The difference between needs and funding implies that the values we have invested in infrastructure, gradually loses economic value due to lack of maintenance.

**(Josephson, no date) refers to an internal report made by Erik Josephson, person in professional charge for roads in Nedre Eiker. It contains automatic calculations/reports withdrawn from RoSy and QGIS*

Damages and defects that are allowed to develop leads to repair costs increase. Decay accelerating and the situation become even more costly to deal with in the future.

The prognosis for the operation and maintenance needs, road assets and low standard roads takes into account the normal climate and winter situations, where it is natural that the damage on a road will rise in scope. It is thus not taken into account extra hard and long winters. The same applies to material price. If commodity price of asphalt will rise out of the norm it will be an effect. Damage development of the road network can escalate if the climate and raw material development evolve negatively.

2.2.1 Strategies for maintenance planning

Municipal roads can be maintained by different strategies, depending on what is desired to attach importance to from both political and administrative side. A Strategic Plan for road maintenance assigns how maintenance of municipal roads to take place in order to achieve a desired outcome:

- Remove decay in accordance with set targets
- Ensure that maintenance is carried out at the right time

Common to strategies must be to maintain the values or replicate values decreased because of the municipality's financial situation. There can be prepared a strategy which ensures improvement of decay and that regular maintenance actions are carried out at the right time.

The maintenance of the road asphalt surface can be done like this:

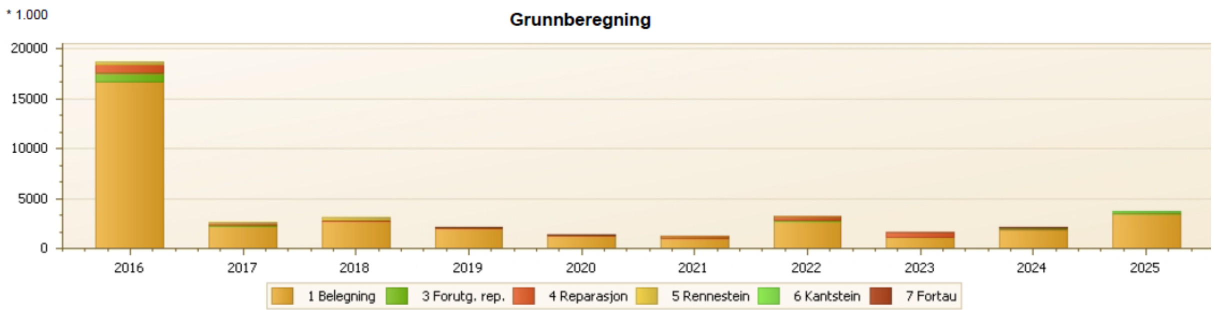
- That the asphalt surface has a certain desired functional standard
- That the constructions holds a minimum requirement for desired bearing capacity
- That wear layers meets the minimum level of acceptable aging, ie decomposition conditions should comply with specific requirements.

The above conditions are valued for each road based on reported damages, some bearing capacity measurement and test of material.

Present value costs are calculated with knowledge of "lifetime cost" of various relevant maintenance methods. Different maintenance strategies drawn up and cost / benefit values (B / C numbers) are calculated. From this information, a maintenance plan is created (Finnerud and Sweco, no date), (Josephson, no date).

2.2.2 Maintenance needs

One road may emerge as several sections if the damage image varies, or if we have laid asphalt surface only on parts of the road. Few municipalities can afford to maintain roads properly. If we look at the optimal way to maintain road network in Municipality of Nedre Eiker, the municipality will need the following investment / maintenance funds:



	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	
1 Belegning	16 727	2 210	2 687	2 001	1 226	1 031	2 769	1 132	1 889	3 468	**35 140**
3 Forutg. rep.	788	86	62	6	11	7	26	13	32	80	**1 111**
4 Reparasjon	934	226	129	67	111	175	455	473	129	25	**2 724**
5 Rennestein	203	29	220	22		11	24			66	**575**
6 Kantstein				27					9	73	**109**
7 Fortau				22	21				8		**51**
1. I budsjett	**18 652**	**2 551**	**3 098**	**2 145**	**1 369**	**1 224**	**3 274**	**1 618**	**2 067**	**3 712**	**39 710**
10 Sikkerhetspreparasjon	2	3	4	7	9	14	13	1	3	3	**59**
11 Veiskulder	109							946	123		**1 178**
2. Ikke i budsjett	**111**	**3**	**4**	**7**	**9**	**14**	**13**	**947**	**126**	**3**	**1 237**
	18 763	**2 554**	**3 102**	**2 152**	**1 378**	**1 238**	**3 287**	**2 565**	**2 193**	**3 715**	**40 947**

Figure 2:5 - Necessary maintenance budget to eliminate the proportion of low standard roads (optimal maintenance) (Finnerud and Sweco, no date)

The first amount may be called the maintenance backlog on roads. (see chapter 2.2.6 for further description of maintenance backlog). In order to obtain a road network that in the following years only need relatively few assets, we expect to invest a larger amount in the first year. The amount may be much higher than what we usually use in annually road maintenance. Calculations show that the road to Municipality of Nedre Eiker has an investment requirement of approximately NOK 18.7 million in the first year. The amounts shown for the years 2017 up to 2025, it is what we must expect to spend annually when the lag is retrieved. With the state the roads have today, these amounts correspond to an average of approximately NOK 2.4 million annually. As this is only the means that must be used for road maintenance on paved roads, it must be expected that the maintenance of the entire road network is higher than NOK 2.4 million as the amount does not involve maintenance of gravel roads and roads with paving stones / concrete.

The most optimal maintenance method is calculated from the professional experience we have about the condition of the roads, as well as the traditions of the municipality for maintenance. Furthermore the road classes, if it is a main or residential road, are also an important parameter in the calculation. If the traffic is low, it is in many cases optimal to allow slightly higher degree of injury on the roads.

Discussion of strategies to catch up with the maintenance backlog in roads and traffic areas

A strategy to catch up a backlog will be about priorities within the current financial framework. For municipalities, it is very limited opportunities for external funding.

The reward scheme in for example "Buskerudbyprosjektet" (Buskerudbyen, no date) can be an opportunity for certain types of projects, such as pedestrian / bicycle paths and initiatives that can promote public transport. The same may apply special traffic safety measures where we can applicate for support. But these external sources will still be modest in relation to need.

2.2.3 Operation, maintenance and management of road assets

Operation and maintenance of roads is a major field of study that includes many important topics. To ensure safety for people and the environment, it is important that we have good control over everything from road being built to properly operated, maintained, and eventually laid down, in other words all stages in the life cycle of the road. In addition to safety and the environment, we must also have control of the economy. It is costly to build and operate roads, but it can also be costly if we do not have good control of the road condition and maintenance needs.

"The operation of the road network covers all tasks and procedures that are necessary for the roads to function well for of road user's daily use. These activities are snow removal, sanding with salt and sand, road markings, washing and cleaning, correct signs, maintenance of greenery, traffic management and road information. Maintenance of the road network includes actions to safeguard the physical infrastructure. This means actions to maintain the standard of road pavements, ditches, bridges, tunnels, road equipment and technical installations / systems in accordance with set quality standards." (Aurstad et al., 2015)

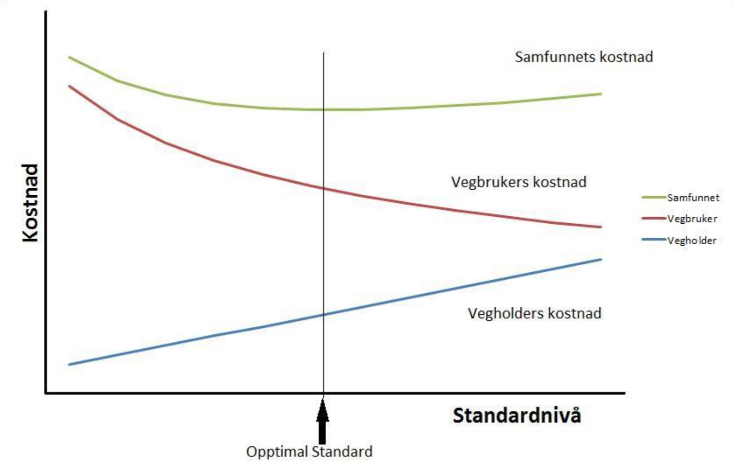


Figure 2:6 - The societal optimal standard for operations and maintenance tasks is the sum of road owner costs and road user costs (Aurstad et al., 2015)

(Figure 2:6) shows that the sum of the road owner and user charges is society's total cost. The optimal standard for operation and maintenance is therefore at the level where the societal cost is lowest. But it is also important to pay attention to road safety. If the road is prone to accidents, it can not only provide great costs that may not seem so well in this figure, but also social impacts in terms of harm to people.

One roads life cycle consists of three phases; planning, construction and operation. It is in the operational phase, which is the longest phase; we find operation and maintenance tasks. It is also important to be aware that it is planning that creates the foundation that we can operate and maintain the road in a good way. Planning must consider the need for space for snow, the need for side area, drainage, the need for turning places or emergency parking etc.

We could really differentiate between three elements when it comes to the road operation phase; investment, operation and maintenance. There is extensive maintenance that might be defined as investment. But basically investment is measures that upgrade the road, such as capacity (number of lanes) or security (central dividing). With operating it means efforts and activities that are necessary in everyday to ensure that traffic arrives. These activities will vary in different seasons, and of course winter can be experienced as most challenging. Operating activities can be:

- Snow clearing
- Gritting / salting
- Cleaning the lane or side equipment such as signs
- Cut grass and vegetation along the roadside
- Ditch cleaning.

Operating activities should be conducted in a manner that is at least possible impact on road users. Maintenance of the roads is efforts and activities that safeguard the physical condition of the roads and side facilities over a longer perspective. These are activities that require greater interaction, and will affect road users over shorter or longer periods. Examples of activities may be:

- Paving
- Periodic maintenance of bridges or tunnels
- Drainage
- Replacement of side construction equipment such as crash barriers or lighting systems.

As previously mentioned, more costly maintenance is defined as investment and this is then usually measures that upgrade the road in one way or another. Examples of such maintenance or upgrade are:

- Major rehabilitation or construction of new drainage and sewerage systems
- Upgrading / repair of the foundation of the road
- Stabilization security
- Larger re-asphalting and laying of new asphalt layer on the road
- noise measures
- Walls along the way
- Larger installations and tasks on bridges and quays

2.2.4 Road assets

Road assets are an expression of the road's value and the sum of the individual layers as the road consists of after deducting damage. This is done by finding road areas multiplied by the average m^2 price and deduct the value loss the damages represent. We can use various principles for valuing road network. The purpose of the valuation and the actual use of the road capital value will have a decisive influence on the choice of principle and also the requirements for the methods used in practical determination of value.

The road asset of the roads of Nedre Eiker is calculated from the paved roads and the side facilities that are registered in the PMS RoSy. The road's value is reduced by the recorded damages on the road.

As the roads wear out, deteriorate the value of the individual elements in road construction as follows:

	High city	Low city	Residential road	Walking and bicycle paths
Wearing layer	160 kr	140 kr	110 kr	200 kr
Binding / bearing layer	260 kr	220 kr	180 kr	80 kr
Reinforcement layer	200 kr	200 kr	200 kr	150 kr
Frost protection	150 kr	150 kr	150 kr	200 kr
Planum	100 kr	100 kr	100 kr	100 kr
Total value per m²	870 kr	810 kr	740 kr	700 kr
Kerbstones	400 kr	400 kr	400 kr	400 kr
Sidewalk	300 kr	300 kr	300 kr	300 kr
Gutter	300 kr	300 kr	300 kr	300 kr

Table 2:2 - Calculation of road assets of Nedre Eiker. Prices pr. m^2 are set to the listed values. This is an average value of these types of roads in the municipality (Finnerud and Sweco, no date), (Josephson, no date)

Explanation of contents of Table 2:2:

For "High City" is following values assumed:

The wear layer has as newly laid an average value of 160.00 NOK / m^2.

The wear layer loses all its value throughout the lifecycle. At 0 years of remaining useful life, the value of the wear layer 0.00 NOK / m^2.

Asphalt base course has as newly laid an average value of 260.00 NOK / m^2. Asphalt base course loses its value through its life cycle. At 0 years of remaining useful life equal to the lowest value of the asphalt base course similar to the underlying gravel base course (subbase), ie 200.00 NOK / m^2.

Gravel base layer (reinforcing layer) has an average value of 200.00 NOK / m^2.

Frost protection layer has an average value of 150.00 NOK / m^2.

Planum (road bed) has an average value of 100.00 NOK / m^2.

For the three lowermost layers (reinforcing, frost protection and road bed), the following applies: They do not lose their value, as long as the road is drivable.

If the road collapses due to lack of capacity (in risk area) we will lose all of the layers value at once, inclusive the wear and bearing layer. This means, in other words a lack of (poor) base course will give a greater risk that the road's overall value deteriorate.

For the other categories "Low City," "Residential Road" and "Walking and bicycle paths" the values are set in a similar manner. Table 2:2 also shows the value of "kerbstones," "Sidewalk" and "gutter".

A fall in the road assets is an indication that it wears more than that invested in the maintenance of the road network. A new wear layer degrades slowly at first but the degradation rate accelerates as the wear layer gets older.

The value of the road network in Municipality of Nedre Eiker:......NOK. 401.8 million.
Max value of estimated road areas (without injury):........................NOK 431.4 million.
(Finnerud and Sweco, no date), (Josephson, no date)

2.2.5 Value developments

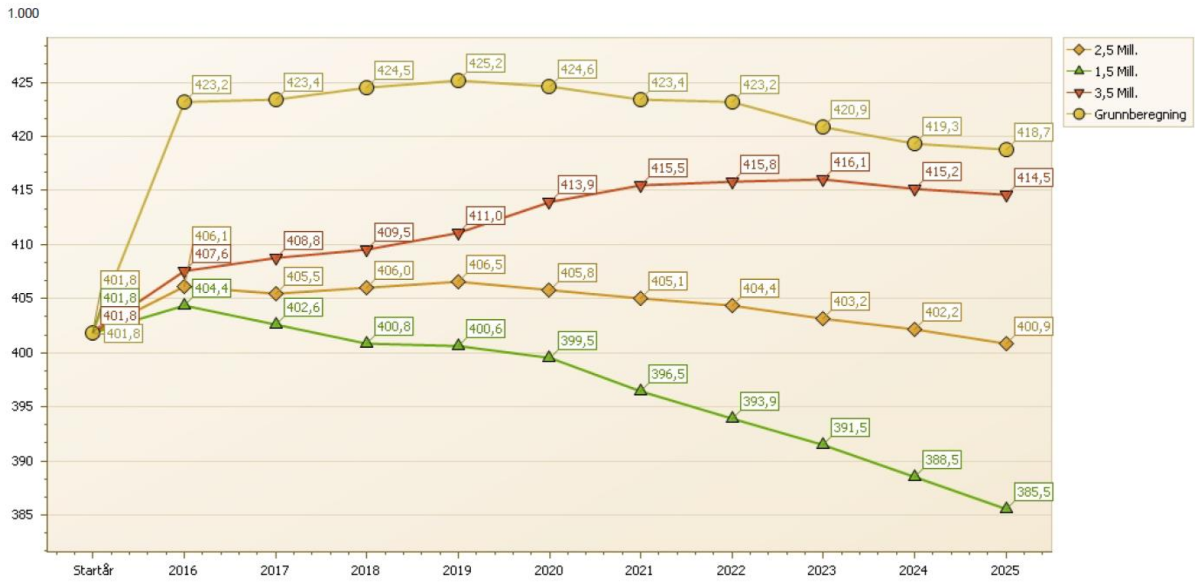


Figure 2:7 - Development of road assets at different maintenance budgets (Finnerud and Sweco, no date)

The above graph shows how the road assets will evolve over the next 10 years by the different calculation scenarios. The «yellow» curve shows the road assets at "optimal solution" - in the sense that we use the money that is necessary to obtain the maintenance backlog and then adequate maintenance to maintain road assets. The condition is a normal price development of the asphalt. At a budget of NOK 1.5 million will road assets be reduced to NOK 385.5 million after 10 years. A budget of approximately NOK 2.5 million will be able to maintain the current level of road capital.

Using RoSy we can choose the road sections which municipality achieves the greatest gain for the current budget. This particularly applies to roads with current residual life in the range -1 to -5 years, because these routes can be put in order with better benefit / cost (B / C) than distances with a lower residual life (-6 years and below). On the other hand, are sections with residual life of -6 and lower only gets worse and worse, and therefore will require a greater amount of funds to be reconditioned. This is the primary reason for increased backlog and reduced road assets; the roads are maintained too late.

Investment analysis

"Optimum level for operation and maintenance involves the solutions that provide the lowest total cost to society over time." (Aurstad et al., 2015)

By putting the 4 budgets against each other, we have a better picture of where we can assume that the municipal road network and cost will evolve over the next 10 years (Finnerud and Sweco, no date), (Josephson, no date):

Budget NOK 1.5 million.

Using NOK 1.5 million annually for 10 years, low standard roads will increase to approximately 35% of the municipal road network (roads with asphalt). The road assets will be reduced by approximately NOK 16.3 million. In addition, the risk we run by having a poor road network will increase overall costs. The roads which basically would have managed with a re-asphalting may have a need for resettlement. The budget will not be able to keep the current level.

Budget NOK 2.5 million.

By using Cr. 2.5 million annually for 10 years, low standard roads will represent approximately 18.5% of the road network. The road assets be reduced to NOK 400.9 mil. The budget would reduce low standard roads, but cannot quite keep road assets at current levels.

Budget NOK 3.5 million.

By using Cr. 3.5 million annually for 10 years, low standard roads will be reduced to represent approximately 5% of the road network. The road assets will increase to approximately kr. 414.5 million and the risk factor is reduced significantly.

Basic calculation (optimal solution)

By using the optimal solution, there are no low standard roads after one year, and road assets increased to approximately kr. 418.7 million. The optimal means basic calculation. Ie the use of as much money as is necessary to obtain the lag, and then what is necessary not to make new low standard roads in the subsequent years.

The total cost over 10 years would by optimal calculation have a lower total cost than other budgets. The risk that road network loses economic value due to lack of maintenance is at a minimum with the basic calculation.

It is not taken into account socioeconomic costs (risks). This will be in addition. Increased material cost beyond normal, unforeseen costs associated with climate change is not taken into account. Municipal roads with other coatings than asphalt, such as gravel / concrete / stone, are not taken into account and the cost of maintenance of these roads will be in addition. Maintenance costs for parking, signs, replacement of manholes / drains, street lighting, speed bumps, drainage and other accessories are not included in the calculation.

These calculations are performed in relation to the current road with the substructure they have, or lack of these substructure, and therefore involves only a budget that brings the road surface up to an acceptable level right after completing maintenance. If the roads should be rebuilt from scratch, the cost scenario will be quite different. Benefit / cost will change, and the calculations will be more advanced. In simple terms, it will in this case mean that all municipal roads that are missing substructure have to be rebuilt, and with today's municipal finances this is an unthinkable scenario. In contrast, large parts of the municipality's water and sewer system are placed in connection with the roads, and many of these facilities need to be replaced over the next few years. In this context it would be very sensible rehabilitating the roads and building them up from scratch again. Benefit / cost will be very beneficial because the masses can be replaced and the roads to be built up again to the surface standard they were in before the work of water and sewage started by using the financing over water and sewer budget that assets been obtained from fees. It is common practice in municipalities to finance the reconstruction of roads in this way (Krøvel-Velle, 2016). It will only be a possible upgrade of the road's function, and if we want to upgrade the road with a greater widening or construct sidewalks or pedestrian / bicycle path that has not been there before, we need to finance this in other ways.

2.2.6 Facts about lags and consequences of inadequate maintenance

Delayed or inadequate maintenance of roads reduces life and functional capacity. Road constructions decompose slowly due to use and age. Road surfaces are of great importance for road life. If the top layer of the structure is not properly maintained it leads to cracking, holes, alligator cracking and drying, which allows water to enter the road constructions. This will initiate a more rapid decomposition of the structure which in turn causes the repair scope can be very extensive. Optimum maintenance is therefore much to keep the road surface in a sufficient good condition and take action before damage occurs.

Lag caused by neglected maintenance over time, are usually regarded as costs of measures to bring the road network up to normal standard (reclaim capital).

A significant part of the municipal road network, sidewalks and pedestrian and cycle paths have a disturbing bad condition. In many places it is no longer sufficient to resurfaced, but it is also necessary with mass replacement and building new foundation before it is resurfaced.

The annual spending in NEK has long covered mainly costs of operation (winter maintenance, cleaning, vegetation clearing, etc.). There has been no room for adequate systematic maintenance. Re-asphalting and associated rehabilitations are carried out only within the investment framework when possible. Table 2:3 shows an overview of how much there is that is set aside for maintenance of roads in the period 2005 to 2015 in relation to what is set aside for winter. With the exception of 2013, it allocated very little maintenance of the municipal roads and streets.

	Maintenance	Winter maintenance
2015	800 000	2 850 000
2014	900 000	3 050 000
2013	3 183 000	3 050 000
2012	900 000	3 050 000
2011	894 000	3 142 500
2010	894 000	3 142 500
2009	894 000	2 642 500
2008	844 000	2 392 500
2007	944 000	2 500 000
2006	944 000	1 610 000
2005	869 000	1 535 000
Total	12 066 000	28 965 000

Table 2:3 - Summary of budget for maintenance of roads in Nedre Eiker 2005 – 2015 (Josephson, no date)

When the condition falls below a certain level, the necessary action must be executed to bring the road's functioning up to its original level. There will always be a question about what condition the road had "like new". A number of municipal roads are old and built to old standards. Rehabilitation of these roads means in reality a rebuilding or upgrading to current standards in accordance with SVV's road standards.

In the annual priorities of action must determine whether these road parcels shall be restored to a condition "that was originally built" or "to the current requirements." It is in other words, whether to accept a dual road network as regards standard.

2.3 Requirements and framework

In Norway, it’s the Norwegian Public Roads Administration (NPRA) (Statens Vegvesen, SVV) who sets performance standards in the Norwegian road network. They publish books that will ensure that the requirements and guidelines are being followed during construction, operation and maintenance of the road network. This should ensure an acceptable standard of the road network through the requirements and recommendations for operation and maintenance of public roads. Many municipalities have developed their own road standards based on NPRA Manuals (SVV’s handbooks). The purpose of the municipal road standards is that they should be adapted to the local authority, and be easy to understand for its inhabitants. Such a road standard is made for roads of Nedre Eiker simultaneously with this report are written (Josephson, no date).

An effective and predictable road network is an important prerequisite for a country's economic prosperity, and the demands of the authorities establish the framework for a good economic management of road assets.

2.4 Considerations of frost (frost heave), drainage and groundwater levels

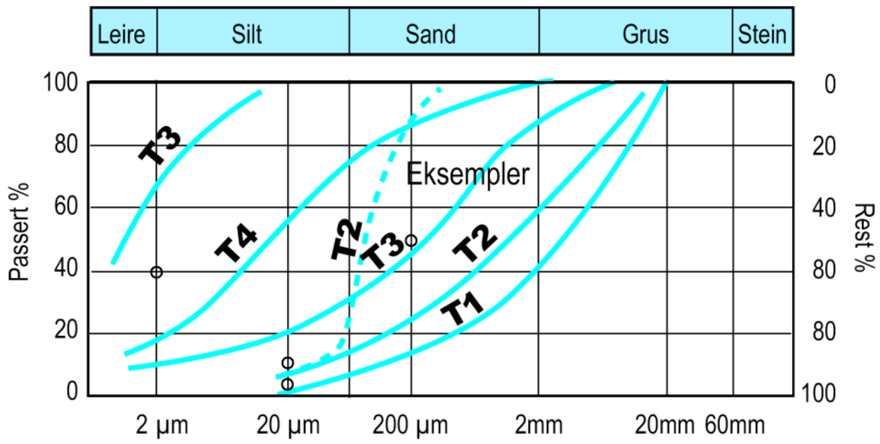


Figure 2:8 - Examples of "frost dangerousness classes" (Vegdirektoratet, 2014b)

Since much of the soil conditions in Nedre Eiker consists of clay and silt(Table 2:7), it would be natural to assume that frost dangerousness classes T3 and T4 will be applicable to many of the roads.

Telefarlighetsklassifisering				
Telefarlighetsgruppe		Av materiale < 22,4 mm		
		Masse-%		
		< 2 µm	< 20 µm	< 200 µm
Ikke telefarlig	T1		< 3	
Litt telefarlig	T2		3 - 12	
Middels telefarlig	T3	1)	> 12	< 50
Meget telefarlig	T4	< 40	> 12	> 50
Bæreevneklassifisering				
Undergrunn			**Bæreevnegruppe**	
Fjellskjæring, steinfylling,	T1		1	
Grus, Cu ≥ 15,	T1		2	
Grus, Cu < 15,	T1		3	
Fjellskjæring, steinfylling,	T2		3	
Sand, Cu ≥ 15,	T1		3	
Sand, Cu < 15,	T1		4	
Grus, sand, morene,	T2		4	
Grus, sand, morene,	T3		5	
Leire, silt, morene	T4		6	
Myr 2)			7	
Andre materialer				
Lettklinker, skumglass			4	
Ekstrudert polystyren (XPS)			4	
Ekspandert polystyren (EPS-blokker)			6	

1) Også jordarter med mer enn 40 % < 2 µm regnes som middels telefarlig T3.
2) Bæreevnegruppe 7 Myr inngår ikke i de forskjellige dimensjoneringstabellene og må behandles spesielt. Ofte vil tiltak bestå i forsterkning av grunnen, se kap 2.

Figure 2:9 - Subdivision of subsoil in frost dangerousness- and bearing capacity groups (Vegdirektoratet, 2014b)

“Vegdirektoratet (2014b) Håndbok N200, Vegbygging” states the following*: soil conditions will be surveyed by sampling and classification of soils in the road alignment. Required need for basic research, as the basis for design of the road construction shall be identified with the methodology shown in Figure 2:10.*

Within areas of need basic investigation shall be the minimum extent be as shown in Figure 2:11. In addition, there shall be a minimum of 1 sampling profile pr. homogeneous section. Testing scope is provided that quarternary geological conditions and terrain indicates homogeneous soil conditions. Mapping considering the need for frost protection to be included in the survey and include an assessment of frost heave exposure.

<table>
<tr><th></th><th colspan="2">Grunnforhold:
Sannsynlig T3-T4 materialer</th><th>Grunnforhold [1]:
Sannsynlig T1-T2 materialer</th></tr>
<tr><td>Grunnforhold fra kvartær-geologisk kart</td><td colspan="2">- Tykk morene
- Randmorene
- Elveavsetning
- Breelv- og bresjø-/innsjøavsetning
- Hav- og fjordavsetning, strandavsetning, tykt dekke
- Marin strandavsetning
- (Vindavsetning og fyllmasse – vurderes spesielt)</td><td>- Tynn morene [2]
- Hav- og fjordavsetning, strandavsetning, tynt dekke [2]
- Skred- og forvitringsmateriale
- Tynt humus/torvdekke
- Bart fjell
- (Torv/myr - vurderes normalt av geotekniker)</td></tr>
<tr><td rowspan="2">Veglinje i fylling</td><td>Fyllingshøyde > Frostdybde</td><td>Fyllingshøyde < Frostdybde</td><td rowspan="2">Trenger ikke grunnundersøkes</td></tr>
<tr><td>Trenger ikke grunnunder-søkes</td><td>Skal grunnunder-søkes</td></tr>
<tr><td>Veglinje i skjæring</td><td colspan="2">Skal grunnundersøkes</td><td>Begrenset grunnundersøkelse for å fastslå området med T1-T2</td></tr>
</table>

1) Hvis veglinjen går i grensen mellom grunnforhold T3-T4 og T1-T2 skal området klassifiseres som T3-T4 pga. kartenes unøyaktighet (+/- 50m på et 1:50 000 kart)
2) Forutsetningen for å ikke utføre grunnundersøkelser er at det skal beskrives rensk til fast fjell innenfor disse områdene

Figure 2:10 - Need for site investigations for design of the superstructure (Vegdirektoratet, 2014b)

We see in Figure 2:10 that both river deposition, marine and fjord deposits is likely frost hazardous materials. These are in two of the zones where there are many roads in Nedre Eiker (zone 41 and 50) (See Table 3:1).

Vegtype	Antall profiler pr. km hvor det tas prøver
Hovedveger ÅDT > 1500	8
Hovedveger ÅDT ≤ 1500 Samleveger og atkomstveger	4 [1)]

1) Det bør fokuseres på områder der spesielle problemer knyttet til bæreevne og/eller ujevne telehiv er ventet. For eksempel overganger mellom fylling/skjæring og undergrunn med ulik telefarlighet (fra kvartærgeologisk kart), fundamentering på bløt undergrunn eller erfaringer med eksisterende veg som tilsier problemer.

Figure 2:11 - The minimum number of samples for determining the bearing capacity group within the range of needs for site investigations acc. Figure 2:10 (Vegdirektoratet, 2014b).

"Vegdirektoratet (2014b) Håndbok N200, Vegbygging" also says: *Dimensioning frost protection in the pavement should be based on local conditions with regard to the annual mean temperature and frost.*

SVV handbook N200 (Vegdirektoratet, 2014b) also has a council table for the annual mean temperature and frost levels. For Nedre Eiker this table shows:

Kommune-nummer	Kommune-navn	Årsmiddel-temperatur	Frostmengder, h°C				Korreksjonsfaktorer	
			F_2	F_5	F_{10}	$F1_{00}$	Min	Maks
625	Nedre Eiker	5,5	7000	13000	17 000	29 000	0.99	1.21

Table 2:4 - The annual mean temperature and frost quantities Nedre Eiker (Vegdirektoratet, 2014b)

The requirements for frost protection that indicated in Figure 2:13, applies to places where materials in the ground are in frost dangerousness class T3 or T4. According to Figure 2:8, Figure 2:9, Figure 2:13 and Figure 2:12, most of the roads in Nedre Eiker will be T3 and T4.

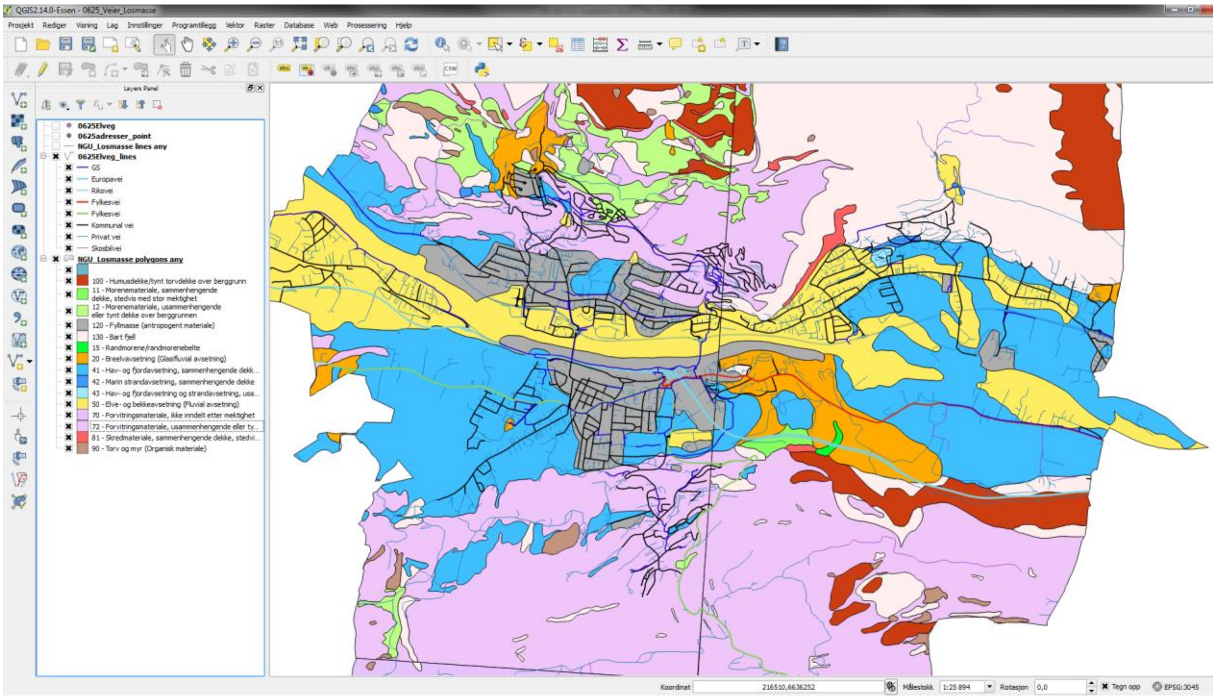


Figure 2:12 - Extract from QGIS showing roads divided into soil zones in Municipality of Nedre Eiker.

ÅDT	Ant. kjørefelt	Telefarlig-hetsklasse	Frostsikring	
			Dim. frostmengde	Maks [1)] tykkelse overbygning
> 8000	4 eller flere	T3, T4	F_{100}	2,4 m
> 8000	< 4	T3, T4	F_{10}	2,4 m
1501 - 8 000		T3, T4	F_{10}	1,8 m
≤ 1500		T3, T4	Tiltak for å unngå ujevnt telehiv skal vurderes [2)]	1,8 m

1) Begrepet «maks» betyr i denne sammenheng at den angitte tykkelse normalt er tilstrekkelig til å unngå uakseptable telehiv selv om frostdybden er større.
2) Tiltak for å unngå ujevnt telehiv skal baseres på frostmengden F10.

Figure 2:13 - Designed frost amount and maximum thickness of superstructure. (Vegdirektoratet, 2014b)

For municipal roads in Nedre Eiker will only be relevant AADT <8000, so design frost will be F10 for all roads.

For roads with ADT less than 1,500 will a need for frost protection be evaluated on sections where problems related to uneven frost heave can be expected.

Figure 2:14 shows how the bearing capacity of different soils is changing throughout the year. We see that "silt" and "clay" have a critical bearing capacity in the spring. These soil types are found in soil zone 41 which has many roads in Nedre Eiker (See Table 3:1).

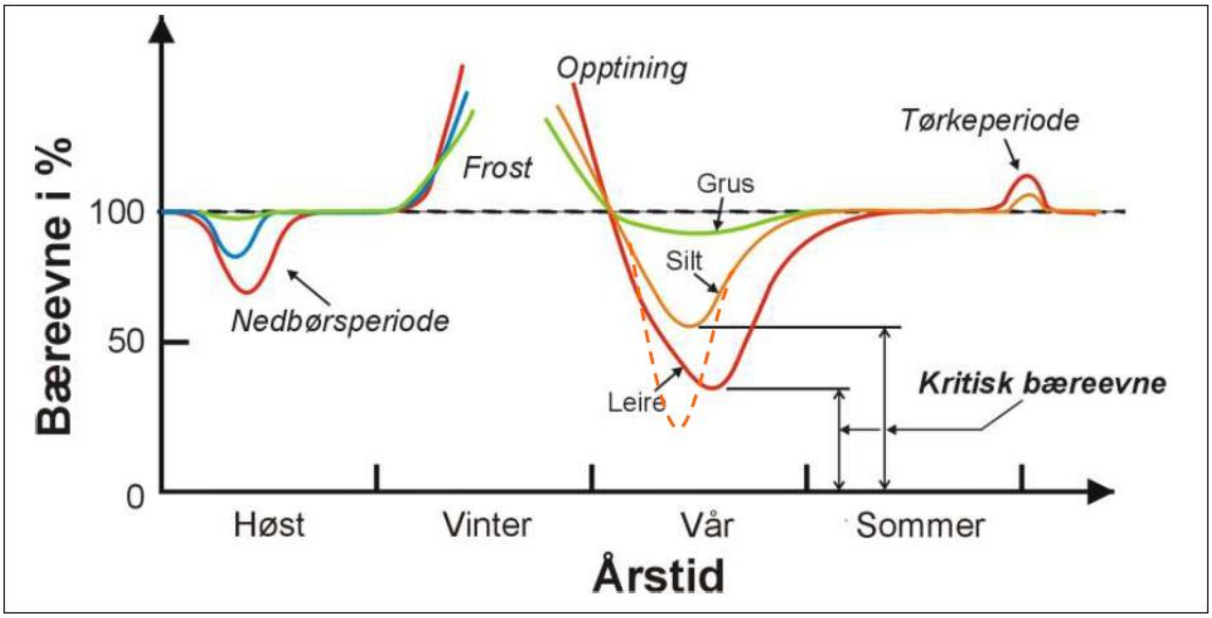


Figure 2:14 - How the bearing capacity change during the year (Berntsen, 2015)

SVV's handbook N200 says that a road that is not protected against frost will still have sufficient capacity throughout the year if it is dimensioned according to N200 "Vegbygging" (Vegdirektoratet, 2014b).

Lowering of groundwater levels can have a positive effect on the roads carrying capacity. Figure 2:15 (Berntsen, 2016) shows how much effect we can get by lowering the groundwater level by 30 cm.

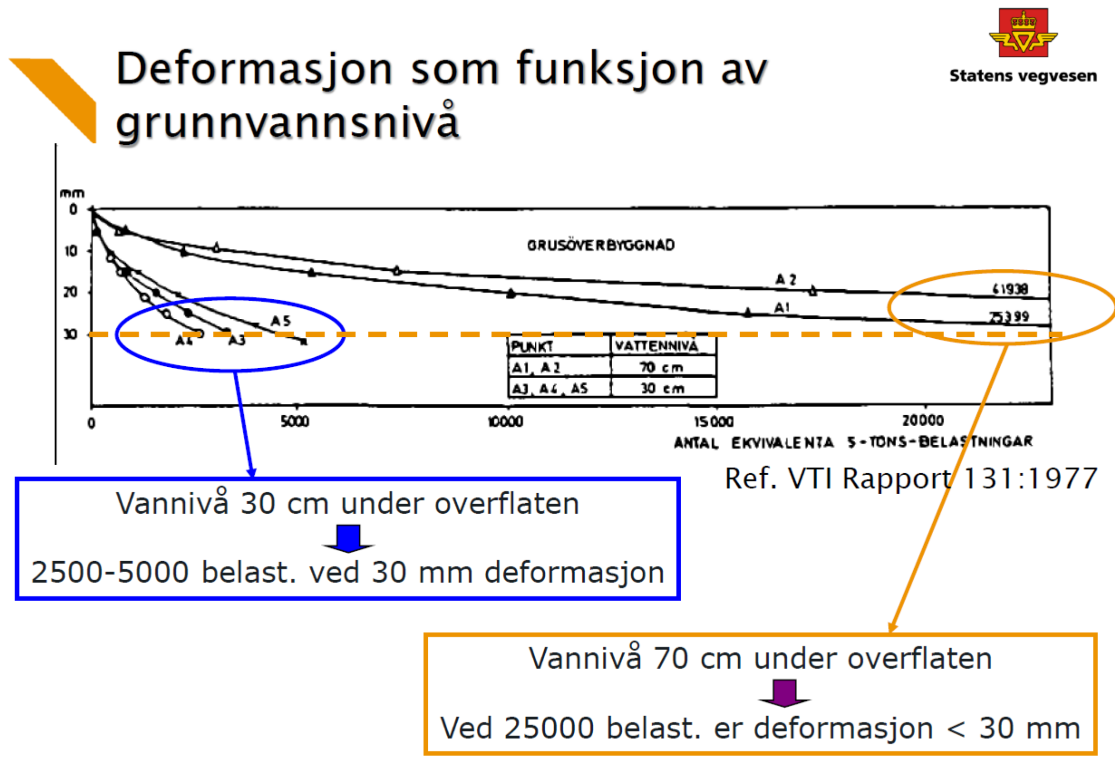


Figure 2:15 - Effect of lowering of groundwater levels (Berntsen, 2016)

Geir Berntsen (SVV) claims in his presentation "Teknakurs -Vegteknologi, Drenering', Vegteknologi 2016 Conference, Hell hotell Værnes, Norway" (Berntsen, 2016) the following:

- *Dewatering and drainage system must be designed so that it has sufficient capacity and is possible to Maintaining*
- *Inadequate drainage gives poor bearing capacity and short life span of roads*
- *Inadequate drainage can cause frost heave and "iskjøving"* (ed note: building up large blocks of ice along road cuts)
- *It is possible to increase the life of the roads by at least a factor of 1.5-2 by improving drainage*
- *Maintaining the drainage system is perhaps the most profitable maintenance actions for road owner who also provides a durable and economical road maintenance systems*
- *Effective drainage maintenance should therefore be prioritized over other maintenance actions*Dette er verdt å merke seg med tanke på mulige tiltak for veiene i Nedre Eiker.

2.5 Condition analysis of road network

This thesis is about how the condition of the road surfaces of municipal roads in Nedre Eiker is, and how this breaks down in different parts of the municipality on the basis of the local soil conditions. There are many ways to define the condition of the pavement, and SVV's Manual V261, «Damage catalog for bituminous pavements" (Vegdirektoratet, 1996) uses the character code L, M and H (low, medium and high) to describe the severity of the injury. In addition, the damage extent of an impact depends on how serious the road is damaged. The way the extent is detected is to measure and set the beginning and ending of the damage. This gives a measure of the damage distribution in the longitudinal direction. In addition, it may also be useful to express the damage distribution in the road or the lane width. Often, there will also be performing several types of damage in the same place. If there are two damages in the same location, the registration is in principle independent although in practice they are registered in the same inspection.

2.6 Requirements for state of the road network

SVV's Manual R610 "Standard for operation and maintenance of national roads" (Vegdirektoratet, 2014c) provides guidelines for how national roads in Norway will be operated and maintained. It also states the requirements for the operation and condition of roads, bridges, tunnels, page ranges and page plant with equipment and installations.

Standard requirements in Manual R610 are indicative and not legally binding for road owner unless it is specified in the contract. In practice, the attainable standard depends on available funding. In case of inadequate budget it must be prioritized, which aims to achieve the best economic benefit.

The purpose of the handbook is to provide uniform conditions with regard to road safety and traffic flow for all road users for the same type of road.

2.7 Collection of data

2.7.1 Collection of state data from the road network

Data from the road network is a prerequisite for good management of road assets. Any data collected should be comprehensive enough to provide an adequate overview, and accurate enough to provide sufficient detail. Good quality data is a prerequisite for making the right decisions during operations and maintenance. A comprehensive state registration is carried out by SWECO commissioned from and in cooperation with Nedre Eiker, and all data is registered in RoSy.

The state registrations as the basis for this report are carried out by a road technician from Sweco in collaboration with Erik Josephson. Registration is performed using the registration system "CamSurvey" which is described on page 14 (State Registration of road network). Municipal roads are "kilometrert", ie using the length measurement from a defined starting point, we know all the time where the road we are.

The registration form contains the following data:

RoadNumber	The roads official number
RoadName	Name of the road
Chainage0:	Name of the point where the road starts (often a cross section with another road)
Chainage:	Where on the road in meters from "Chainage0"
Place:	Where om the road in cross direction
OnRoad:	On or off road (yes/no), of road can be a registration in a ditch or in the verges
ObjectName:	Name of registration, see Table 2:6
Timestamp:	Time of registration
Result:	Varies according to «ObjectName», can be width in meters, type of asphalt (ASF, AGB etc.) material in ditch (eg. sand or gravel), height of kerb in cm or type of damage.
RegistrationId:	A unike number for the regitration

Table 2:5 - Main types of registration for road conditions (RoSy)

Type of registrations (ObjectName)		
Width	Bridge	Stripping 1
End Lane	Rail	Settlement 1
Pause Left Cross Section	Post	Patches 1
Pause Right Cross Section	Other Cross Section	Winter Patch 1
Gutter C	Small Cracks	Asf pavement
Gutter G	Large Cracks	Pavement Type
Kerb C	Crazing	Dangerous Defect
Kerb G	Pothole	Poor Bearing Capacity
Path CG	Stripping	Poor support
Foot Path A	Settlement	Milling not Possible
Foot Path 1	Rutting	SD Allowed
Bicycle	Loss of Chippings	Wearing Course Problems
Parking	Patches	Max Overlay Height
Foot-Cycle way	Winter Patch	Kerb Raising Allowed
Bus	Verges not OK	Levelling
Green Line	Kerb Height	Comfort General
Verges	Ditch Cleaning	GPS
Ditch	Gutter Regulation	Note
Kerb Deep	Kerb Regulation	Trip Hazard 1
Kerb 1	Foot way Regulation	Trip Hazard
Protection Line	Start Section	Cross Service Level F
Crossroad	Stop Section	Cross Service Level K
Other Add Area	Fixed Section	Paviour Defect 1
Other Add Area 1	Small Cracks 1	Paviour Defect
Gully	Large Cracks 1	Asfalt Defect 1
Gully Detailed	Crazing 1	Asfalt Defect
Tree	Raveling 1	Residual Life
Green Spot	Pothole 1	

Table 2:6 - Type of registrations in PMS RoSy (ObjectName)

After sorting and grouping of the types of damages that are registered, we have this list which is used in this thesis:

- Small cracks
- Large cracks
- Crazing
- Desiccation
- Hole
- Settling of ground
- Rutting
- Winter Patch
- Stone loss
- Patched area

- Profile alignment
- Shelling

2.7.2 Collection of geological data

As mentioned in chapter 1.2.2, Execution of fieldwork is the main source for the geological data are obtained from the Norwegian Geological Survey's (NGU) cartography. Here's a map called "Løsmassekart" (Norges Geologiske Undersøkelse, no date) that can be downloaded for personal use (http://download.ngu.no/download/ShoppingServlet?dataset=600).

After the map layer is loaded into QGIS and categorized for the type of "Jordart" (Type of soil) will look like in Figure 2:16.

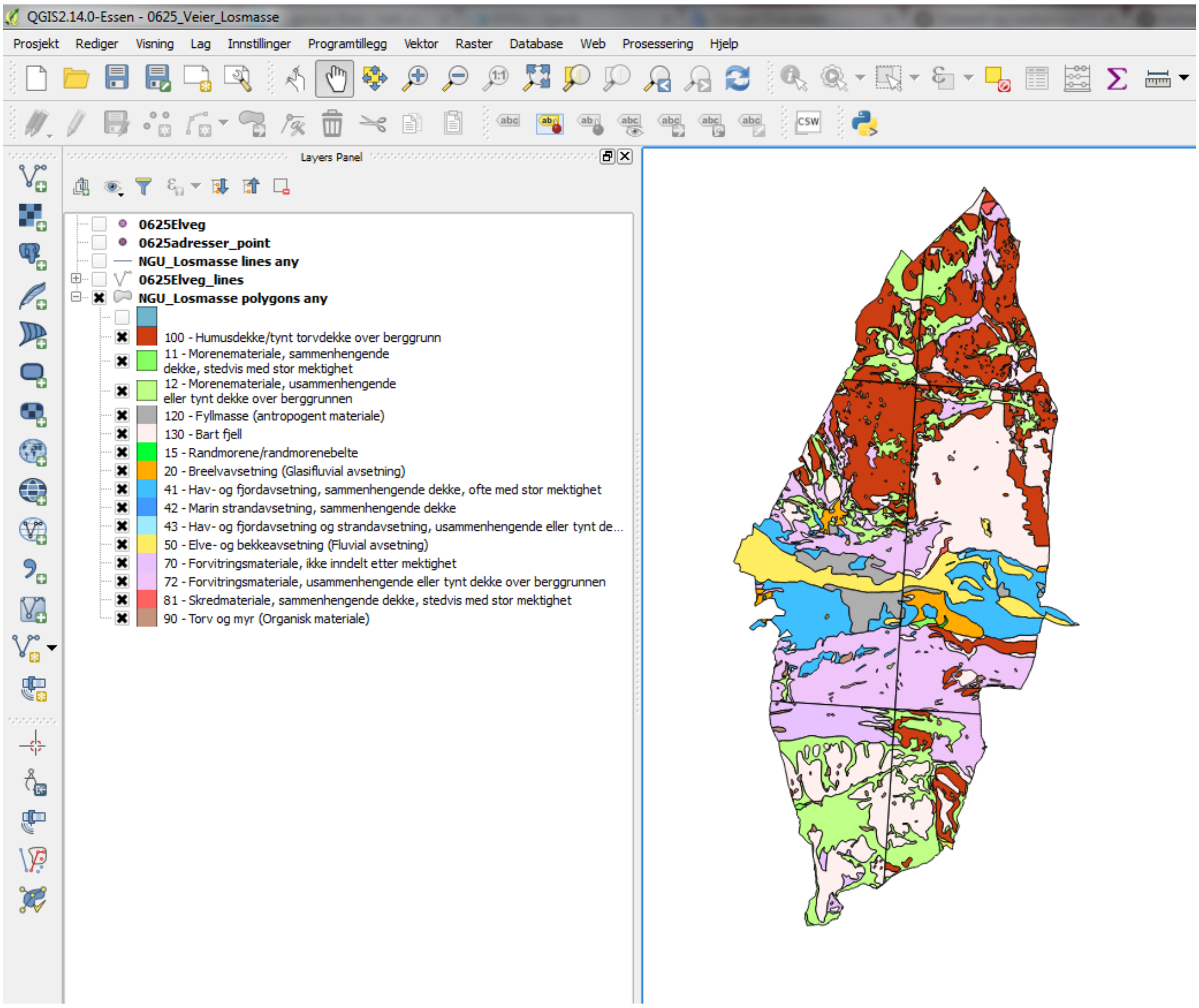


Figure 2:16 - Map layer from NGU loaded into QGIS

The description of the different soil types, groundwater potential and infiltration capability is derived from the document «Presentasjonsregler for løsmassedata» (Norges Geologiske Undersøkelse, 2015a) and «Produktspesifikasjon Losmasser ver3» (Norges Geologiske Undersøkelse, 2015b). The soils found in Nedre Eiker, and are relevant in this thesis are presented in Table 2:7, Table 2:8 and Table 2:9.

Ground conditions code	Description	Definition of soil type
12	Moraine material, incoherent or thin cover over the bedrock	Materials picked up, transported and deposited by glaciers. It is usually hard packed, poorly sorted and can include everything from clay to stone and block. Areas with shallow moraine deposits / frequent mountain outcrops. The thickness of the deposits is normally less than 0.5 m, but it can completely locally be something more.
20	Glacial river deposits (Glasifluvial deposition)	Material transported and deposited by glacial rivers. The sediment consists of unordered, often oblique layers of different grain size from fine sand to rocks and boulders. Glacial river deposits often have clear surface forms like terraces, ridges and fans. The thickness is often several tens of meters.
41	Ocean and fjord deposition, continuous cover, often with large thickness	Fine-grained, marine deposits with thickness from 0.5 m to several tens of meters. Deposition type also includes avalanche heaps of quick clay slides, often indicated by the addition symbol. There are few or no mountain outcrops in the area.
42	Marin beach deposition, continuous cover	Marine beach washed sediments with thickness greater than 0.5 m, formed by wave and current activity in the coastal zone, in places such as beach ridges. The material is often rounded and well sorted. The grain size varies from sand to block but sand and gravel are the most common. Strand provisions are as a relatively thin cover over bedrock or other sediments.
43	Marine and fjord reserve and beach deposition, incoherent or thin cover over the bedrock	Fine-grained, marine deposits with thickness from 0.5 m to several tens of meters. Deposition type also includes avalanche heaps of quick clay slides, often indicated by the addition symbol. There are few or no mountain outcrops in the area.
50	River and stream deposition (Fluvial deposition)	Material transported and deposited by rivers and streams. The most typical forms are alluvial plains, terraces and fans. Sand and gravel dominate, and the material is sorted and rounded. The thickness varies from 0.5 to more than 10 m.
72	Weathering Material, incoherent or thin cover over the bedrock	Soils formed in situ by physical or chemical breakdown of bedrock. Shallow area with numerous mountain outcrops.
81	Landslide material continuous cover in places with large thickness	Deposits formed by rockfall, rockslides, avalanches or soil avalanches from steep hillsides. Symbol shows dominant avalanche type. The thickness is more than 0.5 m and few mountain outcrops in the area.
120	Filling material (anthropogenic material)	Soils supplied off or heavily influenced by human activity., Mainly in urban areas.
130	Bare mountain	Used on areas which are mostly lacking soils, more than 50% of the area is mountainous in the day.

Table 2:7 - Description of the various soils / sediments found in Nedre Eiker. (Norges Geologiske Undersøkelse, 2015a) and (Norges Geologiske Undersøkelse, 2015b)

It is also relevant to look at groundwater conditions and soil infiltration capacity for water, and these data were derived from the same mapping and documentation soils.

Ground-water Code	Name	Description
2	Assumed substantial groundwater potential	Include mainly glaciofluvial and alluvial deposits, and some mighty beach deposits where groundwater is connected to rivers / lake. Other large glaciofluvial and alluvial deposits with autogenous groundwater magazine may also be included.
3	Limited groundwater potential	Small groundwater withdrawals may be possible from less glaciofluvial and alluvial deposits that are not associated with rivers / lake. Sand and gravel containing moraines, beach deposits and lake- / glacier lake deposits dominated by sand and landslide material may also be included.
4	Not groundwater potential in soils	Include mainly fine-grained moraines, marine and fjord deposits or thin, incoherent deposits of rock debris and bare mountain and moorland.

Table 2:8 - Description of groundwater potential of the different soils / sediments found in Nedre Eiker. (Norges Geologiske Undersøkelse, 2015a) and (Norges Geologiske Undersøkelse, 2015b)

Infiltration capacity code	Name	Description
1	Well suited	Soils grain size distribution and permeability, and soil depth and terrain conditions indicates good infiltration capability. Adequate thickness of sand and gravel above the groundwater level. Includes large glaciofluvial and alluvial deposits, and some mighty beach deposits and sorted parties in the terminal moraine.
2	Medium suited	Soils grain size distribution and permeability, and soil depth and terrain conditions indicates medium infiltration capability. Limited thickness of sand and gravel above the groundwater level or greater reserves with somewhat reduced infiltration capacity. Include mainly thick sand and gravel rich moraine deposits, heavy / contiguous cover of weathering material, sand beach deposits and bresjø- / lake deposits.
3	Unsuitable	Soils grain size distribution and permeability, and soil depth and terrain conditions indicate poor infiltration capability. Small / shallow deposits, locally with no infiltration capacity or thick deposits with little infiltration capacity.
4	Unfit	Soils grain size distribution and permeability, and soil depth and terrain conditions indicates very poor or no infiltration capability. Includes dense clay-dominated deposits, rough block and stone material, marsh, fillers, thin deposits of rock debris with little infiltration capacity, and bare mountain.
5	Unrated	Infiltration capacity is not rated because sufficient data are lacking.

Table 2:9 - Description of infiltration capability of the different soils / sediments found in Nedre Eiker. (Norges Geologiske Undersøkelse, 2015a) and (Norges Geologiske Undersøkelse, 2015b)

2.7.3 Data processing

When all data is collected the next step to sort and categorize them. The geological soil conditions must be placed on the map so that it is possible to find both the number and length of municipal roads within each "zone". It is important to form an image on the length road within each zone so that it becomes visible how distributed, and that this relationship may be taken into account when injury and life on the roads should be considered.

Furthermore, it is important to identify the damage types, categorize them and form a picture of what damage is most frequent, which injuries are most dominant based on the severity and extent. When processing data starts and we will prepare for data analysis, it is important that we take into account the objective of the project.

> The objective of this thesis is to look for relationships between the condition of the roads and the type of soil that the road is built on, and consider whether it is possible to plan maintenance of the road on the basis of soil conditions, especially in those cases where the road is missing base course and subbase.

Through data processing, all different type of injury, the prevalence of them and severity is identified. Furthermore, the data processing placing the roads state in the different soil conditions zones so that it will be possible to see whether certain types of injuries are more prevalent than others in specific soil conditions. The roads remaining lifetime will also give a picture of the soil type can provide an additional negative impact on the road state development. It may also be useful to define groundwater potential and infiltration capacity of the ground to see if there's any connection between this and roads.

2.8 Data analysis

After identification of the damage, it is right to say something more about what kind of damages we have, and how severe the damage is. The more information one can extract from the measurements, the greater will be the benefit.

Some parameters can be used to describe damage to the road surface is the following:

- Length: The length of the damage to the road's longitudinal direction.
- Width: How wide is the damage to the road / lane
- Depth: How deep runs damage
- Location: Where the roadway is the damage
- Localization: In which soil- / groundwater potential / infiltration capability zone is damage localized.

In this project it is important to analyze the damage types and prevalence of those in each of the different ground conditions zones (soil- / groundwater potential- / infiltration capacity-zone). It will also be of great importance to find possible causes of the various damages to explain damages on the basis of ground conditions. In this work, Statens Vegvesen's manuals can be a useful tool, in addition, there are good literature from the United States, for example (Holewinski et al., 2003), (Highways Department, Research & Development Division, 2013) and (Miller and Bellinger, 2003).

Furthermore, it will be important to establish the length of municipal roads within each of the zones with soil. This is to be able to see the amount of damages in relation to the amount of road to be found in the various zones. This will give a more accurate picture of the damage distribution for each zone than the exact amount of damages, the number, length or area.

Parts of the damage are registered with the length of the injury or longitudinal road is damaged, this may include longitudinal cracks. Other damages are registered with injured area, this may be crazing or rutting. Since damages will not be assessed against each other there will not be of any significance that the amount of damages is registered in different ways, the goal is to see how the individual damage types occurring in the different zones with soil.

2.8.1 Classification of damages

Classification of damages can be done on the basis of geometry, location or the underlying cause of the damage. The objective of classification is to structure information in order to take better advantage of this.

Cracks / crazing / potholes, rutting and surface texture deficiencies prove to be the most prominent injuries.

Cracks are classified in six different categories, based on boundary conditions of geometric parameters:

- Transverse cracks: Cracks that extend more than 3 times so far across the road as lengthwise.
- Longitudinal cracks: cracks extending three times as far in the longitudinal direction than that in the width direction and / or only be registered in 1 zone.
- Edge cracks: Longitudinal cracks which is 25 cm or closer to the roadside.
- Crazing: network of cracks, with 3 or more squares in each longitudinal direction. Routes over 30 cm in diameter are considered as independent cracks.
- Holes: Damage with a diameter greater than 5 cm, where all the asphalt in the middle is gone.
- Rutting: uneven roadway due to wear from studded tires or a weak base course that makes the road fail under load of the wheels of cars.
- Settlements: uneven roadway because of declining base course / road bed.

2.8.2 Evaluation of severity

When one has classified the injuries it may be useful to also say something about the severity. Most injuries evolve over time, and may eventually provide an accelerated development damage if preventive measures are not implemented in time.

General methodology

Severity of injury can be divided into different levels based on how much the damage has been allowed to develop. One way to do this is to first classify the damage, so to assess the severity of the limit values for the characteristic parameters, such as size, width, depth, etc.

Examples of assessment of the severity of injury are found in SVV's “Skadekatalog” V261 (Vegdirektoratet, 1996). There are also examples and descriptions in SVV's report 365; " Lærebok for drift og vedlikehold av veier" (Aurstad et al., 2015) that are based on the same. Through literature search was difficult to find research evidence SVV's publications but there are a great deal of literature from other countries that certainly can contribute to further work on roads in Nedre Eiker. Among others there are good publications such as “Miller, J.S. and Bellinger, W.Y. (2003) Distress identification manual for the long-term pavement performance program. US Department of Transportation”. (Miller and Bellinger, 2003) and “Holewinski, J.M., Soon, S.-C., Drescher, A. and Stolarski, H.K. (2003) Investigation of factors related to surface-initiated cracks in flexible pavements – Final report. University of Minnesota: Minnesota Department of Transportation”. (Holewinski et al., 2003).

An example of manual assessment of the severity of holes is found in Distress Identification Manual (Miller and Bellinger, 2003). Here we share the various categories into three degrees of severity: low, moderate and high. The severity defined by quantitative parameters. It's not as important to assess the severity of the injuries in this thesis, but knowledge of the assessment is useful. It is still important to have knowledge of what damage is most severe in terms of assessment of the consequences of lack of substructure in the different ground conditions zones.

2.9 Use of data

After the identification and classification of damages we are left with a lot of information that can be used to evaluate the road state. Further work is to analyze this information to form a picture of the actual situation of the roads in Nedre Eiker, and place damages into zones for the different soils.

2.9.1 Pavement Management System

The overarching goal of the PMS is to provide road manager a solid basis for decisions. This includes analyzing the consequences of different solutions, coordinate activities within the organization and ensure proper coordination. Municipality of Nedre Eiker has implemented the Pavement Management System "RoSy" which was put into operation and was operational early in 2016. Since RoSy is an important and valuable tool in the efforts to investigate roads in Nedre Eiker to establish a good and sustainable maintenance and upgrade plan.

PMS consists mainly of three subsystems:

1. Collection: A system for regularly collecting data from state of road network. This is now up and running in Nedre Eiker
2. Database: A database system for sorting and storage of collected data. Database RoSy is in place, and all historical data has been entered. It remains now to bring in data from ongoing state registration.
3. Analysis: An analysis system for evaluating strategies for the operation, maintenance and rehabilitation.

An effective PMS requires sufficient information for each decision level. It is therefore important that all necessary data is collected and updated regularly to ensure that the analyzes at any time reflects the current situation. Nedre Eiker has signed a 5 year agreement with Sweco for data collection and analysis report that will help the municipality be able to make right decisions in relation to the operation and maintenance of municipal roads.

Another important part in the further work is the use of state indices and predictive models relating to RoSy, which will contribute to the development of life cycle assessments for roads. This must be developed and been implemented in Nedre Eiker's PMS.

2.9.2 Collection, analysis and use of data from the road network in Norway

Responsibility for roads administration in Norway lies with the NPRA (Statens Vegvesen, SVV), which uses a separate PMS linked to a national road data bank (NVDB). It is carried out for annual registration of data from national and county roads. NPRA does not detect conditions on municipal roads, but it can still be useful to study the condition of the county and state roads. Furthermore, it will be important for the municipality to record data from their roads into the national road database, which will happen automatically from RoSy.

2.9.3 Frameworks – SVV's Håndbok V261 (Vegdirektoratet, 1996)

SVV has a separate framework for the assessment and classification of injuries in road surfaces given in Manual V261 - Damage catalog for bituminous road surfaces (Vegdirektoratet, 1996). The purpose of the damaging directory is to facilitate a systematic and consistent damage assessment.

In manual damages are divided into 6 main groups which are further divided into subgroups based on different characteristic parameters. Then there will be the guidelines for assessing the severity of injury and distribution.

The severity of an injury classified into three levels: low, medium and high. The scale refers to the consequences the damage may have for the roads further degradation, road safety and accessibility.

The damage distributions are recorded either in the longitudinal direction, across or by frequency within a site. The prevalence are divided into 3 levels.

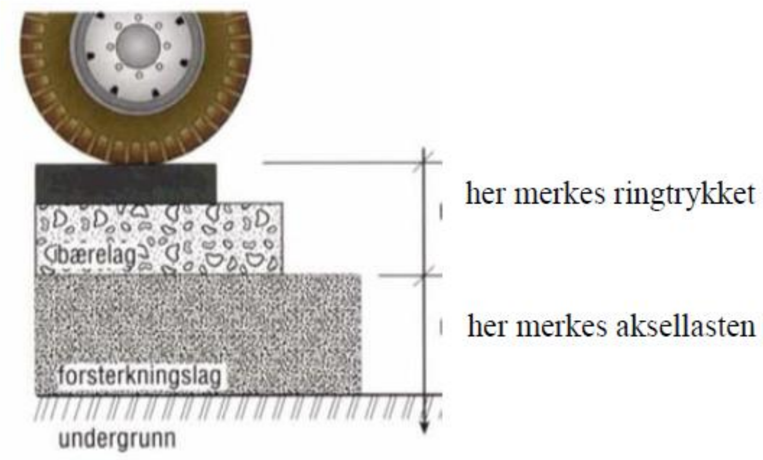


Figure 2:17 - The different layers of a road outlined in VEGDIREKTORATET 1996. Håndbok 193 - Skadekatalog for bituminøse vegdekker (Vegdirektoratet, 1996).

Figure 2:18 - A more detailed outline of the construction of a road (Autstad et al., 2015)

In "Vegdirektoratet 1996. Håndbok 261 - Skadekatalog for bituminøse vegdekker" it is almost to be understood that roads is constructed like Figure 2:17 and Figure 2:18 shows. This manual can be partly be misleading when looking at causes of injuries in roads that lack the building up which Statens Vegvesen describe in their manuals.

2.10 Causes of damages in the road surface

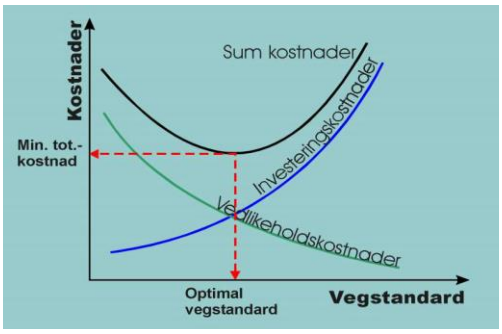


Figure 2:19 - Optimal road standards and proper quality (Aurstad et al., 2015)

The roads can be damaged in many ways. To know what we look for when we examine roads in Nedre Eiker we must look at what damage mechanisms we have on Norwegian roads. SVV has over many years built up books that both show how roads will be built up, and what damage we can get. Norwegian roads are exposed to traffic to a greater or lesser extent, and we thus also always susceptible to damage. Many of these damages can be as expected, that means that there are damages we know will come as a result of normal wear and tear. This is abrasion that may be caused either by vehicle traffic, or weather. But roads can also be exposed to damages of more unexpected nature. A good example is the floods that have hit southern and eastern Norway now in late summer / autumn. This flood has washed away large sections of roads or adjoining hills that have made the road unstable. In addition, there are injuries caused by other unusual natural disasters such as landslides, rock falls or avalanches. Damage caused by flooding and subsequent landslides or slippages we know took place in Nedre Eiker. The question is how much damage this has resulted in an overall context. There are also unexpected injuries that occur due to improper dimensioning, material production and / or execution. Such damage can be represented in Nedre Eiker considering that most roads have received a asphalt layer placed directly on top of an old gravel surfaces. Regarding the expected damage or wear, we can counteract these both with how much we invest in the road construction when the road is built, and through planned preventive maintenance. Since the roads we talking about here already built, we cannot do anything about the road reconstruction without building roads again. This will require large investments, but will also reduce the need for frequent maintenance. There will always be a challenge to find the best balance between investment cost and maintenance cost. The optimum road standards with the right quality, we find where the sum of investment costs and maintenance costs are lowest (Figure 2:19 - Optimal road standards and proper quality (Aurstad et al., 2015)).

There are several factors that contribute to degradation and wear of roads. These can be divided into basic factors, the road stresses and properties and lifetime. This is illustrated in Figure 2:20:

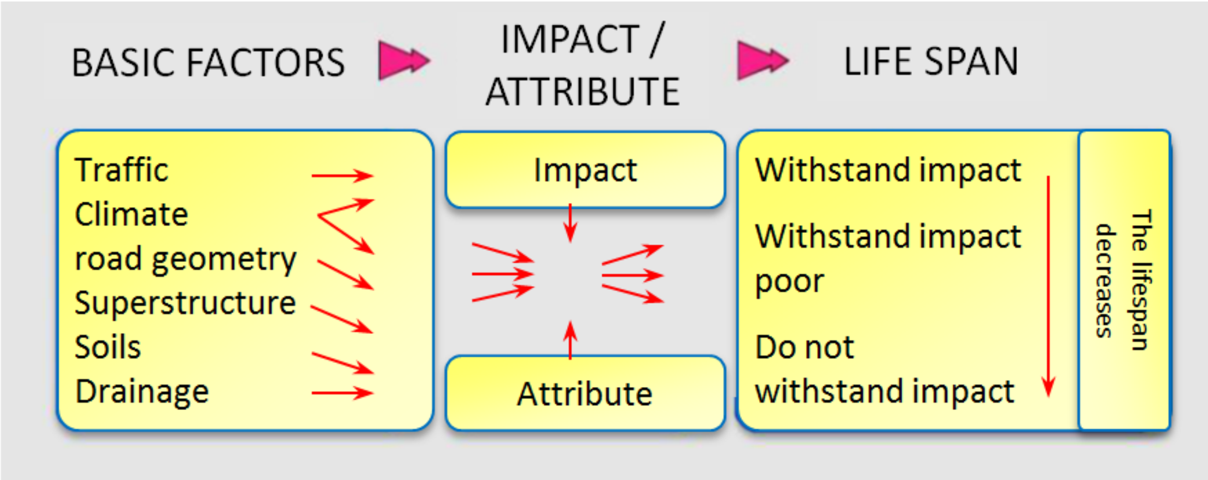


Figure 2:20 - Degradation factors. (Aurstad et al., 2015)

Traffic strain on the road can be divided into axle load, ring pressure, studded tires, speed, tire temperature, horizontal forces, distortions and more. Climate affects the rainfall, air temperature, temperature in the road, frost, stream freezing / thawing etc. Stresses and properties may be material quality and drainage. All these strains may change weaken road carrying capacity and life.

Damage to the road can be divided as follows:

- Tracks and permanent deformation:
    - Studded wear, rutting resulting from the use of studded tires.
    - Deformations in the pavement may be due to unstable grain curve and error type / quantity of binder. Such deformation is largely dependent on both temperature and strain. Therefore, heavy and slow traffic at high temperatures (hot sunny days) most critical.
    - Deformations in the substructure will arise if tensions because of traffic exceed certain limits. Little side support will also help to ensure that the road is more susceptible to permanent deformation.
    - Deformation in the subsurface can occur as a result of soil conditions vary along / across the road. Poor drainage may also contribute to deformation in the subsurface.
- Cracks
    - Fatigue cracks are related to repeated deformation in the asphalt surface, caused by the repeated loads of vehicle passages.
    - Low temperature cracks at relatively rapid changes in temperature the asphalt will expand / contract. If it happens faster than the asphalt visco-elastic properties can follow, the asphalt will crack.
- Edge loss may occur as a result of high load far out on the edge of the road (narrow roads) and / or poor lateral support.
- Frost damages, frost heave in winter and bearing capacity failure of the spring thaw is a serious problem for many low-traffic roads. Major underlying layer of water that freezes, providing frost heave, if these thaws quickly without water is able to drain away, there is a thaw situation with bearing capacity failure. Full protection against

frost heave requires thick layer of stone material or a layer artificial isolation. Manual N200 (Vegdirektoratet, 2014b) describes how roads should frost dimensioned.

- Persistence / aging - water / precipitation, freeze / thaw cycles, solar radiation (UV), temperature variations etc.

Good drainage is essential for roads in Nedre Eiker both considering that the road network is prone to flooding and that the groundwater level is very high.

To prevent water will inflict damage on the road or adjacent areas, it is important that we have a good drainage of the road. Drainage means in short that we have to lead water away from the road and surrounding areas. The water can come from rainfall, melting water, and groundwater or from ditches, slopes, streams and rivers located near the road area. SVV's Manual R610, "Standard for operation and maintenance of national roads" (Vegdirektoratet, 2014c), sets requirements for drainage system for a road. It says, for example: "*The drainage system is to prevent water accumulation on the road, walking and bicycle paths, sidewalks and road body to maintain traffic safety, avoid increased breakdown of the road and avoid contaminants along the road*".

Surface water drains shall counteract reduced road safety due to reduced friction, aquaplaning, splashing water, water that freezes and increased rolling resistance / fuel efficiency.

Surface drainage shall also prevent / reduce erosion on land on the side of the road and gravel roads. Surface water drains shall prevent infiltration of water into the road construction which may cause faster decomposition / shorter life on the road. This can be especially important in large parts of the municipality that are exposed to large amounts of surface water associated with floods.

Drainage of road construction is essential to ensure the road's structure and sustainability. Water in the road construction can contribute to leaching of material, frost heave, bearing capacity failure and reduced life cover. To help ensure that water is drained effectively out of the road construction it is important that we have a material in construction that does not have too much fine material, as well as the right kind of fine material. Too much / error fine material helps to keep water in the road construction, which allows significantly fewer loads will give large permanent deformation of the road. The level of the groundwater level provides the same negative effect if the is too high. An example from Statens Vegvesens «Lærebok for Drift og Vedlikehold av veger». (Aurstad et al., 2015) show that by lowering the groundwater level 40 cm, increased road ability to withstand loads from 2500 to 5000 loads to over 25000 before a deformation of 30 mm occurred (See chapter 2.4, Considerations of frost (frost heave), drainage and groundwater levels page 41). Good drainage of the road and the road construction will also make a positive contribution to counteracting frost heave.

Requirements for various drainage elements and initiatives are shown in the maintenance standard: "Vegdirektoratet (2014c) Håndbok R610, Standard for drift og vedlikehold av riksveger. Statens Vegvesen". We differentiates on the open and closed drainage systems, where examples of open systems is avvrenning from the roadway, stormwater ditches, drainage ditches and trenches in the terrain outside the road area, all this can be connected to culverts with manholes to direct water through the road and down into the natural drainage system as streams and rivers that can take in the water. Closed the drainage and storm water systems are drainage systems that have been piped underground; it is used mainly in cities and densely populated areas. Nedre Eiker has many open and closed drainage systems.

2.10.1 Main groups – damage types

We have the following main types of damage that may occur on our roads:

- **Longitudinal cracks**
  - Causes may include: Traffic load near the road edge, uneven frost heave, widening, inadequate wedging out between different soils, sliding / washout, poor longitudinal asphalt joint, longitudinal joints in the underlying concrete pavement. Cracks below 5 mm have little seriousness while cracks over 20 mm is serious.
- **Transverse cracks**
  - Frost heave, deformation associated with eg culverts, shrinkage in cement stabilizing base course, low temperature cracking, excavation work, joints in the underlying concrete pavement. Cracks below 5 mm have little seriousness while cracks over 20 mm are serious.
- **Crazing**
  - Insufficient carrying capacity in relation to the loads on the the road construction, poor drainage, too thin surface cover, water sensitive materials to close to the surface road surface is too stiff in relation to the underlying layers. The severity is determined by the size of the grid of cracking.
- **Potholes**
  - Further development of alligator cracking, parties with bad road pulp quality, thin surface cover in combination with poor adhesion to the substrate, parties with thin wearing course on a base of gravel. Severity is determined by the size of the hole.
- **Surface texture deficiencies**
  - Damage to the surface not covered by any of the other main groups. Severity is determined by traffic safety and driving comfort.
- **Any unevenness**
  - Depressions, uneven frost heave, the storage of materials as a result of frost heave motion, after compression, shear deformations in the materials. Severity is determined by traffic safety, driving comfort and evenness measured with a straightedge.
- **Rutting**
  - Deformations in road surface or underlying layer, studded tires. Severity is determined by the depth of the tracks and the number of tracks.

2.10.2 Dimensioning and reinforcement

Dimensioning and reinforcement of a road is described in handbook N200 ”Vegbygging” (Vegdirektoratet, 2014b). The most important thing to know and understand for those working with operation and maintenance is the basis for dimensioning.

2.10.3 Road structure

To know how a road designed and reinforced, we must also know how it is built up. Figure 2:18 shows the different "layers" in road construction. The road surfaces will give drivers a smooth surface to run on, it usually has a thickness of 4-8 cm. The road surfaces consist usually of a bonding layer and a wear layer. The wear layer is often laid out a couple of years after the carrying layer so that the carrying layer has time to "settle" in this way can we correct small irregularities when the wear layer is added. Under road surfaces we find the carrying layer which shall distribute traffic loads down to the reinforcing layer. This layer frequently consists of bituminous materials. For roads with low traffic we may use crushed stone with a strict requirement for gradation so that the layer will be stable. Support layer often consists of upper and lower support layer. The thickness is usually from 10 to 20 cm. Reinforcement layer should be thick enough so that it ensures that the underground is not overloaded, even after millions of loads which constitute dimensioning period. Reinforcement layer often consists of crushed stone 22/180 mm or more finely crushed stone materials. The thickness of the reinforcing layer varies, and on a underground of clay the thickness can well be 70-90 cm. Under the reinforcing layer can we have a frost protection layer which may consist of sand / gravel materials, shattered mountain, lightweight clinker, foam glass or insulation boards of extruded polystyrene. Previously, it was customary to add a filter layer of gravel about 15 cm between the reinforcing layer and subsoil. Today we use instead a geotextile that replaces the function of this layer.

The overall size of the road construction must be sufficient that the subground to withstand the load from all the vehicles to pass over it (Figure 2:17). In order to ensure the carrying capacity of a low traffic road, the thickness of the superstructure be about 60 cm, while on a road with a higher traffic load, such as a county, it is normally necessary with a thickness of about 100 cm, if in addition necessary to frost secure way can the thickness of the building come up to 200 cm.

Since 2014, the Statens vegvesens Handbook N200 "Vegbygging" (Vegdirektoratet, 2014b), which provides guidelines and basis for design of Norwegian roads. Chapter 5 of this manual describes roadbase and how this should be dimensioned.

2.10.4 Reinforcement of roads

After 20 years it will probably be a need to reinforce the road. The condition of the surface cover can be a good indicator of the condition of the rest of the road construction. If life of asphalt layer is lower than expected, it will be necessary to assess whether only the surface has to be renewed, or whether the road will be strengthened, possibly totally renovated. This will be an economic question being considered. If the road is not reinforced, there may be a short time to the surface to be renewed once again.

Old ways have to be reinforced, and then it would be appropriate to do this so that we can increase the allowed axle load to at least 10 tons. Replacement of carrying and reinforcement layer is an expensive process, it is like building a new road, and the road may be closed to traffic during periods. We must try to minimize such replacement to local areas and / or only the top layers. Often, better drainage and lowering of the groundwater level give a good effect on the carrying capacity. These are also relatively inexpensive measures in relation to replacing reinforcement layer. If there is too much frost susceptible material in the road construction, we can build new layers of road constructions. Furthermore, also the reinforcement of the edges by making them wider has a positive effect on the bearing capacity. (Aurstad et al., 2015).

As mentioned, a large proportion of roads in Nedre Eiker is without superstructure (substructure). With lack of superstructure is meant when it is not built up with approved masses that can withstand both frost and traffic load. Roads are built right up on the sediments that existed in the area with only a thin gravel layer under the asphalt (Evensen, 2016). It would therefore be an economic question how roads should be maintained or upgraded. Using knowledge of how damage development in the different soil zones, the municipality will have an expertise that can contribute as basis for determining whether roads should be fully renovated, drained or if it is ok to proceed with only surface maintenance.

3 Fieldwork

Fieldwork was conducted in conjunction with a state registration of municipal roads. The state registration was performed by a road technician from Sweco in collaboration with Nedre Eiker. In addition, it was carried out much field work to confirm the findings of state registration and verification of the geological conditions that NGU's map showed.

3.1 Execution of the fieldwork

Recording of asphalt surface damages were as mentioned performed by a road technician from Sweco. Registration was performed using a system called "CamSurvey" (see "State Registration of road network" on page 14). Fieldwork to confirm findings from state registration was carried out visually and by means of photography.

Both damage type of road surface, geometry and side construction equipment was recorded and uploaded into the pavement management system RoSy.

It was recorded large amounts of data for municipal roads, and what was the value of this exercise are damage types of injuries, damage localization, type of road, pavement and remaining lifetime.

All municipal roads were evaluated and the results are recorded in RoSy (Figure 3:1).

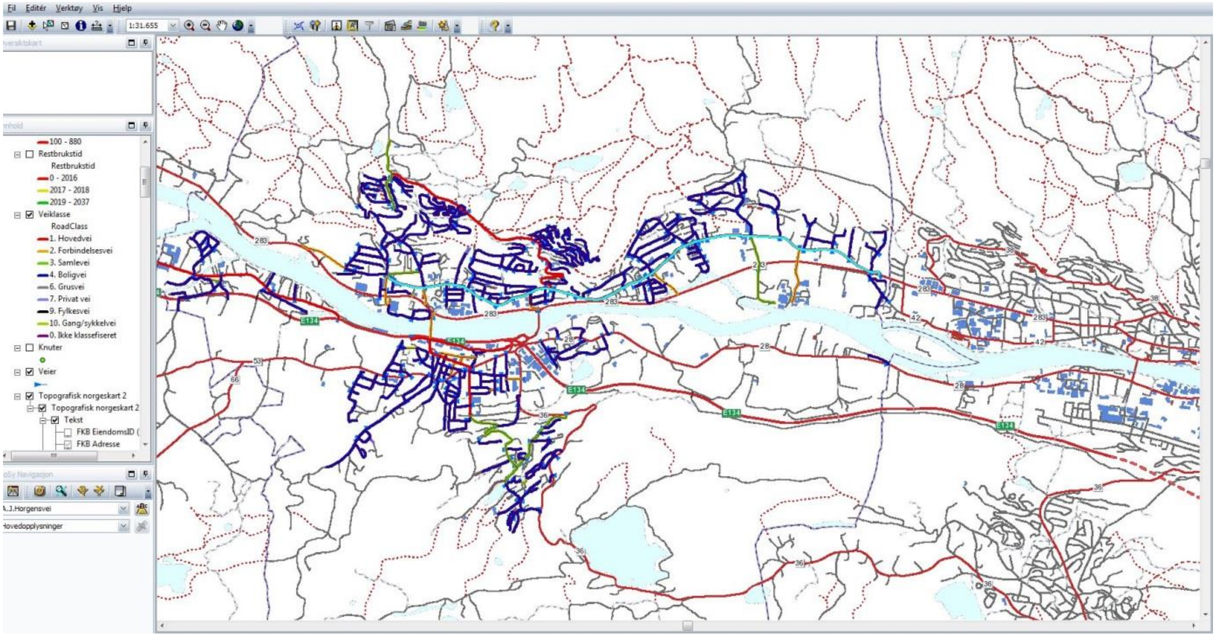


Figure 3:1 – Roads in RoSy MAP

Figure 3:2 – Example of damages on an asphalt road (Photo: Erik Josepshon)

3.2 Processing of data

After the fieldwork was the collected data added to RoSy pavement management system. Thereafter map layer that contains all state data and remaining lifetime were exported to the Gis tool QGIS. In QGIS was the map data with ground conditions from NGU, road data from Statens kartverk and state data from RoSy added together, and it was withdrawn attribute tables showing data from all sources simultaneously. These data were processed and analyzed using MS Excel.

Using queries were all information about the individual damages extracted and assembled in damage type groups.

The damage types were identified and put into groups are:

- Small cracks
- Large cracks
- Crazing
- Desiccation
- Hole
- Settling of ground
- Rutting
- Winter Patch
- Stone loss
- Patched area
- Profile alignment
- Shelling

It was set up 10 different soils conditions where there are roads, these are shown in Table 2:7 - Description of the various soils / sediments found in Nedre Eiker. (Norges Geologiske Undersøkelse, 2015a) and (Norges Geologiske Undersøkelse, 2015b)

Using maps made from NGU it was also defined 3 distinct zones for groundwater potential and 5 zones for the degree of infiltration capability.

Table 2:8 - Description of groundwater potential of the different soils / sediments found in Nedre Eiker. (Norges Geologiske Undersøkelse, 2015a) and (Norges Geologiske Undersøkelse, 2015b)
and
Table 2:9 - Description of infiltration capability of the different soils / sediments found in Nedre Eiker. (Norges Geologiske Undersøkelse, 2015a) and (Norges Geologiske Undersøkelse, 2015b) describes these

See Figure 4:2, Figure 4:3 and Figure 4:4 showing map section from QGIS for soil conditions, groundwater potential and infiltration capability.

Since there are varying length road in the different soil, groundwater and infiltration capacity zones, it should be taken into account when assessing the extent of damages per site.

Length municipal road per soil conditions type			
Length of road	Soil code	Description	Percentage
2 180 meters	12	Moraine material, incoherent or thin cover over the bedrock	1,99 %
4 173 meters	20	Glacial river deposits (Glasifluvial deposition)	3,81 %
18 191 meters	41	Ocean and fjord deposition, continuous cover, often with large thickness	16,60 %
810 meters	42	Marin beach deposition, continuous cover	0,74 %
315 meters	43	Marine and fjord reserve and beach deposition, incoherent or thin cover over the bedrock	0,29 %
25 316 meters	50	River and stream deposition (Fluvial deposition)	23,10 %
25 931 meters	72	Weathering Material, incoherent or thin cover over the bedrock	23,66 %
45 meters	81	Landslide material continuous cover in places with large thickness	0,04 %
27 748 meters	120	Filling material (anthropogenic material)	25,32 %
4 888 meters	130	Bare mountain	4,46 %
109 597 meters	Total		100 %

Table 3:1 - Length municipal road per ground condition type

Length municipal road per groundwater type			
Length of road	Code	Description	Percentage
29 489 meters	2	Assumed substantial groundwater potential	26,91 %
810 meters	3	Limited groundwater potential	0,74 %
79 298 meters	4	Not groundwater potential in soils	72,35 %
109 597 meters	Total		100 %

Table 3:2 - Length municipal road per groundwater potential

Length municipal road per infiltration capability			
Length of road	**Code**	**Description**	**Percentage**
29 489 meters	1	Well suited	26,91 %
810 meters	2	Medium suited	0,74 %
28 471 meters	3	Unsuitable	25,98 %
23 079 meters	4	Unfit	21,06 %
27 748 meters	5	Unrated	25,32 %
109 597 meters	Total		100 %

Table 3:3 - Length municipal road per infiltration capability

Since there are so variable length road within the various zones, it will be necessary to calculate the number of injuries per meter road within the various zones.

4 Results from the fieldwork

4.1 Results from the survey of soil conditions

Using QGIS (Quantum GIS) is the municipal roads in Nedre Eiker been mapped in relation to soil conditions in the municipality. Map layer showing roads are extracted from Geonorge (https://kartkatalog.geonorge.no/search?text=elveg) and is developed by Statens Kartverk. The map layer showing soil conditions are collected from Norges Geologiske Undersøkelse (NGU) (http://www.ngu.no/emne/datasett-og-nedlasting).

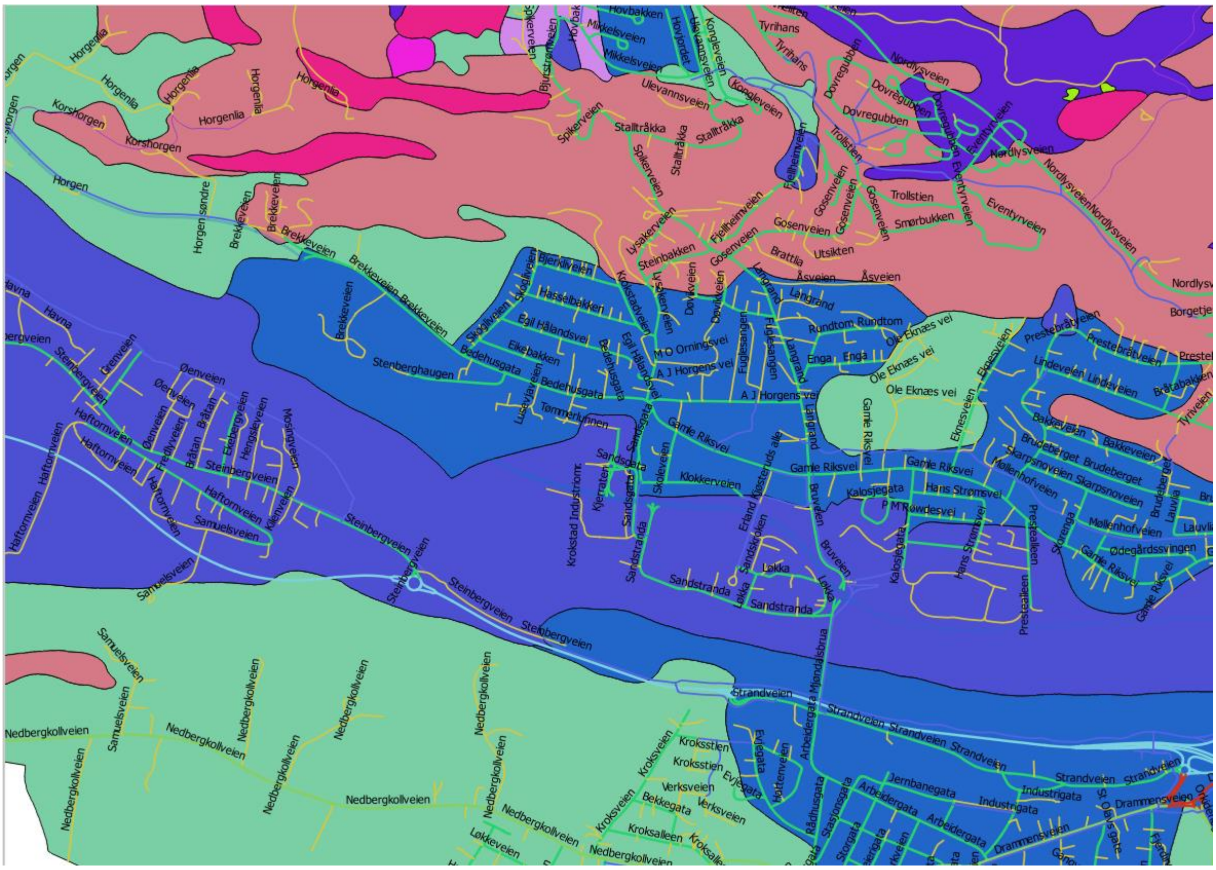


Figure 4:1 - Detail of map with roads and soil zones Nedre Eiker shown in QGIS

There are 10 different soil conditions that underlie the municipal the road network in Nedre Eiker. These break down as follows:

Code from NGU	Description
12	Moraine material, incoherent or thin cover over the bedrock
20	Glacial river deposits (Glasifluvial deposition)
41	Ocean and fjord deposition, continuous cover, often with large thickness
42	Marin beach deposition, continuous cover
43	Marine and fjord reserve and beach deposition, incoherent or thin cover over the bedrock
50	River and stream deposition (Fluvial deposition)

72	Weathering Material, incoherent or thin cover over the bedrock
81	Landslide material continuous cover in places with large thickness
120	Filling material (anthropogenic material)
130	Bare mountain

Table 4:1 - Types of soils in the ground to be found in Nedre Eiker (Norges Geologiske Undersøkelse, 2015a)

The data QGIS gave were further analyzed in Excel in order to determine the length of municipal roads distributed to the different soil conditions. First, all classifications of roads measured, this gave this distribution:

Veitype	Lengde
«GS-vei»	28 453 meters
«Europavei»	17 128 meters
«Riksvei»	12 609 meters
«Fylkesvei_1»	5 420 meters
«Fylkesvei_2»	12 309 meters
Municipal	**110 450 meters**
«Privat»	196 566 meters
«Skogsbil»	66 130 meters

Table 4:2 Roads divided into classifications in Nedre Eiker municipality (Statens Kartverk, 2001)

The summation of municipal roads in QGIS provides 110 450 meters, which corresponds well with the council's own estimates of municipal roads. The road length QGIS provides are therefore considered to be reliable.

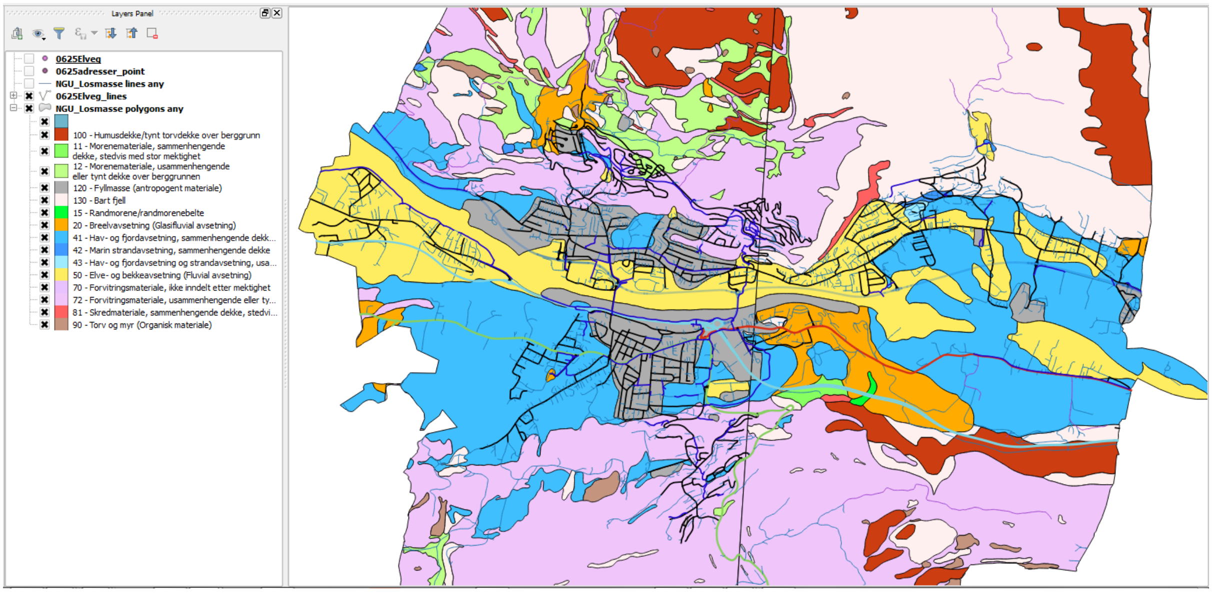


Figure 4:2 - Map section from QGIS showing soil zones, municipal roads appear with a black line.

Ground condition	12	20	41	42	43	50	72	81	120	130
Road length	2180	4173	18191	810	315	25316	25931	45	27748	4888

Table 4:3 - Length road pr soil zone (extracted from QGIS)

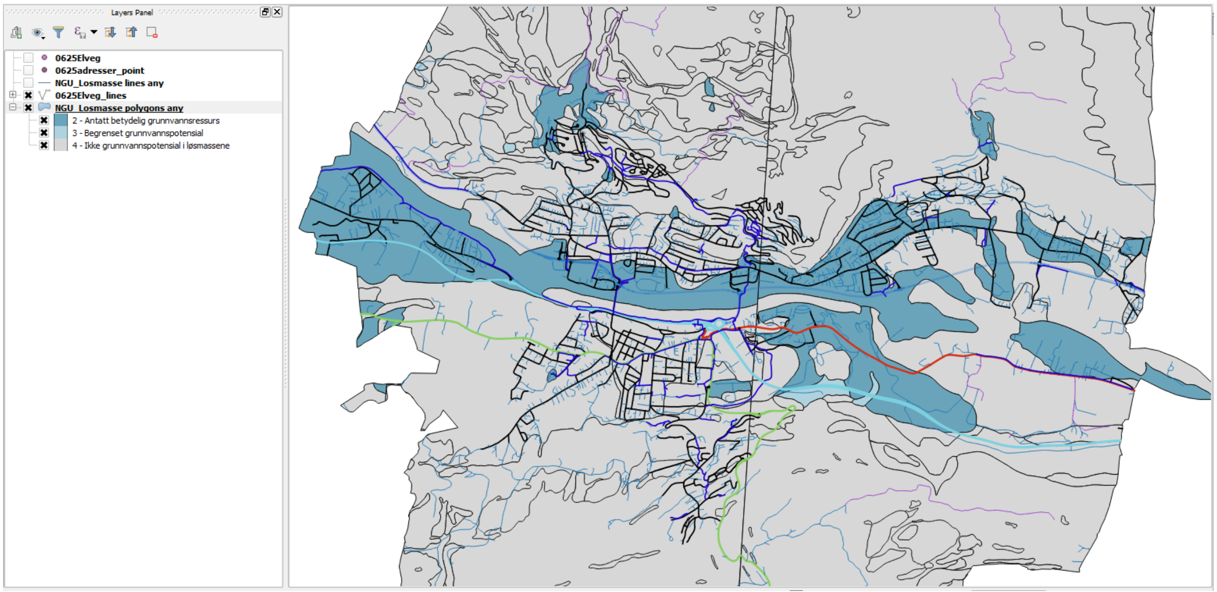


Figure 4:3 - Map section from QGIS showing groundwater potential zones, municipal roads appear with a black line.

Groundwater potencial	2	3	4
Road length	29489	810	79298

Table 4:4 - Length road pr groundwater potential zone (extracted from QGIS)

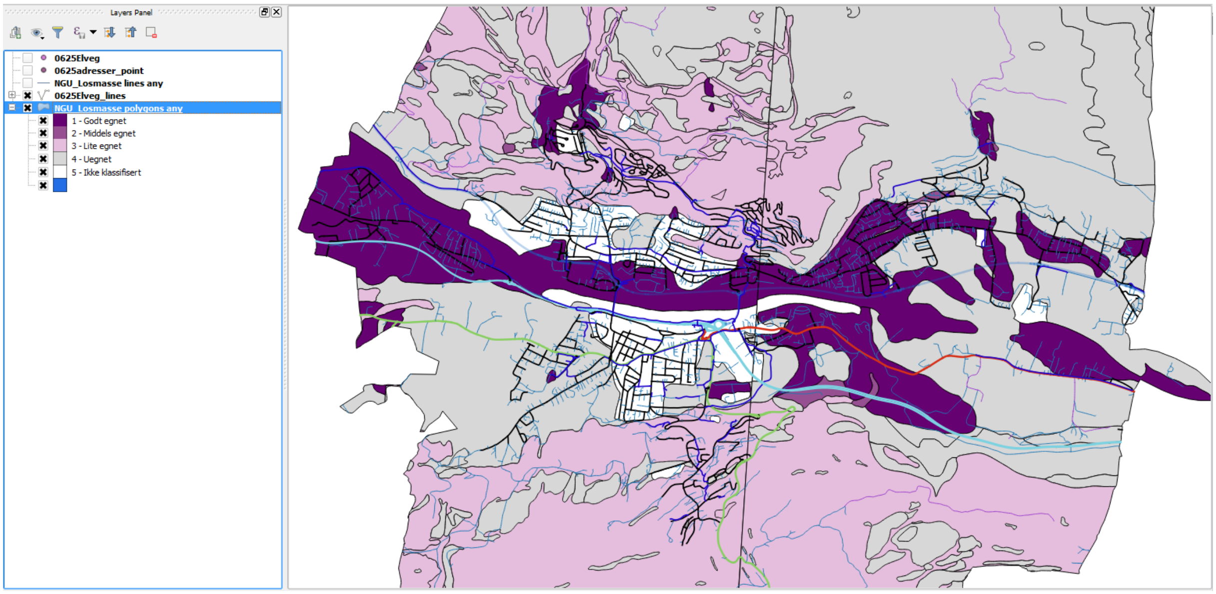


Figure 4:4 - - Map section from QGIS showing infiltration capability zones, municipal roads appear with a black line.

Infiltration capacity	1	2	3	4	5
Road length	29489	810	28471	23079	27748

Table 4:5 - Length road pr infiltration capability zone (extracted from QGIS)

4.2 Results of state registration of roads

4.2.1 Tables and Charts

Length/area of damages per ground condition										
Damage \ Ground condition	12	20	41	42	43	50	72	81	120	130
Small cracks	4,26	5,37	72,45	4,59	0,97	54,46	68,69	-	52,46	4,74
Large cracks	337,83	403,33	7 054,83	213,88	8,60	4 971,69	4 602,50	-	7 932,89	1 406,45
Crazing	249,07	646,42	4 645,19	271,33	54,37	5 111,97	6 316,45	44,84	8 512,13	1 259,23
Desiccation	277,53	717,79	2 189,37	101,84	227,97	6 630,23	6 197,06	58,90	4 686,06	1 147,25
Hole	6,34	8,04	29,03	0,82	1,57	68,77	113,93	0,33	46,46	27,70
Settling of ground	20,66	37,37	458,49	6,93	45,46	549,03	285,14	7,70	782,18	86,03
Rutting	55,98	74,03	2 075,91	16,50	-	2 901,41	538,21	-	2 512,39	306,57
Winter Patch	5,84	10,38	47,59	8,14	-	115,58	136,17	-	148,90	28,41
Stone loss	-	-	-	-	-	-	-	-	-	-
Patched area	260,56	592,09	4 453,43	435,63	69,63	3 925,51	6 606,32	20,08	5 581,68	1 478,07
Profile alignment	-	-	-	-	-	-	-	-	-	-
Shelling	2,52	9,81	52,05	1,24	-	129,48	146,11	0,67	179,20	4,93
Road length	2180	4173	18191	810	315	25316	25931	45	27748	4888

Length/area of damages per ground condition / length road per ground condition										
Small cracks	0,00	0,00	0,00	0,01	0,00	0,00	0,00	-	0,00	0,00
Large cracks	0,15	0,10	0,39	0,26	0,03	0,20	0,18	-	0,29	0,29
Crazing	0,11	0,15	0,26	0,33	0,17	0,20	0,24	1,00	0,31	0,26
Desiccation	0,13	0,17	0,12	0,13	0,72	0,26	0,24	1,31	0,17	0,23
Hole	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,00	0,01
Settling of ground	0,01	0,01	0,03	0,01	0,14	0,02	0,01	0,17	0,03	0,02
Rutting	0,03	0,02	0,11	0,02	-	0,11	0,02	-	0,09	0,06
Winter Patch	0,00	0,00	0,00	0,01	-	0,00	0,01	-	0,01	0,01
Stone loss	-	-	-	-	-	-	-	-	-	-
Patched area	0,12	0,14	0,24	0,54	0,22	0,16	0,25	0,45	0,20	0,30
Profile alignment	-	-	-	-	-	-	-	-	-	-
Shelling	0,00	0,00	0,00	0,00	-	0,01	0,01	0,01	0,01	0,00

Table 4:6 - Length/area of damages per ground condition (extracted from QGIS)

How damages are distributed among the various soils zones are analyzed in Table 4:6. The result of this is presented in the diagrams that follow on the next two pages. Since roads in Nedre Eiker not evenly distributed throughout the different zones of soil, then is the number of injuries per meter is included in the analysis.

It turns out that there are four types of damage that excels in four different soil zones. The 4 damage types that excel are "Large cracks", "Crazing", "Desiccation" and "Patched area." The 4 soil zones which are prominent in terms of damages are 41, 50, 72 and 120. This is basically logical since it is also in these zones, most roads are located. The explanation of the soils to be found in these zones are given in Table 2:7, and reproduced here:

Ground conditions code	Description	Definition of soil type
50	River and stream deposition (Fluvial deposition)	Material transported and deposited by rivers and streams. The most typical forms are alluvial plains, terraces and fans. Sand and gravel dominate, and the material is sorted and rounded. The thickness varies from 0.5 to more than 10 m.
72	Weathering Material, incoherent or thin cover over the bedrock	Soils formed in situ by physical or chemical breakdown of bedrock. Shallow area with numerous mountain outcrops.
120	Filling material (anthropogenic material)	Soils supplied off or heavily influenced by human activity. Mainly in urban areas.

Table 4:7 - Description of soil conditions zones with the most damage to roads (Norges Geologiske Undersøkelse, 2015a) and (Norges Geologiske Undersøkelse, 2015b)

The locations of the zones can also be seen in the map in Figure 4:2.

"Rutting" are also somewhat more represented than the rest of damages, and this damage is most prevalent in zones 41, 50 and 120.

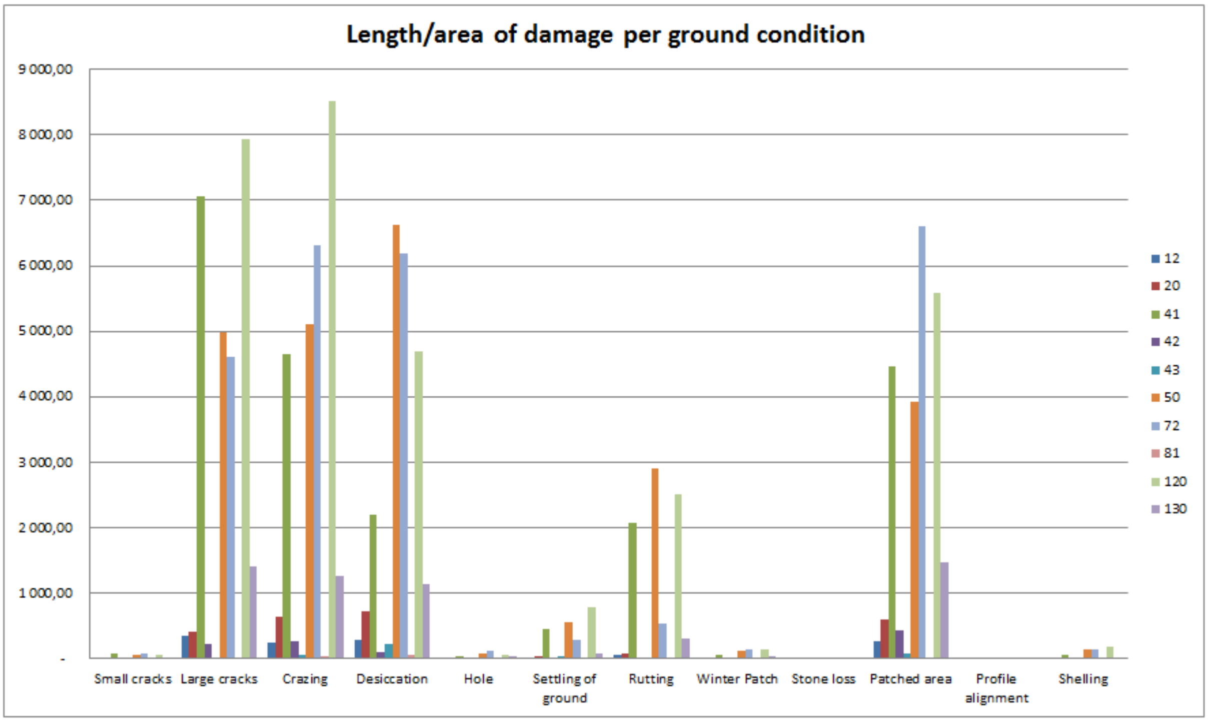


Figure 4:5 - Length/area of damage per ground condition, grouped by type of damage

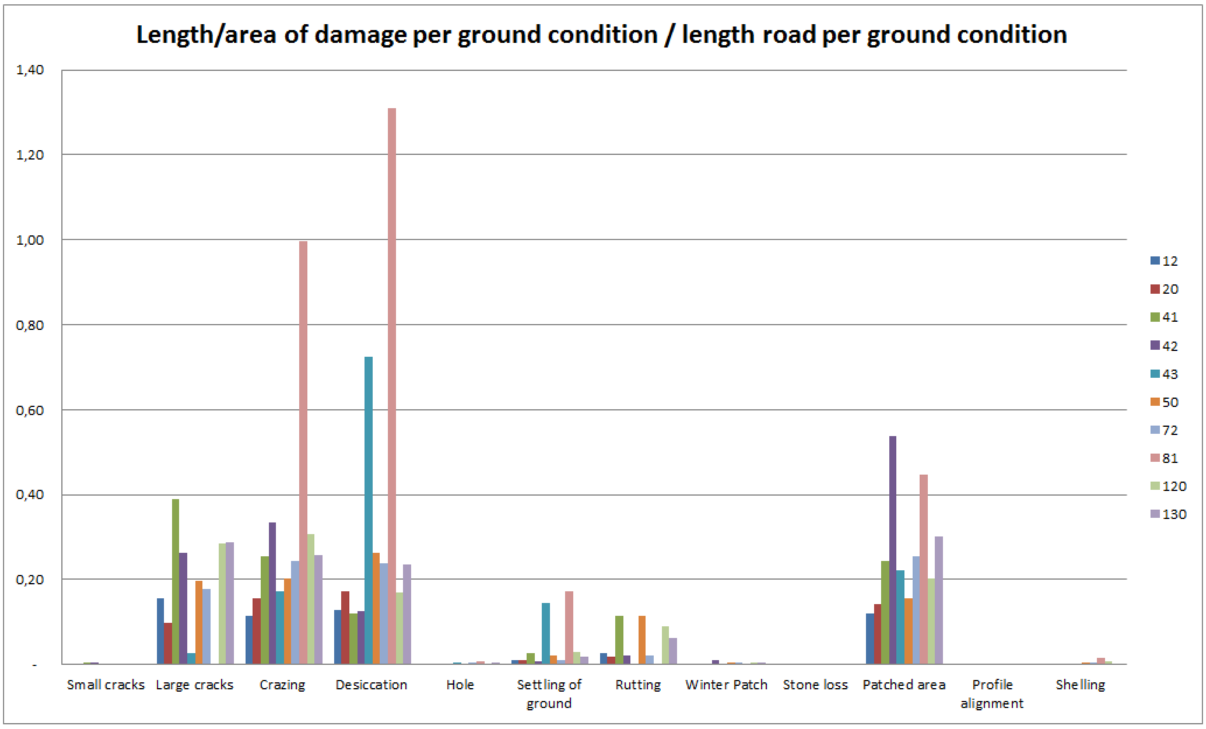


Figure 4:6 - Length/area of damage per ground condition / length road per ground condition, grouped by type of damage

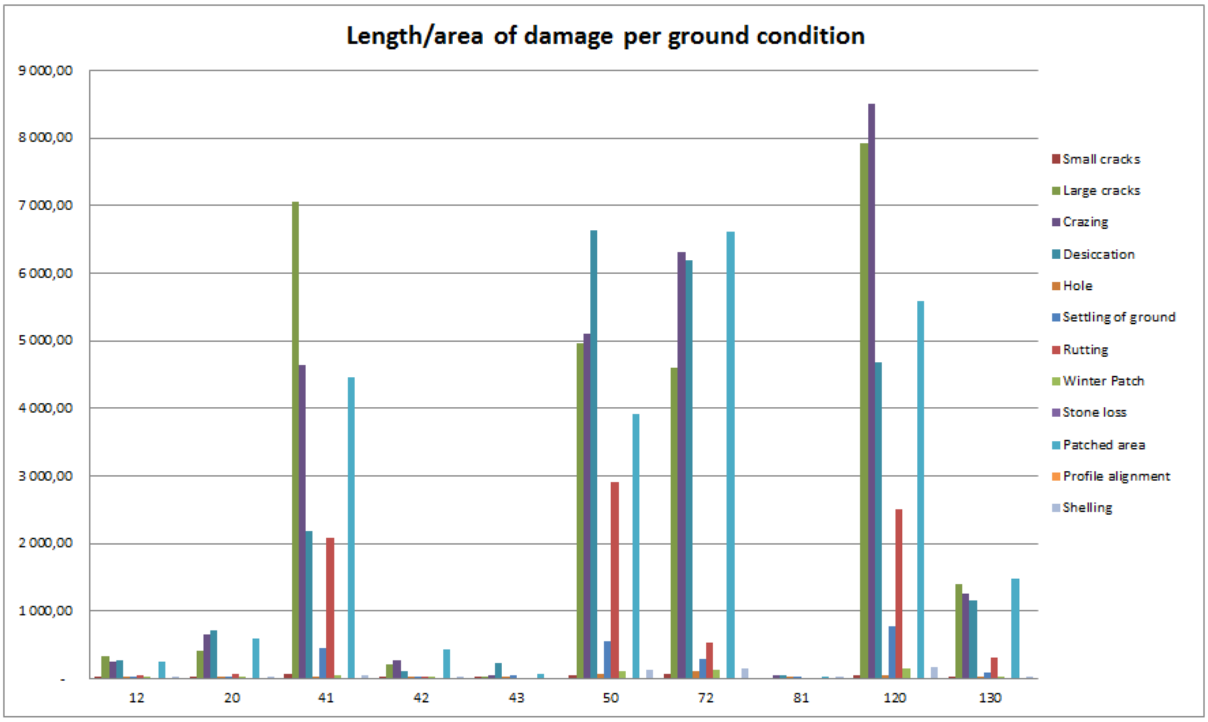


Figure 4:7 - Length/area of damage per ground condition, grouped by ground conditions

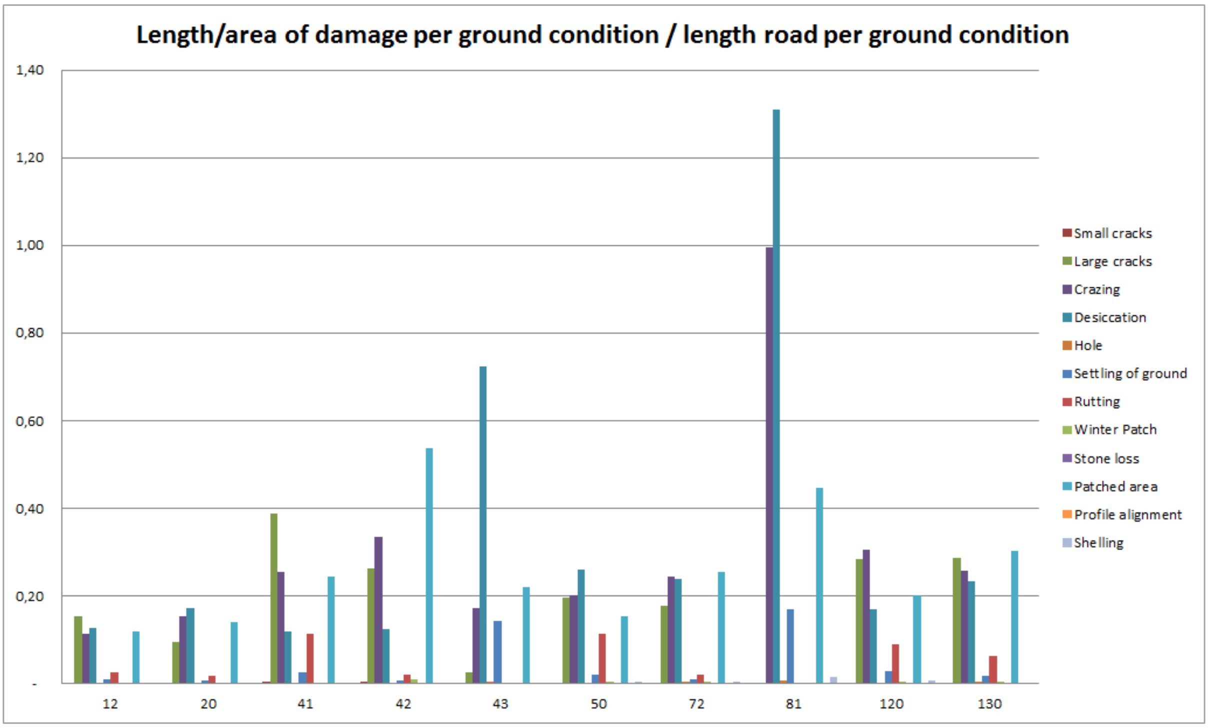


Figure 4:8 - Length/area of damage per ground condition / length road per ground condition, grouped by ground conditions

The zones 42, 43 and 81 prove to be very large when we consider the percentage of injuries per meter road. Since there are so short roads in these zones will attach to considerable uncertainty these roads. It is only 810 meters road in Zone 42, 315 meters in zones 43 and just 45 meters in Zone 81 (Table 4:3 and Figure 4:46). Therefore the result is presented without these zones in the next two diagrams.

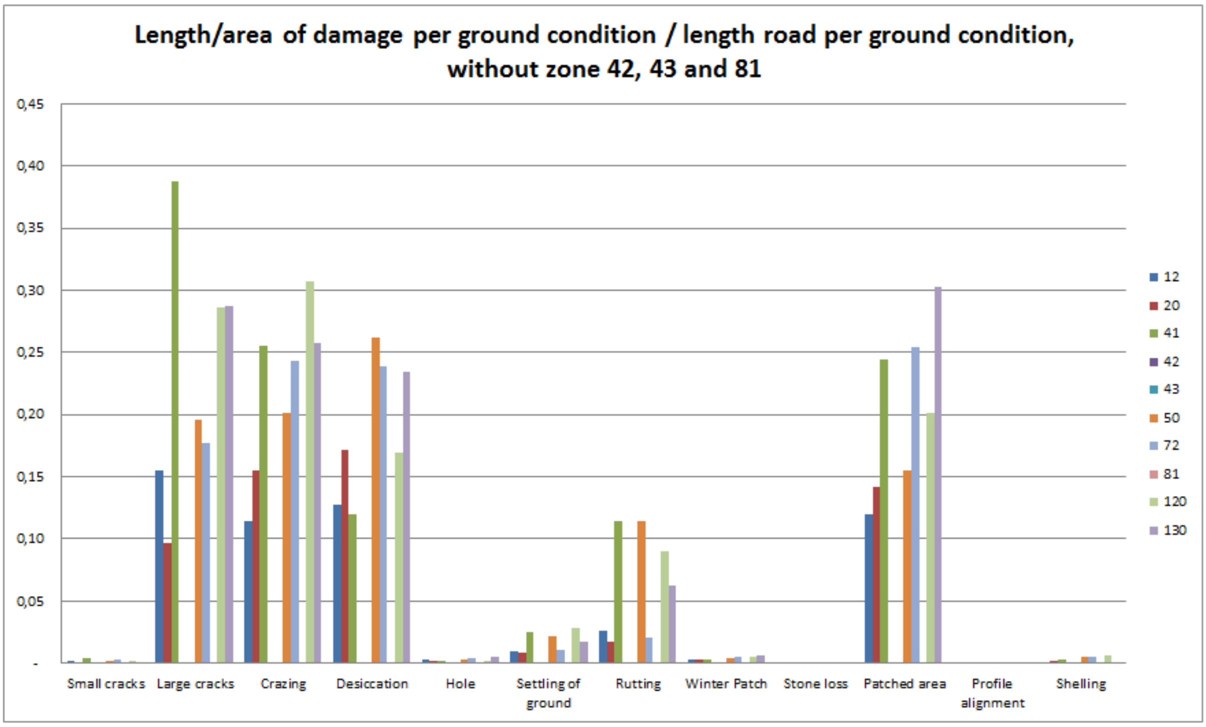


Figure 4:9 - Length/area of damage per ground condition / length road per ground condition, without zone 42, 43 and 81, grouped by type of damage

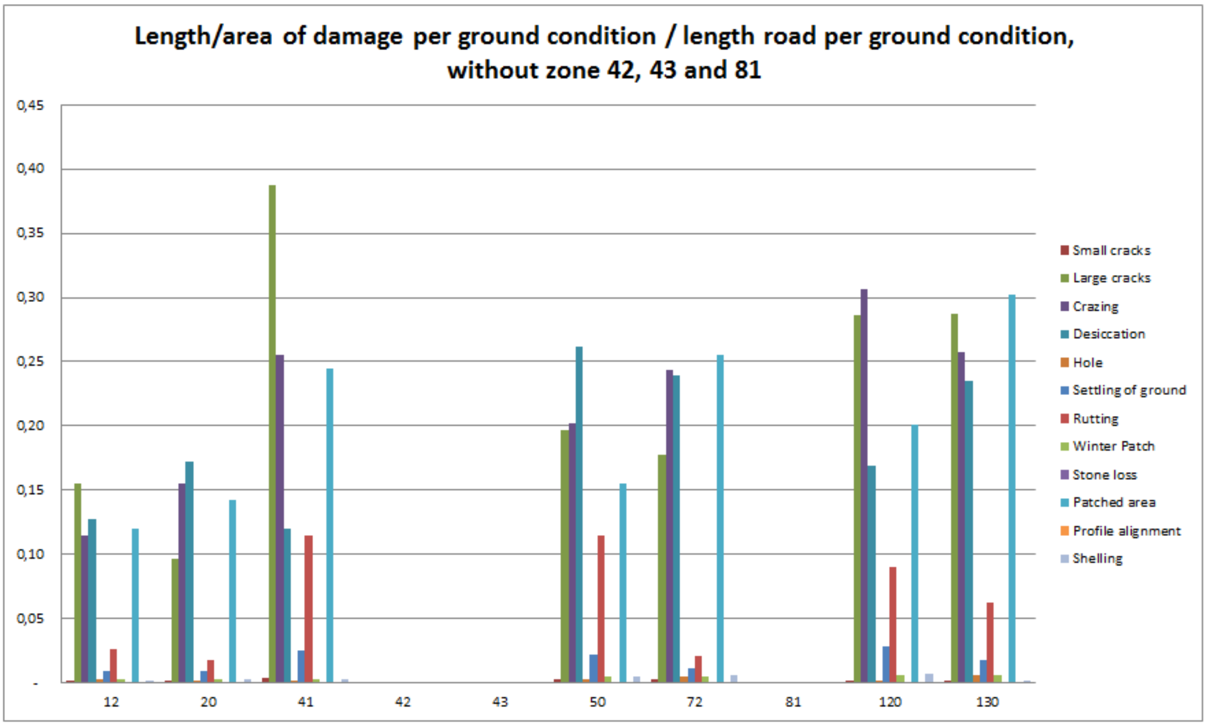


Figure 4:10 - Length/area of damage per ground condition / length road per ground condition, without zone 42, 43 and 81, grouped by ground condition

Number of damages per ground condition										
Ground condition / Damage	12	20	41	42	43	50	72	81	120	130
Small cracks	5,00	7,00	29,00	3,00	2,00	26,00	46,00	-	42,00	6,00
Large cracks	11,00	18,00	79,00	6,00	2,00	84,00	114,00	-	107,00	25,00
Crazing	7,00	17,00	62,00	3,00	3,00	58,00	94,00	1,00	79,00	19,00
Desiccation	3,00	14,00	53,00	3,00	1,00	72,00	61,00	1,00	68,00	17,00
Hole	5,00	9,00	21,00	2,00	1,00	21,00	36,00	1,00	20,00	11,00
Settling of ground	4,00	11,00	53,00	2,00	2,00	56,00	59,00	1,00	92,00	16,00
Rutting	1,00	2,00	28,00	1,00	-	20,00	13,00	-	31,00	8,00
Winter Patch	4,00	8,00	12,00	2,00	-	24,00	34,00	-	28,00	7,00
Stone loss	-	-	-	-	-	-	-	-	-	-
Patched area	11,00	21,00	71,00	6,00	3,00	68,00	114,00	1,00	99,00	24,00
Profile alignment	-	-	-	-	-	-	-	-	-	-
Shelling	2,00	5,00	22,00	2,00	-	32,00	32,00	1,00	30,00	7,00

Road length	2180	4173	18191	810	315	25316	25931	45	27748	4888

Number of damages per ground condition / length road per ground condition										
Small cracks	0,002	0,002	0,002	0,004	0,006	0,001	0,002	-	0,002	0,001
Large cracks	0,005	0,004	0,004	0,007	0,006	0,003	0,004	-	0,004	0,005
Crazing	0,003	0,004	0,003	0,004	0,010	0,002	0,004	0,022	0,003	0,004
Desiccation	0,001	0,003	0,003	0,004	0,003	0,003	0,002	0,022	0,002	0,003
Hole	0,002	0,002	0,001	0,002	0,003	0,001	0,001	0,022	0,001	0,002
Settling of ground	0,002	0,003	0,003	0,002	0,006	0,002	0,002	0,022	0,003	0,003
Rutting	0,000	0,000	0,002	0,001	-	0,001	0,001	-	0,001	0,002
Winter Patch	0,002	0,002	0,001	0,002	-	0,001	0,001	-	0,001	0,001
Stone loss	-	-	-	-	-	-	-	-	-	-
Patched area	0,005	0,005	0,004	0,007	0,010	0,003	0,004	0,022	0,004	0,005
Profile alignment	-	-	-	-	-	-	-	-	-	-
Shelling	0,001	0,001	0,001	0,002	-	0,001	0,001	0,022	0,001	0,001

Table 4:8 - Number of damages per ground condition (extracted from QGIS)

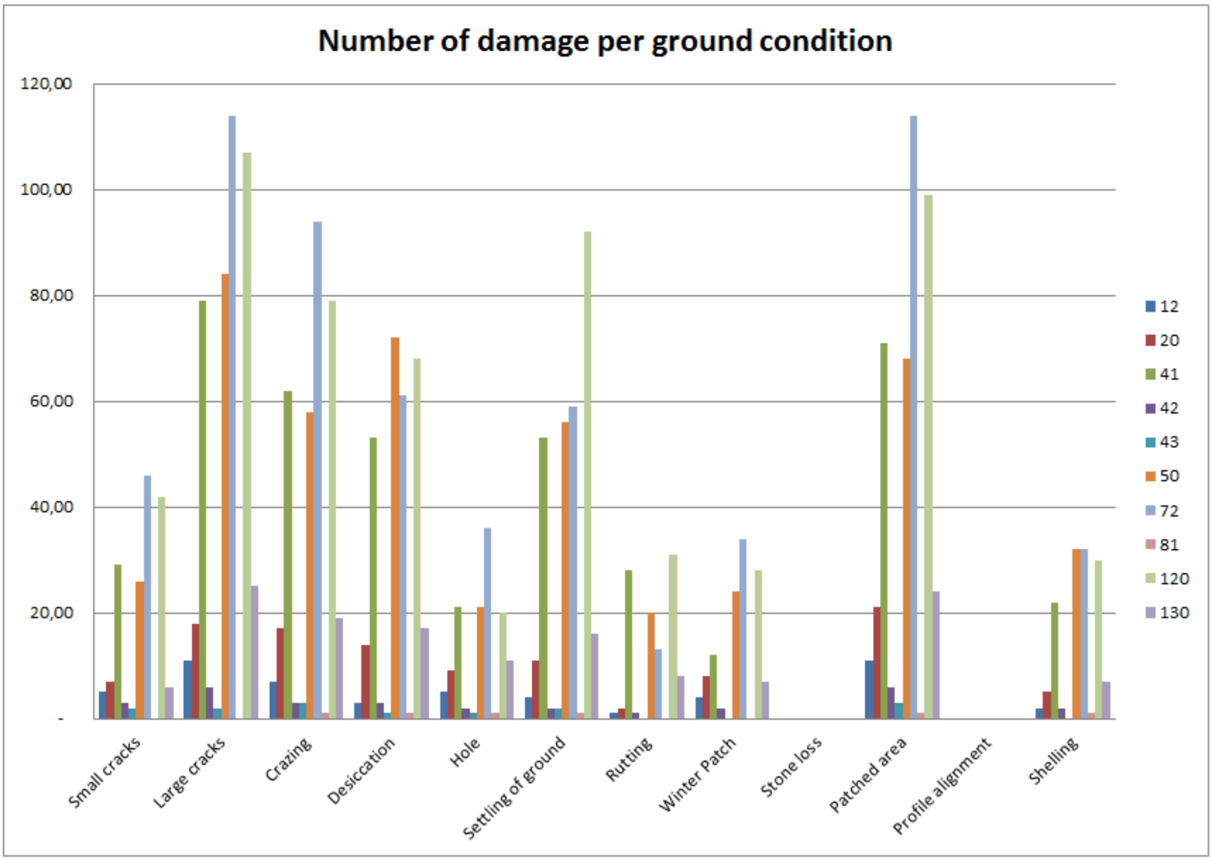


Figure 4:11 - Number of damage per ground condition, grouped by type of damage

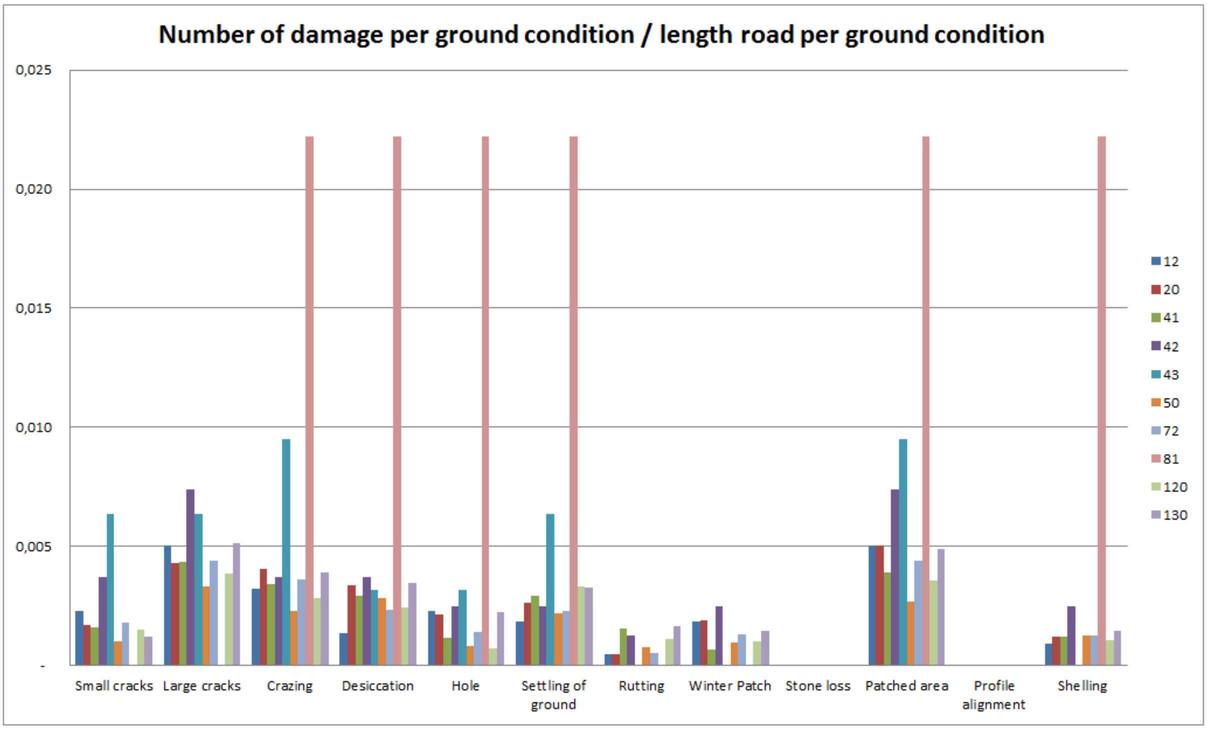


Figure 4:12 - Number of damage per ground condition / length road per ground condition

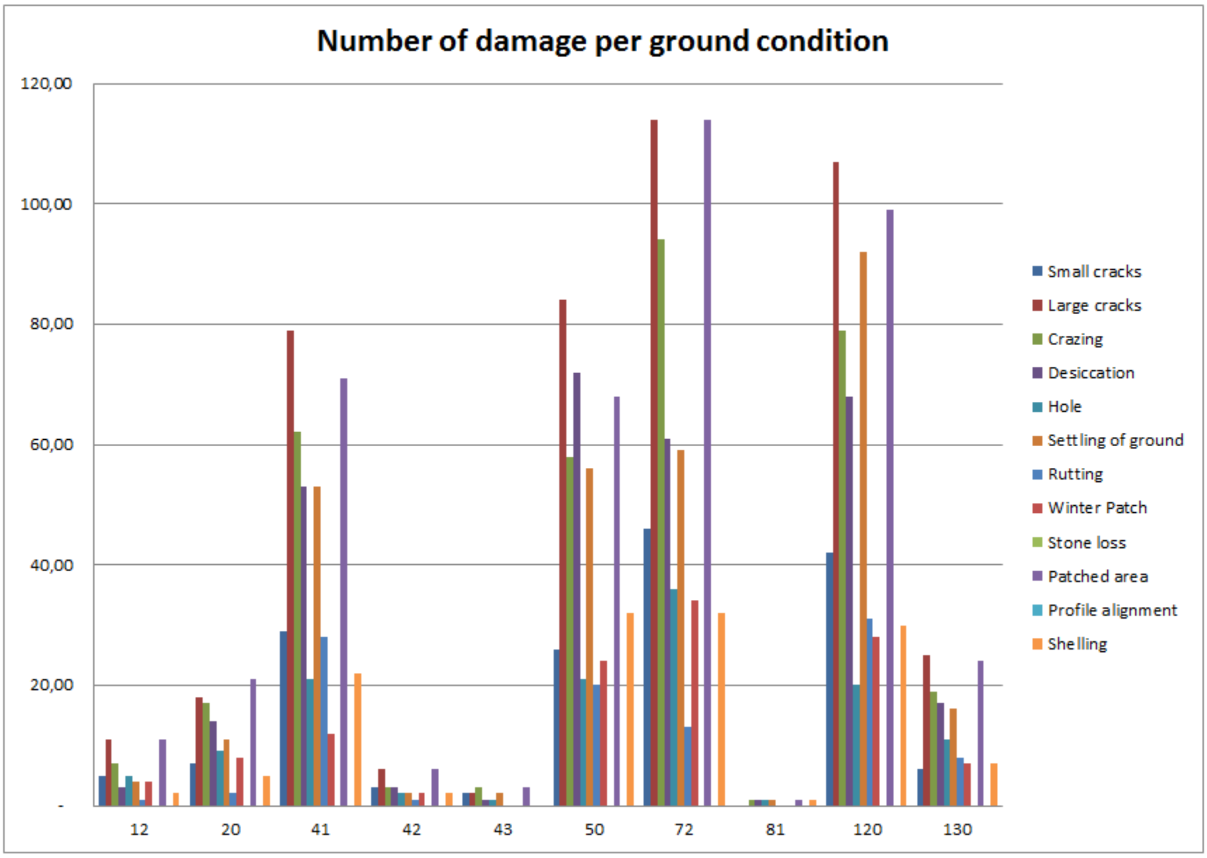


Figure 4:13 - Number of damage per ground condition, grouped by ground condition

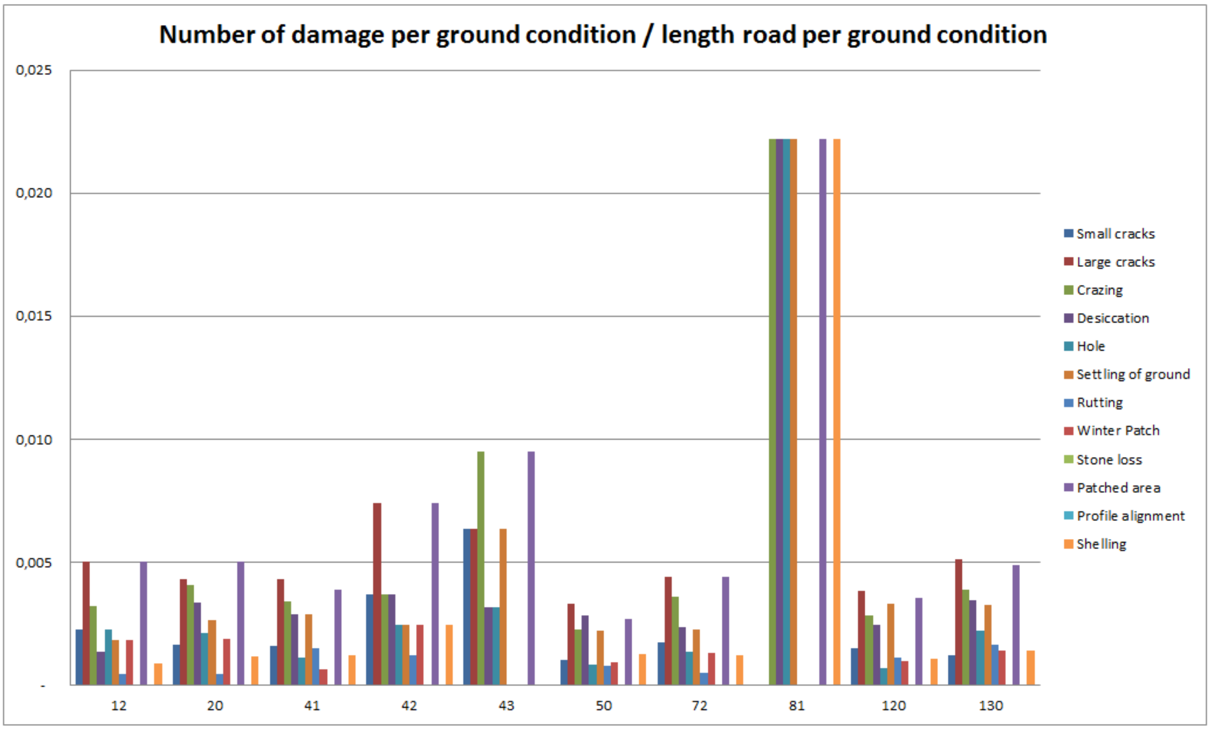


Figure 4:14 - Number of damage per ground condition / length road per ground condition, grouped by ground conditions

It is also stated here that the sediments 42, 43 and 81 gives a distorted picture; therefore these are removed in the next two diagrams:

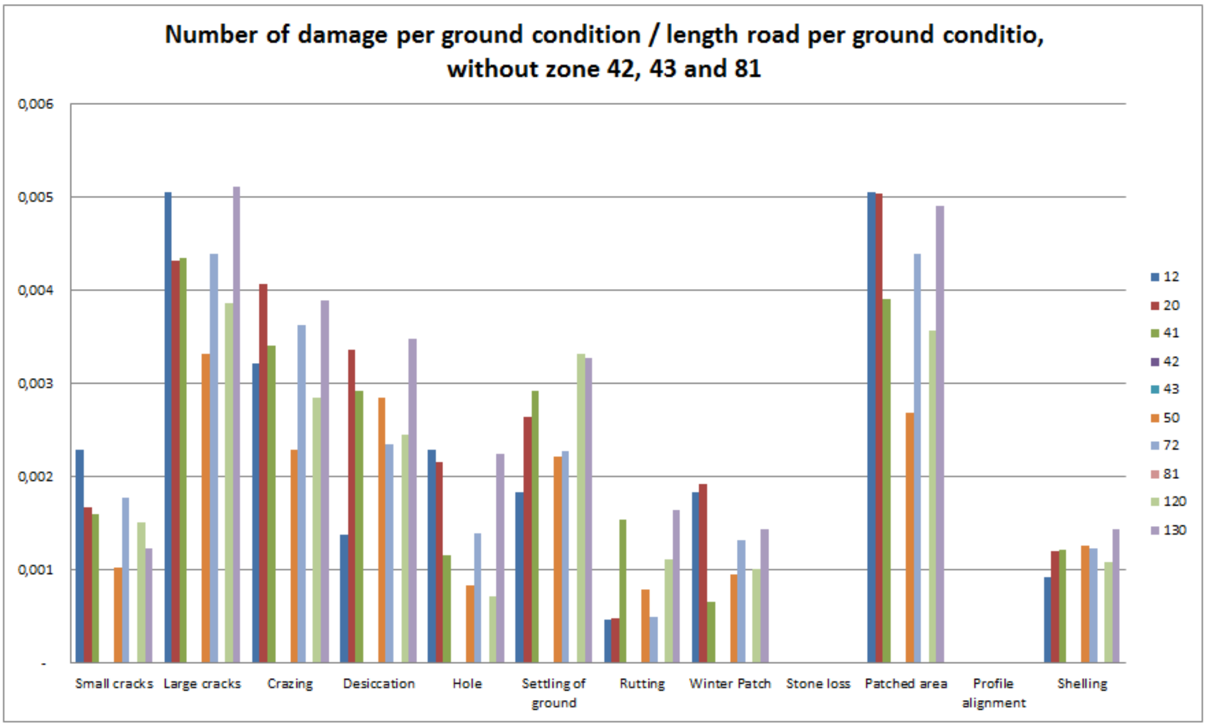


Figure 4:15 - Number of damage per ground condition / length road per ground condition, without zone 42, 43 and 81, grouped by type of damage

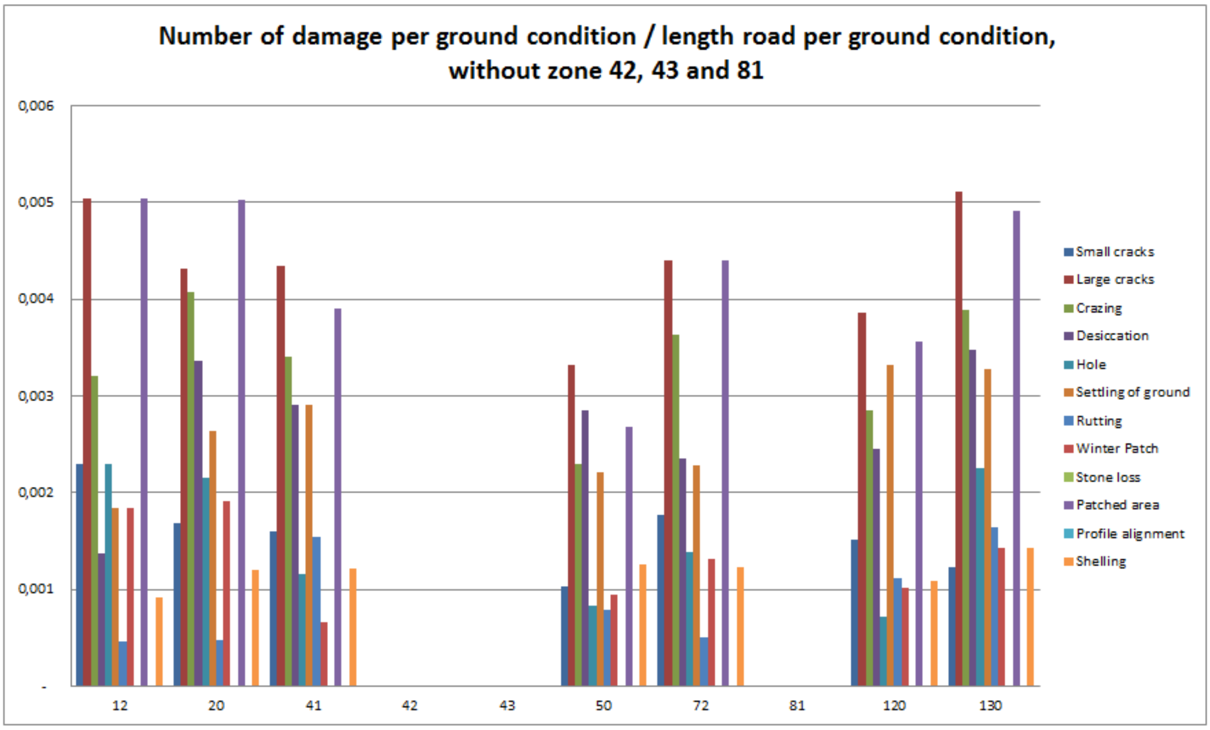


Figure 4:16 - Number of damage per ground condition / length road per ground condition, without zone 42, 43 and 81, grouped by ground condition

Length/area of damages per groundwater potential			
Ground condition / Damage	2	3	4
Small cracks	59,83	4,59	203,58
Large cracks	5375,02	213,88	21343,10
Crazing	5758,39	271,33	21081,28
Desiccation	7348,02	101,84	14784,15
Hole	76,81	0,82	225,36
Settling of ground	586,41	6,93	1685,66
Rutting	2975,45	16,50	5489,05
Winter Patch	125,96	8,14	366,90
Stone loss	0,00	0,00	0,00
Patched area	4517,59	435,63	18469,77
Profile alignment	0,00	0,00	0,00
Shelling	139,29	1,24	385,48

Road length	29489	810	79298

Length/area of damages per groundwater potential / length road per groundwater potential			
Small cracks	0,002	0,006	0,003
Large cracks	0,182	0,264	0,269
Crazing	0,195	0,335	0,266
Desiccation	0,249	0,126	0,186
Hole	0,003	0,001	0,003
Settling of ground	0,020	0,009	0,021
Rutting	0,101	0,020	0,069
Winter Patch	0,004	0,010	0,005
Stone loss	0,000	0,000	0,000
Patched area	0,153	0,538	0,233
Profile alignment	0,000	0,000	0,000
Shelling	0,005	0,002	0,005

Table 4:9 - Length/area of damages per groundwater potential (extracted from QGIS)

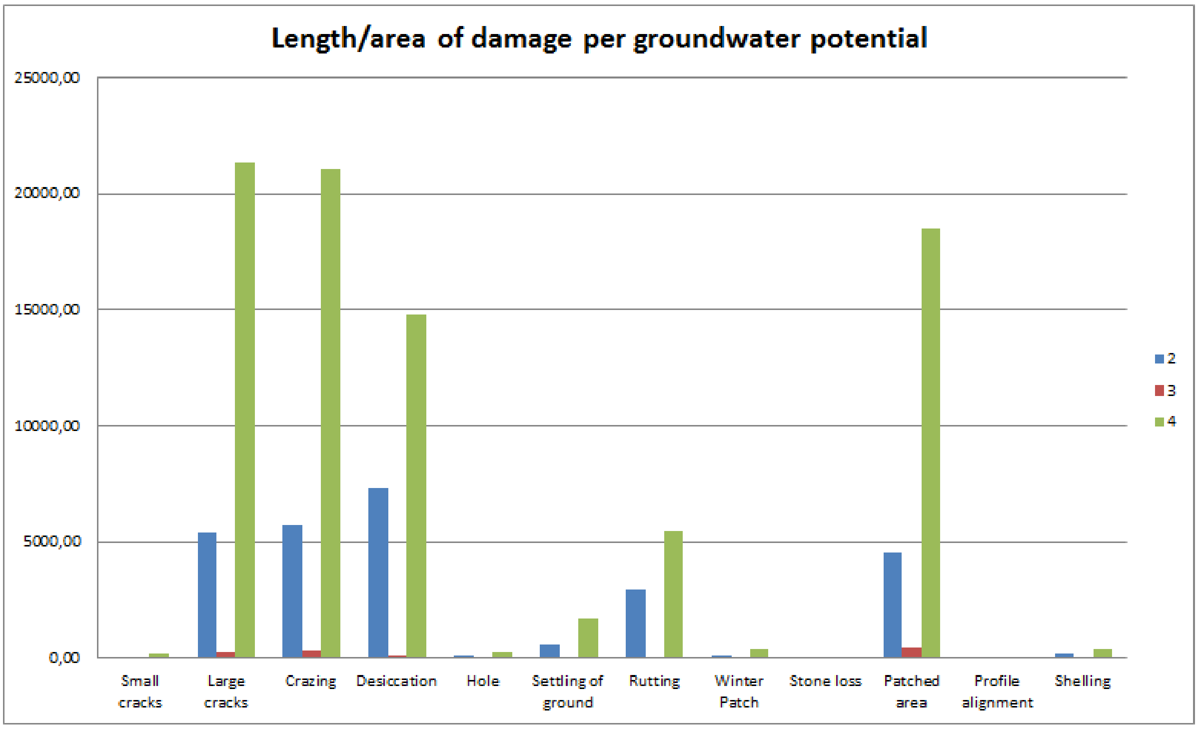


Figure 4:17 - Length/area of damage per groundwater potential, grouped by type of damage

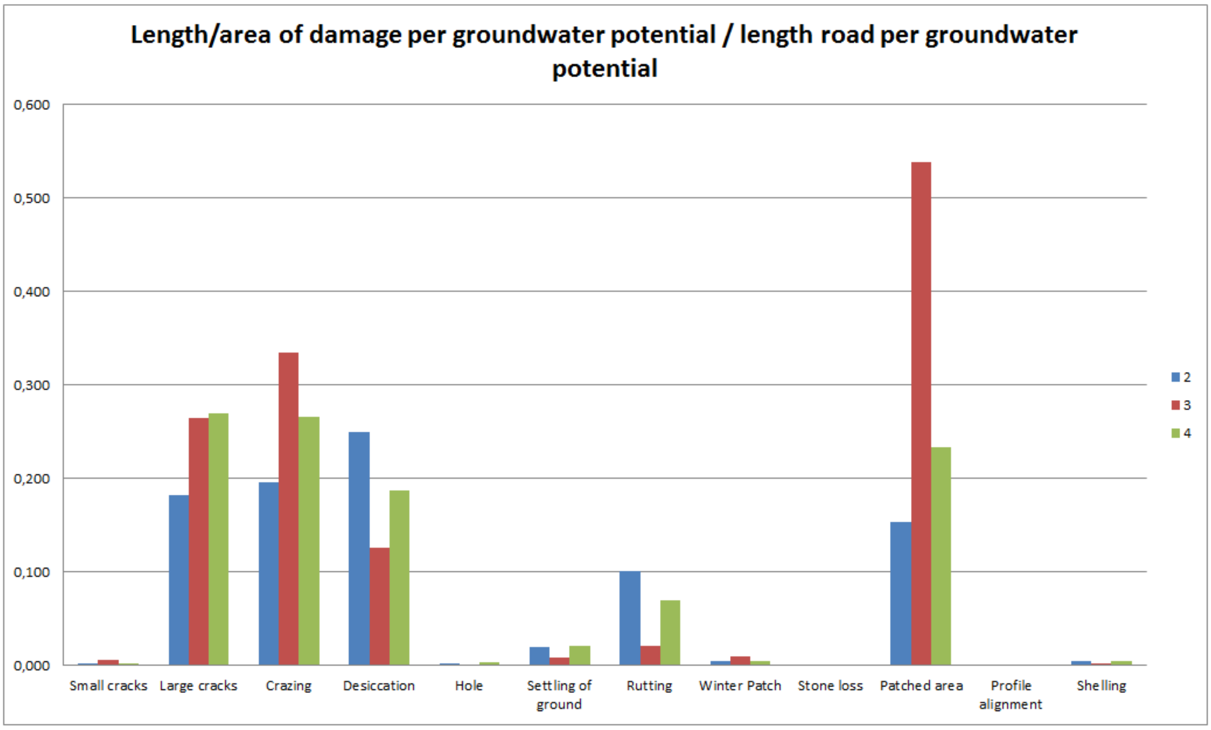


Figure 4:18 - Length/area of damage per groundwater potential / length road per groundwater potential, grouped by type of damage

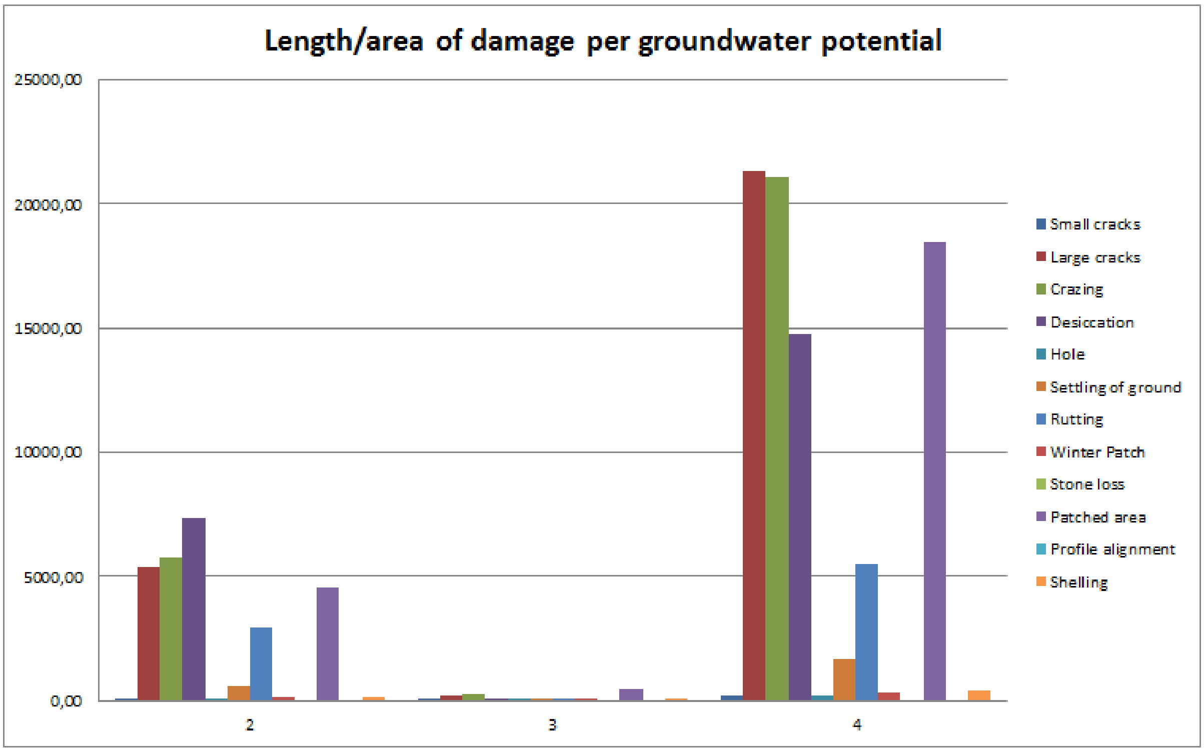


Figure 4:19 - Length/area of damage per groundwater potential, grouped by groundwater potential

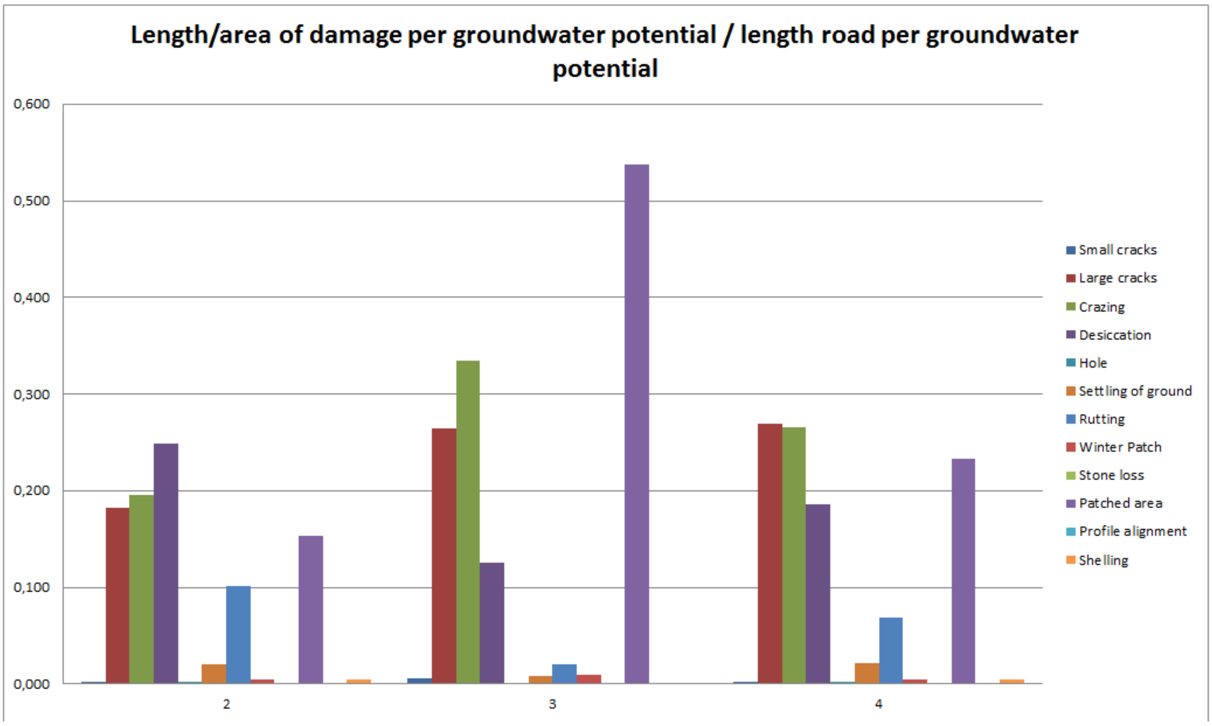


Figure 4:20 - Length/area of damage per groundwater potential / length road per groundwater potential, grouped by groundwater potential

As for some of the zones in soil conditions, the road length for zone 3 is so short compared to the other zones that it can be linked some uncertainty to this zone. Zone 3 has just 810 meters road (Table 4:4). In the next two diagrams is it therefore removed.

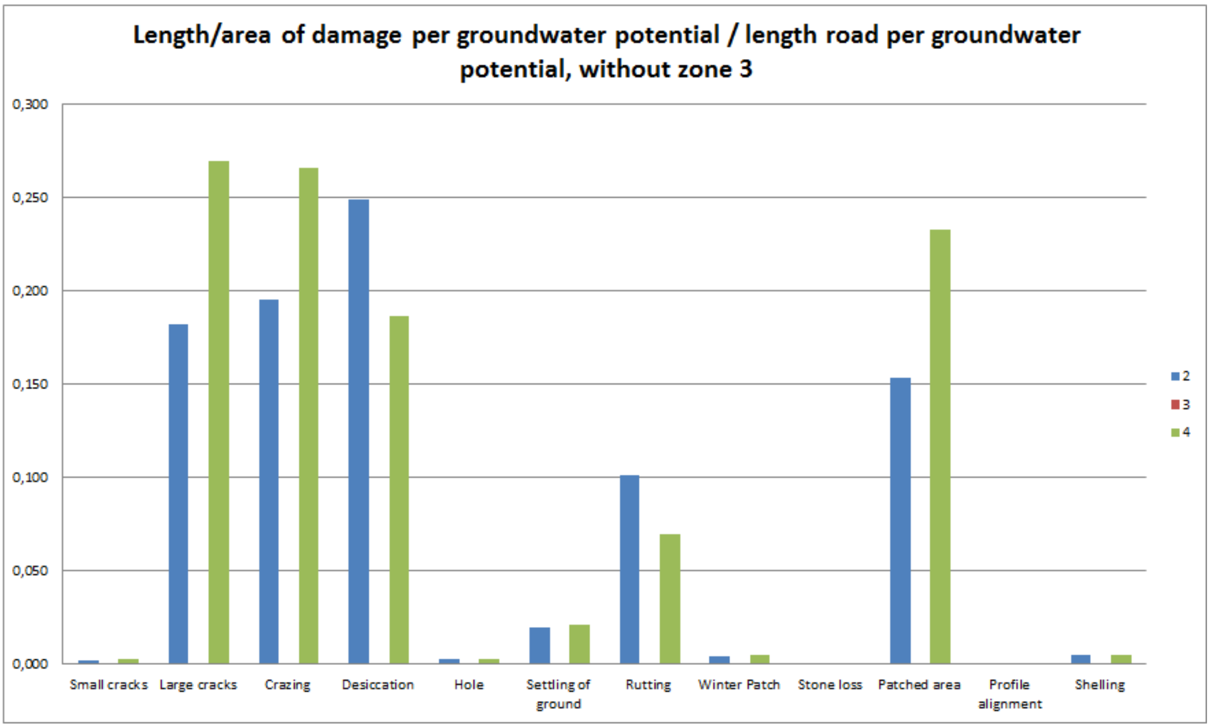


Figure 4:21 - Length/area of damage per groundwater potential / length road per groundwater potential, without zone 3, grouped by type of damage

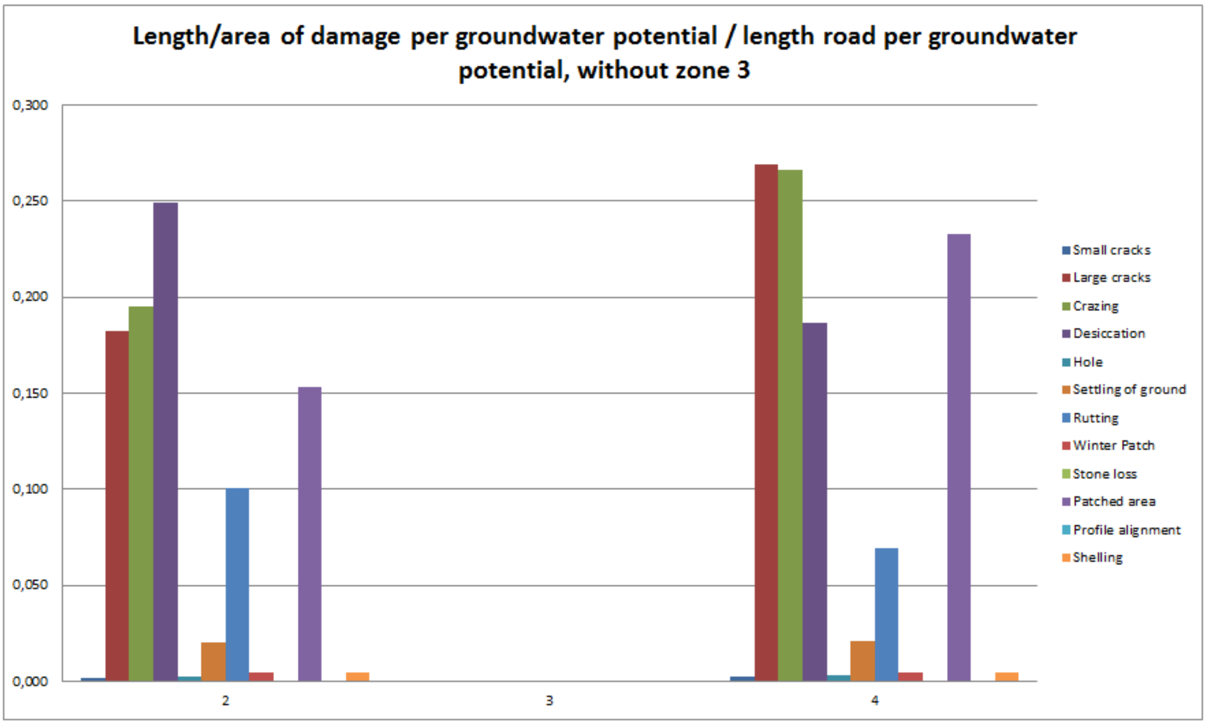


Figure 4:22 - Length/area of damage per groundwater potential / length road per groundwater potential, without zone 3, grouped by groundwater potential

Number of damages per groundwater potential			
Ground condition / Damage	2	3	4
Small cracks	33	3	130
Large cracks	102	6	338
Crazing	75	3	265
Desiccation	86	3	204
Hole	30	2	95
Settling of ground	67	2	227
Rutting	22	1	81
Winter Patch	32	2	85
Stone loss	0	0	0
Patched area	89	6	323
Profile alignment	0	0	0
Shelling	37	2	94
Road length	29489	810	79298
Number of damages per groundwater potential / length road per groundwater potential			
Small cracks	0,001	0,004	0,002
Large cracks	0,003	0,007	0,004
Crazing	0,003	0,004	0,003
Desiccation	0,003	0,004	0,003
Hole	0,001	0,002	0,001
Settling of ground	0,002	0,002	0,003
Rutting	0,001	0,001	0,001
Winter Patch	0,001	0,002	0,001
Stone loss	0,000	0,000	0,000
Patched area	0,003	0,007	0,004
Profile alignment	0,000	0,000	0,000
Shelling	0,001	0,002	0,001

Table 4:10 - Number of damages per groundwater potential (extracted from QGIS)

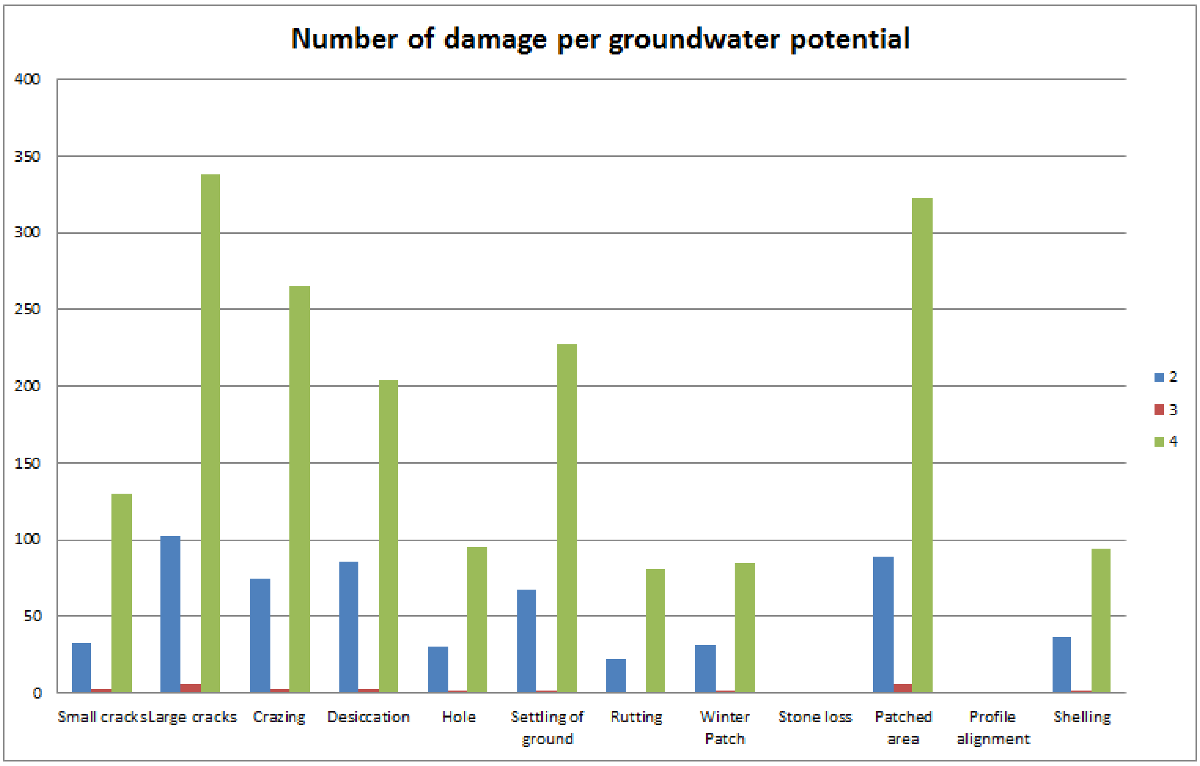


Figure 4:23 - Number of damage per groundwater potential, grouped by type of damage

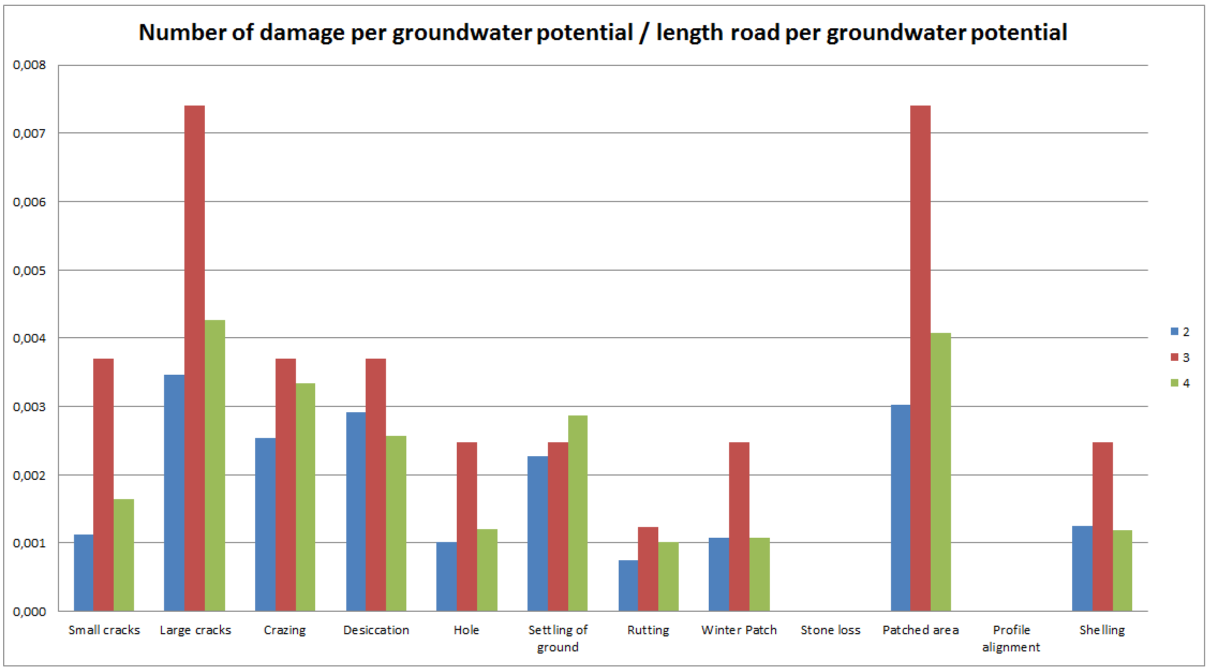


Figure 4:24 - Number of damage per groundwater potential / length road per groundwater potential, grouped by type of damage

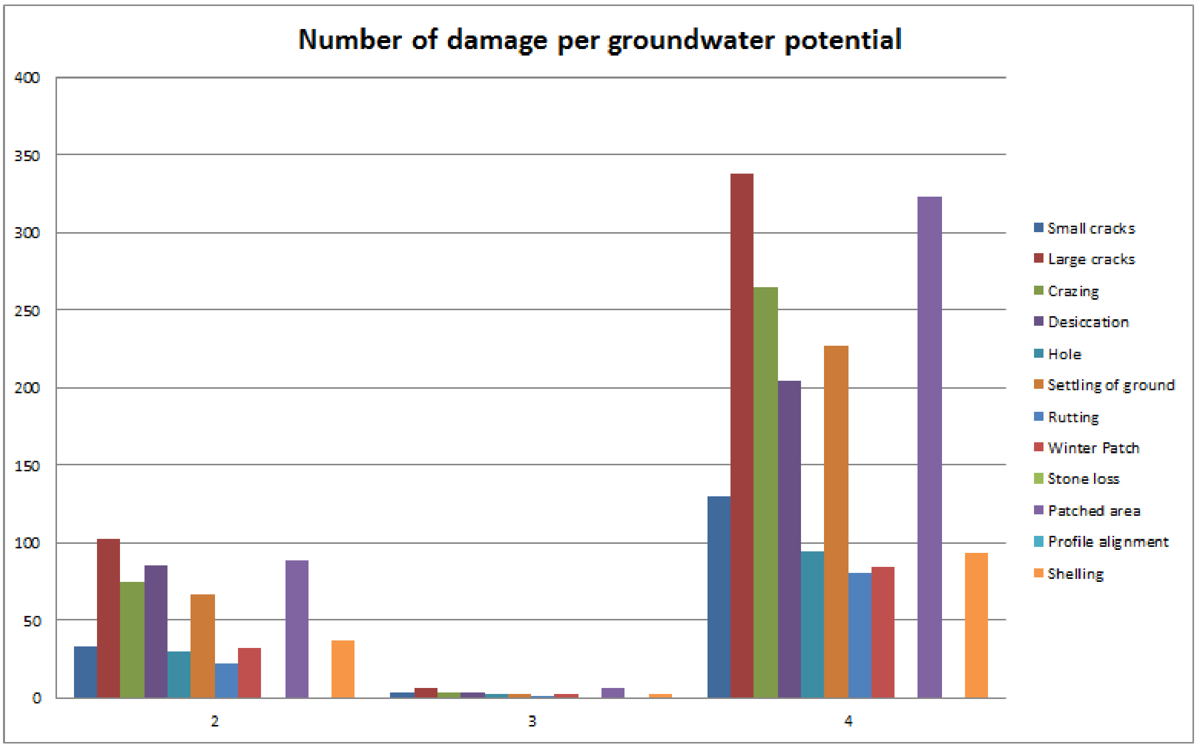


Figure 4:25 - Number of damage per groundwater potential, grouped by groundwater potential

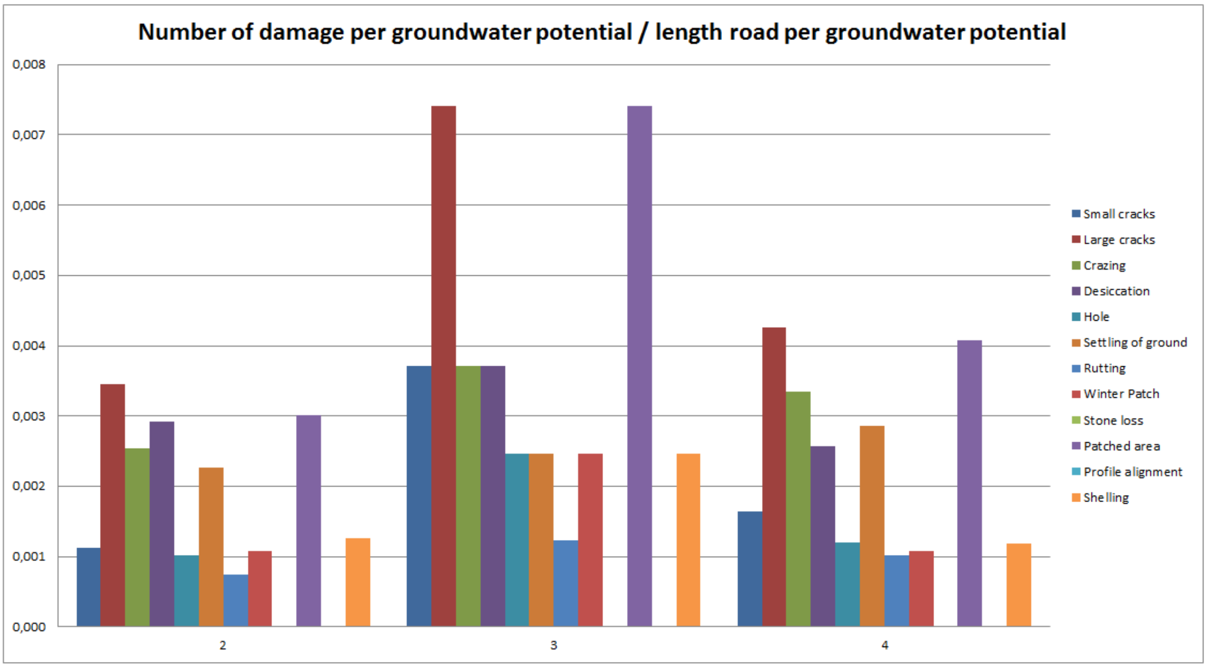


Figure 4:26 - Number of damage per groundwater potential / length road per groundwater potential, grouped by groundwater potential

Here too we see the problem with that Zone 3 could "disrupt" the result in the other zones, so it is removed in the next two diagrams.

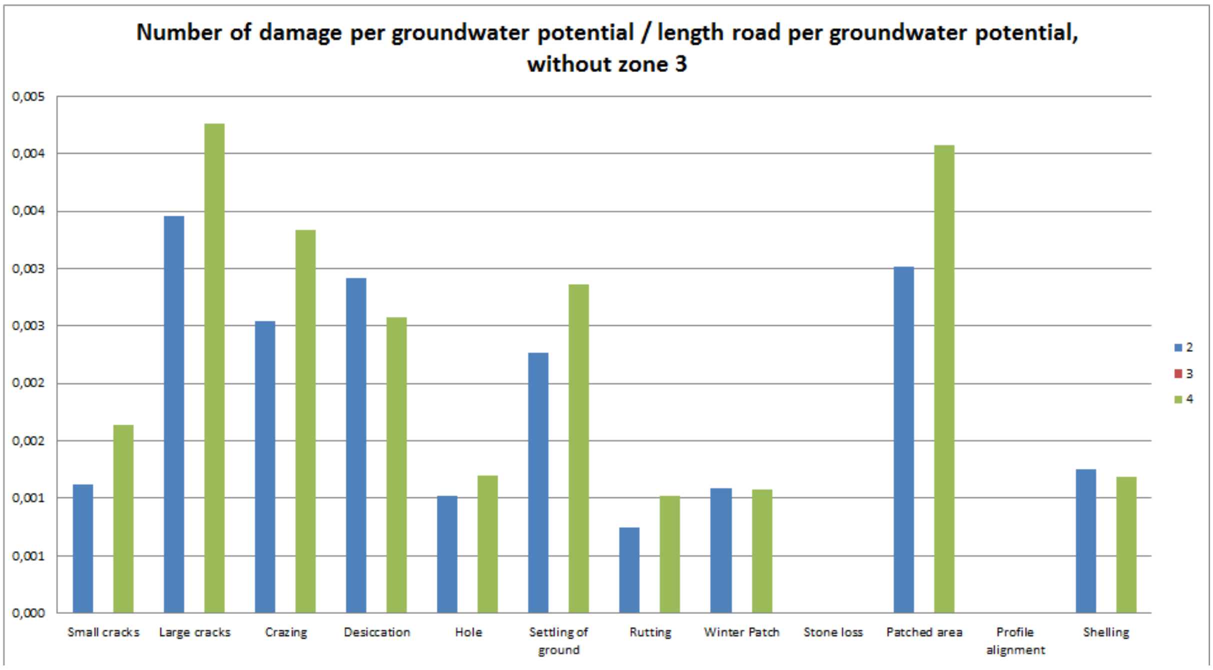


Figure 4:27 - Number of damage per groundwater potential / length road per groundwater potential, without zone 3, grouped by type of damage

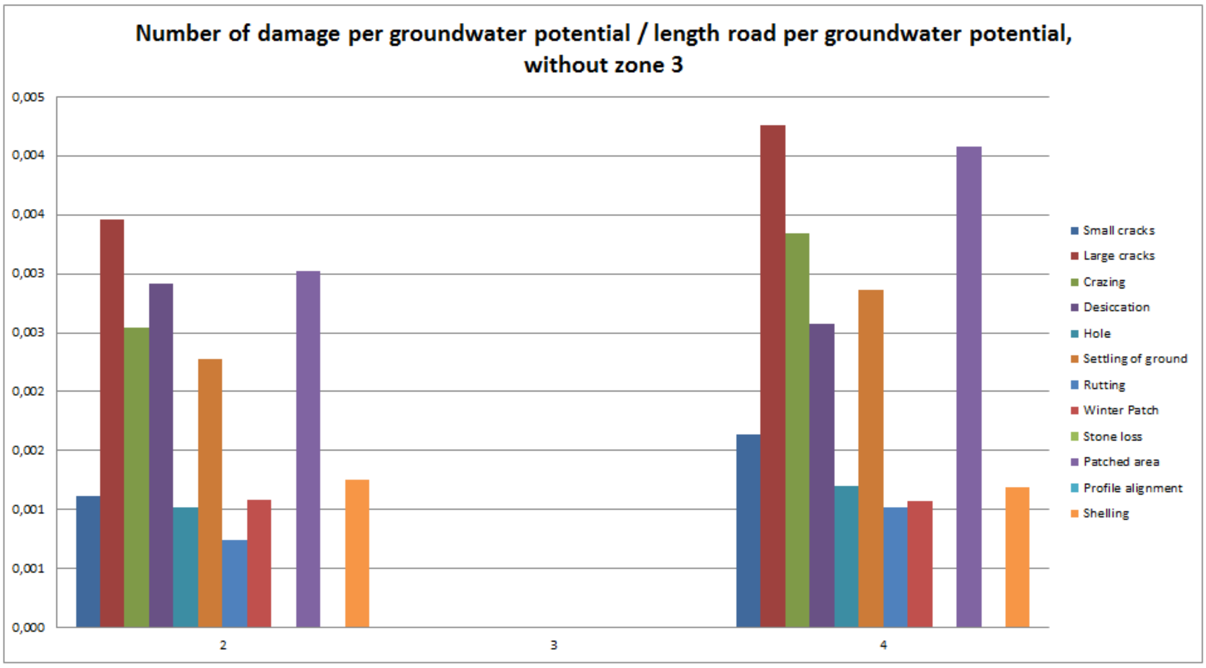


Figure 4:28 - Number of damage per groundwater potential / length road per groundwater potential, without zone 3, grouped by groundwater potential

Length/area of damages per infiltration capacity					
Ground condition / Damage	1	2	3	4	5
Small cracks	59,83	4,59	73,92	77,20	52,46
Large cracks	5375,02	213,88	4948,93	8461,28	7932,89
Crazing	5758,39	271,33	6664,73	5904,42	8512,13
Desiccation	7348,02	101,84	6761,46	3336,62	4686,06
Hole	76,81	0,82	122,17	56,73	46,46
Settling of ground	586,41	6,93	358,96	544,53	782,18
Rutting	2975,45	16,50	594,19	2382,48	2512,39
Winter Patch	125,96	8,14	142,01	76,00	148,90
Stone loss	0,00	0,00	0,00	0,00	0,00
Patched area	4517,59	435,63	6956,59	5931,50	5581,68
Profile alignment	0,00	0,00	0,00	0,00	0,00
Shelling	139,29	1,24	149,30	56,98	179,20

Road length	29489	810	28471	23079	27748

Length/area of damages per infiltration capacity / length road per infiltration capacity					
Small cracks	0,002	0,006	0,003	0,003	0,002
Large cracks	0,182	0,264	0,174	0,367	0,286
Crazing	0,195	0,335	0,234	0,256	0,307
Desiccation	0,249	0,126	0,237	0,145	0,169
Hole	0,003	0,001	0,004	0,002	0,002
Settling of ground	0,020	0,009	0,013	0,024	0,028
Rutting	0,101	0,020	0,021	0,103	0,091
Winter Patch	0,004	0,010	0,005	0,003	0,005
Stone loss	0,000	0,000	0,000	0,000	0,000
Patched area	0,153	0,538	0,244	0,257	0,201
Profile alignment	0,000	0,000	0,000	0,000	0,000
Shelling	0,005	0,002	0,005	0,002	0,006

Table 4:11 - Length/area of damages per infiltration capacity (extracted from QGIS)

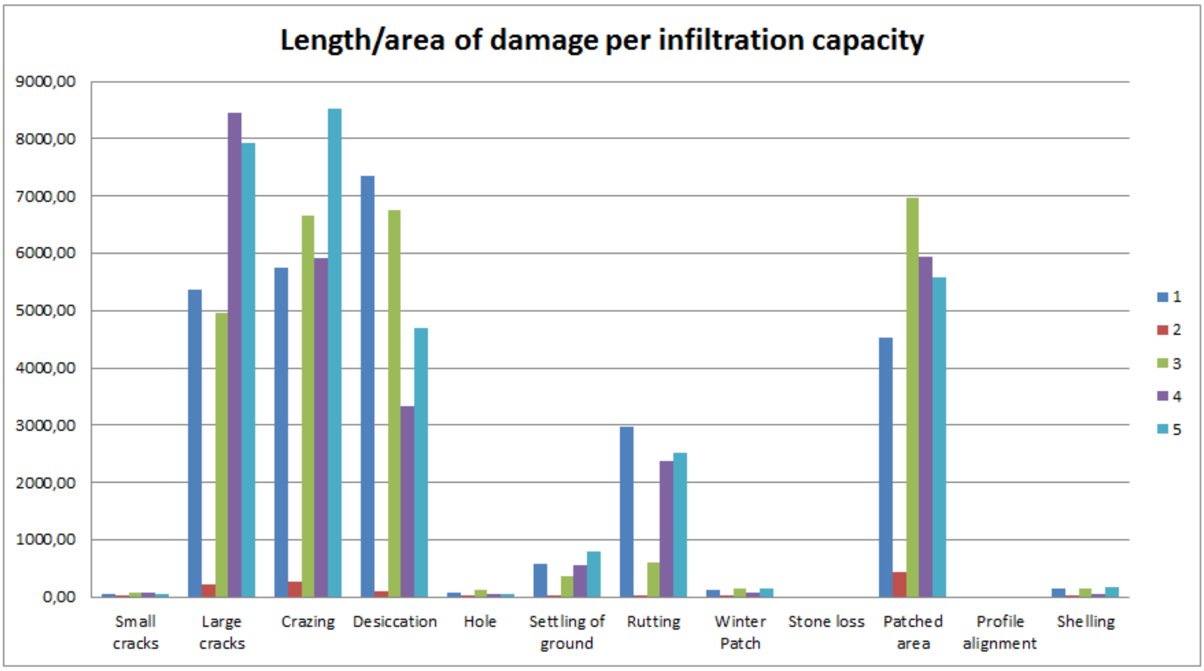


Figure 4:29 - Length/area of damage per infiltration capacity, grouped by type of damage

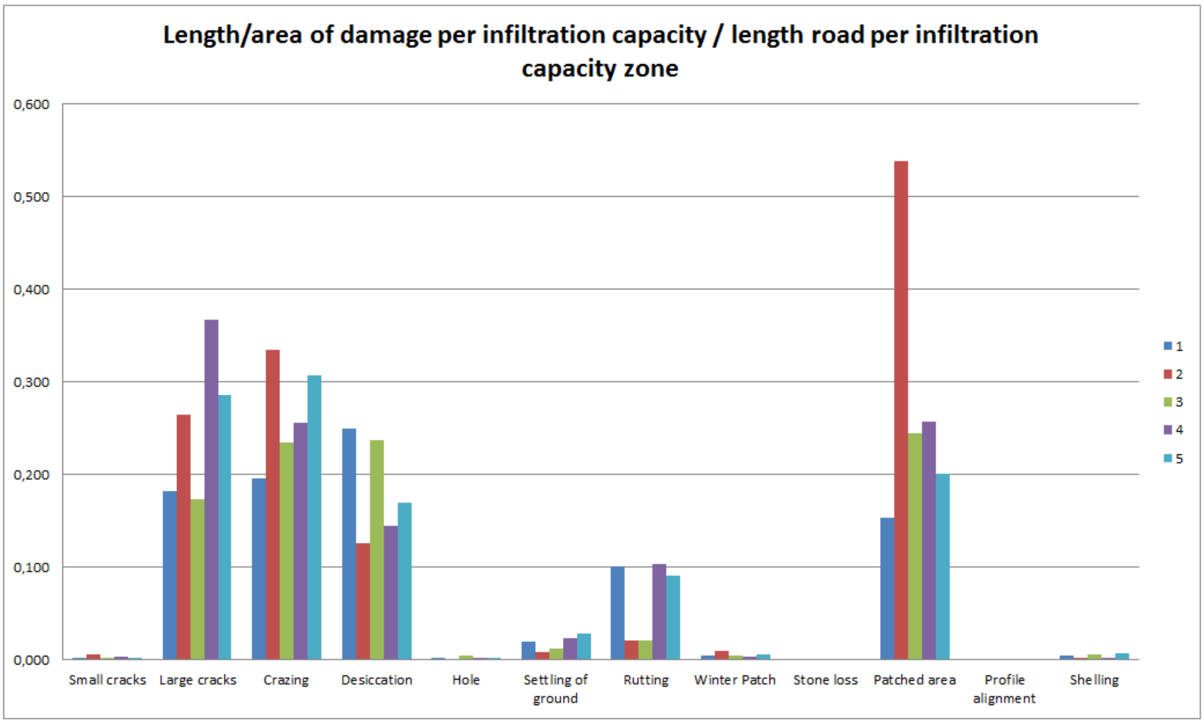


Figure 4:30- Length/area of damage per infiltration capacity / length road per infiltration capacity zone, grouped by type of damage

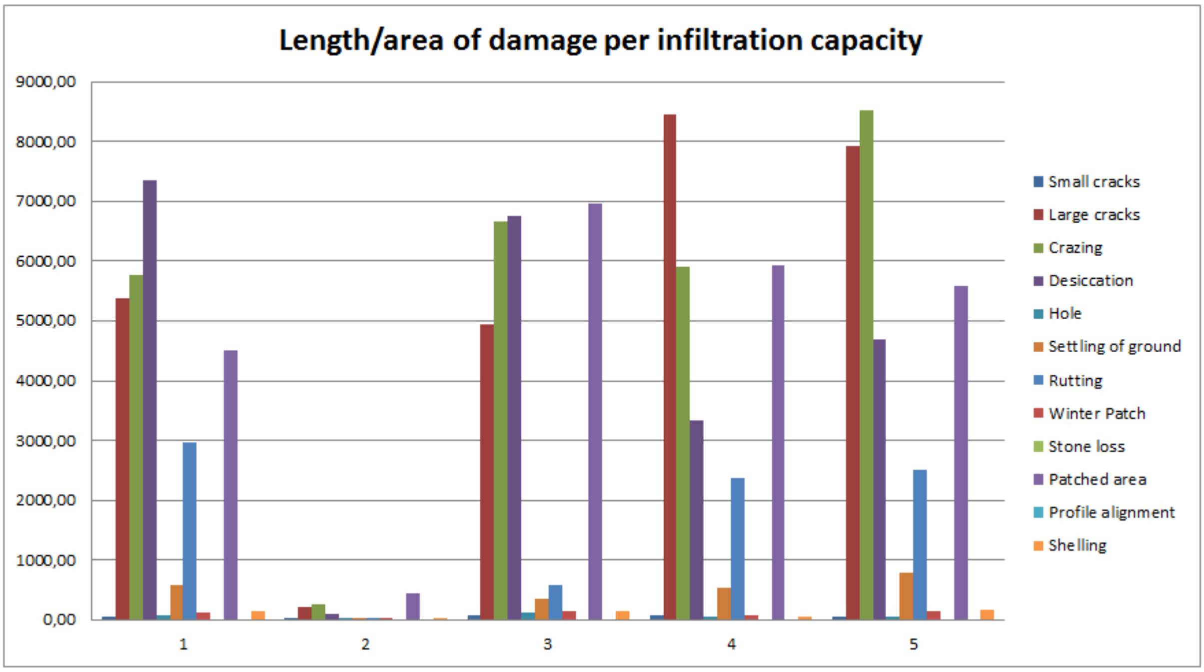


Figure 4:31- Length/area of damage per infiltration capacity, grouped by infiltration capacity

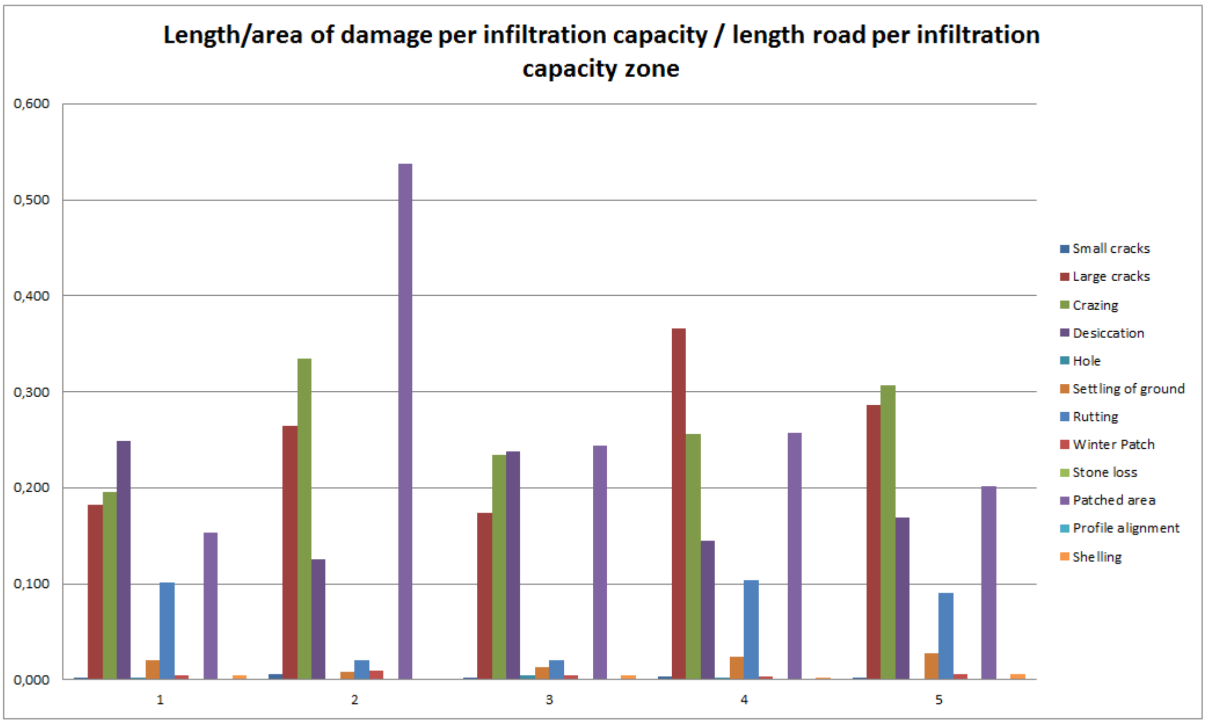


Figure 4:32- Length/area of damage per infiltration capacity / length road per infiltration capacity zone, grouped by infiltration capacity

Also when it comes to infiltration capability we have a zone that has only a short section of road so it can be linked some uncertainty to this zone. Zone 2 has only 810 meters road (Table 4:5) In the next two diagrams is it therefore removed.

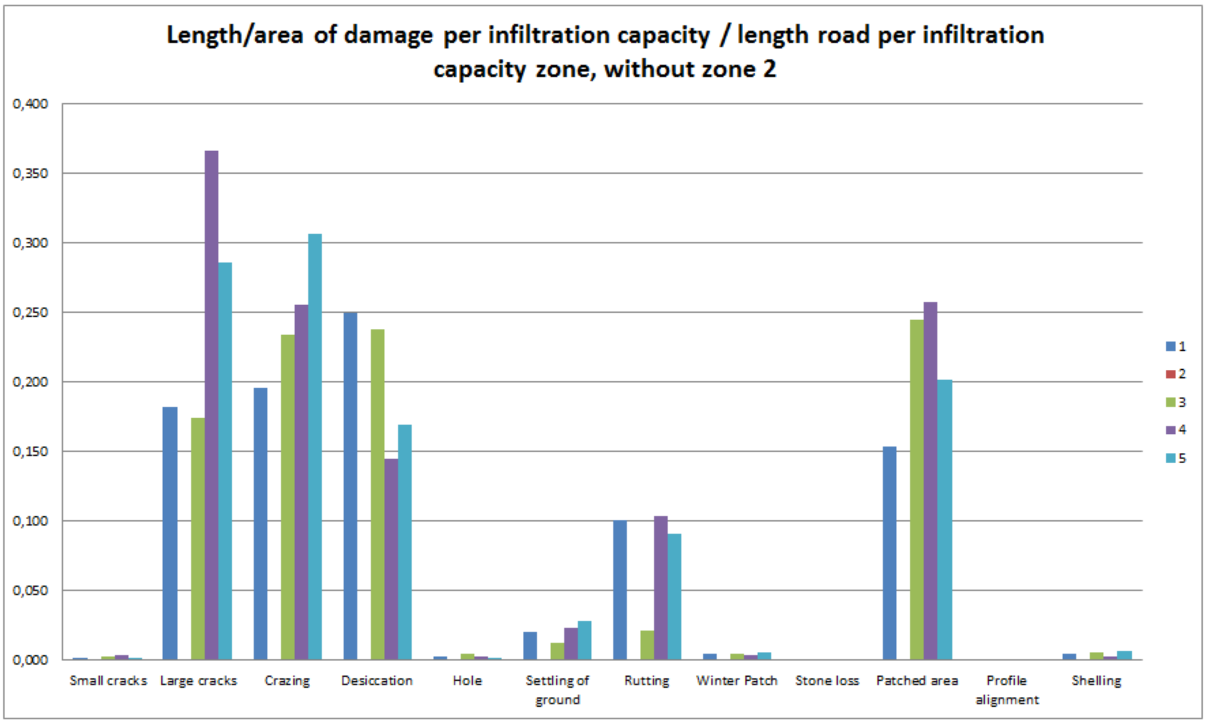


Figure 4:33 - Length/area of damage per infiltration capacity / length road per infiltration capacity zone, without zone 2, grouped by type of damage

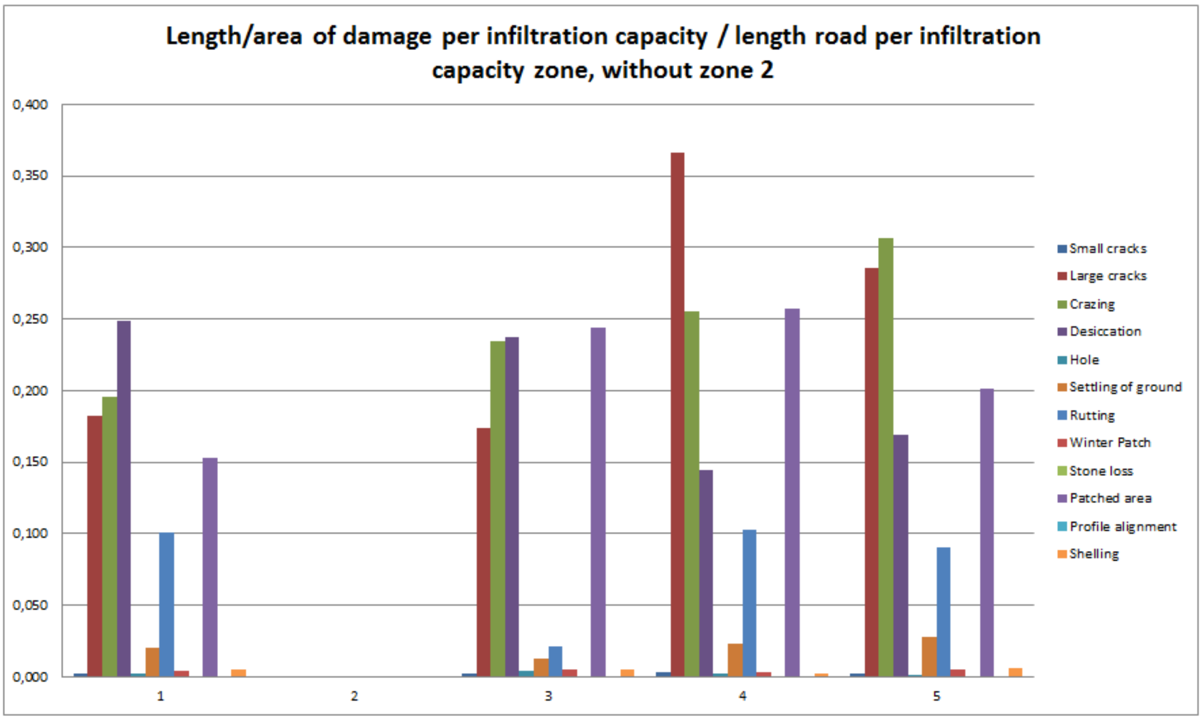


Figure 4:34 - Length/area of damage per infiltration capacity / length road per infiltration capacity zone, without zone 2, grouped by infiltration capacity zone

Number of damages per infiltration capacity					
Damage \ Ground condition	1	2	3	4	5
Small cracks	33	3	53	35	42
Large cracks	102	6	127	104	107
Crazing	75	3	105	81	79
Desiccation	86	3	66	70	68
Hole	30	2	43	32	20
Settling of ground	67	2	66	69	92
Rutting	22	1	14	36	31
Winter Patch	32	2	38	19	28
Stone loss	0	0	0	0	0
Patched area	89	6	129	95	99
Profile alignment	0	0	0	0	0
Shelling	37	2	35	29	30

Road length	29489	810	28471	23079	27748

Number of damages per infiltration capacity / length road per infiltration capacity					
Small cracks	0,001	0,004	0,002	0,002	0,002
Large cracks	0,003	0,007	0,004	0,005	0,004
Crazing	0,003	0,004	0,004	0,004	0,003
Desiccation	0,003	0,004	0,002	0,003	0,002
Hole	0,001	0,002	0,002	0,001	0,001
Settling of ground	0,002	0,002	0,002	0,003	0,003
Rutting	0,001	0,001	0,000	0,002	0,001
Winter Patch	0,001	0,002	0,001	0,001	0,001
Stone loss	0,000	0,000	0,000	0,000	0,000
Patched area	0,003	0,007	0,005	0,004	0,004
Profile alignment	0,000	0,000	0,000	0,000	0,000
Shelling	0,001	0,002	0,001	0,001	0,001

Table 4:12 - Number of damages per infiltration capacity (extracted from QGIS)

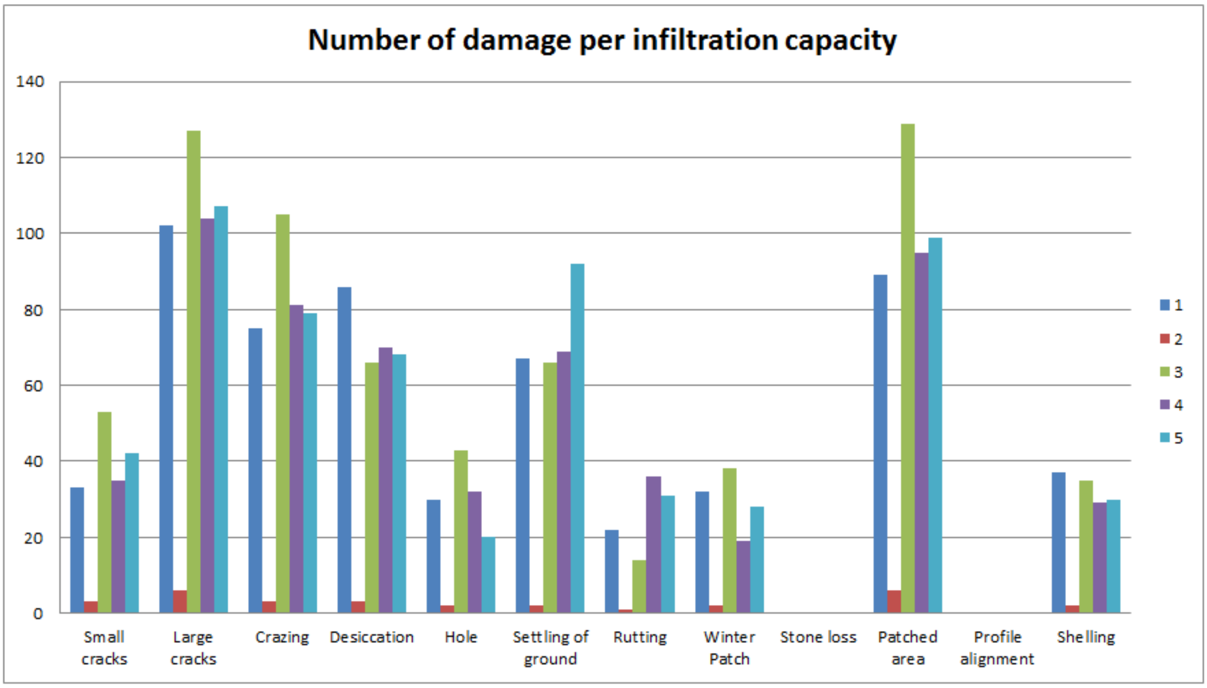


Figure 4:35 - Number of damage per infiltration capacity, grouped by type of damage

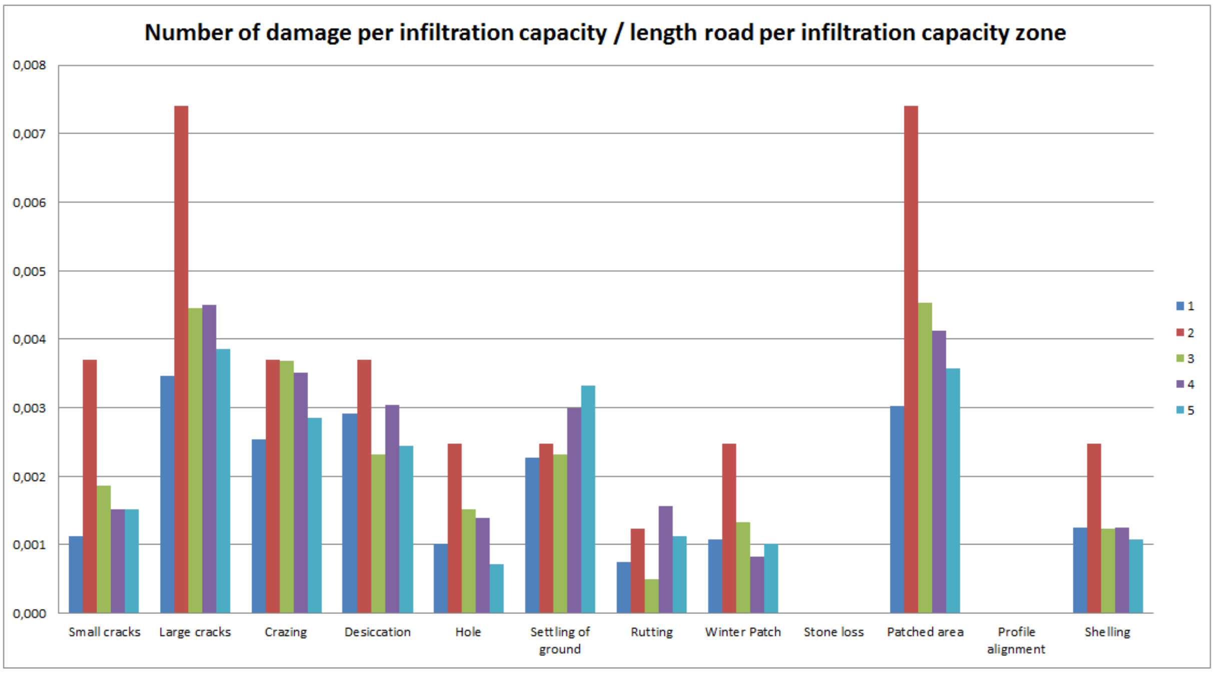


Figure 4:36 - Number of damage per infiltration capacity / length road per infiltration capacity zone, grouped by type of damage

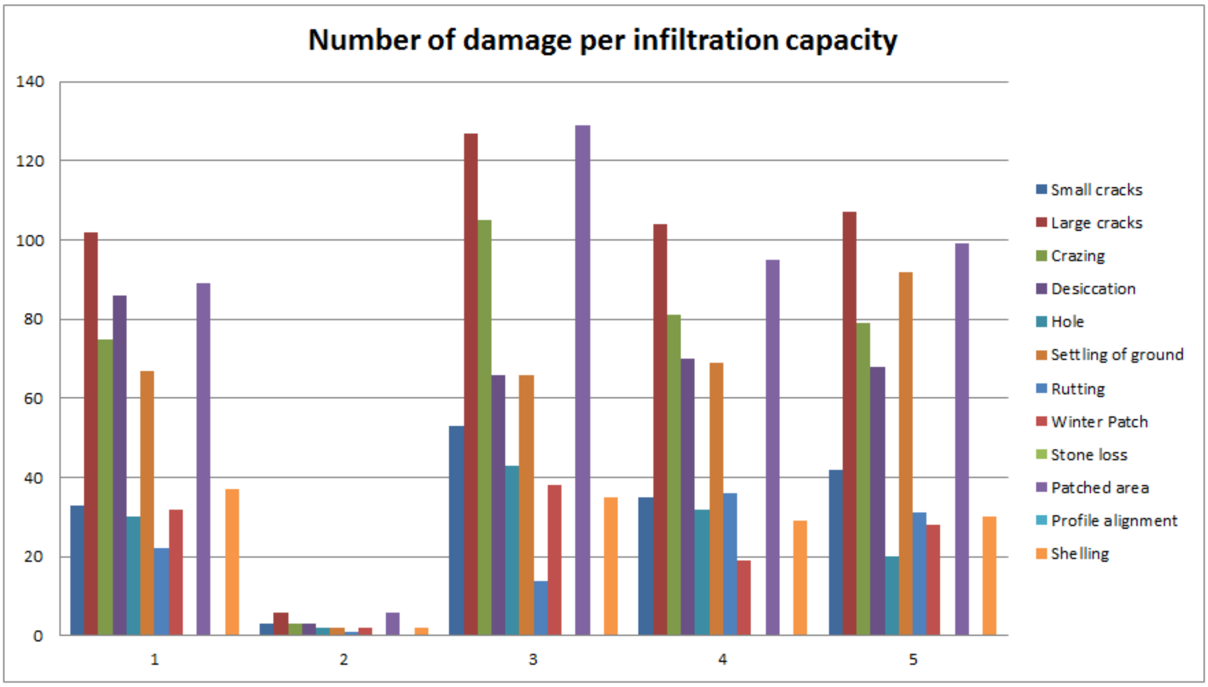


Figure 4:37 - Number of damage per infiltration capacity, grouped by infiltration capacity

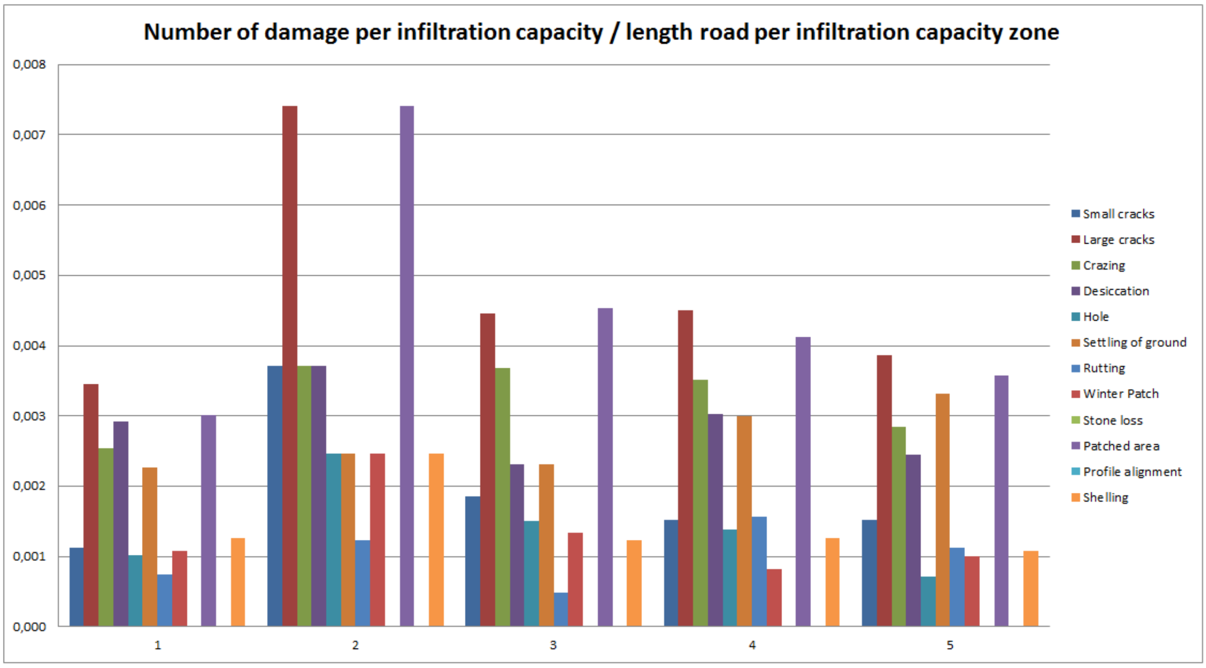


Figure 4:38 - Number of damage per infiltration capacity / length road per infiltration capacity zone, grouped by infiltration capacity

Here too we see the problem with that Zone 2 can "disturb" the result in the other zones, also here it is removed in the next 2 charts.

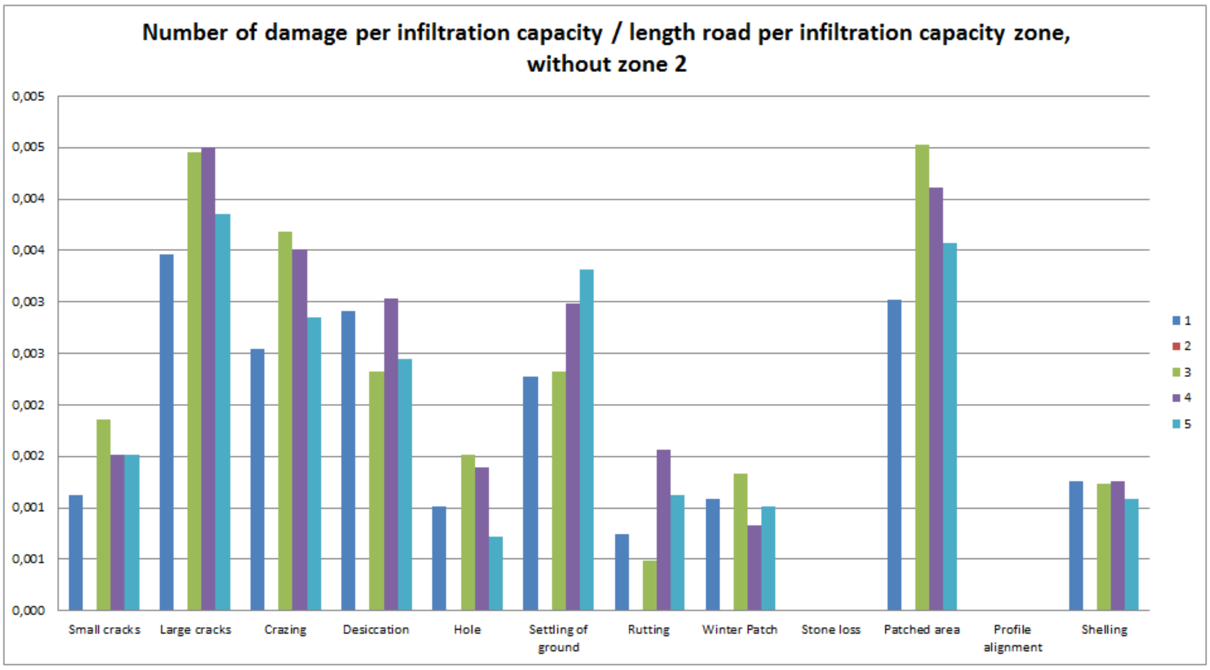


Figure 4:39 - Number of damage per infiltration capacity / length road per infiltration capacity zone, without zone 2, grouped by type of damage

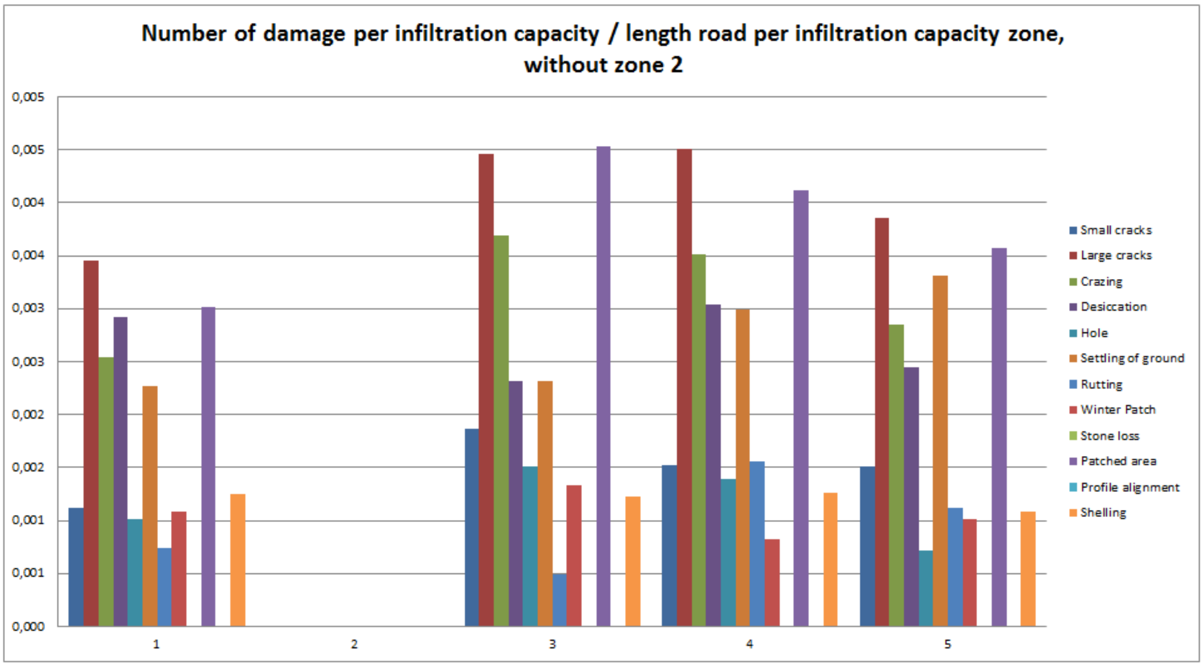


Figure 4:40 - Number of damage per infiltration capacity / length road per infiltration capacity zone, without zone 2, grouped by infiltration capacity zone

4.2.2 Damages in different soils conditions

Data collection in this project collected very large amounts of data, spread over a large area and several different geological zones. It can be difficult to extract some conclusions of all these data, and then the conclusion should be based on assessments of trends that appear in the results.

The starting point for this project was to look at relationships between soil conditions and roads condition and development. Since it is in Nedre Eiker most data was available, this municipality is used as case studies for the project. It turned out that it was difficult to see a direct relationship between soils and condition of the road, and then conditions groundwater vast potential and soil and foundation infiltration capacity were also included in the investigations.

Using the Geological Survey of Norway (NGU) maps there was identified 10 different soil zones where there are roads in Nedre Eiker (Table 2:7). Length road in the different zones vary quite widely. 4 zones have 89% of the roads, 3 zones have less than 1% and the last 3 have from 2 to 5%.

The damage to the roads was registered with the total number and extent of each soil zone. To form an image of the frequency, the number of damage and amount distributed on the section of road within each zone. It then turned out that the shortest roads had a very large proportion of injuries per meter track in relation to the others, this was the roads in zones 42, 43 and especially 81 (Figure 4:6, Figure 4:8, Figure 4:12 and Figure 4:14). The reliability of these results can be questioned since the stretch studied is so short, zone 81 has just 45 meters road. Therefore, these zones were taken out of the diagrams so that they would not interfere with the other results (Figure 4:9, Figure 4:10, Figure 4:15 and Figure 4:16). It is also important to look at the results of these short roads. If damage frequency is as large as the analysis shows, it will be very important to take this into account when the decision to build new roads in these soil zones. It should be possible to investigate several roads located on these soils, but it must be done in areas other than Nedre Eiker.

The result for the rest of soil zones shows a fairly uniform distribution in all zones. But there is the damage types"large cracks", "crazing", "desiccation" and "patched area" that occur most often. "Patched area" is an area that has had an acute damage that has been repaired using an "asphalt patch", so it's hard to tell what the original damage was.

In addition, we see that "rutting" is acting somewhat in zones 41 and 50. These are soils that can go very deep, and consists of fine-grained marine and fjord deposits and sand and gravel containing river and stream deposits. According to «Håndbok V261 – Skadekatalog for bituminøse vegflater» (Vegdirektoratet, 1996) and «Lærebok Drift og vedlikehold av veger» (Aurstad et al., 2015) a cause for «rutting» can be a weak support layer. (Aurstad et al., 2015) also states that as the use of studded tires has decreased, it turns out clearer than previously assumed that rutting is caused by deformations in road construction. HIGHWAYS DEPARTMENT, CATALOGUE OF ROAD DEFECTS, Research & Development Division, 2013 (Highways Department, Research & Development Division, 2013) claims that possible causes for rutting is: "*Settlement of underlying courses and subgrade under traffic*" and

"*Structural failure of subgrade*", among others. It is therefore natural to draw a conclusion that the lack of a good substructure increases the risk of rutting in soil conditions with soils that are both compressible and deep.

Large cracks are a dominant type of damage in several soil zones. Crazing is also common in all soil types, both crazing and large cracks are cracks in the asphalt surface, and often have the same causes. Vegdirektoratet, 1996, Handbook V261 says that cracking and crazing may be due to different materials over the road's cross-profile, poor drainage, inadequate bearing capacity and uneven frost heave. "Lærebok Drift og vedlikehold av veger" (Aurstad et al., 2015) per taking up that deformations in both substructure and deformations in the road bed, ie in the soil, can be a major cause of cracks in the asphalt surface. It would be natural to conclude that if there is no substructure, the risk of that deformation in the soil will cause cracking to be great. Catalogue of road defects (CORD) (Highways Department, Research & Development Division, 2013) claims that possible causes for cracking are:

- *deformation*
- *fatigue failure of the surfacing or pavement structure*
- *ageing of the surfacing*
- *reflection of movement of underlying layers*
- *shrinkage*
- *poor construction*

Several of these may be caused by unstable soil / ground conditions. Both cracks and crazing occur in all soil conditions types, even where there is bare mountain. We would think that mountain should be so solid that it be able to provide a good basis for roads. Since it still is such a large percentage of cracks in these roads, there must be more causes for cracks than unstable subsoil We see from the literature that drainage conditions also can be a cause, and if we look at infiltration capability in areas where there are bare mountain, we find that it is little responsive to water. This indicates that it is difficult to remove water. For roads that have a large percentage of cracks and crazing and situated in soil zones where there is either high groundwater potential or have poor infiltration capacity, it will probably be more profitable to drain the area where the road is located, and if possible lower the groundwater level. (See 2.4, Considerations of frost (frost heave), drainage and groundwater levels)

The cause of the damage type "Desiccation" is often aging of the asphalt surface, or it may be a manufacturing defect or defects in laying of the asphalt. This damage type will occur regardless of whether the road has good bearing and reinforcement layer, and will therefore not be affected by soil conditions or the type of soil. On the other hand the «Lærebok Drift og vedlikehold av veger» (Aurstad et al., 2015) states that the causes of so-called aging are many climatic and environmental stresses. Water is one such type of impact that can have many negative effects and cause including bearing capacity and frost heave problems. In addition, precipitation, freeze / thaw cycles, radiation, temperature shifts, etc. can cause the pavement changes properties over time by it "ages" and is both stiffer and crispier. An aged asphalt surface will thus be much more susceptible to cracking and weathering. Using a good surface drainage we can improve the asphalt layers resistance to aging, and thereby preventing an early development of cracks due to a stiff asphalt surface. But Catalogue of road defects

(CORD) (Highways Department, Research & Development Division, 2013) and ‘Håndbok V261 - Skadekatalog for bituminøse vegdekker” (Vegdirektoratet, 1996) states that there are mainly error in the asphalt mixture or errors in paving that are causing this issue. It is therefore difficult to draw a clear conclusion in relation to the causes and possible action in relation to the matters that will be essential to prevent or delay this type of damage.

It has also been difficult to find former literature to support / explain these results. Most of the literature about state development of roads has as a precondition that the road is built from the ground up with reinforcement and bearing layer, but that there are many injuries caused by poor foundation. This may of course mean that there is no established substructure under road surfaces, but the literature says little about how different soil conditions will affect the road condition. However, there are some literatures on various soils that are frost susceptible and can create adverse conditions for the road, for instance ‘Statens Vegvesens rapporter Nr. 365, Lærebok Drift og vedlikehold av veger’(Aurstad et al., 2015) and “Håndbok N200, Vegbygging” (Vegdirektoratet, 2014b).

4.2.3 Damages in different zones for groundwater potential

If we look solely at how damages is distributed according to where the various groundwater potential zones are, we see no clear distinction if it is significantly more damages under one zone than the other. In fact, it appears that there is a hint of more damages where there is little groundwater potential, ie in zone 4 which has the description "Not groundwater potential in the soil (Table 2:8). The description also states that the zone "Include mainly fine-grained moraines, marine and fjord deposits or thin, incoherent deposits of rock debris and bare mountain and marsh". The map in Figure 4:41 show the location of the zones for groundwater potential, and we see that zone 4 is withdrawn relative to the center of the valley. According to among other “Statens Vegvesens rapporter Nr. 365, Lærebok Drift og vedlikehold av veger” (Aurstad et al., 2015), there should be a greater risk of damage to roads which is located where the groundwater level is high, so this result goes partly against the literature.

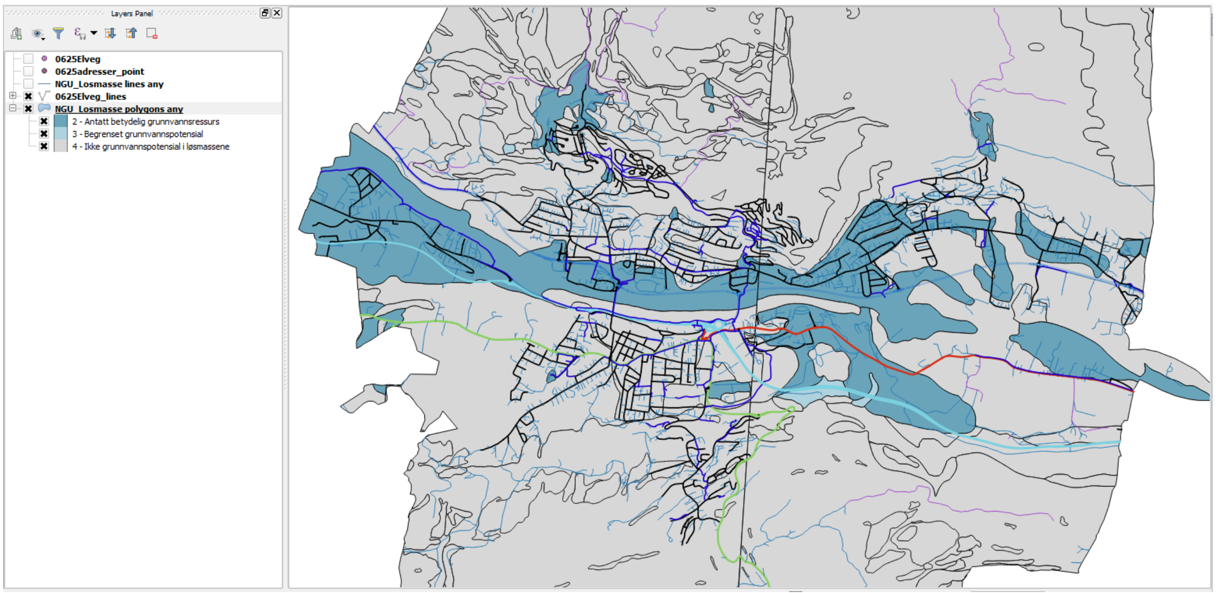


Figure 4:41 - Screenshot from QGIS showing groundwater potential, municipal roads appear as a black line.

4.2.4 Damages in different zones of soils infiltration capacity

The results for damage to roads in the different zones of infiltration capability also shows a relatively even distribution of damage to the various zones (Figure 4:33 and Figure 4:34). But there is a slight tendency that there are fewer damages in zone 1 that has the description "Well suited - soils grain size distribution and permeability, and soil depth and terrain conditions indicates good infiltration capability. There are adequate thickness of sand and gravel above the groundwater level. Includes large glaciofluvial and alluvial deposits, and some mighty beach deposits and sorted parties in the terminal moraine" (Table 2:9). It is particularly the damages "Cracks", "Crazing" and "Patched area" that designates which types of damage there are fewer of in zone 1. The maps in Figure 4:41 and Figure 4:42 Figure shows that infiltration zone 1 is located in the same area as groundwater zone 2. Since it is good infiltration capability for water in this area, it may explain why there are less damages in an area with more groundwater. Since the soil have good infiltration capabilities, it will also be natural to conclude that the drainage properties are good. The literature is studied in this thesis states that good drainage is a major advantage for the roads bearing capacity and resistance to traffic and environmental loads, and thus less damages to the asphalt surface.

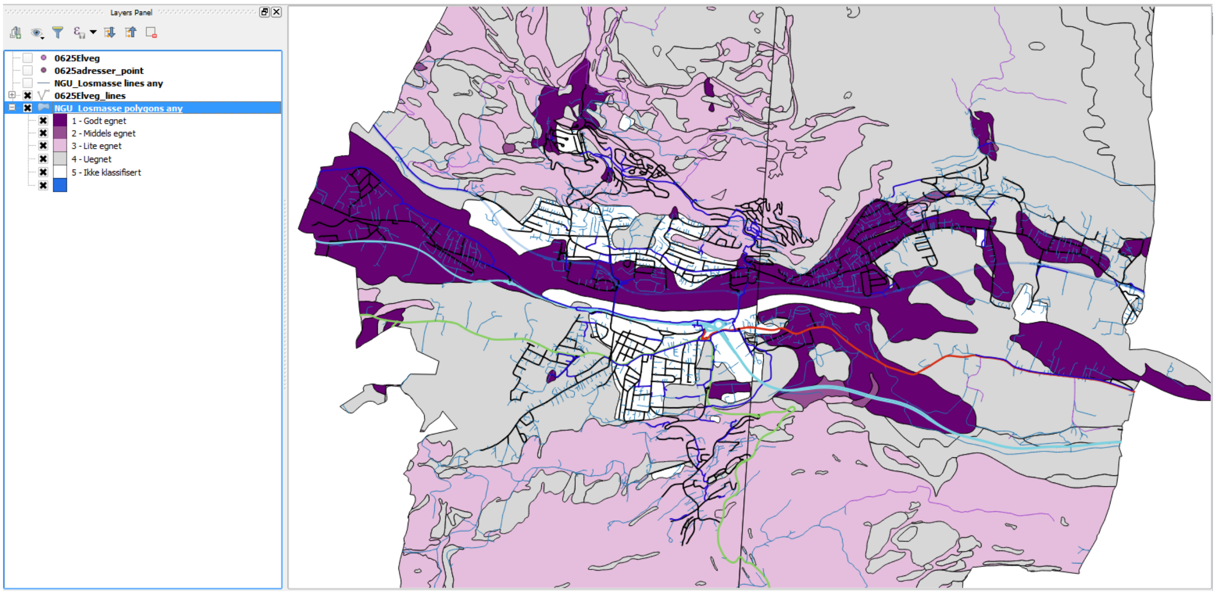


Figure 4:42 - Screenshot from QGIS showing infiltration capability in the soil, municipal roads appear as a black line.

4.3 Results from the evaluation of lifetime of the roads

In addition to the state registration is the residual lifetime of the municipal the roads in Nedre Eiker calculated. This residual lifetime can be calculated with PMS RoSy based on the prevalence of damages registered in the state registration in relation to predefined limits for the amounts of damages municipality can accept, and the traffic load in SA10 axle load. The amount of vehicles with SA10 is measured with traffic meter (See “Traffic measurement”, page 18), or based on historical measurements from RoSy or Statens Vegvesens “National road data bank” (NVDB) (Statens Vegvesen, 2013). The mentioned damage limits vary according to the type of road. An example of these limits is in "Figure 2:1 - Example of a damage image with damages residual life and damage limits for "Gamle Riksvei". Rest lifespan of the roads spread over soil zones distributed as follows:

Length (m) of roads that expires per year												
Ground condition / Year	12	20	41	42	43	50	72	81	120	130	Total	Percentage
2016	560	834	5176	77	114	6932	7121	46	6652	978	28490	26 %
2017 and 18	0	846	2133	331	135	2358	1193	0	2012	546	9553	9 %
2019 and 20	46	0	875	0	0	690	1156	0	1337	0	4104	4 %
2021 and 22	707	327	518	0	11	1142	1409	0	1189	0	5303	5 %
2023 and 24	0	140	1073	94	0	1748	1799	0	3672	901	9426	9 %
2025 and 26	238	437	961	0	0	2552	1657	0	3529	992	10367	9 %
2027 and 28	0	147	268	0	0	432	1852	0	2388	499	5585	5 %
2029 and 30	321	76	526	0	0	643	1665	0	1583	0	4814	4 %
2031 and 32	0	0	0	0	0	0	0	0	3835	0	3835	3 %
2033 to 39	0	0	0	0	0	0	0	0	1403	0	1403	1 %
											82879	76 %
Total length road (m)	2180	4173	18191	810	315	25316	25931	45	27748	4888	109597	100,00 %

Table 4:13 - Length (m) of roads that expires per year

According to Table 4:13 it is stated that 26% of the roads have no residual life left, ie they are worn out.

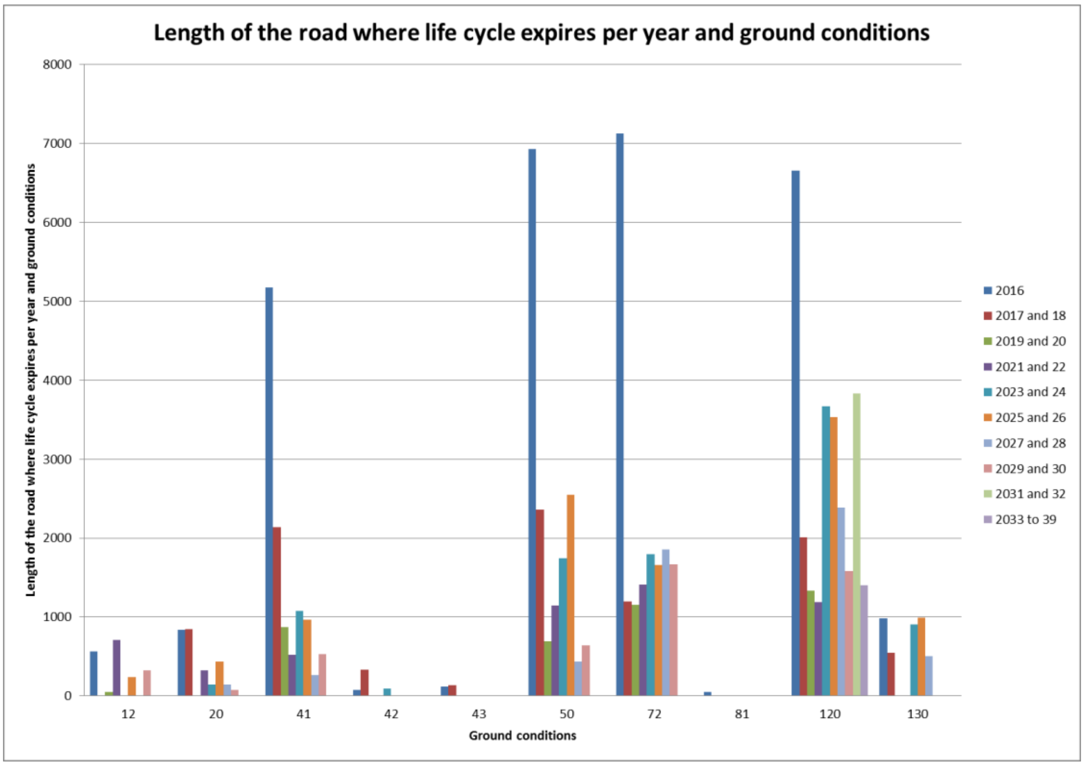


Figure 4:43 - Length of the road where life cycle expires per year and ground conditions, grouped by ground conditions

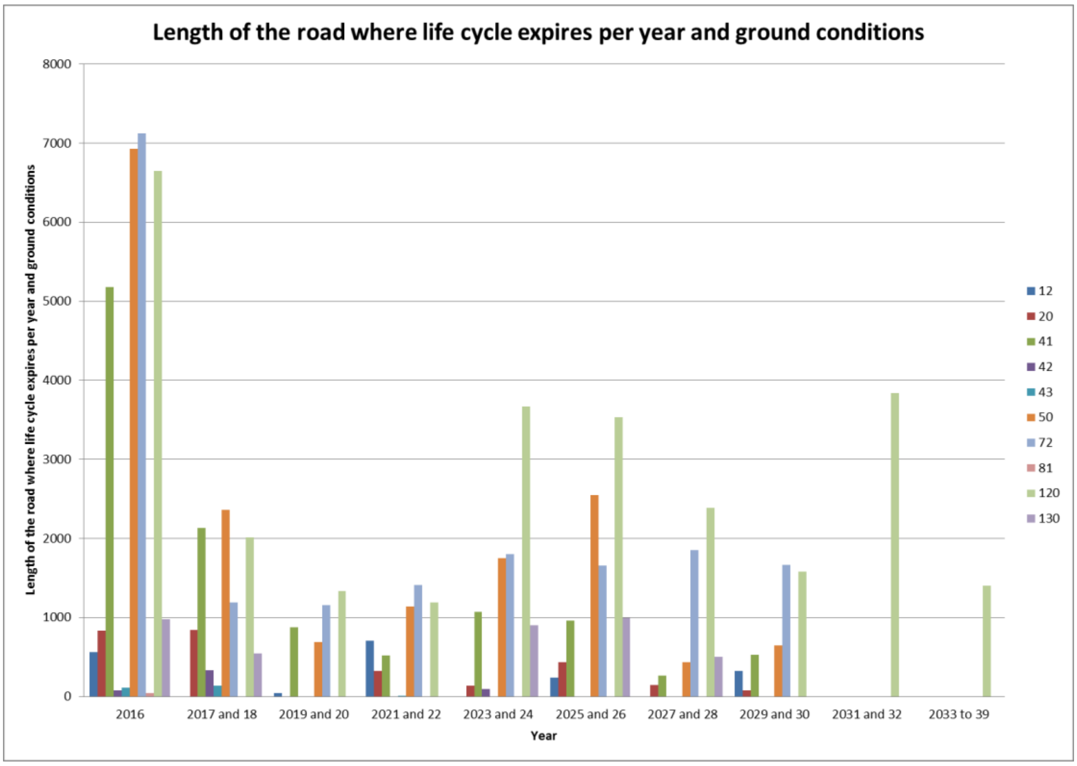


Figure 4:44 - Length of the road where life cycle expires per year and ground conditions, grouped by year of expire

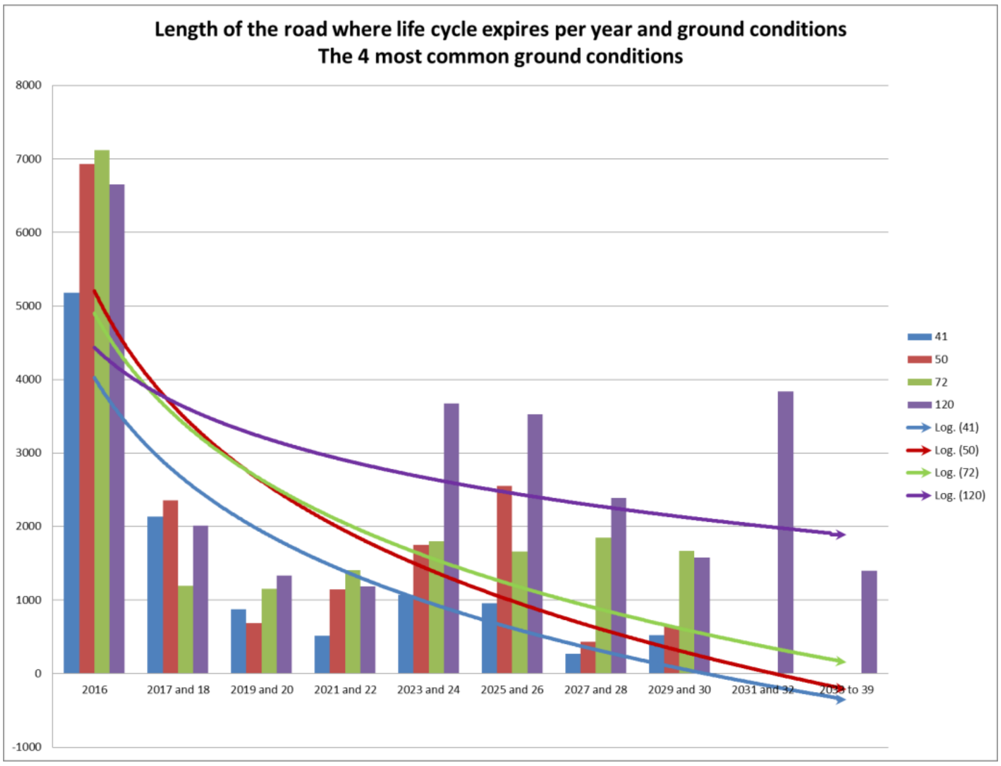


Figure 4:45 - Length of the road where life cycle expires per year and ground conditions, the 4 most common ground conditions. Grouped by year of expire.

It turns out that here too there is soil zones 41, 50, 72 and 120 which are distinguished, and as said, this will make sense since there is in these zones most of the roads are located (Figure 4:46). For an overview of the zones with the most of the roads, zones with few roads have been removed in Figure 4:45. Here it is evident that there are a very large percentage of the roads that have no residual lifespan left. According to Table 4:13 it is stated that for 26% of the roads the lifetime has expired. This is somewhat more than the percentage low standard roads computed in chapter 2.1.5 and shown in Figure 2:2 - Localization of low standard roads in Nedre Eiker In other words, there are some roads even though lifetime is estimated to 2016, they still have a standard that is acceptable.

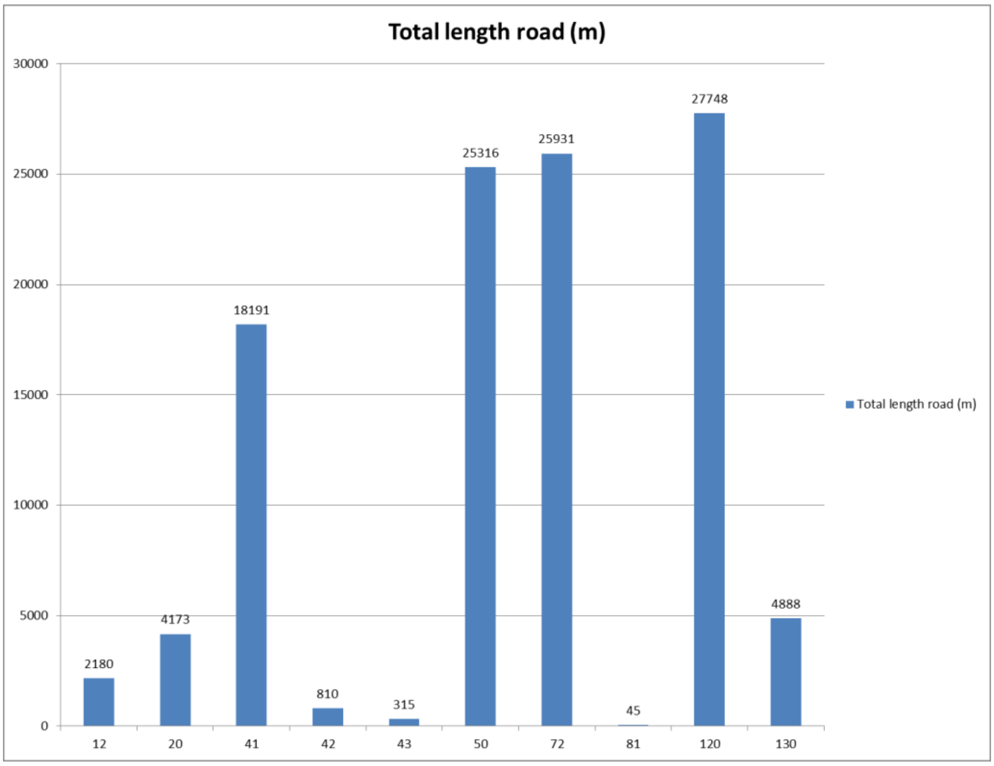


Figure 4:46 - Total length of roads in Nedre Eiker grouped by ground conditions

5 Discussion, recommendations and conclusions

5.1 Discussion

In this section, the results of the state registration and collection of geological data with the subsequent analyzes will be discussed in relation to current literature. Possible uncertainties and sources of error will also be considered

5.1.1 Uncertainties and sources of error in fieldwork

There are a number of potential sources of error and uncertainties that may cause discrepancies in the results from the fieldwork. This applies to both the data and the methodology that was used. The state registration is carried out by a professional road technician who has such registrations as his daily profession. Yet it is a pure manual and visual recording, and at such registrations will always be a risk that errors can occur in the registrations. Nevertheless, state registration can be considered reliable. As mentioned the registration is conducted by Sweco and their road technician commissioned by Nedre Eiker and Erik Josephson. Sweco is seems like a company with great expertise in this area, and they got the assignment and agreement on municipal PMS after a careful consideration of the municipality of Nedre Eiker.

The maps from the Geological Survey of Norway (NGU) have formed the basis of the geological data in this thesis. NGU emerges as an organization with very high skills on geology, and they say, among other things on its website: "NGU has for decades carried out quaternary geological mapping in Norway." http://www.ngu.no/emne/kvart%C3%A6rgeologiske-kart-l%C3%B8smassekart (Norges Geologiske Undersøkelse, 2015b). The maps from NGU and the data they contain to be considered very reliable.

The road maps (ELVEG) (Statens Kartverk, 2001) is taken from Statens kartverk and developed by Statens Vegvesen (SVV). SVV's roadmap is under continuous development and is continuously updated. This is also Norway's official map database for roads, and may be considered reliable. The length of the municipal roads that are extracted from ELVEG also corresponds almost exactly with the municipality's own calculations for municipal roads.

All map layers are compiled in the GIS tool QGIS and using this, all data from the maps are drawn out in the attribute tables and exported to Excel. This is pure technical computer operations and data transfer. The processing of data in Excel is performed by Erik Josephson, and here there is a possibility of human error. Yet the results seem to correspond with reality in a positive way, so data processing is considered reliable.

5.1.2 Results in relation to the theory

The 4 damage types that excels are "Large cracks", "Crazing", "Desiccation" and "Patched area." The 4 soil zones prominent when it comes to damages are 41, 50, 72 and 120. That it is most injuries on the roads in these soil zones are as expected since most of the roads is located in these zones. In addition, "Rutting" are somewhat prominent in three zones (41, 50 and 120)

According to SVV's Skadekatalog V261 (Vegdirektoratet, 1996), Statens Vegvesens rapporter Nr. 365, Lærebok Drift og vedlikehold av veger (Aurstad et al., 2015) and Catalogue of road defects (CORD) (Highways Department, Research & Development Division, 2013) we find the following possible causes of these injuries:

Damage	Cause
Rutting	• The wear from studded tires • Inadequate compaction in surfacing or base • Plastic deformation of bituminous materials (flow) observed longitudinally. It is accelerated by the combined effect of traffic and high temperature. • Settlement of underlying courses and subgrade under traffic

	• Structural failure of subgrade
Patching	• Have no causal description in the literature. But this is probably attempt to repair local damage in the asphalt surface. Most likely there have been potholes in the asphalt surface that has been filled with cold asphalt.
Cracks	• Traffic loads near the road edge, edge cracks. • Uneven frost heave over the road cross section. • Widening. • Inadequate wedging out between different soils. • Differential settlement of subgrade, e.g. between the cut and fill • Shear deformations or sliding out. • Poorly executed longitudinal extension when paving. • Longitudinal seams in the underlying concrete pavement. • Tree roots
Crazing	• Inadequate bearing capacity in relation to the loads on road construction. • Poor drainage has reduced the structure's bearing capacity. • Too thin asphalt surface. • Water sensitive materials in road construction are too close to the asphalt surface. • Pavement is so stiff that it fails to follow the movements of the underlying layer.
Desiccation	• Errors in asphalt masses when paving • Bad / wrong binder in the asphalt • Ageing

Table 5:1 - Summary of damages and causes according to SVV's Skadekatalog V261 (Vegdirektoratet, 1996), Statens Vegvesens rapporter Nr. 365, Lærebok Drift og vedlikehold av veger (Aurstad et al., 2015) and Catalogue of road defects (CORD) (Highways Department, Research & Development Division, 2013)

There are quite a few possible reasons for these damages. The challenge is to find the most likely causes. We should look at the reasons and considering the according to what we know about the municipality of Nedre Eiker; It is a municipality that is prone to flooding, there has been a low maintenance budget the last 10-year period, probably this is a trend in the municipality, it is likely that it is laid asphalt surface directly on top of old dirt roads in many parts of the municipality. In the context of the causes of the most prominent the damages this will make sense to highlight the reasons that may be due to low budget and poor subsurface.

Probably is the cause of many of the damages in poor material quality and / or poor construction that time the roads were paved, in addition, it is likely that many of the roads have gotten asphalt surface directly on top of old dirt roads, this means that it is a poor construction of roads that makes them are vulnerable to frost heave, and they have a poor bearing capacity which means that the traffic load breaks the roads down faster than if it had been a well-structured support layer with good drainage. According to the interview with Geir O. Evensen (Evensen, 2016) there were very many of the municipal gravel roads paved in the early 1960s. He also confirms that the roads were only corrected with a road grader and it was laid out a thin layer of gravel as substrate for the asphalt surface. This is in conflict with all standards and guidelines that SVV has given for building a good road, it is reasonable to conclude that the lack of support and reinforcement layer in municipal roads now turns out as many roads in poor condition, with damages caused by poor substructure.

Both SVV’s literature as “Håndbok V261 - Skadekatalog for bituminøse vegdekker” (Vegdirektoratet, 1996), “Statens Vegvesens rapporter Nr. 365, Lærebok Drift og vedlikehold av veger” (Aurstad et al., 2015)” and “Catalogue of road defects (CORD) (Highways Department, Research & Development Division (2013))” highlights poor road foundation as a major cause of the damage types we observed in this study. It is not found any literature describing the concrete effect of adding a asphalt surface directly on top of an old gravel road without foundation.

According to “Statens Vegvesen (2014) Håndbok N200, Vegbygging” (Vegdirektoratet, 2014b) several soil zones in Nedre Eiker have materials in the ground that are considered frost susceptible, and it should have been conducted soil surveys before the roads were built.

Through literature search in this thesis is established that Statens Vegvesen requires that soil surveys will be carried by certain conditions (see chapter 2.4, Considerations of frost (frost heave), drainage and groundwater levels page 41). Through both interview with Geir O. Evensen (Evensen, 2016), the state registration and search in historical internal documents in the municipality of Nedre Eiker we can conclude that it is not carried out such soil surveys in Nedre Eiker. Furthermore, it is ascertained that many of the municipality's roads are constructed without substructure. State registration shows that the municipal roads have damage that is typical of bad (missing) substructure.

5.2 Recommendations

In this thesis it is viewed upon challenges to the municipality of Nedre Eiker in terms of the municipal roads. Considering the results of the state investigation, data from NGU's map base and information obtained partly from publications from Statens Vegvesen, it is recommended that the municipal roads in Nedre Eiker must be carefully considered in connection with further maintenance. It seems pretty clear that the decay of roads in the municipality is significantly larger than the renewal, and if the maintenance backlog should not be prohibitively, the municipality should take action quickly.

The objective of this master thesis was to study the condition of the roads in relation to ground conditions. Through literature search revealed that there is very little literature that looks at the relationship between the state developments on the roads compared to local ground conditions. The literature tells us that we must build roads with good substructure, and possibly a frost protection layer as well. These are good guidelines for construction of new roads, but it does not help as much for existing roads that have been built without this foundations. If the roads are to be built all over again, it will pose huge costs. But by studying the roads in relation to the foundation where they are, it will be possible to choose more cost-effective upgrade solutions.

Soil zone 50

Figure 4:2 and Table 4:3 show the length of the road and localization of soil conditions. Here we see that soil zone 50 is located close to the river that runs through the municipality. This is a soil type that is transported and deposited by rivers and streams. Sand and gravel dominate, and the material is sorted and rounded. Table 4:4 and Figure 4:3 show the length of the roads and location of groundwater potential. This states that same area as soil zone 50 has a supposed substantial groundwater potential. Furthermore, Table 4:5 and Figure 4:4 shows length of the roads and location of zones of infiltration capability. These show that the area of soil zone 50 is also well suited in terms of infiltration capability. Considering what the literature says about groundwater and drainage it will be appropriate to consider draining the roads well in this soil zone, and possibly consider whether it is possible to lower the groundwater level. This will be a significantly cheaper solution than building the roads over again, and it will probably make the roads longer lasting so that the asphalt surface also lasts longer.

Soil zone 41

Soil zone 41 is marine and fjord deposits, consisting of fine-grained, marine deposits and landslide masses from quick clay slides. Soils usually go very deep in this type of zone. This is according to SVV's literature sites that have materials that are frost dangerous and should therefore have a good substructure. According to map data from NGU these areas have not groundwater potential and an unsuitable infiltration capability. This means that the effect of draining this area is not as good as for soil zone 50. However, by draining the roads we will still be able to remove much of the water that damages the road, thus extending its lifetime. Meanwhile, the road is sensitive to frost, and as Figure 2:14 shows, this road will be susceptible to degradation especially in spring. For the roads in zone 41 it will therefore be most optimal to build road again from scratch. If it is possible to plan this in the context of upgrading sewage plants, then it will be most cost effective.

(See Figure 4:2, Figure 4:3 and Figure 4:4 in addition to Table 4:3, Table 4:4 and Table 4:5)

Soil zone 72

Soil zone 72 is weathered material that is like a patchy or thin cover over the bedrock. Deposits are formed on site at physical or chemical breakdown of the bedrock. The maps show that these are areas which are mainly located on slopes on the side of the valley that forms the center through the municipality. The map of the groundwater shows that there is no ground water potential in the area and that infiltration capacity is unsuitable. Because this soil may only is situated with a thin cover over the bedrock, it will be very expensive to build roads in this area with substructure, especially if the rocks has to be blasted away. We also know that rock will be a solid foundation, so in these areas it will likely be very cost effective to implement a good drainage, alternatively with a thin base course if the road will be dug up in another context. Lowering of groundwater level will not be applicable when there is no groundwater potential here.

(See Figure 4:2, Figure 4:3 and Figure 4:4 in addition to Table 4:3, Table 4:4 and Table 4:5)

Soil zone 120

Soil zone 120 are filling material (anthropogenic material) incorporated or heavily influenced by human activity. This is a type of soil which may consist of different qualities, and it is impossible to know what it is without making local surveys. There is work performed on water and sewer facilities along any of these roads that are located in this area during 2015-16 (Stadiongata, Såsengata, Midtveien and Skolegata), where soils consisted mostly of clay at the same level as in zone 41. It is also carried out work on the water and sewerage system elsewhere in the same zone (Skoleveien and A J Horgens vei), and here consist the soils of a type that was more like zone 50, ie more gravel and sand. NGU's map says that there is no groundwater potential in this zone, and the infiltration ability is not classified. This is therefore a soil zone where it is almost impossible to determine what it consist of, and it is therefore necessary to consider each individual road on site. This should then be done using samples of the soil, either by digging up or making a test drilling to bring up soil material. Actions in this area will therefore depend on the characteristics of the soil.

(See Figure 4:2, Figure 4:3 and Figure 4:4 in addition to Table 4:3, Table 4:4 and Table 4:5)

5.3 Conclusion

This study shows that the municipal road network in Nedre Eiker has a large maintenance backlog. There are many critical damages on the roads that should be repaired immediately.

There were four soil types who excelled in this study. The conclusions of each are as follows:

Soil zone 41: The zone contains frost hazardous materials, and the best action would be to build up the road again with a new substructure. The costs can be kept down if some work can be performed in combination with water and sewer upgrade. An effective drainage can extend the life of the asphalt surface, but will not eliminate problems with frost.

Soil zone 50: The zone contains a lot of sand and gravel, which suggests that a good drainage will be able to extend the road life. In addition, it will be effective to lower the groundwater level whenever possible.

Soil zone 72: The zone contains a thin incoherent layer weathering material. An efficient drainage system could extend its lifetime. Construction of a new thick substructure will probably have a poor benefit / cost. Alternatively, it could pay off with a thin supporting layer under the asphalt surface if the road will be dug up for other reasons.

Soil zone 120: This is a zone which may contain many different soil qualities. This area must be carried out geological surveys to determine the best actions. But drainage is an action that always will provide an improvement, so this will give (small) gains if there is no economy to greater improvements and sampling.

Based on the results of the state registration, data from the geological maps, road and traffic information and knowledge from the literature search, it is concluded that it is possible to find profitable and sustainable solutions for roads with many damage and short lifespan based on the soils and water features the ground has. This study used only Municipality of Nedre Eiker as case, and it was only 4 prominent soil conditions here. Anyway, the study shows that there are differences on how we should take action at the different locations. Therefore concludes this report finally that there are effective solutions to road maintenance even though the road is built on a poor foundation. An extended study can find good solutions for several types of soils and ground conditions than is presented in this report.

5.4 References

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