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The Effect of Pavement Texture on Need for Salt in Winter Maintenance of Bicycle Roads

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Report Title:	Date: 06.06.17			
The Effect of Pavement Texture on Need for Salt in Winter Maintenance of Bicycle Roads Effekten av vekkdekke på behovet for salt ved vinterdrift av sykkelveger	Number of pages (incl. appendices): 112			
	Master Thesis	X	Project Work	

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Abstract:

In Trondheim, Norway, an increase in winter maintenance standard of bicycle roads has caused some damages, and it has become clear that the bicycle roads have a large variation in quality and material along short stretches. This rose a question, which was how the pavement texture affects winter maintenance actions, such as salting. The aim of this study was to acquire data about how the need for salt is affected by difference in cross fall, type of asphalt and surface texture. Field studies have been carried out on a bicycle road, on three observation points with large difference in pavement texture. The method has been to measure water on road surface during days with different weather conditions, then calculating a theoretical need for salt using phase diagrams for freezing point depression of dissolved salt in water. The results were compared in a statistical analysis to see if there was a significant difference. The conclusion was that a new and raw asphalt needs twice as much salt as an old type of asphalt. Furthermore, it was concluded that an uneven cross fall will give variations in need of salt and need more salt than an even road surface with good drainage.

Keywords:

1. Winter maintenance - Vinterdrift
2. Salt - Salt
3. Bicycle - Sykkel
4. Road - Veg

Veronika L. Husa

Preface

This master's thesis is written for the Department of Civil and Environmental Engineering at the Norwegian University of Science and Technology (NTNU) and in cooperation with the Directorate of Public Roads in Trondheim. This thesis consists of two parts, a process report and a manuscript for a scientific paper.

The process report includes a more detailed description of the process, method and execution, while the scientific paper presents a shorter description of the method, discussions and the results. Writing the thesis in this way was recommended from both the Department at NTNU and my supervisor, Alex Klein-Paste. I have a bachelor's degree in civil engineering from Bergen University College, so fieldwork and report writing was familiar to me. Writing a scientific paper was, however, a new experience, and it was an extra motivation when I got the invitation to write and submit a full paper at the *XVth International Winter Road Congress*. I hope the results from this thesis, especially the scientific paper, can be used for further research.

Finally, I would like to thank my supervisor at NTNU, Alex Klein-Paste, for feedback, discussion and assistance in the selection of project. Furthermore, I would like to thank my co-supervisors Katja-Pauliina Rekilä and Johan Whalin at the Norwegian Public Roads Administration, for good input and assistance in planning and executing the experimental work of the master's thesis. I also want to thank Rolf Magne Brødreskift at Trondheim municipality operation center, for input and operating data.

Summary

There has been a greater focus on winter maintenance of pedestrian and bicycle roads to increase the number of pedestrians and bicyclist during the winter. One measure has been to increase the winter operating standard of walking and cycling roads to a bar road strategy. This leads to frequent mechanical removal of snow and the use of salt as a preventative method. Several bicycle roads in Trondheim, Norway, are not dimensioned for such a high-frequency of winter maintenance, and some damage has occurred. It became clear that bicycle roads have large differences in quality and material.

In practice, the same amount of salt is used along stretches with different types of asphalt, cross falls and surface texture, and bicycle roads can have large variations in pavement along short stretches. To understand how the need for salt may vary along a bicycle road, it is important to investigate whether different types of pavement texture can have an effect. The idea was that a road which dries up quickly is likely to have less water on it if the temperature drops. Therefore, such a road would require less salt than one which does not dry up as quickly.

In this study, field studies have been conducted on a bicycle road in Trondheim. The field studies have been conducted at three different observation points along the road where there were clear differences between both the asphalt type and the cross fall. The observation points were divided into three measuring points across the road, resulting in 9 measuring points. During the field studies, water amount and temperatures were measured over time, while weather conditions and winter operations were documented. The water measurements were then used in a data analysis to calculate a theoretical need for salt, using a phase diagrams for freezing point depression of dissolved salt in water. The results were then compared in a statistical analysis to see if there was a significant difference between the selected observation points on the bicycle road.

From the results of this study, the conclusion has been that a new and raw asphalt needs twice as much salt as an old type of asphalt. Furthermore, it was concluded that the cross fall would have an impact on the need for salt. It has not been investigated why the asphalt type affects the need for salt and how large the impact of the cross fall might be.

The results can be used to evaluate performed salting actions to see if the chosen spreading rate could have been lower, by using registered weather after the salting action and the calculated salt amount on a comparable field day from this study.

Sammendrag

Det har blitt et større fokus på vinterdrift av gang- og sykkelveger for å øke andelen gående og syklende om vinteren. Et tiltak har vært å øke vinterdriftsstandarden på gang- og sykkelveger til en bar veg strategi. Dette medfører hyppig mekanisk fjerning av snø og bruk av salt som en preventativ metode. Flere sykkelveger i Trondheim, Norge, er ikke dimensjonert for en slik høyfrekvent vinterdriftsstandard, og en del skader har oppstått. Det er kommet tydelig frem at sykkelveger har store forskjeller i kvalitet og materiale.

I praksis blir samme saltmengde brukt langs strekninger med forskjellig type asfalt, tverrfall og overflatetekstur, og sykkelveger kan ha store variasjoner i vegdekke langs korte strekninger. For å kunne forstå hvordan behovet for salt kan variere langs en sykkelveg, er det viktig å undersøke om forskjellig type vegdekker kan ha en effekt. Tanken var at en veg som tørker raskt, sannsynligvis vil ha mindre vann på den hvis temperaturen faller. Derfor ville en slik veg kreve mindre salt enn en som ikke tørker opp like fort.

I denne studien har feltundersøkelser blitt utført på en sykkelveg i Trondheim. Feltundersøkelsene har blitt gjennomført på tre forskjellige observasjonspunkter langs vegen hvor det var tydelige forskjeller mellom asfalttype og tverrfall. Observasjonspunktene ble delt inn i tre målepunkter på tvers av vegen, som ga tilsammen ni målepunkter. Ved feltundersøkelsene ble det målt vannmengde og temperaturer over tid, mens værforhold og utført vinterdrift ble registrert. Vannmålingene ble deretter brukt i en dataanalyse for å beregne et teoretisk behov for salt, ved bruk av et fasediagram for frysepunkt til oppløst salt i vann. Resultatene ble deretter sammenlignet i en statistisk analyse for å se om det var en signifikant forskjell mellom de valgte observasjonspunktene på sykkelvegen.

Fra resultatene in denne studien, har konklusjonen vært at en ny og rå asfalttype vil ha behov for dobbelt så mye salt enn en eldre asfalttype. Videre ble det konkludert med at tverrfallet vil ha en innvirkning på saltbehovet. Det er ikke undersøkt hvorfor asfalttypen påvirker behovet for salt, og hvor stor effekt tverrfallet har. Resultatene kan bli brukt til å evaluere utført salttiltak for å se om den brukte saltmengden kunne vært mindre. Dette kan gjøres ved å sjekke registret nedbør og temperatur etter salttiltaket, og sammenligne med en feltundersøkelse på lignende en dag fra denne studien og saltmengden som ble beregnet for den dagen.

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Abbreviations

NTP	National Transport Plan
NPRA	Norwegian Public Roads Administration
NaCl	Sodium Chloride
$MgCl_2$	Magnesium Chloride
VTI	Swedish National Road and Transportation Research Institute
rh_u	Average Structure Depth [mm]
d	Diameter [mm]
m	Mass [g] [g/m^2]
A	Area [m^2]
T_f	Freezing Point Temperature [C°]
c	Concentration
μ	Value for Need of Salt [g/m^2]
Σ	Sum
OP	Observation Point
MP	Measuring Point

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Part I:

Process Report

1. Introduction

1.1. Background

Winter maintenance of pedestrian and bicycle roads is important for the choice of bicycle as mode during the winter. In Norway, it is mentioned in the National Transport Plan (NTP, 2013-2023) that globalization, income growth and strong population growth demands that the transport sector, especially in urban areas, must be developed in a more environmentally friendly direction (Norwegian Directorate of Public Roads, 2012). To meet this challenge, it is further described in the NTP that the Government's cycle strategy aims at increasing the cycling share from today's 4% to 8% by the end of 2023.

For bicycling to be attractive, it is important that new and existing pedestrian and bicycle roads have good surface quality. The surface quality depends on, among other things, the experienced pavement friction and comfort of the bicyclist. Here, operation and maintenance are of great importance, especially during wintertime. The Government's bicycle strategy also mentions that one of the strategies to increase the amount of bicyclist is to improve the operation and maintenance of pedestrian and bicycle roads, including winter maintenance. In aspect of this strategy, a project was started in the winter of 2015/2016 in Trondheim, Norway, by the organization called Miljøpakken, where the goal is that 50km of bicycle roads in Trondheim should be free of snow and ice in the winter (Miljøpakken, 2017). The purpose for this project is to increase the amount of people choosing bicycle as a transportation mode during the winter. The project was continued in the winter of 2016/2017.

Trondheim's main bicycle road network was therefore upgraded to the winter maintenance standard *GsA*. For winter maintenance of a bicycle road, there are given requirements for friction control by the Norwegian Public Roads Administration (NPRA) in Manual R610 (NPRA, 2013). The methods for GsA are mainly based on the use of salt as a preventive measure to maintain and restore bare roads, and that mechanical removal of snow should be used before salting. To obtain this standard, a frequent winter maintenance is required. In Trondheim, the increased winter maintenance has caused some damage on the road surfaces, and it has become clear that the bicycle roads in Norway have not been dimensioned for such loads and frequency the new winter maintenance strategy gives. The bicycle roads have a large variation in material and quality, and the difference in pavement texture, such as damages, asphalt type, surface texture and cross fall, can be large along short stretches. It is desirable to maintain the increase of winter maintenance, and the Directorate of Public Roads in Trondheim has already started to document its effect on the road surface. In addition, there will eventually be a need for either re-asphalting or re-structuring of the damaged bicycle roads, which could lead to an even larger variation in pavement texture along the bicycle roads.

In practice, the same amount of salt is used along stretches with different pavement textures. To maintain a good surface quality during the winter, it is important to understand how the need for salt can vary along a bicycle road with different pavement texture. This is important not only to achieve, but also to maintain the bare road strategy and keeping the bicycle roads attractive to use during the winter. Furthermore, winter maintenance actions such as mechanical removal of snow and salting are time consuming and expensive and it is well known that salt is damaging to the environment (Åge Sivertsen et. al, 2012). In general, there is a lack of studies on how the pavement texture effects winter maintenance actions. With an understanding of how the pavement texture may affect these actions, there may be a possibility of increasing efficiency or a reduction of salt use. Good winter maintenance with low use of salt, can achieve rapid drying of surface water and little slush and snow on the road surface, thereby increasing the surface quality (Åge Sivertsen et. al, 2012).

1.2. Objective, Scope and Limitations

The objective of this study was to acquire data about how the pavement texture affects the need for salting on a bicycle road. Field studies were carried out on a bicycle road in Trondheim, Norway. To understand how the need for salt varies, the field studies were carried out on observation points with different type of asphalt and cross fall on the same bicycle road. The idea was that a road which dries up quickly is likely to have less water on it if the temperature drops. Therefore, such a road would require less salt than one which does not dry up as quickly.

This study concentrates on the need for salting of bicycle roads, and the amount of salt after winter maintenance actions were not measured due to practical issues and access to equipment. In addition, only the available weather conditions and performed winter maintenance actions during the study period were tested.

1.3. Report Outline

This report consists of a process report and a manuscript for a scientific paper. The aim has been for the scientific paper to stand alone, while the process report is a further description of the project with references to the paper. Finally, the appendices for the process reports are presented in part 3.

2. The Use of Salt in Winter Maintenance of Bicycle Roads

To understand how the pavement texture affect the need for salt on a bicycle road, one must to understand the practice for determination of the salt amount. This chapter is divided into two parts. The first part is a presentation of relevant theory about salting methods and how to determinate the amount of salt in these methods. The second part is a literature review of previous relevant research studies or projects.

2.1. Salting Methods for Snow and Ice Control

Salt can be used as a chemical method for snow and ice control, and there are three different action for how salt can be used in winter maintenance. The first one is called *anti-icing*, which prevent the water on road surface from freezing. Then *anti-compaction*, where salt is used to make mechanically removal of snow easier. Finally, salt can be used to melt ice, which is called *de-icing*. The different methods, and mechanisms behind them, are described in the following subsections.

The NPRA has a guideline for operators in winter maintenance, which explains the practice for determination of which salting action to perform and how much salt one should use (Gryteselv et al, 2013). The choice of which action to perform and salt amount is based on the properties of salt described in the three different actions, weather forecasts and experience.

2.1.1. Anti-icing

Anti-icing is an action where salt is used to prevent water on the road surface from freezing. Clean water will normally freeze at 0C°. With dissolved salt in the water, the freezing point can be lowered and thereby keep the water from freezing if the temperature is above the new freezing point. Furthermore, the freezing process can be retarded or it could give a reduction of mechanical strength in a future ice formation. In anti-icing, the amount of salt in an action is determined by the basics of freezing point depression (Gryteselv et al, 2013).

Freezing point depression

The thermodynamics and entropy of freezing point depression of a solution, such as a salt and water solution, is described in *Atkin's Physical Chemistry* (Mullin, 2010). The freezing point of water is reduced when foreign molecules are present, and is generally illustrated in a phase diagram.

It is often stated that water has a colligative property, which means that it does not depend on which other molecules are present, but rather how many molecules are dissolved in the water for reduction of freezing point. This has been found not to be true, and freezing point depression will depend on which chemical is dissolved in the water (Wåhlin et al., 2017). Therefore, one should use a phase diagram specific for the chemical used in the freezing point depression. Furthermore, if there is to be a reduction in freezing point, the salt must be dissolved. A solubility curve is often plotted in the same phase diagram as the freezing curve for the chemical, and it is important to know the difference between them.

In Figure 1, a phase diagram for sodium chloride (NaCl) is shown. The phase diagram shows the freezing point given at a concentration of salt dissolved in the water and salt solution. The line between point A and B is the freezing point curve, while the line between B, C and D is the solubility curve. Point B is called the eutectic point, and shows the maximum amount of salt, NaCl, that can be dissolved in the salt and water solution (Mullin, 2001).

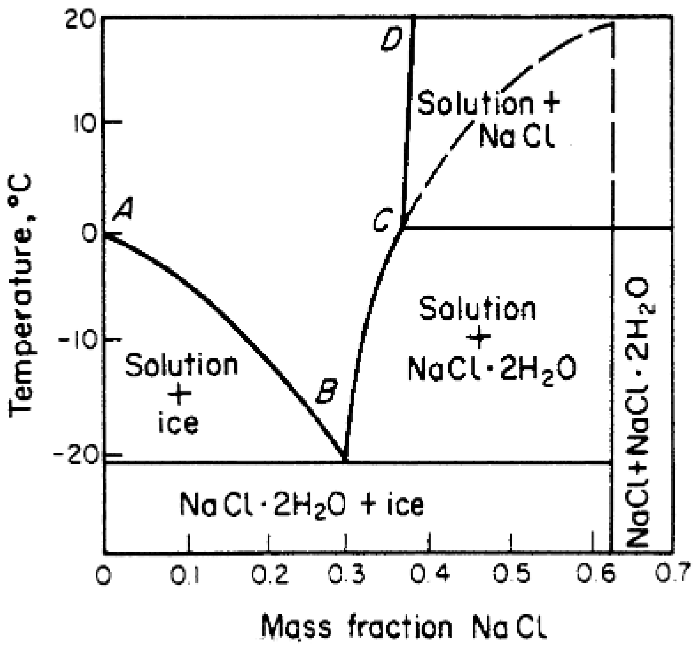

Figure 2.1: Phase Diagram for NaCl and Water Solution (Mullin, 2001)

Phase diagrams can be used to determine the need for salt when knowing how much water is present on the road surface and the expected temperature, by using the freezing curve to see how large the concentration of salt needs to be at a freezing point lower than the expected temperature. The concentration can then be calculated into a salt amount by using the given water amount on the road surface. The practice of the use of salt in anti-icing is based on weather forecast and expected temperatures and precipitation. The determination of water on the road surface is made through visual assessments, and then the salt amount is decided based on experience and given concentration of salt for a moist, wet or very wet road and the weather forecast, road design and traffic.

The guidelines state that one should use as little amount of salt as possible, and the salting action should be performed as close to weather events as possible (Gryteselv et al, 2013). Even though the guidelines are based on the use of a phase diagram, the determination of salt amount is not as accurate as a theoretical approach.

Retardation of the Freezing Process

The given freezing point of salt dissolved in water, from the phase diagram, only tells when the first water molecules are formed into ice crystals. As dissolved salt lowers the freezing point of water, there will be a retardation of the freezing process if the water has started to freeze. This is explained stepwise by Murakini (Murakini, 1997). When water in a salt and water solution starts to freeze, some of the water molecules will form ice crystals and the freezing point in the remaining liquid will be lowered due to higher salt concentration. As the freezing process continues, the salt concentration in the remaining liquid will continue to increase.

This process will continue until the remaining fluid is *saturated* with salt, which happens at the eutectic point. The freezing process of the solution will therefor extend from the freezing point to the eutectic point, thus retarding the process. The eutectic point, as mentioned above, is shown as point B in Figure 1.

Reduction of Mechanical Strength in Ice

In 2010, Klein-Paste and Wåhlin conducted a study on anti-icing, to investigate if the salt also controlled the mechanical properties of the ice formation when a water and salt solution had frozen(Klein-Paste and Wåhlin, 2011).

The conclusion was that salt would control the mechanical properties and it would be possible for traffic to break ice when anti-icing is used as a preventative action. When water with salt begins to freeze, water molecules will form ice crystals around the remaining liquid. If the salt concentration is kept above the eutectic point and the temperature is below the freezing point of the remaining liquid, there will be small pockets of liquid in the ice structure which weakens the ice.

2.1.2. Anti-compaction

Anti-compaction is another preventative action, where salt is used before and under snowfall to prevent snow from compacting into hard layers that are difficult to remove.

Snow is compacted through a process called *sintering*, which is described by Szaboa and Schneebelij (Szaboa and Schneebelij, 2007). When snow is compressed by a load or force, snow crystals are brought closer together and more crystals meet each other. As snow on roads is often close to the melting point, bonds will start to form between snow crystals. Such bonds are formed very quickly when water is present, for example in wet or moist snow (slush). Molecular bonds between the road surface and the snow can also be formed. Such bonds are called adhesion.

The practice around anti-compaction and the need for salt in the reduction of hardness of snow, does not have any clear guidelines. It is only stated in the guidelines that snow and slush must always be removed before salting, and frequent ploughing with good quality is a prerequisite for achieving good driving conditions and low salt consumption (Gryteselv et al, 2013).However, Wåhlin and Klein-Paste have tested the penetration hardness of snow with different salt solution content and it was found that relatively small amounts of salt is needed to reduce the strength of the compacted snow (Wåhlin and Klein-Paste, 2015). It was also found that salt solutions have a lower effect on compacting at low temperatures.

2.1.3. De-icing

De-icing is a reactive action, which means that it is used to restore the desired state of the road. The main principle behind this action is that salting is used to melt ice formed on the road surface. Soo Kim and Yethiraj have published a study on describing and understanding of the kinetic aspects of melting ice with salt (Kim and Yethiraj, 2008). Since salt is only used as a preventive action in winter maintenance of bicycle roads, this method is not described further (NPRA, 2013).

2.2. A Review of Existing Studies

There are a few studies of winter maintenance on bicycle roads. The focus of these studies has been on the practice and performance of winter maintenance on bicycle roads. For salting on roads, there were mainly found studies on car roads. The literature is divided into two parts, one for exiting studies on winter maintenance of bicycle roads and one for studies involving the investigation of salt amount on road surfaces.

Winter Maintenance of Bicycle Roads

In a Swedish study, attitudes to bicycling in the winter were analysed in general, and in relation to winter maintenance of bicycle roads in particular, (Bergström and Magnusson, 2003). The survey was conducted with responses from a thousand employees in four large companies situated in two Swedish cities. The result showed that there is a clear difference in the choice of transport mode between the winter and the summer. The number of car trips increased by 27 % from summer to winter, while the number of bicycle trips dropped by 47 %. The main reasons for the decrease in the number of bicycle trips during winter were slippery conditions and low temperatures. In a Norwegian survey conducted in Trondheim, bicyclists were asked what prevents them from using a bicycle in the winter. Bicycle roads where snow was not removed was the biggest obstacle (Terje Giæver and Lindland, 1998). It should be noted that in the Norwegian survey, many of the participants frequently used bicycles, where as in the Swedish study the responses was from employees of the companies with a larger variation in choice of mode.

Bergström has presented a visual method for assessing road conditions on bicycle roads based on a Swedish method normally used for car roads (Bergström, 2002). The method is divided into three parts, the first being a definition of four general road surface conditions; Bare surface, ice and snow, wheel tracks and spots (variation). The other two parts describe the road conditions in more detail, such as in the form of consistency. It is emphasized that a picture that illustrates the road relationship should always be added to the visual assessment.

A non-traditional method of winter maintenance of bicycle roads, using a *power broom* for snow removal and salt for de-icing was tested by Bergström (Bergström, 2002). The result of this experiment was that the method would provide a better service level, but the cost is two to three times higher than for more traditional methods. An investigation was conducted to see if the bicyclist noticed a difference in the state of the bicycle road with this method, and they did. Nevertheless, it was not possible to conclude that the amount of bicyclist in winter would be higher by using this method.

In 2012-2013, Karhula conducted interviews and surveys in four Nordic cities; Copenhagen in Denmark, Linköping and Umeå in Sweden and Oulu in Finland, to find best practices for winter maintenance of bicycle roads (Karhula, 2014). The results of this project are summarized as principles for winter maintenance:

- *Keep your promise.*
- *"Do not try to do everything at once. Select a prioritised route of a suitable length for high-quality maintenance trough out the year."*
- *"Monitor the level of maintenance throughout the winter and maintain ongoing dialogue with the contractors."*
- *"It is easier to develop maintenance when you know the situation on the streets."*
- *"Take maintenance requirements into account when planning the routes. Significant savings can be achieved by planning the places for snow storage, for example."*
- *"Select the most appropriate maintenance methods for the weather conditions in the city."*

In 2014 Riersen completed a master's thesis, where one of the issues investigated was that current winter performance does not result in the given winter maintenance standard in Trondheim, Norway, and therefore prevents more people from using the bike in the winter (Riersen, 2014). The hypothesis was not rejected, but rather strengthened. The result was based on evaluation of the standard performed on bicycle routes in Trondheim, inspections and review of surveys, personal assessment by Riersen and remarks from the users of the bicycle routes.

Salt Amount on Road Surfaces

Lysbakken has defined mechanisms that can describe the loss of salt after application (Lysbakken, 2008). These mechanisms were found by field observations of salt amount on the road surface after salt action was performed. The mechanisms were defined as *blow-off*, *spray-off*, and *run-off*. They are influenced by several parameters, which can be grouped as traffic parameters, weather parameters and road characteristics. One of the results from the field observations showed that the amount of water on the road surface directly controlled the development of salt amount on the road surface. In addition, it is defined that the mechanism behind the amount of salt that dissolves depends on the amount of water on the road surface. More salt will be dissolved on a wet road surface, than on a dry one.

The field observations performed by Lysbakken were a part of a larger project, and in another part the loss of salt after application is divided into three parts; initial loss, the dissolution of salt and loss of salt after application. Where loss of salt after application can be divided into the three previously mentioned mechanisms (Lysbakken, 2010).

Blomquist and Gustafsson conducted field tests for the measurement of salt on the road (Blomquist and Gustafsson, 2012). It is emphasized that loss of salt has been shown to be extremely dependent on how wet the road surface is. To define future salt amount, it is therefore important to have accurate measurements for both salt and water amount on the road surface. Two methods of salt measurements were tested; SOBO 20 and WDS (wet dust sampler), while a highly absorbent textile called Wettex were used for water measurements. The results were that WDS is better in measuring dry solids, while salt solutions that have dried on the road surface can be measured by both WDS and SOBO.

Hunt, Mitchell and Ricchardson have presented a study where the goal was to develop a forecast model for salt amount after application of salt solution, as a function of time, traffic and type of road surface (Christopher L. Hunt, 2004). The study concluded that this was mainly dependent on traffic. Furthermore, the study also shows that the type of road surface has a significant effect on the decrease of salt over time.

The Swedish National Road and Transportation Research Institute (VTI), has performed research on performance in salting of bicycle roads in the winter periods 2013-2014 (Blomquist and Niska, 2016) and 2014-2015 (Blomquist and Niska, 2016). The performance of removal of snow with a swab roll and salting with saline or pre-wetted salt, was investigated in this study. One of the methods used to investigate the performance, was measuring residual salt on different bicycle roads. It is mentioned that the most important process that effects the amount of residual salt is drainage of road surface water. All the road surface liquid will not drain from the surface and how much that remains on the surface when the drainage stops, depends on the surface's slope and texture (roughness).

Finally, Klein-Paste and Wåhlin has performed a study on anti-icing and determination of salt amount (Klein-Paste and Wåhlin, 2013). In this study, a theoretically minimum chemical concentration necessary to ensure sufficient tire-pavement friction were calculated and showed that 60 % less salt is needed compared to the concentration predicted by the freezing point depression theory.

3. Methodology

The methodology is divided in three parts. First, the method and procedure for conducting a literature study on relevant theory and exciting study are presented. Secondly, a description of the methods used during field work. Finally, the procedure for the data analysis of the results after field work is described.

3.1. Literature Study

The literature study has been a research study mapping former relevant experiments, theory and literature about winter maintenance of bicycle roads, where actions such as the use of salt and mechanical removal of snow was considered as the main topics. Therefore, the research was limited to cold regions, where winter maintenance is applicable. The search tool used was mainly the online search engine *Oria*, which allows search and access in the University Library and Norwegian Academic Libraries. In addition, *Google Scholar* was used as a secondary tool and some literature was provided by the supervisors for this thesis. Only literature in Scandinavian languages and English was used in this study.

It was easy to find research papers and articles on winter maintenance of car roads, while literature on winter maintenance of bicycle roads was limited. The standards for winter maintenance of bicycle and pedestrian roads are mostly based on experience from car roads, and due to efficiency, it is common for a bicycle road to have the same winter maintenance standard as the car road nearby. However, some literature on car roads was relevant to understanding how mechanical removal and salting actions work, when they are normally used and how the salt amount is determined.

Since the purpose of this study was to acquire knowledge about how the pavement texture affect the need for salting in winter maintenance of a bicycle road, it was also desired to find literature including research on performance of winter maintenance on different surface conditions. The relevant literature found in this study, is described in Chapter 2.

3.2. Field Work

To investigate the whether the pavement texture affect the need for salt, field studies were carried out on a bicycle route near Osloveien in Trondheim, Norway, called *Tyholtruta*. The overall method was to conduct field studies where water on the road surface was measured during different weather and winter maintenance situations, on observation points with different asphalt conditions. The data collection during the field studies consisted of:

- Weather parameters
  - Air temperature
  - Dew point temperature
  - Road surface temperature
  - Precipitation
- Winter maintenance data
  - Type of action
  - Time of action
  - Salt spreading rate
- Water on road surface

Since the guidelines for salt amount in anti-compaction are not clear, the approach of salt determination in anti-icing was decided to use to get a theoretical need for salt for the bicycle road. As mentioned in chapter 2, the amount of salt necessary in anti-icing can be determined by using the water amount on road surface, a phase diagram for the given chemical and freezing point depression. Therefore, the water amount was measured to get the raw data for the calculation of the need for salt, while the other data were chosen to describe the situation during the field studies. In addition, measurements of cross profiles, length profiles and surface texture were conducted to get a description of the pavement texture. How the water measurements were conducted and the procedure for collection of data is described in Part II, Chapter 3.

The observations were conducted regularly from January to April 2017. Figure 3.1 shows the location of the observation site, with yellow marking. The data collection and measurements from the field work are presented in appendices 2, 3 and 4.

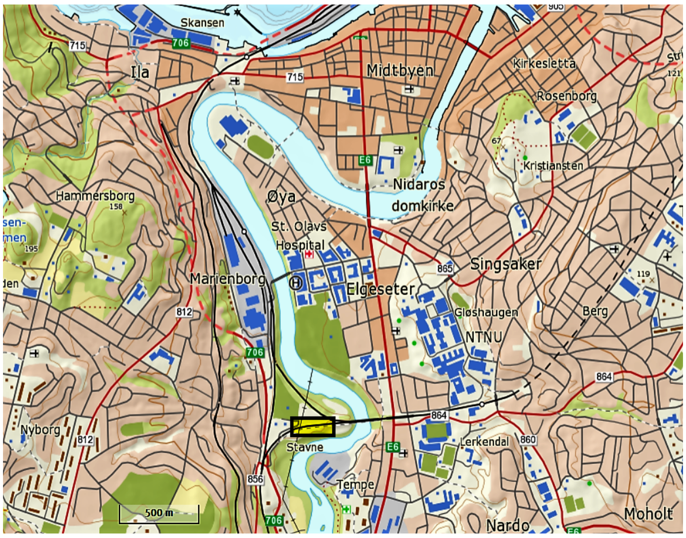

Figure 3.1: Observation Site in Trondheim (The Norwegian Mapping Authority, *Norgeskart*)

3.2.1. The Observation Site

The bicycle route at the observation site, has a maintenance standard given by the NPRA and it requires a bare road strategy (NPRA, 2013). This means that the road on the bicycle route shall be free of snow and ice, except during snowfall. After snowfall, the road shall be free of snow and ice within two hours. For this winter maintenance strategy, the method for friction control is using salt as a preventative action, and to regain and obtain a bare road. Furthermore, it is required that mechanical removal of snow shall be used before the use of salt to achieve a bare road. On this route, salt is spread mostly as dry NaCl with 30% magnesium chloride ($MgCl_2$) solution, except during snowfall when only NaCl is used. The bicycle route at the observation site is a typical pedestrian and bicycle road, with no traffic roads nearby.

The measurements had to be taken at points with different pavement texture, to get results that could be used to compare the effect of pavement texture. Three observation points were chosen based on their road profile and asphalt condition, and they are shown figure 3. The observation points were given numbers from one to three, which was marked on the road with yellow paint as shown in the picture. Observation point 1 and 2 have a new and raw type of asphalt, while observation point 3 has an old type of asphalt.

Figure 3.2: Pictures of Observation Points

It was decided to divide the observation points in to nine points, three point for each observation point, to get more measurements and better description of the pavement texture. The location of the measuring points at the observation points is illustrated in 3.3, where the given numbers consist with the number for the observation points. Further in the thesis the marked points will be referred to as measuring points, while an observation point is referred to the area around the measuring points.

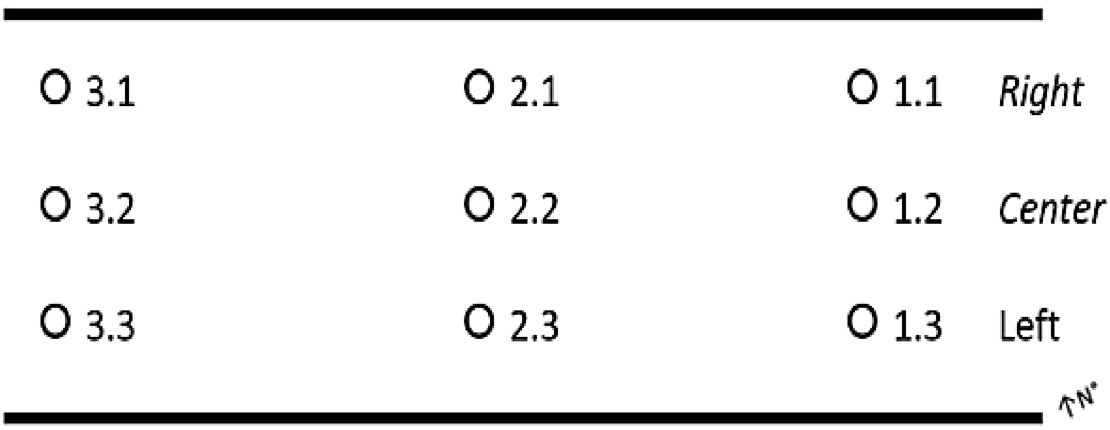

Figure 3.3: Illustration of Measuring Points at The Observation Site

It was necessary to have a good description of the pavement texture at the observation points, to get a explanation for possible differences in results. In chapter 2, the research performed by VTI mentioned that the surface slope and roughness had the biggest effect on the road surface water (Blomquist and Niska, 2016). Therefore, it was decided to measure road profiles and surface roughness at each observation point.

A profilometer was used to measure the road profiles at the observation points. To illustrate the road profiles, pictures of the measurements were used to calculate the difference in height along the surface. The measurement were calculated as a variation in centimetres from the lowest point on each cross-section and illustrated in a graph. The road profile was measured across each observation point, and along the road at the measuring points. This gave one cross profile and three length profiles for each observation point. The results from this can be found in appendix 2 and figure 3.4 shows the profilometer used in this study.

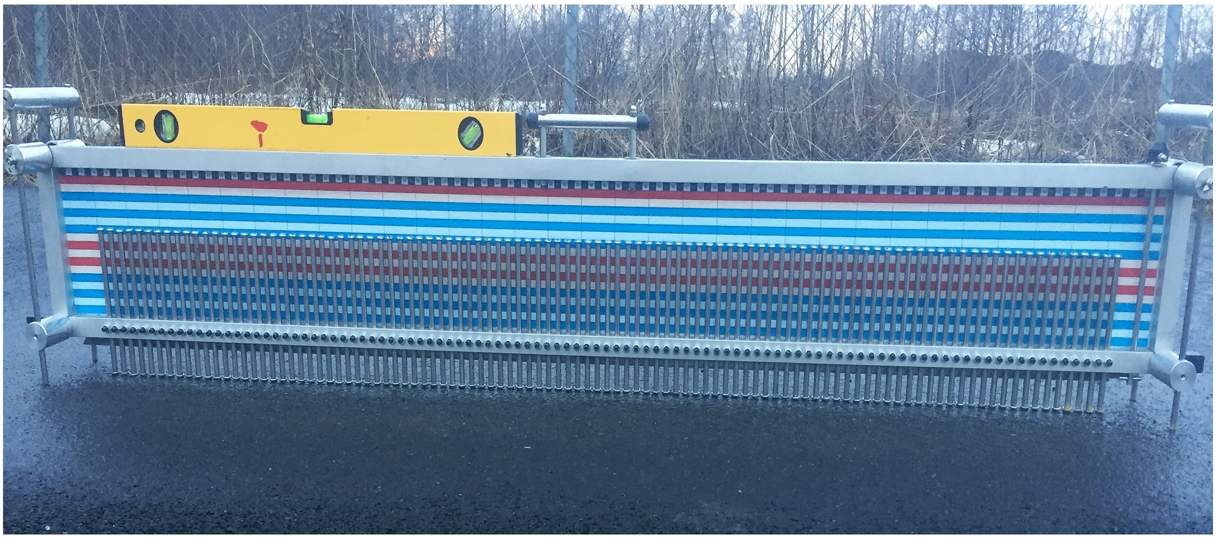

Figure 3.4: The Profilometer and Leveler Used to Measuring Road Profiles

To describe the asphalt texture on the observation site, illustrations in form of close-up pictures are presented in Part II, Section 3.1. For further description, the method called *Sand Patch* was used to determine the road surface roughness, where a given amount of single-graded sand is used to determine an average structure depth of the surface texture. This method and its procedure is described further in Part II, Section 3.1, and was conducted according to Manual R211 by the NPRA (NPRA, 1997). The procedure and equipment used is illustrated in figure 3.5.

Figure 3.5: Procedure for Sandpatch

The roughness was measured at approximately the measuring points for each observation point. With this approach, three measurements at each observation point along it's cross section were performed. The calculation and the results for the road surface roughness are presented in Appendix 4.

To summarize, table 3.1 shows a description of surface and asphalt conditions at the observation points.

Surface and asphalt conditions			
Observation point	**Cross fall**	**Type of asphalt**	**Average texture depth**
1	Uneven, with different slopes	New and raw, with some cracks	0,8 mm
2	Even, with gentle slope	New and raw, with some cracks	0,7 mm
3	Even, with steep slope	Old and with few cracks	0,8 mm

Table 3.1: Description of Surface and Asphalt Conditions

3.2.2. Procedure for Field Studies

Before a field day, the weather forecast made by the nearest weather station at Voll, Trondheim, was checked. The weather forecast was used to see when precipitation was expected to start or stop. It was desirable that the field studies should start right after precipitation had stopped. The data that was collected on a field day was water measurements over time (hours), and this was supplied with descriptive data.

After precipitation, the measurements of water started. The amount of water was measured at the measuring points marked in figure 3.3. The measurements at an observation point were taken approximately at the same time, while measurements on every measuring point was conducted within approximately 15-20 minutes. During the water measurements, the road and air temperatures was measured for each observation point. Thereby, nine measurements of water were conducted, and three air and road temperatures were measured. This procedure was then repeated after minimum one hour. However, if winter maintenance was conducted or precipitation started during a field study, the water measurements were stopped and started again after the action or the precipitation had stopped.

After a field day, the registered precipitation, temperatures and humidity made by the weather station was collected to get an even further description of the situation during the measurements. The collection of winter maintenance data, if this was relevant, was collected during or after a field day and is explained further in Part II, Section 1.2.

3.3. Data Analysis

The aim for the data analysis was to see if there was a difference in need for salt between observation and measuring points, and to see if the difference was significant. To analyse the results from the field work, Excel was used as a documentation and calculation tool. The given and measured data from each field day was presented in an Excel sheet with description of weather conditions, winter maintenance actions and illustrated with graphs to show the measured data over time (in hours). The measured water amount was then calculated to an average value for the observation point using the measured value for the three measuring points along the cross profile. To illustrate water amount for the different observation points on a field day, the data analysing program *MiniTab* was used. The calculated average water amount was plotted against what time of day it was measured. This resulted in a diagram for each field day. This diagram is presented in Part II, Chapter 4.

A theoretical need for salt was calculated using the data from the water measurements in the same Excel sheets as for the field work data, using the approach for anti-icing and freezing point depression. The calculation is described in Part II, section 3.4. It was decided to calculate the need for salt to prevent freezing of the measured water amount at temperatures -1 C°, -2,5 C° and -5 C°. With this procedure, the needed amount of salt in g/m^2 were calculated for each water measurement. To obtain a more realistic value for salt amount, the calculated amount was adjusted according to the research on anti-icing conducted by Klein-Paste and Wåhlin (2013). As explained in Chapter 2, only 40 % of the salt amount calculated from freezing point depression is necessary to get a satisfied pavement friction. Therefore, every calculated salt amount was reduced by 60%.

The calculated salt amounts are presented in Appendix 3 for each observation day. Only the calculated salt amount from -5 C° was used in further calculations. Before proceeding with the calculations, abnormal values such as measurements under precipitation or winter maintenance action were neglected. It was found that these values were not representative and some values resulted in abnormally high amounts of salt. The data used in this calculation and the results are presented in the appendix 3, and the neglected abnormal values are marked in red in further calculations in the appendices.

A statistical analysis was conducted using MiniTab, where a two-sample two-tailed t-test was conducted to see if there was a significant difference between the calculated salt amounts. By using a two-sample t-test one can compare to samples of data to see if the difference between them are significant. The chosen level of significance was 95%, and a two-tailed t-test will give a significant result if there is a 95% chance that the difference will be different from zero. From the calculation of salt amounts, it was possible to get a data set for each measuring and observation point and use this in the t-test. The difference calculated in MiniTab would then be between salt amounts calculated from water measurements taken at approximately the same time. The difference between measurement points aligned between observation points, measuring points across observation points and the average values for the observation points were analysed.

A two-sample one-tailed t-test was used to determine which of the observation points had a higher salt amount. With a one-tailed t-test, the difference must be significantly higher than zero. This test was only performed on the results which showed a significant difference in the two-tailed t-test. The input data and the calculation results from MiniTab are presented in Appendix 5, with a histogram to test the assumption of normality in the data of the difference between the observation points. How to conduct a T-test manually and in MiniTab is described in *Applied statistics for traffic engineers* (Blakstad, 1995). The results from the statistical analysis showed which observation and measuring points had a significantly higher need for salt. To illustrate the difference even further, it was decided to calculate an average percentage in difference between each observation point.

The percentage was found by calculating the difference between the average values for two observation points, and then divide the value for difference on the value for the observation point that was shown to be significantly lower than the other. With this, the results gave an average percentage of how much more need for salt one observation point had compared to another. To illustrate the difference between measuring points, it was chosen to calculate an average value for the salt amounts and then chose the lowest value as a base point. The value for the other points were divided by the chosen base point, resulting in relative values of difference. The relative values were then plotted against its location across the road in a diagram. With this, one could see which of the measuring points had a higher or lower average need for salt.

4. Results

In this study, several measurements were performed over time on days with different weather conditions. Five successful full field days are used in the calculations of the results, and they are presented in Part II, Chapter 4, and discussed in Chapter 5. The presented results are after the data analysis, and all the raw data from the field work, results from MiniTab, calculations of average percentages and average values for measuring points are to be found in appendix 3, 5 and 6.

5. Progress Description

The starting point for this thesis, was a project that led to an increase in winter maintenance standard in 2015 for the main bicycle roads, in Trondheim center (Miljøpakken, 2017). From this project, it had become clear that the bicycle roads i Trondheim have a large variation in pavement texture over relatively short distances. The objective and theme for this thesis was developed over time, and in collaboration with the internal and external supervisors from NPRA, Alex Klein-Paste, Katja-Pauliina Rekila and Johan Wåhlin, the final research idea was determined in January 2017.

This chapter describes the process of the project and where the supervisors has taken part in the project. The review of literature and theory, was conducted by the master student with some recommendation from the supervisors. The execution of field work and data analysing was done by the master student, while the supervisors took part in the planning of how to conduct the field studies and data processing. The development of the scientific paper was done by the master student and with comments and feedback from Johan Wåhlin, where the illustration of the results, discussion and conclusions was the focus.

5.1. Study Plan

The first objective for the thesis was to acquire knowledge about how the need for salt would be affected by the road surface conditions on bicycle roads. Further, it was to document variation in performance of the winter maintenance standard GsA, in aspect of different pavement textures. However, the objective changed during the field work. The documentation of winter maintenance was difficult to perform, due to a mild winter with little snow. Therefore, the investigation of snow removal was removed and the thesis was then limited to a focus on water measurements and need for salt.

Discussions and meetings with the supervisors of the thesis was conducted regularly. In the beginning, most of the discussions were with the internal supervisor at NTNU, Alex Klein-Paste. Further along in the thesis, the discussions and meetings included the supervisors from NPRA, Katja-Pauliina Rekila and Johan Wåhlin. These meetings and discussions were related to determination of research idea, conduction of field work and some methods for data analysing. These discussions helped the student with both practical work and inspiration for new ideas.

5.2. Execution and Planning of Field Work

The field work started in January 2017, when the observation points at the observation site was chosen. The supervisors from NPRA were included in the decision and the conduction of measuring the road profiles. First, it was decided to use only two observation points, but as the thesis research question was further developed, an additional observation point was included to get a larger variation of pavement texture in the collection of data. At the same time, it was decided to divide the observation points into three points across the road.

After the measurements of the road profiles, the field studies with water measurements started at the end of January. The methods that was used in the field studies was decided before the project started with discussion with the supervisors. The field studies were carried out by the student regularly from January to the end of April 2017. Several field studies were conducted on days with different weather conditions. The decision of which days were suitable for field observations was made by using weather forecast. The weather forecasts were not always accurate, leading to some unsuccessful field days. Therefore, some of the field work was not included further in the thesis.

After the field observations, it was decided with the supervisors at NPRA that a further description of the asphalt texture for the observation points was necessary. With help from colleagues at NPRA with experience in this field, it was decided to use the Sand Patch method to measure surface texture. This was conducted by the student in May 2017, and Trondheim municipality operation center assisted with washing of the road with operating vehicles before the measurements.

5.3. Processing Data and Conclusions

To process the data, it was decided in cooperation with the supervisors from the NPRA to conduct a statistical analysis. The statistical analysis of the results were conducted in a data analysis program *MiniTab 17*. The program was found by the student in literature from the course TBA4320 - Traffic Safety and Risk Evaluation at NTNU. The program was very user-friendly and easy to learn. Excel was chosen by the student to document and illustrate both field work data and results. The illustration of results and conclusion were discussed with the supervisor, Johan Wåhlin. Remarks from and dialogues with other workers at NPRA were also taken into account.

5.4. Learnings

The main learnings from this thesis was the planning and conduction of field work, and analysing field work data. I have never conducted any field work in this scale before. During the analysing of the data, I learned that not all data collection is relevant and how important the documentation of data collection is, both to describe the conditions for data collection and to make conclusions. Further, I have learned a lot about the practice of salting and winter maintenance of bicycle roads. In addition, I have learned to take changes into account during a project process. Even though I had a detailed plan for field work and processing results, I experienced that some plans must be adjusted along the way.

6. Remarks and Further Work

The objective in this study was to investigate how different pavement textures affect the needed amount of salt in winter maintenance of bicycle roads. The water measurements were obtained at three observation points with different asphalt and cross fall. Based on the results and discussion presented in Part II, the main findings were:

- A new and raw asphalt needs twice as much salt as an old type of asphalt. It is not clear why the asphalt type affect the need for salt.
- The cross fall on a bicycle road can have an impact on the difference in need for salt. It is not clear how large the impact of the cross fall might be.

No conclusions about how the roughness of the texture may affect the need for salt were made, since the roughness measurements showed that the observation points had approximately the same surface roughness. Furthermore, there were not made a conclusion on which type of asphalt is *better* according to salting actions, only that one needs less salt than the other. The results in this study can be used to evaluate performed salting actions, to see if the spreading rate could be less, by using registered weather after a salting action has been performed and salt amounts calculated on a comparable field day from this study. Additionally, the results and conclusions could be used in further evaluation of salting on bicycle roads.

To get a better evaluation and to understand more about connection between winter maintenance performance and pavement texture, more studies should be conducted. The same study should be conducted again in a winter with more snow and colder temperatures. For a better assessment, it should also have longer field observations with a larger amount of measurements to see if the same conclusions apply when more data are collected. In addition, it was desirable to investigate the variance in performance of mechanical removal of snow in this study. This can be done in a new study at the same time as the water or snow amount is measured, if the weather is suitable.

More studies in this field, can result in a better understanding of how the winter maintenance performance, such as need for salt and mechanical removal of snow, may vary between bicycle roads. This could lead to in a better practice of winter maintenance on bicycle roads, which could result in more attractive bicycle roads in the winter. Finally, observation points with different road surface texture should be chosen in a new study to understand how it may affect the need for salt. One should also get a better description of the road surface texture and type of asphalt.

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Part II:

Manuscript for a Scientific Paper

THE EFFECT OF PAVEMENT TEXTURE ON NEED FOR SALT IN WINTER MAINTENANCE OF BICYCLE ROADS

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ABSTRACT

In Trondheim, Norway, an increase in winter maintenance standard of bicycle roads has caused some damages, and it has become clear that the bicycle roads have a large variation in quality and material along short stretches. This rose a question, which was how the pavement texture affects winter maintenance actions, such as salting. The aim of this study was to acquire data about how the need for salt is affected by difference in cross fall, type of asphalt and surface texture. Field studies have been carried out on a bicycle road, on three observation points with large difference in pavement texture. The method has been to measure water on road surface during days with different weather conditions, then calculating a theoretical need for salt using phase diagrams for freezing point depression of dissolved salt in water. The results were compared in a statistical analysis to see if there was a significant difference. The conclusion was that a new and raw asphalt needs twice as much salt as an old type of asphalt. Furthermore, it was concluded that an uneven cross fall will give variations in need of salt and need more salt than an even road surface with good drainage.

Research highlights: Field studies were carried out on a bicycle road in Trondheim, Norway. Observation points with different cross fall and type of asphalt was chosen. The amount of surface water was measured. A difference in need for salt was calculated, using the theory of freezing point depression of a water and salt solution.

Keywords: Winter; Maintenance; Salt; Bicycle; Road.

1. INTRODUCTION

Winter maintenance of bicycle roads is important for bicycling to be attractive during the winter. In Trondheim, Norway, the main bicycle road network has been upgraded in winter maintenance standard to a bare road strategy, to increase the amount of bicyclist during the winter [1]. The methods for this strategy are use of salt as a preventive measure to maintain and restore bare roads, and that mechanical removal of snow should be used before salting [2].

The bicycle roads in Trondheim, Norway, have a large variation in quality and use of material along short stretches. In practice, the same amount of salt is used along stretches with different pavement texture in form of types of asphalt, cross fall and surface texture. With an understanding of the pavement texture's effect, there may be a possibility of increasing efficiency or reduction in salt use. Reduction in use of salt is both beneficial for the environment and the economic costs. The Norwegian Public Roads Administration [3] states, in their final report for the project called *Salt SMART*, that a low use of salt will enable avoidance of environmental damage along large parts of the road network. In addition, it is mentioned that good winter maintenance with a low use of salt will achieve rapid drying and little slush and snow on the roadway.

There are a few studies on winter maintenance on bicycle roads, but literature on the use of salt and the effect of pavement texture is limited. Lysbakken [4] has defined mechanisms describing the loss of salt after application. Blomquist and Gustafsson [5] conducted field tests for the measurement of salt on the road. The Swedish National Road and Transportation Research Institute (VTI), has published research on performance of salting of bicycle roads in the winter periods 2013-2014 and 2014-2015 [6]. The studies show that the amount of water on the road surface directly controlled the development and dissolution of salt amount on the road surface, and that this is affected by the road surface slope and texture (roughness). However, these studies did not consider the effect of the pavement texture.

The objective of this study was to acquire data on how the need for salt on a bicycle road was affected by difference in cross fall and type of asphalt, by measuring water on the road surface. The idea was that a road which dries up quickly is likely to have less water on it if the temperature drops. Therefore, such a road would require less salt than one which does not dry up as quickly. The amount of salt after winter maintenance actions were not measured, and only the available weather conditions and performed winter maintenance actions during the study period were tested.

2. THE USE OF SALT IN WINTER MAINTENANCE OF BICYCLE ROADS

The use of salt is a chemical method for snow and ice control, and can be divided into three actions: *anti-icing*, *anti-compaction* and *de-icing*. De-icing is a reactive action, which means that it is used to restore the desired state of the road. Since salt is only used as a preventive action in winter maintenance of bicycle roads, this method is not described further [2]. Anti-compaction is a preventative action where salt is used to prevent snow from compacting into hard layers, thereby making mechanical removal of snow easier. Determination of need for salt in anti-compaction actions does not have any clear guidelines. Therefore, the focus in this study has been the need for salt in anti-icing.

Anti-icing is an action where salt is used to prevent water on the road surface from freezing. Clean water will normally freeze at 0 C°. If there is dissolved salt in the water, the freezing point can be lowered or the freezing process can be retarded. The theory of thermodynamics and entropy that reduces the freezing point of a solution, such as a salt and water solution, is described in *Atkin's Physical Chemistry* [7]. The freezing point of water is reduced when foreign molecules are present. Unlike what is often stated, the freezing point depression of water is not collegitive [8], and a phase diagram for a given solution is required to know the freezing point.

A phase diagram is generally used to explain the mechanism for *freezing point depression*, which is different freezing points for a water and salt solution plotted against its corresponding salt concentration. The phase diagram for a water and NaCl solution is shown in figure 1. The line between point A and B is the freezing point curve, while the line between B, C and D is the solubility curve. Point B is called the eutectic point, and shows the maximum amount of salt, NaCl, that can be dissolved in the salt and water solution [9].

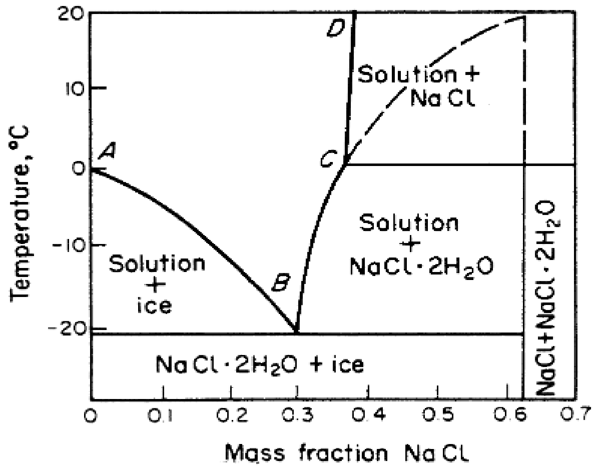

Figure 1: Phase Diagram for NaCl and Water Solution [9]

Phase diagrams can be used to determine the need for salt when knowing how much water is present on the road surface and the expected temperature, by using the freezing curve to see how large the concentration of salt needs to be at a freezing point lower than the expected temperature. The concentration can then be calculated into a salt amount by using the given water amount on the road surface.

3. FIELD STUDIES

Field studies were carried out on a bicycle route near Osloveien in Trondheim, Norway, called *Tyholtruta*. The overall method for the field studies was to measure water on the road surface with different weather and winter maintenance conditions on observation points with different asphalt conditions and to collect data about the pavement texture. The data collection during water measurements consisted of:

- Weather parameters:
  - Air temperature
  - road temperature
  - precipitations
- Winter maintenance data:
  - Type and time of action
  - Application rate
- Water amount on road surface

The measurements were performed over time on days with different weather conditions. The procedure was to use the weather forecast for an indication of predicted weather and plan the field days, where it was desirable to get measurements on days with rain or snow at different temperatures. On a field day, the measurements were intended to start right after the precipitation had stopped or after a winter maintenance action were performed. The measurements of water amount and temperatures, were taken each hour in approximately 4-6 hours at the left side, the center and the right side of the road at three observation points.

1.1. The Observation Site

The bicycle route at the observation site, has a maintenance standard given by the Norwegian Public Roads Administration (NPRA) and it requires a bare road strategy [2]. This means that the road on the bicycle route shall be free of snow and ice, except during snowfall. After snowfall, the road shall be free of snow and ice within 2 hours. On this route salt is spread mostly as dry sodium chloride (NaCl) with 30% magnesium chloride ($MgCl_2$) solution, except during snowfall when only NaCl is used. The observation site is a typical pedestrian and bicycle road, with no traffic roads nearby. Three observation points were chosen, based on their road profile and asphalt condition, with an interval of approximately 30m. Observation point 1 is located east of observation point 2, while observation point 3 is west of observation point 2. The observation points were divided into three measuring points across the road, resulting in nine measuring points. The measuring points were located at the left side, the center and the right side of the road at the observation points.

To illustrate the type of asphalt at the observation points, close-up pictures are shown in figure 2. Observation point 1 and 2 has a relatively new and raw asphalt, while observation 3 has an old type of asphalt.

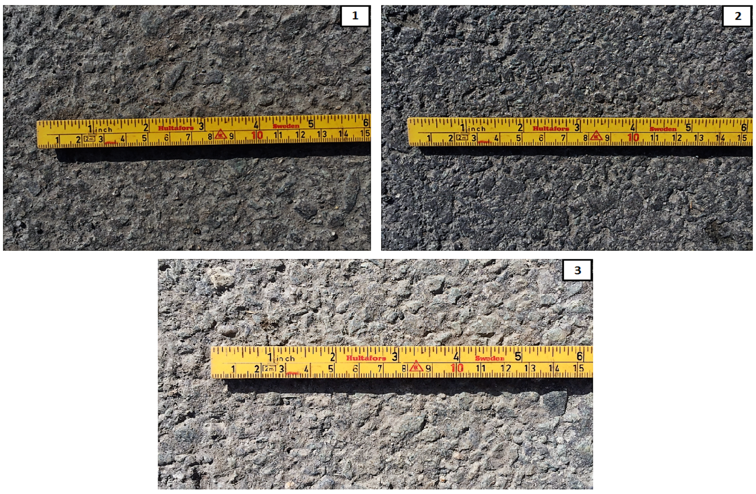

Figure 2: Asphalt Texture at Observation Points

A profilometer was used to measure a surface's profile. The profilometer was placed on the road and adjusted with the leveller, and the height from the road to the top of the profilometer was measured. The cross profiles were measured across each observation point, and the length profiles were measured at each observation point. The length profiles were found to be approximately even with no slope at observation point 2 and 3, while observation point 1 had a slack slope. The cross profiles are illustrated in figure 3. In the figure, the location of the measuring points is marked with red and numbers that consist with the corresponding observation point.

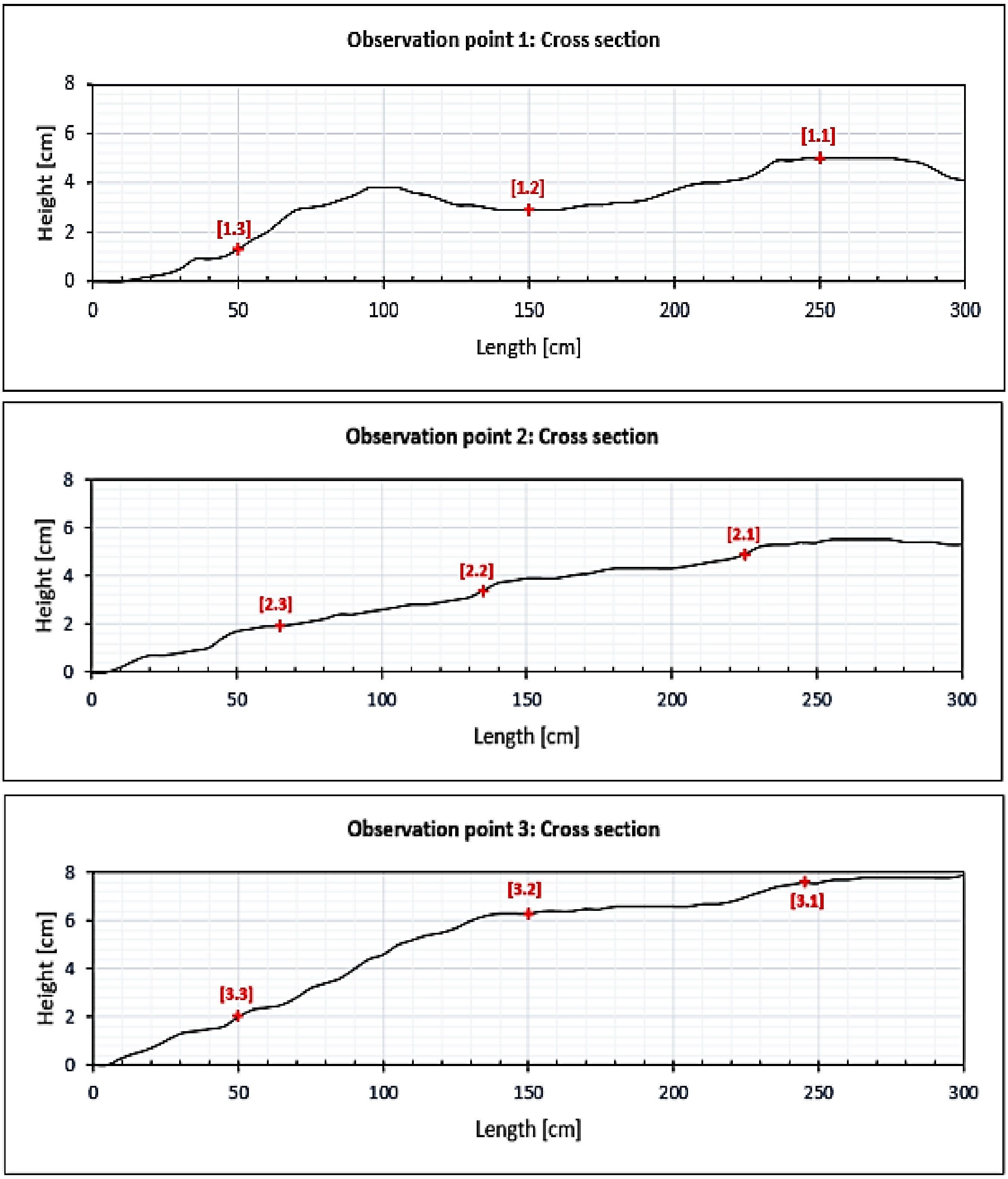

Figure 3: Road Cross Profiles of The Observation Points

The method called *Sand Patch* was used to determine the surface roughness. This method and procedure is described in Manual R211 by the NPRA [10]. In this method, distribution of a fine single-graded amount of sand on the road surface is used to determine the average structure depth (roughness). Before measuring, the measuring point must be brushed clean. The sand is then poured on the road surface so that the sand forms a cone. The transparent plate is placed on the center of the cone top. With gentle rotational movement of the plate, the sand is distributed over the road surface into a circle. The movements are continued until the plate touches the surface texture. If the surface is too uneven, a spatula can be used. When the distribution is complete, the diameter of the sand circle is measured in at least three places.

The roughness is calculated from the following formula using an average of the measured diameters of the sand circle:

$$rh_u = \frac{38200}{d^2} \quad [mm] \tag{1}$$

where "d" is the average diameter of the sand circle given in mm.

The roughness at the observation points was measured in the cross sections, at the measuring points marked in red numbers in figure 3. The results from the measurements are given in tabular 1.

Road surface Roughness [rh$_u$]				
Observation point	**Left side**	**Center**	**Right side**	**Average**
1	0,8 mm	0,8 mm	0,7 mm	0,8 mm
2	0,7 mm	0,7 mm	0,6 mm	0,7 mm
3	0,8 mm	0,8 mm	0,9 mm	0,8 mm

Table 1: Road Surface Roughness at Observation Points

1.2. Data collection and documentation

During measurements, the air and road surface temperature was measured with a handheld thermometer. The average air temperature and precipitation was documented using registrations by the nearest weather station, located approximately 3km from the observation site. The winter maintenance data was given directly from the maintenance truck, during and after the field observations, either by information given by the driver or a GPS (Global Positioning System) based logging system. The given data was type and time of action, and spreading rate if salt was used. This was collected to explain possible variations in results.

1.3. Measuring Road Surface Water

The road surface water was measured with a textile called Wettex. Wettex is a highly absorbent textile that can absorb the present liquid by placing a textile piece on the road surface. The water amount was measured by pushing the textile against the road surface for approximately 10 seconds. The amount of liquid can then be determined by using a textile piece with known dimensions, and weighing the piece before and after the procedure. As shown in equation 2, the quantity of water is then given in g/m^2.

$$m_{water} = \frac{m_{after} - m_{before}}{A_{textile}} \quad [\frac{g}{m^2}] \tag{2}$$

Where *m* is the weight of the textile, and *A* is the area of the textile, which was given as 0,10865 m^2 in this study. The water measurements were taken approximately at the measuring points marked in red in figure 3.

The use of Wettex and its uncertainties is described further in the NPRA's Technical Report nr. 2523 [11], where a 95 % confidence interval is given as:

$$R = \pm(0,1 \times m_{water} + 20)\frac{g}{m^2} \tag{3}$$

Where m_{water} is given in g/m^2.

1.4. Data Analysis

The data from the water measurements were calculated to a theoretical need for salt by using the mechanism behind anti-icing, called *freezing point depression*. The procedure in this study was to decide a hypothetical future temperature that the measured water amount would be exposed to, and then calculating how much salt that needed to be dissolved in the water to keep it from freezing by using the formula for freezing point depression shown in figure 4. The formula is a curve adaptation to data from *CRC Handbook of Chemistry and Physics* [12].

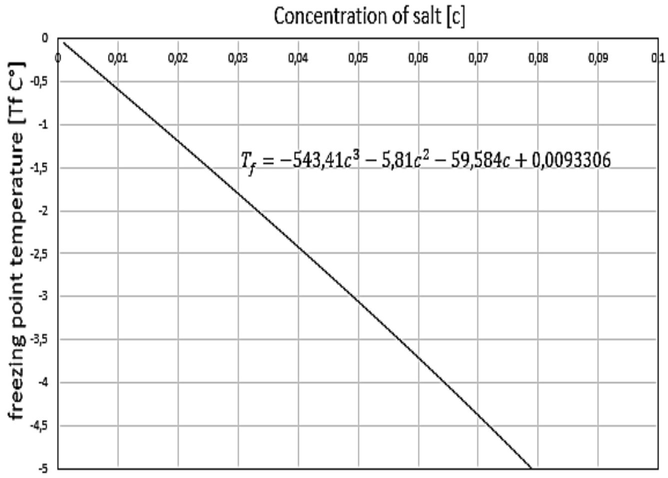

Figure 4: Freezing Curve for NaCl and Water Solution [12]

Where T_f is the freezing point of the salt and water solution, and c is the concentration of dissolved salt in the solution. It was decided to calculated the need for salt if the measured water amount on the road surface should have a freezing point at -5C° and with the curve and formula given in figure 4, the needed concentration of salt is given as approximately 7,9% (c=0,079). With the measured water amount, m_{water}, and the given concentration, c, the needed salt amount, m_{salt}, can then be decided by the following formula:

$$c = \frac{m_{salt}}{m_{water} + m_{salt}} \quad \longrightarrow \quad m_{salt} = \frac{c}{1-c} \times m_{water} \quad [\frac{g}{m^2}] \tag{4}$$

By using this procedure, one assumes that the measured water amount is at the same time as the hypothetical given temperature and that there is no residual salt on the road surface from previous actions. Furthermore, according to Klein-paste and Wåhlin (2013, only 40 % of the salt amount calculated from freezing point depression is needed to get a satisfied pavement friction. This is considered in calculation of the need amount for salt by reducing the salt amount with 60 %.

A statistical analysis of the salt amount was conducted using the data analysing program *MiniTab*. A two-sample two-tailed t-test was used to see if there was a significant difference in need for salt between average values for observation points and measuring points. The chosen level of significance was 95%, and the difference is significant different than zero if the results have a p-value lower than 0,05. Further, the results that had a significant difference was used in a two-sample one-tailed t-test to see which of the observation points had a higher salt amount. This means that if the p-value is lower than 0,05, the difference is significantly higher than zero. How to conduct a T-test manually and in MiniTab is described in *Applied statistics for traffic engineers* 1995.

4. RESULTS

In this study, there was performed several measurements and documentation over time on days with different weather conditions. Five successfully field days are used in the calculations of the results, and they are summarized in table 2. Abnormal values caused by winter maintenance or precipitation during measurements were removed before presentation and calculation of results. Thereby, the presented results are after precipitation has stopped or winter maintenance action performed.

Date	Duration [start-end]	Weather description	Temperatures [start-end C°]	From Weather-Station	Salting	Snow removal
26.01	09:30-14:43	Clouds, and light rain before	Air: 5,1-5,4 Road: 2,8-2,1 (% RH: 85-86)	0 mm	No action	No action
22.02	12:00-15:12	Clear up, and snow before	Air: 3,5-2,5 Road: 1,9-1,9 (% RH: 93-85)	06:00-11:00; 3,6mm	Start: 11:15 7,5 g/m^2	Start: 11:15 (center)
18.03	11:10-14:13	Sunny, and snow before	Air: 3,6-2,5 Road: 4,4-6,4 (% RH: 92-77)	03:00; 0,4 mm	No action	Start: 11:00 (right side)
28.03	09:15-15:24	Switching from sunny to rain/snow	Air: 3,2-3,9 Road: 1,1-2,8 (% RH: 77-72)	06:00-08:00 0,2 mm	No action	No action
22.04	15:15-17:15	Clouds and light snow before	Air: 2,8-4,7 Road: 0,8-2,6 (% RH: 84-85)	Not available	No action	No action

Table 2: Field Days Resulting in Data Set

The total numbers of measurements and the maximum and minimum measured water amount with the corresponding calculated salt amount, is shown in table 3. In the table, the water and salt amount is divided in observation points for each field day. The maximum and minimum values are taken from measuring points, and are not average values for the observation points.

Date	Number of measurements	Water amount g/m^2 [min-max]	Salt amount g/m^2 [min-max]
26.01	27	Observation point 1: 43,3 - 122,4 Observation point 2: 60,7 - 133,5 Observation point 3: 63,5 - 101,2	Observation point 1: 1,5 - 4,2 Observation point 2: 2,1 - 4,6 Observation point 3: 2,2 - 3,5
22.02	36	Observation point 1: 69,0 - 281,6 Observation point 2: 69,9 - 281,6 Observation point 3: 69,0 - 161,1	Observation point 1: 2,4 - 9,7 Observation point 2: 2,5 - 8,92 Observation point 3: 2,4 - 5,5
18.03	36	Observation point 1: 26,7 - 538,4 Observation point 2: 8,3 - 194,2 Observation point 3: 1,8 - 151,9	Observation point 1: 0,9 - 18,5 Observation point 2: 0,3 - 6,7 Observation point 3: 0,08 - 5,2
28.03	45	Observation point 1: 23,0 - 102,2 Observation point 2: 24,9 - 67,2 Observation point 3: 23,0 - 68,1	Observation point 1: 0,8 - 3,5 Observation point 2: 0,8 - 2,3 Observation point 3: 0,8 - 2,3
22.04	27	Observation point 1: 104,0 - 382,0 Observation point 2: 31,3 - 210,8 Observation point 3: 2,8 - 155,5	Observation point 1: 3,7 - 13,1 Observation point 2: 1,1 - 7,2 Observation point 3: 0,1 - 5,3

Table 3: Maximum and Minimum Values of Water and Salt Amounts

In figure 5, the results from the field work are shown with a calculated average of the measured water amount for each observation point. The different observation days are plotted in five diagrams that shows the variation of water amount over time. The results show that observation point 3 has the lowest amount of surface water in three of the observation days, and it is lower than observation point 2 at almost every measurement.

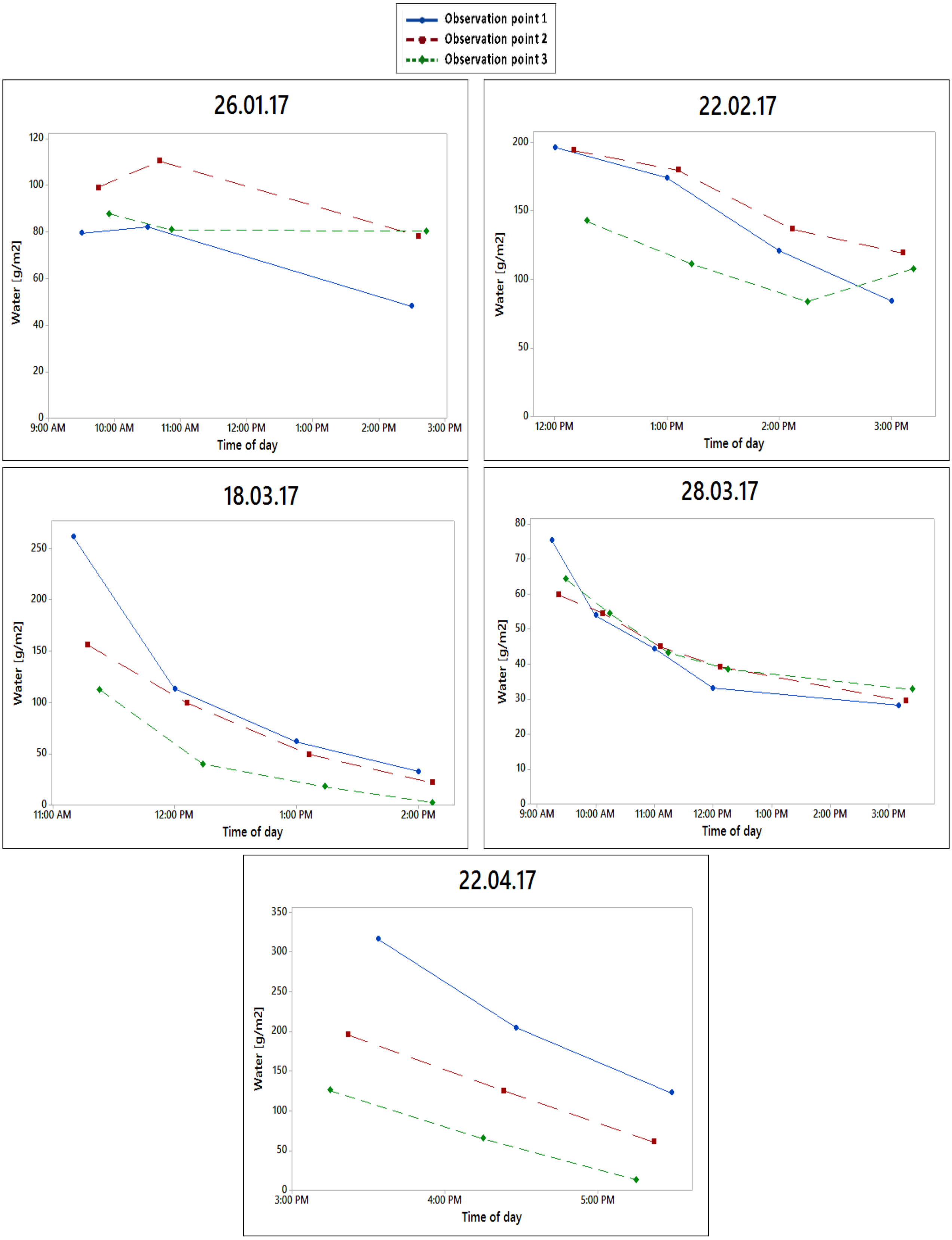

Figure 5: Average Measured Water Amount for Observation Days

On March 28th the measurements for the observation points are very similar, with some deviation from observation 1. Observation point 1 and 2 has the highest measured water amount. In addition, one can see that January 26th, which has fewest measured values, Observation point 3 doesn't follow the same pattern as for the other observation days. The high values on March 18th and April 22th, can be explained by, respectively, by snow removal and the weather described in 2. At 3pm on 22th of February, the measured water amount at observation point 3 has an increase, compared with the measurement before. This could be explained by snow melting from the side of the road. Thereby resulting in an increase of water on the road surface.

In figure 6 the average amount of salt for each measuring point are plotted relative to the value for measuring point 3.1, which is the right side of observation point 3. This means that the figure shows how much more the average values are than the value for point 3.1, which is set to 1 (100 %).

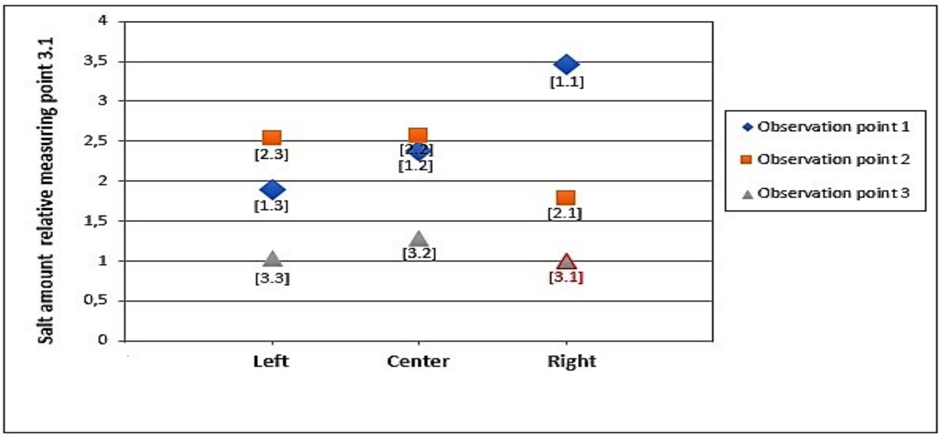

Figure 6: Average Amount of Salt at Measuring Points [t_f=-5 C°]

From the figure, one can see that the right side of observation point 1 has the highest value, 3,5 times the amount of value 3.1, and the values for observation point 1 and 2 is higher than for observation point 3. Observation point 1 has a variation of 1,7 between the lowest and highest value, while observation point 2 and 3 has respectively a variation of 0,9 and 0,3. The largest variation between the measuring points are on the right side of the road. In addition, the largest variation can be found between the measuring points on the right side of the road.

The results that were significant from the T-test are shown in table 4, which means that the differences that not were significant are not presented. The presented results in the table shows that observation point 3 has a significant lower need for salt than observation point 1 and 2. The difference between observation point 1 and 2 was not significant. Across observation point 1, which has the most uneven cross fall, there is a significant difference between the right side of the road and the left. The right side of the roads has higher values then the left. Along the road on the right side, there is a significant difference between observation point 1 and 2, and between 1 and 3. At the left side and the center of the road, there is only a significant difference between observation point 2 and 3, where 2 has the highest values.

T-test of difference [One-tailed]			
Difference between observation points	**T-value**	**P-value**	**DF**
μ(OP$_1$) - μ(OP$_3$)	2,55	0,008	28
μ(OP$_2$) - μ(OP$_3$)	2,26	0,015	33
Difference between measuring points	**T-value**	**P-value**	**DF**
μ(MP$_{1R}$) - μ(MP$_{1L}$)	2,39	0,012	27
μ(MP$_{1R}$) - μ(MP$_{2R}$)	2,62	0,007	24
μ(MP$_{1R}$) - μ(MP$_{3R}$)	3,06	0,003	22
μ(MP$_{2L}$) - μ(MP$_{3L}$)	2,75	0,005	31
μ(MP$_{2M}$) - μ(MP$_{3M}$)	2,24	0,016	30
Abbrivations: OP= Observation Point, M= Measuring Point, R= Right, L= Left, C= Center, DF= Degrees of freedom and μ= values for salt amount.			

Table 4: Results from Two-Sample One-Tailed T-Test

The average percentage of difference between observation points are shown in table table:4, where only average values for the observation points were used in this calculation.

Average percentage of difference in need for salt	
Equation	**Calculated percentage**
$\frac{\Sigma[\mu(OP_1) - \mu(OP3_{2R})]}{\Sigma[\mu(OP_3)]} \times 100\%$	171,2 %
$\frac{\Sigma[\mu(OP_2) - \mu(OP_3)]}{\Sigma[\mu(OP_3)]} \times 100\%$	104,6 %
$\frac{\Sigma[\mu(OP_1) - \mu(OP_2)]}{\Sigma[\mu(OP_2)]} \times 100\%$	16,1 %
Abbrivations: OP= Observation Point, Σ= Sum and μ= values for salt amount.	

Table 5: Average Percentage of Difference in Observation Points

The results show that observation point 1 needs approximately 171,2% higher values of salt amount than observation point 3, while observation point 2 has 104,6% higher values than observation point 3. This means that observation point 1 has a 2,7 times higher need for salt than observation point 3, and observation point 2 has approximately twice as high need for salt than observation point 3. Observation point 1 has only 16,1% higher values than observation point 2, which consists with difference not being significant.

5. DISCUSSION

In this study, the measured water amount over time on the road surface has been the base for the calculations and results. The approach has been that more water indicates a higher need for salt, which is simple and only theoretical. In reality, several factors will affect the need for salt. For instance, the time of action. The expected weather must be considered. If it is expected more precipitation, the needed amount of salt will increase. The same will apply to temperature, expected lower temperatures will lead to an increase in needed amount of salt. One could also considered how much the need for salt would be with the approach of anti-compaction of snow, but there is not given any clear guidelines on this. However, with measuring water amount, one can get an indication of how much salt the measuring points need if the water should not freeze, at given temperatures below zero, by using the method for anti-icing. Thereby, using this to see how the need for salt may vary between given measuring points. In addition, the calculations have some limitations. For example, the calculation for the percentage is only a calculation of the average values and it cannot be said if the results from the calculation would apply if more raw-data was collected.

The results in this study can be used to evaluate performed salting actions, to see if the spreading rate could be less, or in further evaluation of salting on bicycle roads. For example, in table 2 it is stated that a salting action was performed at 11:15 on the 22th of February, one hour before the measurements started, with a spreading rate of 7,5 g/m^2. The same amount of salt was spread for the entire bicycle road. The highest registered amount of snow that following night, 17:00 to 09:00 at the nearest weather station, was 0,4 mm and the lowest measured temperature was -3,6°. Since the registered amount of snow during the night was low, one can assume that the amount of water and snow on the road surface will most likely be lower than the measured water amount at 3 PM. The calculated salt amount in shown in table 3, where the minimum at that day represents the salt amount at 3 PM, which was 2,4 g/m^2. The calculated amount of salt has taken account for a temperature at -5°, which is 1,4 lower than the registered temperature that night. This indicates that the chosen spreading rate at 7,5 g/m^2, was too high. Further, the highest salt amount at observation point 3 were 5,5 g/m^2, which is 3-4 g/m^2 lower than for observation point 2 and 3. The spreading rate could therefor also have been even lower at this point.

5.1. Difference in Type of Asphalt

The results in this study clearly shows that observation point 3 has the average lowest amount of water at the measurements, and thereby a lower need for salt. This is confirmed in the statistical analysis, where it is shown that both observation point 2 and 1 has a significantly higher need for salt than observation point 3. The calculated average percentage of difference showed that observation point 1 needs approximately 171.2% more salt than observation point 3, and that observation point 2 needs 104,6% more than observation point 3. Observation point 1 and 2 has the same type of asphalt, which is a raw and relatively new asphalt. Observation point 3, has an old type of asphalt. The cross fall for the observation points are shown in figure 3, and one can see that observation point 2 and 3 have a the same cross fall, but observation point 3 has a little steeper slope. The similarities give the opportunity to compare these two observation points. With this, one can say that an old type of asphalt has a lower need for salt than a new and raw type of asphalt. The difference between observation point 1 and 3 could be affected by the cross fall in observation point 1, and therefor will the average percentage of difference in asphalt type be 104,6%.

Why the asphalt affects the need for salt is not investigated in this study. It is only clear that the asphalt type has an effect, but not why. However, some thoughts and discussion on why the results are different for the asphalt types are made. One explanation could be that the evaporation of water has a different rate at the observation points. Another, could be that the water can drain down into the road structure. It could be that the old asphalt is more porous and has a higher absorption of water than the new and raw asphalt. The bitumen in the newer asphalt can act as an impregnation that prevents the water from entering the structure, and the water remains on the surface. This is not investigated, but the explanation can be linked to the research of A. Dawson on water in the pavement surfacing, where its explained that different asphalt mixtures have different permeability values for water [15].

It is well known that salt can have environmental consequences, and if salt dissolved in water goes down in the structure, this may have a negative consequence. It was found in a Canadian research that salt create conditions favourable to an ice enrichment process and contribute to a substantial increase in the frost susceptibility of granular materials [16]. If dissolved salt in water is drained down in to the structure of the bicycle road, this may cause an increase in differential heaving and thermal cracking. The structure becomes can become more frost susceptible because of the salt and the water can freeze, and thereby creating frost heave. This could lead to more cracks and unevenness in the road surface, especially if there is a large variation in the permeability of the road surface on short stretches. Therefore, one cannot say that is better to only have this type of asphalt because it needs less salt during the winter.

5.2. Difference in Cross Fall

From figure 3, one can see that observation point 1 has a very rough cross fall with large variation and that observation point 2 has a more even cross fall with a gentle slope. Since observation point 1 and 2 has the same type of asphalt, one can use the results from these observation points to evaluate the effect of the cross fall. The type of asphalt and surface roughness is the same for the two observation points, and the difference is in the cross falls. Figure 6 shows that there is a clear difference between the need for salt along the cross profiles for the observation point 1 and 2, and observation point 1 has the largest variation. However, in figure 5, where the average measured water amount is shown, observation point 1 and 2 are switching on having the highest values for the various field days. Further, the statistical analysis showed that there was no significantly difference between observation point 1 and 2.

The statistical analysis also showed that observation point 1 is the only one that has a significant difference in need for salt between the measuring points aligned its cross fall, where the right side, point 1.1, was significantly higher than the left side, point 1.3. From figure 3, One can see that point 1.1 has almost no slope, while point 1.3 has a steep slope. This means that the water could easier drain away at point 1.3 , while at point 1.1 the water has to evaporate or drain down into the structure. If the drainage of the road is insufficient, and the water on the road surface are not drained away, more water will stay on the road surface which indicates more salt is needed to keep the water from freezing. In addition, measuring point 1.1, at observation point 1 has a higher need for salt than measuring point 2.1, at observation point 2. Here, the same principle will apply. From figure 3, one can see that 2.1 has a higher slope than 1.3 and thereby better drainage of water.

Therefore, one can say that an uneven cross fall with a gentle slope may give an increase in the need for salt. How large impact the cross fall may have is not clear, but there are no clear disadvantages of having an even cross fall and thereby good drainage. It's only an advantage to have good drainage, both for the road structure and to decrease the need for salt during the winter. The fact that the cross fall can have a large effect on the surface water is also mentioned in the VTI report [6].

6. CONCLUSIONS

The main findings in this study was that a new and raw asphalt needs approximately twice as much salt as an old type of asphalt. An average percentage of difference was calculated to be 104,6%. It is not clear why the asphalt type affect the need for salt. Furthermore, the cross fall on a bicycle road can have an impact on the difference in need for salt. It is not clear how large the impact of the cross fall might be. To investigate this, a field study with more difference in cross fall between observation points could be conducted. In this case, the type of asphalt and surface roughness should be approximately the same to get a good indication of the effect of difference in cross fall.

The results in this study can be used to evaluate performed salting actions, to see if the spreading rate could be less, by using registered weather after a salting action has been performed and salt amounts calculated on a comparable field day from this study. Additionally, the results and conclusions could be used in further evaluation of salting on bicycle roads.

ACKNOWLEDGMENTS

Thanks to Rolf Magne Brødreskift at Trondheim municipality operation center for input and operating data, and co-workers at the Norwegian Public Roads Administration (NPRA) for discussions and feedback. Also thanks to the NPRA and the Norwegian University of Science and Technology for the financial support of this work.

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Part III:

Appendix

List of Appendix

MASTEROPPGAVE

(TBA4940 VEG, masteroppgave)

VÅREN 2017
for
Veronika Ludvigsen Husa

The effect of pavement texture on need for salt in winter maintenance of bicycle roads

BAKGRUNN

Det har blitt et økt fokus på vinterdrift av gang- og sykkelveger for å øke andelen myke trafikanter om vinteren. Ved vinterdrift av sykkelveger blir salt brukt som en preventiv metode. I praksis blir samme saltmengde brukt langs strekninger med forskjellig type asfalt, tverrfall og overflate tekstur. I Trondheim kan sykkelveger ha store variasjoner i vegdekket langs korte strekninger. For å kunne forstå hvordan behovet for salt kan variere langs en sykkelveg, er det viktig å undersøke om forskjellig type vegdekker kan ha en effekt.

OPPGAVE

Oppgaven inneholder følgende deloppgaver:

1. Beskrive teorien bak saltmetoder i vinterdrift
2. Gjennomgang av litteratur om eksisterende forskning
3. Utføre feltarbeid for å bestemme behovet for salt ved ulike vegdekker
4. Analysere og sammenligne resultater fra feltmålinger
5. Beskrive prosess og utarbeide et forslag til forskningsartikkel

Målet

Målet med oppgaven er å samle inn data om hvordan vegdekke kan påvirke behovet for salt ved vinterdrift på sykkelveger.

Forskningsspørsmål

Forskningsspørsmålet i oppgaven er:
Hvordan påvirker vegdekket behovet for salt ved vinterdrift av sykkelveger?

GENERELT

Oppgaveteksten er ment som en ramme for kandidatens arbeid. Justeringer vil kunne skje underveis, når en ser hvordan arbeidet går. Eventuelle justeringer må skje i samråd med faglærer ved instituttet.

Ved bedømmelsen legges det vekt på grundighet i bearbeidingen og selvstendigheten i vurderinger og konklusjoner, samt at framstillingen er velredigert, klar, entydig og ryddig uten å være unødig voluminøs.

Besvarelsen skal inneholde

- standard rapportforside (automatisk fra DAIM, http://daim.idi.ntnu.no/)
- tittelside med ekstrakt og stikkord (mal finnes på student ved IBM wikiside)
- sammendrag på norsk og engelsk (studenter som skriver sin masteroppgave på et ikke-skandinavisk språk og som ikke behersker et skandinavisk språk, trenger ikke å skrive sammendrag av masteroppgaven på norsk)
- hovedteksten
- oppgaveteksten (denne teksten signert av faglærer) legges ved som Vedlegg 1.

Besvarelsen kan evt. utformes som en vitenskapelig artikkel for internasjonal publisering. Besvarelsen inneholder da de samme punktene som beskrevet over, men der hovedteksten omfatter en vitenskapelig artikkel og en prosessrapport.

Instituttets råd og retningslinjer for rapportskriving ved prosjektarbeid og masteroppgave befinner seg på student ved IBM wikiside

Hva skal innleveres?
Rutiner knyttet til innlevering av masteroppgaven er nærmere beskrevet på http://daim.idi.ntnu.no/. Trykking av masteroppgaven bestilles via DAIM direkte til Skipnes Trykkeri som leverer den trykte oppgaven til instituttkontoret 2-4 dager senere. Instituttet betaler for 3 eksemplarer, hvorav instituttet beholder 2 eksemplarer. Ekstra eksemplarer må bekostes av kandidaten/ ekstern samarbeidspartner.

Masteroppgaven regnes ikke som ferdig levert før kandidaten har levert innleveringsskjemaet (fra DAIM) hvor både Ark-Bibl i SBI og Fellestjenester (Byggsikring) i Sentralbygg II har signert på skjemaet. Innleveringsskjema med de aktuelle signaturene underskrives av instituttkontoret før skjemaet leveres Fakultetskontoret.

Dokumentasjon som med instituttets støtte er samlet inn under arbeidet med oppgaven skal leveres inn sammen med besvarelsen.

Besvarelsen er etter gjeldende reglement NTNUs eiendom. Eventuell benyttelse av materialet kan bare skje etter godkjennelse fra NTNU (og ekstern samarbeidspartner der dette er aktuelt). Instituttet har rett til å bruke resultatene av arbeidet til undervisnings- og forskningsformål som om det var utført av en ansatt. Ved bruk ut over dette, som utgivelse og annen økonomisk utnyttelse, må det inngås særskilt avtale mellom NTNU og kandidaten.

(Evt) Avtaler om ekstern veiledning, gjennomføring utenfor NTNU, økonomisk støtte m.v.
Beskrives her når dette er aktuelt. Se student ved IBM wikiside for avtaleskjema.

Helse, miljø og sikkerhet (HMS):
NTNU legger stor vekt på sikkerheten til den enkelte arbeidstaker og student. Den enkeltes sikkerhet skal komme i første rekke og ingen skal ta unødige sjanser for å få gjennomført arbeidet. Studenten skal derfor ved uttak av masteroppgaven få utdelt brosjyren "Helse, miljø og sikkerhet ved feltarbeid m.m. ved NTNU".

Dersom studenten i arbeidet med masteroppgaven skal delta i feltarbeid, tokt, befaring, feltkurs eller ekskursjoner, skal studenten sette seg inn i "Retningslinje ved feltarbeid m.m.". Dersom studenten i arbeidet med oppgaven skal delta i laboratorie- eller verkstedarbeid skal studenten sette seg inn i og følge reglene i "Laboratorie- og verkstedhåndbok". Disse dokumentene finnes på fakultetets HMS-sider på nettet, se http://www.ntnu.no/iv/adm/hms/. Alle studenter som skal gjennomføre laboratoriearbeid i forbindelse med prosjekt- og masteroppgave skal gjennomføre et web-basert TRAINOR HMS-kurs. Påmelding på kurset skjer til kontakt@ibm.ntnu.no

Studenter har ikke full forsikringsdekning gjennom sitt forhold til NTNU. Dersom en student ønsker samme forsikringsdekning som tilsatte ved universitetet, anbefales det at han/hun tegner reiseforsikring og personskadeforsikring. Mer om forsikringsordninger for studenter finnes under samme lenke som ovenfor.

Oppstart og innleveringsfrist:
Oppstart og innleveringsfrist er i henhold til informasjon i DAIM.

Faglærer ved instituttet: Alex Klein-Paste/Inge Hoff
Veileder hos ekstern samarbeidspartner: Katja-Pauliina Rekilä og Johan Wåhlin

Institutt for bygg, anlegg og transport, NTNU
Dato: 23.05.2017

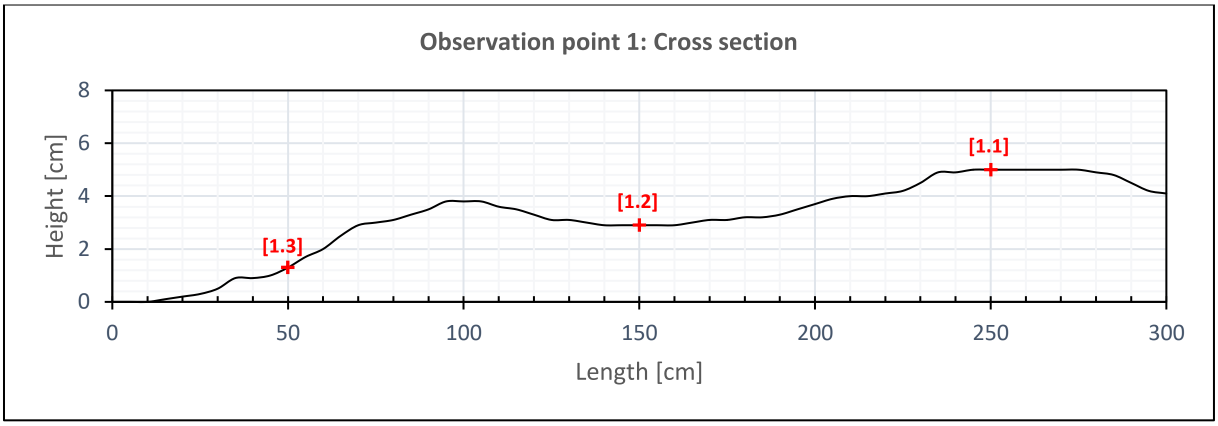
Underskrift

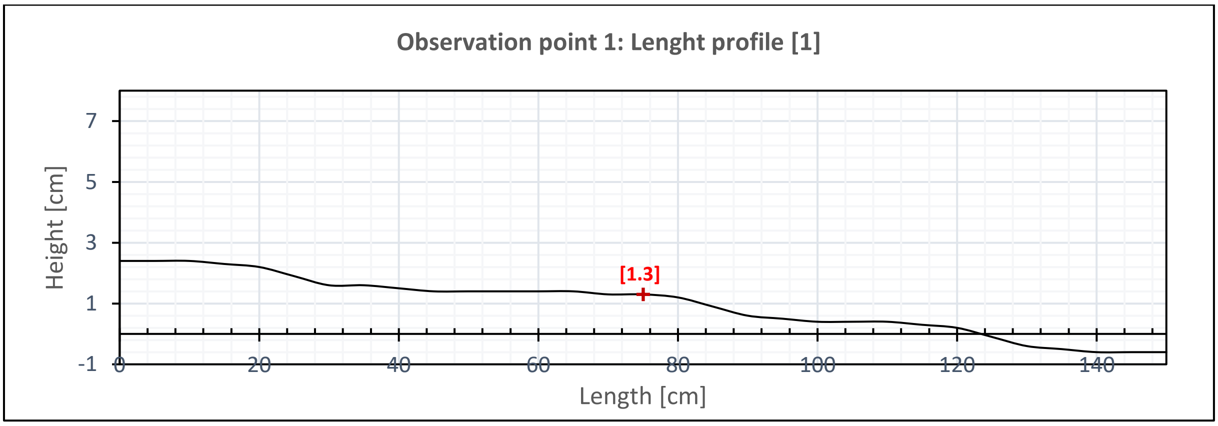
Inge Hoff

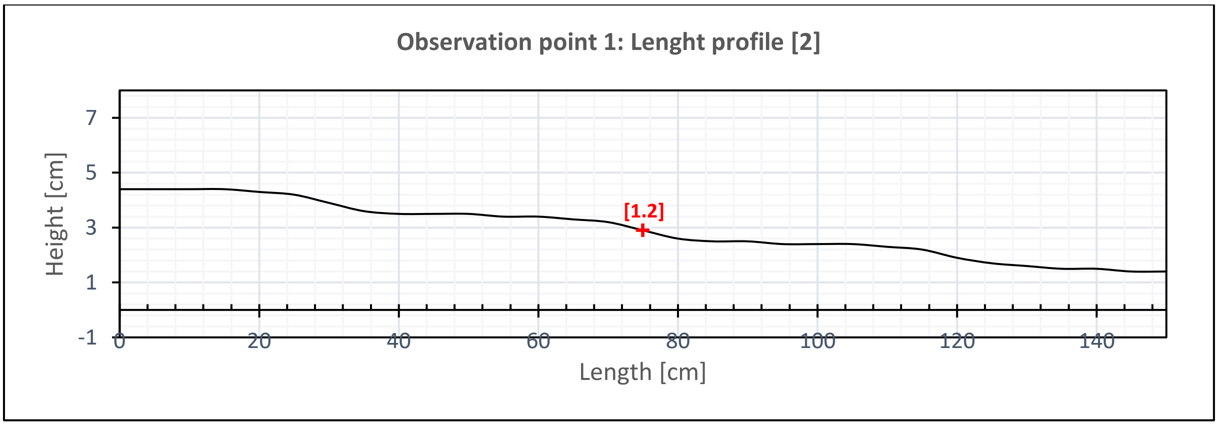
Faglærer

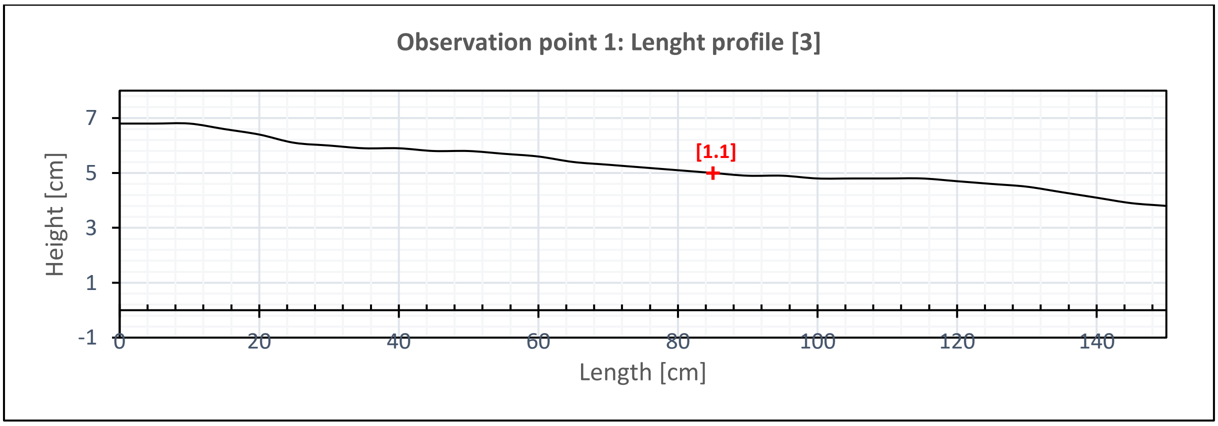
APPENDIX 2: ROAD PROFILES

OBSERVATION POINT 1



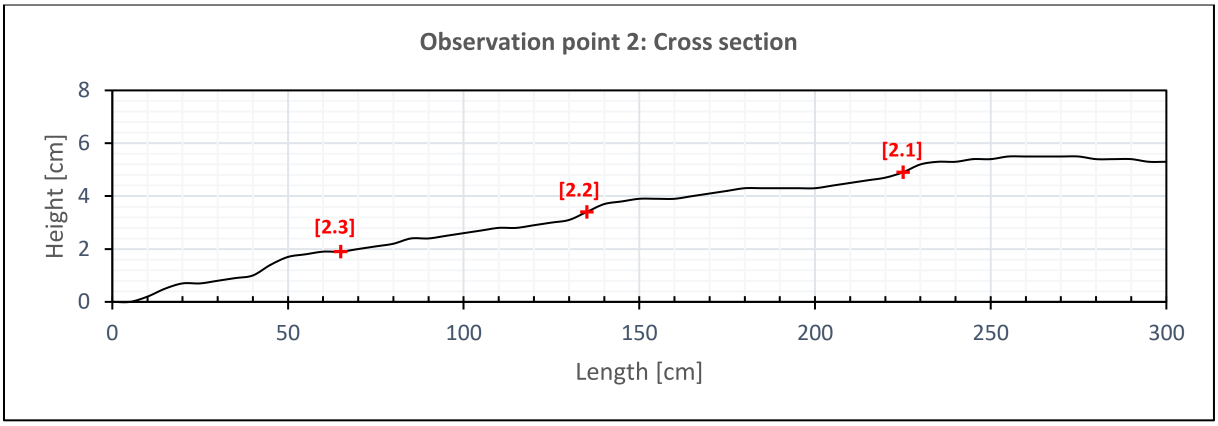


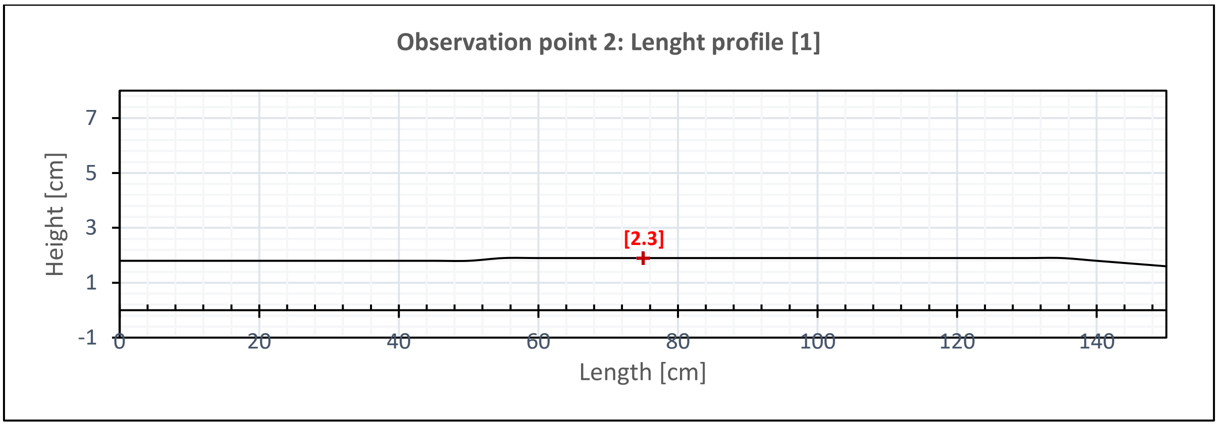


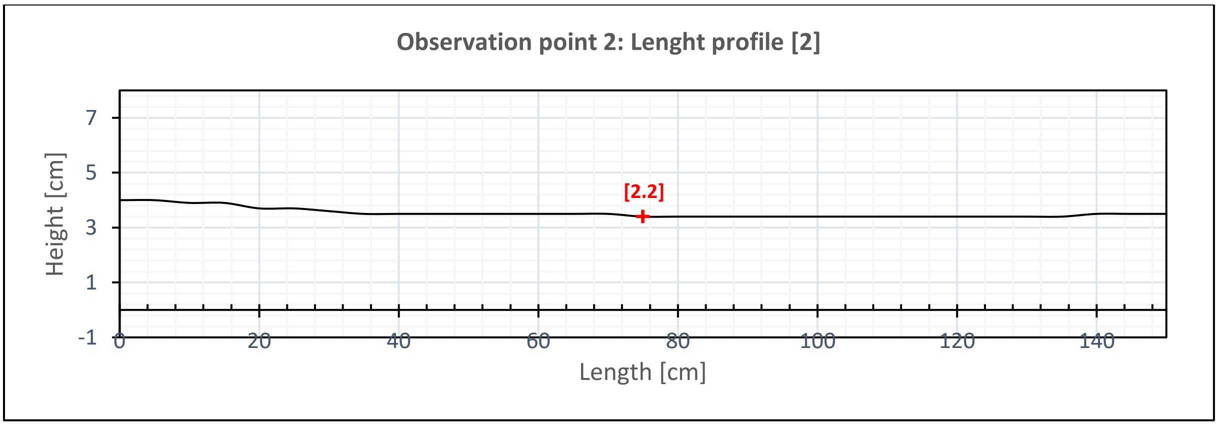


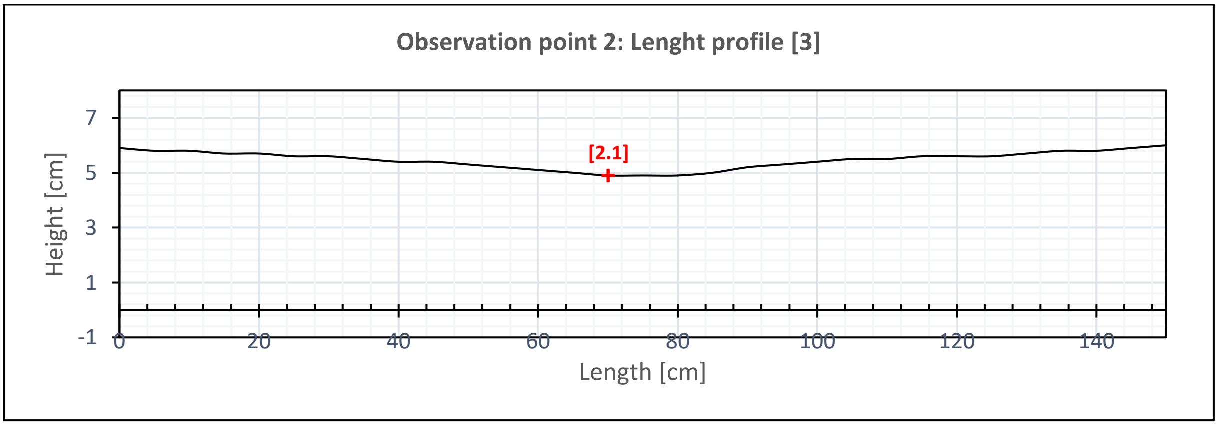
APPENDIX 2: ROAD PROFILES

OBSERVATION POINT 2



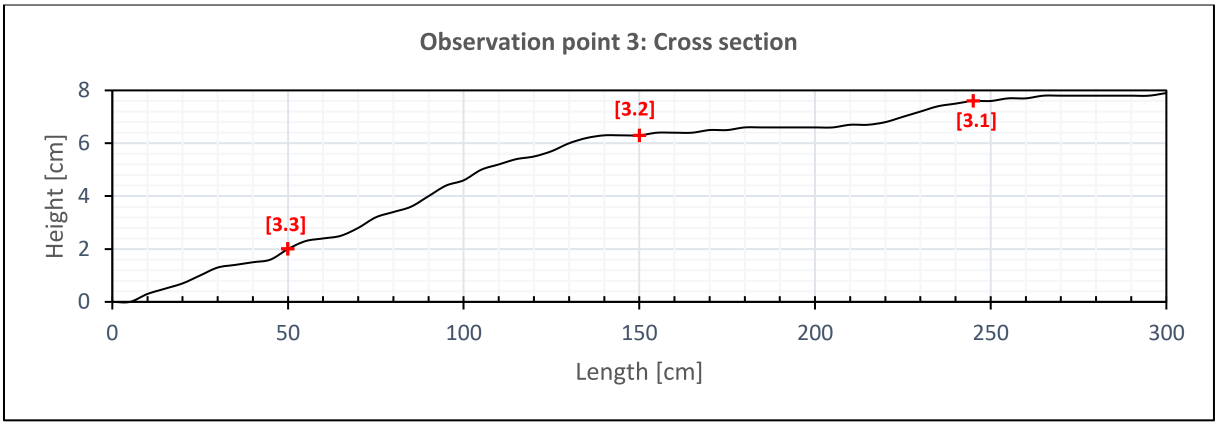


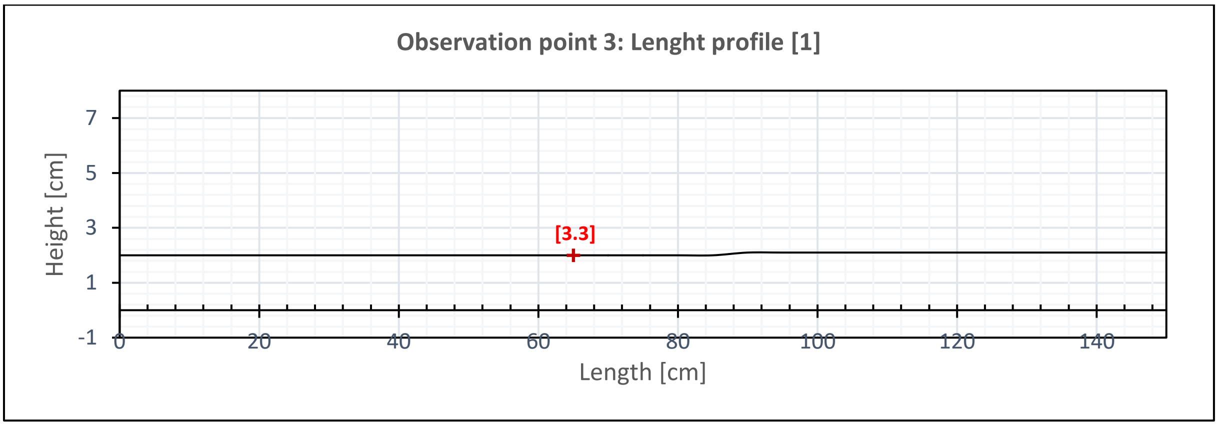


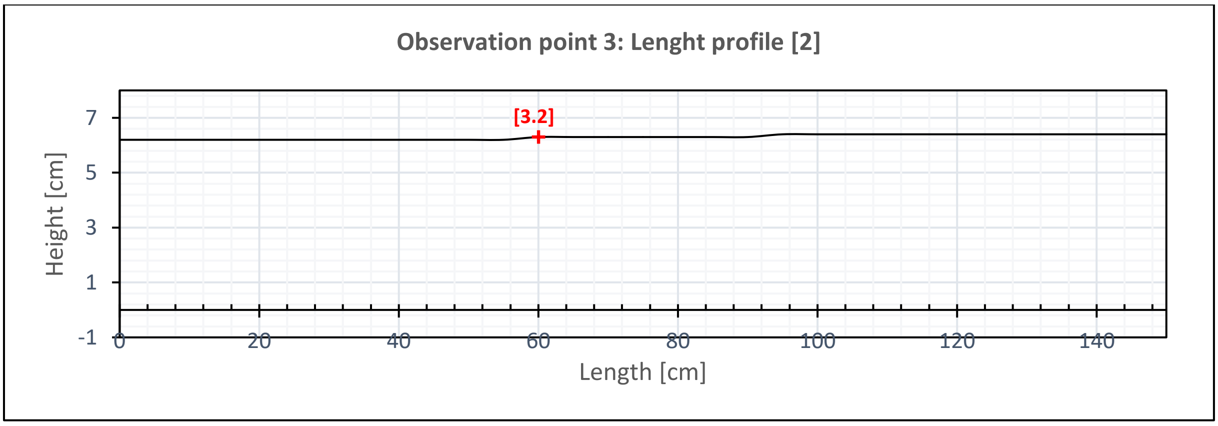


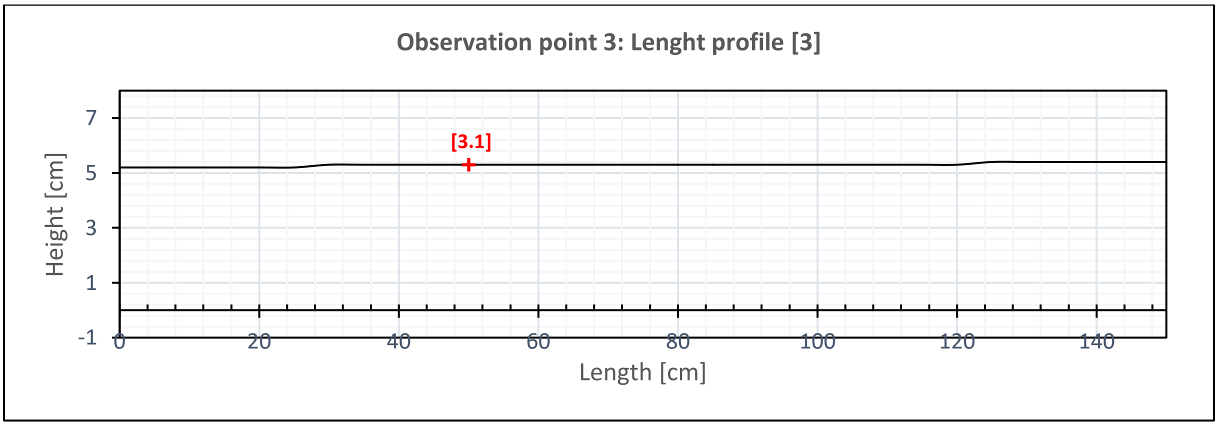
APPENDIX 2: ROAD PROFILES

OBSERVATION POINT 3









APPENDIX 3: RESULTS FROM FIELD WORK

26.01.17 PART 1: MEASURED WATER ON ROAD SURFACE

Wettex areal [m^2]:	0,10865

Position	NR	Weight before	Weight after	Water [g]	Road temperature	Air temperature	Time of day	Water on road surface [g/m2]
1R	1	21,4	27,9	6,5	2,8	5,1	09:30	59,8
1C	2	21,4	34,7	13,3				122,4
1L	3	21,3	27,4	6,1				56,1
2R	4	21,1	27,7	6,6	2,7	5,1	09:45	60,7
2C	5	21,7	36,2	14,5				133,5
2L	6	21,3	32,5	11,2				103,1
3R	7	20,3	30	9,7	2,8	5	09:55	89,3
3C	8	20,6	31	10,4				95,7
3L	9	21,6	30,1	8,5				78,2
1R	10	20	26,8	6,8	2,8	5	10:30	62,6
1C	11	21,5	33,9	12,4				114,1
1L	12	21,4	29	7,6				69,9
2R	13	20,5	29,3	8,8	2,6	5	10:41	81,0
2C	14	21,4	34,3	12,9				118,7
2L	15	22,1	36,4	14,3				131,6
3R	16	20,8	29,3	8,5	2,8	5,1	10:52	78,2
3C	17	19,5	26,4	6,9				63,5
3L	18	19,1	30,1	11				101,2
1R	19	18,5	23,3	4,8	2,9	5,4	14:30	44,2
1C	20	18,5	24,7	6,2				57,1
1L	21	17,8	22,5	4,7				43,3
2R	22	18,3	25,6	7,3	1,6	5,4	14:36	67,2
2C	23	19,3	28,6	9,3				85,6
2L	24	19,4	28,3	8,9				81,9
3R	25	18,7	26	7,3	1,7	5,4	14:43	67,2
3C	26	18,6	27	8,4				77,3
3L	27	22,5	33	10,5				96,6

APPENDIX 3: RESULTS FROM FIELD WORK

26.01.17 PART 2: CALCULATION OF NEED FOR SALT

NR	Tf= -1 °C [1,7% NaCl]	Tf= -2,5 °C [4,1% NaCl]	Tf =-5 °C [7,9% NaCl]	Average [1,7% NaCl]	Average [4,1% NaCl]	Average [7,9% NaCl]
1	1	2,6	5,1			
2	2,1	5,2	10,5			
3	1	2,4	4,8	*1,4*	*3,4*	*6,8*
4	1,1	2,6	5,2			
5	2,3	5,7	11,4			
6	1,8	4,4	8,8	*1,7*	*4,2*	*8,5*
7	1,5	3,8	7,7			
8	1,7	4,1	8,2			
9	1,4	3,3	6,7	*1,5*	*3,8*	*7,5*
10	1,1	2,7	5,4			
11	2	4,9	9,8			
12	1,2	3	6	*1,4*	*3,5*	*7,1*
13	1,4	3,5	6,9			
14	2,1	5,1	10,2			
15	2,3	5,6	11,3	*1,9*	*4,7*	*9,5*
16	1,4	3,3	6,7			
17	1,1	2,7	5,4			
18	1,8	4,3	8,7	*1,4*	*3,5*	*6,9*
19	0,8	1,9	3,8			
20	1	2,4	4,9			
21	0,7	1,8	3,7	*0,8*	*2,1*	*4,1*
22	1,2	2,9	5,8			
23	1,5	3,7	7,3			
24	1,4	3,5	7	*1,4*	*3,3*	*6,7*
25	1,2	2,9	5,8			
26	1,3	3,3	6,6			
27	1,7	4,1	8,3	*1,4*	*3,4*	*6,9*

APPENDIX 3: RESULTS FROM FIELD WORK

NR	0,4 x [1,7% NaCl]	0,4 x [4,1% NaCl]	0,4 x [7,9% NaCl]	0,4 x Average [1,7% NaCl]	0,4 x Average [4,1% NaCl]	0,4 x Average [7,9% NaCl]
1	0,4	1,04	2,04			
2	0,84	2,08	4,2			
3	0,4	0,96	1,92	0,56	1,36	2,72
4	0,44	1,04	2,08			
5	0,92	2,28	4,56			
6	0,72	1,76	3,52	0,68	1,68	3,4
7	0,6	1,52	3,08			
8	0,68	1,64	3,28			
9	0,56	1,32	2,68	0,6	1,52	3
10	0,44	1,08	2,16			
11	0,8	1,96	3,92			
12	0,48	1,2	2,4	0,56	1,4	2,84
13	0,56	1,4	2,76			
14	0,84	2,04	4,08			
15	0,92	2,24	4,52	0,76	1,88	3,8
16	0,56	1,32	2,68			
17	0,44	1,08	2,16			
18	0,72	1,72	3,48	0,56	1,4	2,76
19	0,32	0,76	1,52			
20	0,4	0,96	1,96			
21	0,28	0,72	1,48	0,32	0,84	1,64
22	0,48	1,16	2,32			
23	0,6	1,48	2,92			
24	0,56	1,4	2,8	0,56	1,32	2,68
25	0,48	1,16	2,32			
26	0,52	1,32	2,64			
27	0,68	1,64	3,32	0,56	1,36	2,76

APPENDIX 3: RESULTS FROM FIELD WORK

22.02.17 PART 1: MEASURED WATER ON ROAD SURFACE

Wettex areal [m²]:			0,10865					
Position	**NR**	**Weight before**	**Weight after**	**Water [g]**	**Road temperature**	**Air temperature**	**Time of day**	**Water on road surface [g/m2]**
1R	1	22,3	49,4	27,1	2,1	3,5	12:00	249,4
1C	2	22,6	41,6	19				174,9
1L	3	22,5	40,3	17,8				163,8
2R	4	22,3	35,9	13,6	2	3,5	12:10	125,2
2C	5	21,7	50	28,3				260,5
2L	6	21,9	43,2	21,3				196,0
3R	7	21,9	37,2	15,3	1,5	3,5	12:17	140,8
3C	8	20,9	38,4	17,5				161,1
3L	9	21,2	34,9	13,7				126,1
1R	10	21,6	52,2	30,6	2,8	3	13:00	281,6
1C	11	20,7	33,9	13,2				121,5
1L	12	21,8	34,7	12,9				118,7
2R	13	22	32,4	10,4	2,8	3	13:06	95,7
2C	14	22,1	49,3	27,2				250,3
2L	15	22,5	43,4	20,9				192,4
3R	16	20,4	30,6	10,2	2,6	3	13:13	93,9
3C	17	19,8	34	14,2				130,7
3L	18	20,9	32,7	11,8				108,6
1R	19	20,3	43,1	22,8	1,9	3,6	14:00	209,8
1C	20	20,1	27,6	7,5				69,0
1L	21	20,8	29,9	9,1				83,8
2R	22	21	28,7	7,7	2,8	3,6	14:07	70,9
2C	23	21	41,3	20,3				186,8
2L	24	21	37,5	16,5				151,9
3R	25	20,9	28,4	7,5	2,5	3,6	14:15	69,0
3C	26	21,8	31,6	9,8				90,2
3L	27	22,3	32,3	10				92,0
1R	28	22,6	35,1	12,5	2,3	2,5	15:00	115,0
1C	29	22	29,5	7,5				69,0
1L	30	21,5	29	7,5				69,0
2R	31	22,3	29,9	7,6	1,8	2,5	15:06	69,9
2C	32	22,2	36,8	14,6				134,4
2L	33	22,5	39,2	16,7				153,7
3R	34	22	29,6	7,6	1,6	2,5	15:12	69,9
3C	35	22,6	36,8	14,2				130,7
3L	36	21,5	34,8	13,3				122,4

APPENDIX 3: RESULTS FROM FIELD WORK

22.02.17 PART 2: CALCULATION OF NEED FOR SALT

NR	Tf= -1 °C [1,7% NaCl]	Tf= -2,5 °C [4,1% NaCl]	Tf= -5 °C [7,9% NaCl]	Average [1,7% NaCl]	Average [4,1% NaCl]	Average [7,9% NaCl]
1	4,3	10,7	21,4			
2	3	7,5	15			
3	2,8	7	14,1	*3,4*	*8,4*	*16,8*
4	2,2	5,4	10,7			
5	4,5	11,1	22,3			
6	3,4	8,4	16,8	*3,4*	*8,3*	*16,6*
7	2,4	6	12,1			
8	2,8	6,9	13,8			
9	2,2	5,4	10,8	*2,5*	*6,1*	*12,2*
10	4,9	12	24,2			
11	2,1	5,2	10,4			
12	2,1	5,1	10,2	*3*	*7,4*	*14,9*
13	1,7	4,1	8,2			
14	4,3	10,7	21,5			
15	3,3	8,2	16,5	*3,1*	*7,7*	*15,4*
16	1,6	4	8,1			
17	2,3	5,6	11,2			
18	1,9	4,6	9,3	*1,9*	*4,7*	*9,5*
19	3,6	9	18			
20	1,2	3	5,9			
21	1,4	3,6	7,2	*2,1*	*5,2*	*10,4*
22	1,2	3	6,1			
23	3,2	8	16			
24	2,6	6,5	13	*2,4*	*5,8*	*11,7*
25	1,2	3	5,9			
26	1,6	3,9	7,7			
27	1,6	3,9	7,9	*1,4*	*3,6*	*7,2*
28	2	4,9	9,9			
29	1,2	3	5,9			
30	1,2	3	5,9	*1,5*	*3,6*	*7,2*
31	1,2	3	6			
32	2,3	5,7	11,5			
33	2,7	6,6	13,2	*2,1*	*5,1*	*10,2*
34	1,2	3	6			
35	2,3	5,6	11,2			
36	2,1	5,2	10,5	*1,9*	*4,6*	*9,2*

APPENDIX 3: RESULTS FROM FIELD WORK

NR	0,4 x [1,7% NaCl]	0,4 x [4,1% NaCl]	0,4 x [7,9% NaCl]	0,4 x Average [1,7% NaCl]	0,4 x Average [4,1% NaCl]	0,4 x Average [7,9% NaCl]
1	1,72	4,28	8,56			
2	1,2	3	6			
3	1,12	2,8	5,64	1,36	3,36	6,72
4	0,88	2,16	4,28			
5	1,8	4,44	8,92			
6	1,36	3,36	6,72	1,36	3,32	6,64
7	0,96	2,4	4,84			
8	1,12	2,76	5,52			
9	0,88	2,16	4,32	1	2,44	4,88
10	1,96	4,8	9,68			
11	0,84	2,08	4,16			
12	0,84	2,04	4,08	1,2	2,96	5,96
13	0,68	1,64	3,28			
14	1,72	4,28	8,6			
15	1,32	3,28	6,6	1,24	3,08	6,16
16	0,64	1,6	3,24			
17	0,92	2,24	4,48			
18	0,76	1,84	3,72	0,76	1,88	3,8
19	1,44	3,6	7,2			
20	0,48	1,2	2,36			
21	0,56	1,44	2,88	0,84	2,08	4,16
22	0,48	1,2	2,44			
23	1,28	3,2	6,4			
24	1,04	2,6	5,2	0,96	2,32	4,68
25	0,48	1,2	2,36			
26	0,64	1,56	3,08			
27	0,64	1,56	3,16	0,56	1,44	2,88
28	0,8	1,96	3,96			
29	0,48	1,2	2,36			
30	0,48	1,2	2,36	0,6	1,44	2,88
31	0,48	1,2	2,4			
32	0,92	2,28	4,6			
33	1,08	2,64	5,28	0,84	2,04	4,08
34	0,48	1,2	2,4			
35	0,92	2,24	4,48			
36	0,84	2,08	4,2	0,76	1,84	3,68

APPENDIX 3: RESULTS FROM FIELD WORK

18.03.17 PART 1: MEASURED WATER ON ROAD SURFACE

Wettex areal [m²]:			0,10865					
Position	**NR**	**Weight before**	**Weight after**	**Water [g]**	**Road temperature**	**Air temperature**	**Time of day**	**Water on road surface [g/m2]**
1R	1	22,6	62,7	40,1	4,4	3,6	10:30	369,1
1C	2	22,7	39,7	17				156,5
1L	3	22,2	34,2	12				110,4
2R	4	22,7	37,5	14,8	4,8	3,6	10:42	136,2
2C	5	23	53	30				276,1
2L	6	23,1	58,5	35,4				325,8
3R	7	22,8	30,5	7,7	4,6	3,6	10:53	70,9
3C	8	23,8	32,5	8,7				80,1
3L	9	22,3	31,6	9,3				85,6
1R	10	22,6	81,1	58,5	4,3	2,3	11:10	538,4
1C	11	22,9	38,6	15,7				144,5
1L	12	22,5	33,5	11				101,2
2R	13	22,6	33,8	11,2	5,3	2,3	11:17	103,1
2C	14	22,2	43,3	21,1				194,2
2L	15	22,4	41	18,6				171,2
3R	16	22,5	35,4	12,9	4,3	2,3	11:23	118,7
3C	17	22,5	39	16,5				151,9
3L	18	22,4	29,7	7,3				67,2
1R	19	22,3	50,3	28	4,6	2,1	12:00	257,7
1C	20	22,1	27,5	5,4				49,7
1L	21	22,3	25,8	3,5				32,2
2R	22	22,7	27,9	5,2	5,5	2,1	12:06	47,9
2C	23	22,6	32,2	9,6				88,4
2L	24	23,2	40,9	17,7				162,9
3R	25	22,7	27,9	5,2	5,7	2,1	12:14	47,9
3C	26	22,7	29,2	6,5				59,8
3L	27	22,6	23,9	1,3				12,0
1R	28	22,8	33,6	10,8	2,8	1,2	13:00	99,4
1C	29	22,5	29,8	7,3				67,2
1L	30	22,6	24,7	2,1				19,3
2R	31	22,6	24,6	2	3,3	1,2	13:06	18,4
2C	32	22,6	29,2	6,6				60,7
2L	33	22,7	30,3	7,6				69,9
3R	34	23	25,5	2,5	4	1,2	13:14	23,0
3C	35	22	25	3				27,6
3L	36	22,3	22,7	0,4				3,7

APPENDIX 3: RESULTS FROM FIELD WORK

Wettex areal [m²]:	0,10865							
Position	**NR**	**Weight before**	**Weight after**	**Water [g]**	**Road temperature**	**Air temperature**	**Time of day**	**Water on road surface [g/m2]**
1R	37	22,4	25,3	2,9	7,2	2,5	14:00	26,7
1C	38	22,4	28,5	6,1				56,1
1L	39	22,9	24,6	1,7				15,6
2R	40	22,7	23,6	0,9	5,5	2,5	14:07	8,3
2C	41	22,6	26,6	4				36,8
2L	42	21,9	24,2	2,3				21,2
3R	43	21,4	21,7	0,3	6,2	2,5	14:13	2,8
3C	44	20,6	20,8	0,2				1,8
3L	45	21,5	21,9	0,4				3,7

18.03.17 PART 2: CALCULATION OF NEED FOR SALT

NR	Tf= -1 °C [1,7% NaCl]	Tf= -2,5 °C [4,1% NaCl]	Tf= -5 °C [7,9% NaCl]	Average [1,7% NaCl]	Average [4,1% NaCl]	Average [7,9% NaCl]
1	6,4	15,8	31,7			
2	2,7	6,7	13,4			
3	1,9	4,7	9,5	*3,7*	*9,1*	*18,2*
4	2,4	5,8	11,7			
5	4,8	11,8	23,7			
6	5,6	13,9	27,9	*4,3*	*10,5*	*21,1*
7	1,2	3	6,1			
8	1,4	3,4	6,9			
9	1,5	3,7	7,3	*1,4*	*3,4*	*6,8*
10	9,3	23	46,2			
11	2,5	6,2	12,4			
12	1,8	4,3	8,7	*4,5*	*11,2*	*22,4*
13	1,8	4,4	8,8			
14	3,4	8,3	16,7			
15	3	7,3	14,7	*2,7*	*6,7*	*13,4*
16	2,1	5,1	10,2			
17	2,6	6,5	13			
18	1,2	2,9	5,8	*1,9*	*4,8*	*9,7*
19	4,5	11	22,1			
20	0,9	2,1	4,3			
21	0,6	1,4	2,8	*2*	*4,8*	*9,7*

APPENDIX 3: RESULTS FROM FIELD WORK

NR	Tf= -1 °C [1,7% NaCl]	Tf= -2,5 °C [4,1% NaCl]	Tf= -5 °C [7,9% NaCl]	Average [1,7% NaCl]	Average [4,1% NaCl]	Average [7,9% NaCl]
22	0,8	2	4,1			
23	1,5	3,8	7,6			
24	2,8	7	14	*1,7*	*4,3*	*8,6*
25	0,8	2	4,1			
26	1	2,6	5,1			
27	0,2	0,5	1	*0,7*	*1,7*	*3,4*
28	1,7	4,2	8,5			
29	1,2	2,9	5,8			
30	0,3	0,8	1,7	*1,1*	*2,6*	*5,3*
31	0,3	0,8	1,6			
32	1,1	2,6	5,2			
33	1,2	3	6	*0,9*	*2,1*	*4,3*
34	0,4	1	2			
35	0,5	1,2	2,4			
36	0,1	0,2	0,3	*0,3*	*0,8*	*1,6*
37	0,5	1,1	2,3			
38	1	2,4	4,8			
39	0,3	0,7	1,3	*0,6*	*1,4*	*2,8*
40	0,1	0,4	0,7			
41	0,6	1,6	3,2			
42	0,4	0,9	1,8	*0,4*	*0,9*	*1,9*
43	0	0,1	0,2			
44	0	0,1	0,2			
45	0,1	0,2	0,3	*0*	*0,1*	*0,2*

APPENDIX 3: RESULTS FROM FIELD WORK

NR	0,4 x [1,7% NaCl]	0,4 x [4,1% NaCl]	0,4 x [7,9% NaCl]	0,4 x Average [1,7% NaCl]	0,4 x Average [4,1% NaCl]	0,4 x Average [7,9% NaCl]
1	2,56	6,32	12,68			
2	1,08	2,68	5,36			
3	0,76	1,88	3,8	1,48	3,64	7,28
4	0,96	2,32	4,68			
5	1,92	4,72	9,48			
6	2,24	5,56	11,16	1,72	4,2	8,44
7	0,48	1,2	2,44			
8	0,56	1,36	2,76			
9	0,6	1,48	2,92	0,56	1,36	2,72
10	3,72	9,2	18,48			
11	1	2,48	4,96			
12	0,72	1,72	3,48	1,8	4,48	8,96
13	0,72	1,76	3,52			
14	1,36	3,32	6,68			
15	1,2	2,92	5,88	1,08	2,68	5,36
16	0,84	2,04	4,08			
17	1,04	2,6	5,2			
18	0,48	1,16	2,32	0,76	1,92	3,88
19	1,8	4,4	8,84			
20	0,36	0,84	1,72			
21	0,24	0,56	1,12	0,8	1,92	3,88
22	0,32	0,8	1,64			
23	0,6	1,52	3,04			
24	1,12	2,8	5,6	0,68	1,72	3,44
25	0,32	0,8	1,64			
26	0,4	1,04	2,04			
27	0,08	0,2	0,4	0,28	0,68	1,36
28	0,68	1,68	3,4			
29	0,48	1,16	2,32			
30	0,12	0,32	0,68	0,44	1,04	2,12
31	0,12	0,32	0,64			
32	0,44	1,04	2,08			
33	0,48	1,2	2,4	0,36	0,84	1,72
34	0,16	0,4	0,8			
35	0,2	0,48	0,96			
36	0,04	0,08	0,12	0,12	0,32	0,64

APPENDIX 3: RESULTS FROM FIELD WORK

NR	0,4 x [1,7% NaCl]	0,4 x [4,1% NaCl]	0,4 x [7,9% NaCl]	0,4 x Average [1,7% NaCl]	0,4 x Average [4,1% NaCl]	0,4 x Average [7,9% NaCl]
37	0,2	0,44	0,92			
38	0,4	0,96	1,92			
39	0,12	0,28	0,52	0,24	0,56	1,12
40	0,04	0,16	0,28			
41	0,24	0,64	1,28			
42	0,16	0,36	0,72	0,16	0,36	0,76
43	0	0,04	0,08			
44	0	0,04	0,08			
45	0,04	0,08	0,12	0	0,04	0,08

APPENDIX 3: RESULTS FROM FIELD WORK

28.03.17 PART 1: MEASURED WATER ON ROAD SURFACE

Wettex areal [m²]:		0,10865						
Position	**NR**	**Weight before**	**Weight after**	**Water [g]**	**Road temperature**	**Air temperature**	**Time of day**	**Water on road surface [g/m2]**
1R	1	22,4	33,5	11,1	1,1	3,2	09:15	102,2
1C	2	22,7	28,6	5,9				54,3
1L	3	22,1	29,7	7,6				69,9
2R	4	22,1	29,4	7,3	1,2	3,2	09:22	67,2
2C	5	22,6	28,6	6				55,2
2L	6	22,3	28,5	6,2				57,1
3R	7	22,7	30,1	7,4	0,9	3,2	09:29	68,1
3C	8	22,9	29,6	6,7				61,7
3L	9	22,8	29,7	6,9				63,5
1R	10	23,1	29,7	6,6	2,3	3,4	10:00	60,7
1C	11	22,5	27,4	4,9				45,1
1L	12	22,8	28,9	6,1				56,1
2R	13	22,6	29,9	7,3	2,2	3,4	10:07	67,2
2C	14	22,3	27,8	5,5				50,6
2L	15	22,4	27,4	5				46,0
3R	16	22,9	29,5	6,6	2,2	3,4	10:14	60,7
3C	17	22,4	28,3	5,9				54,3
3L	18	22,6	27,9	5,3				48,8
1R	19	23,2	28,4	5,2	2,5	3,3	11:00	47,9
1C	20	22,6	26,7	4,1				37,7
1L	21	22,3	27,5	5,2				47,9
2R	22	22,7	28,7	6	2,6	3,3	11:06	55,2
2C	23	22,9	26,6	3,7				34,1
2L	24	22,2	27,2	5				46,0
3R	25	20,9	26,4	5,5	2,5	3,3	11:14	50,6
3C	26	22,1	27,1	5				46,0
3L	27	22,6	26,2	3,6				33,1
1R	28	22,8	25,3	2,5	2,5	3	12:00	23,0
1C	29	22,5	26,3	3,8				35,0
1L	30	22,6	27,1	4,5				41,4
2R	31	22,6	27,5	4,9	2,5	3	12:07	45,1
2C	32	22,6	26,3	3,7				34,1
2L	33	22,7	26,9	4,2				38,7
3R	34	23	27,5	4,5	2,5	3	12:15	41,4
3C	35	22	26,5	4,5				41,4
3L	36	22,3	25,9	3,6				33,1

APPENDIX 3: RESULTS FROM FIELD WORK

Position	NR	Weight before	Weight after	Water [g]	Road temperature	Air temperature	Time of day	Water on road surface [g/m2]
1R	37	22,4	24,9	2,5	2,8	3,9	15:10	23
1C	38	21,4	25,2	3,8				35
1L	39	22,9	25,8	2,9				26,7
2R	40	22,7	25,9	3,2	2,6	3,9	15:17	29,5
2C	41	22,7	25,4	2,7				24,9
2L	42	21,9	25,6	3,7				34,1
3R	43	22,5	26,9	4,4	2,8	3,9	15:24	40,5
3C	44	21,9	25,7	3,8				35
3L	45	22,6	25,1	2,5				23

28.03.17 PART 2: CALCULATION OF NEED FOR SALT

NR	Tf= -1 °C [1,7% NaCl]	Tf= -2,5 °C [4,1% NaCl]	Tf= -5 °C [7,9% NaCl]	Average [1,7% NaCl]	Average [4,1% NaCl]	Average [7,9% NaCl]
1	1,8	4,4	8,8			
2	0,9	2,3	4,7			
3	1,2	3	6	*1,3*	*3,2*	*6,5*
4	1,2	2,9	5,8			
5	1	2,4	4,7			
6	1	2,4	4,9	*1*	*2,6*	*5,1*
7	1,2	2,9	5,8			
8	1,1	2,6	5,3			
9	1,1	2,7	5,4	*1,1*	*2,8*	*5,5*
10	1,1	2,6	5,2			
11	0,8	1,9	3,9			
12	1	2,4	4,8	*0,9*	*2,3*	*4,6*
13	1,2	2,9	5,8			
14	0,9	2,2	4,3			
15	0,8	2	3,9	*0,9*	*2,3*	*4,7*
16	1,1	2,6	5,2			
17	0,9	2,3	4,7			
18	0,8	2,1	4,2	*0,9*	*2,3*	*4,7*
19	0,8	2	4,1			
20	0,7	1,6	3,2			
21	0,8	2	4,1	*0,8*	*1,9*	*3,8*

APPENDIX 3: RESULTS FROM FIELD WORK

NR	Tf= -1 °C [1,7% NaCl]	Tf= -2,5 °C [4,1% NaCl]	Tf= -5 °C [7,9% NaCl]	Average [1,7% NaCl]	Average [4,1% NaCl]	Average [7,9% NaCl]
22	1	2,4	4,7			
23	0,6	1,5	2,9			
24	0,8	2	3,9	*0,8*	*1,9*	*3,9*
25	0,9	2,2	4,3			
26	0,8	2	3,9			
27	0,6	1,4	2,8	*0,7*	*1,8*	*3,7*
28	0,4	1	2			
29	0,6	1,5	3			
30	0,7	1,8	3,6	*0,6*	*1,4*	*2,8*
31	0,8	1,9	3,9			
32	0,6	1,5	2,9			
33	0,7	1,7	3,3	*0,7*	*1,7*	*3,4*
34	0,7	1,8	3,6			
35	0,7	1,8	3,6			
36	0,6	1,4	2,8	*0,7*	*1,7*	*3,3*
37	0,4	1	2			
38	0,6	1,5	3			
39	0,5	1,1	2,3	*0,5*	*1,2*	*2,4*
40	0,5	1,3	2,5			
41	0,4	1,1	2,1			
42	0,6	1,5	2,9	*0,5*	*1,3*	*2,5*
43	0,7	1,7	3,5			
44	0,6	1,5	3			
45	0,4	1	2	*0,6*	*1,4*	*2,8*

APPENDIX 3: RESULTS FROM FIELD WORK

NR	0,4 x [1,7% NaCl]	0,4 x [4,1% NaCl]	0,4 x [7,9% NaCl]	0,4 x Average [1,7% NaCl]	0,4 x Average [4,1% NaCl]	0,4 x Average [7,9% NaCl]
1	0,72	1,76	3,52			
2	0,36	0,92	1,88			
3	0,48	1,2	2,4	0,52	1,28	2,6
4	0,48	1,16	2,32			
5	0,4	0,96	1,88			
6	0,4	0,96	1,96	0,4	1,04	2,04
7	0,48	1,16	2,32			
8	0,44	1,04	2,12			
9	0,44	1,08	2,16	0,44	1,12	2,2
10	0,44	1,04	2,08			
11	0,32	0,76	1,56			
12	0,4	0,96	1,92	0,36	0,92	1,84
13	0,48	1,16	2,32			
14	0,36	0,88	1,72			
15	0,32	0,8	1,56	0,36	0,92	1,88
16	0,44	1,04	2,08			
17	0,36	0,92	1,88			
18	0,32	0,84	1,68	0,36	0,92	1,88
19	0,32	0,8	1,64			
20	0,28	0,64	1,28			
21	0,32	0,8	1,64	0,32	0,76	1,52
22	0,4	0,96	1,88			
23	0,24	0,6	1,16			
24	0,32	0,8	1,56	0,32	0,76	1,56
25	0,36	0,88	1,72			
26	0,32	0,8	1,56			
27	0,24	0,56	1,12	0,28	0,72	1,48
28	0,16	0,4	0,8			
29	0,24	0,6	1,2			
30	0,28	0,72	1,44	0,24	0,56	1,12
31	0,32	0,76	1,56			
32	0,24	0,6	1,16			
33	0,28	0,68	1,32	0,28	0,68	1,36
34	0,28	0,72	1,44			
35	0,28	0,72	1,44			
36	0,24	0,56	1,12	0,28	0,68	1,32

APPENDIX 3: RESULTS FROM FIELD WORK

NR	0,4 x [1,7% NaCl]	0,4 x [4,1% NaCl]	0,4 x [7,9% NaCl]	0,4 x Average [1,7% NaCl]	0,4 x Average [4,1% NaCl]	0,4 x Average [7,9% NaCl]
37	0,16	0,4	0,8			
38	0,24	0,6	1,2			
39	0,2	0,44	0,92	0,2	0,48	0,96
40	0,2	0,52	1			
41	0,16	0,44	0,84			
42	0,24	0,6	1,16	0,2	0,52	1
43	0,28	0,68	1,4			
44	0,24	0,6	1,2			
45	0,16	0,4	0,8	0,24	0,56	1,12

APPENDIX 3: RESULTS FROM FIELD WORK

22.04.17 PART 1: MEASURED WATER ON ROAD SURFACE

Wettex areal [m²]:		0,10865						
Position	NR	Weight before	Weight after	Water [g]	Road temperature	Air temperature	Time of day	Water on road surface [g/m2]
1R	1	21,9	49,8	27,9	0,8	2,8	14:16	256,8
1C	2	22,4	47,3	24,9				229,2
1L	3	23,2	38,6	15,4				141,7
2R	4	22,3	35,8	13,5	0,9	2,8	14:09	124,3
2C	5	22,4	36,7	14,3				131,6
2L	6	21,7	38,8	17,1				157,4
3R	7	21,1	30,5	9,4	0,7	2,8	14:00	86,5
3C	8	23,1	30,7	7,6				69,9
3L	9	22,1	34,9	12,8				117,8
1R	10	21,7	63,2	41,5	0,7	2,5	15:34	382
1C	11	22,8	54,2	31,4				289
1L	12	22,6	52,7	30,1				277
2R	13	22,4	45,3	22,9	0,9	2,5	15:22	210,8
2C	14	22,3	42	19,7				181,3
2L	15	22,4	43,6	21,2				195,1
3R	16	21,8	38,7	16,9	0,6	2,5	15:15	155,5
3C	17	22,3	33,4	11,1				102,2
3L	18	22,6	35,6	13				119,7
1R	19	23,7	46,7	23	2,8	3,9	16:28	211,7
1C	20	20,9	44,5	23,6				217,2
1L	21	22,2	42,3	20,1				185
2R	22	22,1	38,6	16,5	1,9	3,9	16:23	151,9
2C	23	23,1	36,6	13,5				124,3
2L	24	22,5	33,4	10,9				100,3
3R	25	22,8	31,2	8,4	2,3	3,9	16:15	77,3
3C	26	22,8	29,8	7				64,4
3L	27	22,7	28,7	6				55,2
1R	28	21,9	34,3	12,4	2,8	4,7	17:29	114,1
1C	29	21,4	37,8	16,4				150,9
1L	30	22,1	33,4	11,3				104
2R	31	23	33,7	10,7	2,5	4,7	17:22	98,5
2C	32	22,9	26,3	3,4				31,3
2L	33	21,1	27	5,9				54,3
3R	34	22,3	24,9	2,6	2,3	4,7	17:15	23,9
3C	35	21,9	23,5	1,6				14,7
3L	36	21,8	22,1	0,3				2,8

APPENDIX 3: RESULTS FROM FIELD WORK

22.04.17 PART 2: CALCULATION OF NEED FOR SALT

NR	Tf= -1 °C [1,7% NaCl]	Tf= -2,5 °C [4,1% NaCl]	Tf= -5 °C [7,9% NaCl]	Average [1,7% NaCl]	Average [4,1% NaCl]	Average [7,9% NaCl]
1	4,4	11	22			
2	4	9,8	19,7			
3	2,5	6,1	12,2	*3,6*	*8,9*	*17,9*
4	2,1	5,3	10,7			
5	2,3	5,6	11,3			
6	2,7	6,7	13,5	*2,4*	*5,9*	*11,8*
7	1,5	3,7	7,4			
8	1,2	3	6			
9	2	5	10,1	*1,6*	*3,9*	*7,8*
10	6,6	16,3	32,8			
11	5	12,4	24,8			
12	4,8	11,8	23,8	*5,5*	*13,5*	*27,1*
13	3,6	9	18,1			
14	3,1	7,8	15,6			
15	3,4	8,3	16,7	*3,4*	*8,4*	*16,8*
16	2,7	6,7	13,3			
17	1,8	4,4	8,8			
18	2,1	5,1	10,3	*2,2*	*5,4*	*10,8*
19	3,7	9,1	18,2			
20	3,8	9,3	18,6			
21	3,2	7,9	15,9	*3,5*	*8,7*	*17,6*
22	2,6	6,5	13			
23	2,1	5,3	10,7			
24	1,7	4,3	8,6	*2,2*	*5,4*	*10,8*
25	1,3	3,3	6,6			
26	1,1	2,8	5,5			
27	1	2,4	4,7	*1,1*	*2,8*	*5,6*
28	2	4,9	9,8			
29	2,6	6,5	12,9			
30	1,8	4,4	8,9	*2,1*	*5,3*	*10,6*
31	1,7	4,2	8,4			
32	0,5	1,3	2,7			
33	0,9	2,3	4,7	*1,1*	*2,6*	*5,3*
34	0,4	1	2,1			
35	0,3	0,6	1,3			
36	0	0,1	0,2	*0,2*	*0,6*	*1,2*

APPENDIX 3: RESULTS FROM FIELD WORK

NR	0,4 x [1,7% NaCl]	0,4 x [4,1% NaCl]	0,4 x [7,9% NaCl]	0,4 x Average [1,7% NaCl]	0,4 x Average [4,1% NaCl]	0,4 x Average [7,9% NaCl]
1	1,76	4,4	8,8			
2	1,6	3,92	7,88			
3	1	2,44	4,88	1,44	3,56	7,16
4	0,84	2,12	4,28			
5	0,92	2,24	4,52			
6	1,08	2,68	5,4	0,96	2,36	4,72
7	0,6	1,48	2,96			
8	0,48	1,2	2,4			
9	0,8	2	4,04	0,64	1,56	3,12
10	2,64	6,52	13,12			
11	2	4,96	9,92			
12	1,92	4,72	9,52	2,2	5,4	10,84
13	1,44	3,6	7,24			
14	1,24	3,12	6,24			
15	1,36	3,32	6,68	1,36	3,36	6,72
16	1,08	2,68	5,32			
17	0,72	1,76	3,52			
18	0,84	2,04	4,12	0,88	2,16	4,32
19	1,48	3,64	7,28			
20	1,52	3,72	7,44			
21	1,28	3,16	6,36	1,4	3,48	7,04
22	1,04	2,6	5,2			
23	0,84	2,12	4,28			
24	0,68	1,72	3,44	0,88	2,16	4,32
25	0,52	1,32	2,64			
26	0,44	1,12	2,2			
27	0,4	0,96	1,88	0,44	1,12	2,24
28	0,8	1,96	3,92			
29	1,04	2,6	5,16			
30	0,72	1,76	3,56	0,84	2,12	4,24
31	0,68	1,68	3,36			
32	0,2	0,52	1,08			
33	0,36	0,92	1,88	0,44	1,04	2,12
34	0,16	0,4	0,84			
35	0,12	0,24	0,52			
36	0	0,04	0,08	0,08	0,24	0,48

APPENDIX 4: SAND PATCH

OBSERVATION POINT 1

Position	Diameter [mm]	Roughness $rh=38200/d^2$
1R	232	0,7
	225	0,8
	226	0,7
	225	0,8
Average:	*227*	*0,7*
1C	216	0,8
	207	0,9
	200	1,0
	234	0,7
Average	*214,25*	*0,8*
1L	232	0,7
	217	0,8
	221	0,8
	229	0,7
Average:	*224,75*	*0,8*
Total roughness		**0,8**

OBSERVATION POINT 2

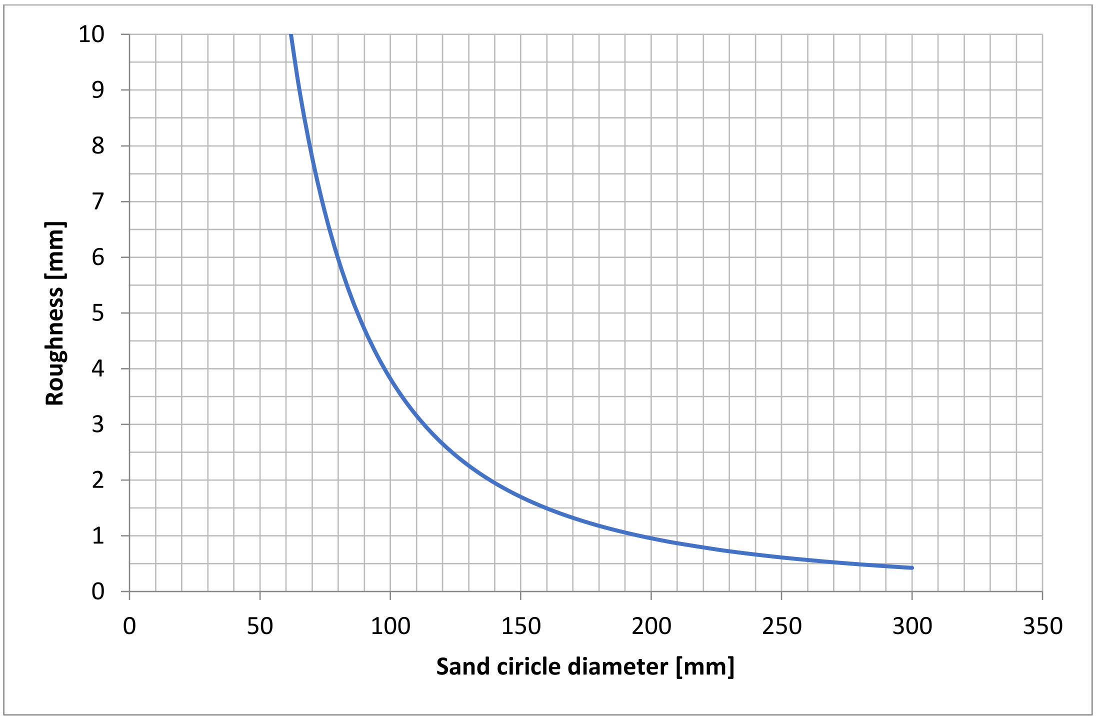
Position	Diameter [mm]	Roughness $rh=38200/d^2$
2R	255	0,6
	233	0,7
	242	0,7
	249	0,6
Average:	*244,75*	*0,6*
2C	232	0,7
	227	0,7
	231	0,7
	232	0,7
Average:	*230,5*	*0,7*
2L	230	0,7
	228	0,7
	229	0,7
	228	0,7
Average:	*228,75*	*0,7*
Total roughness		**0,7**

APPENDIX 4: SAND PATCH

OBSERVATION POINT 3

Position	Diameter [mm]	Roughness $rh=38200/d^2$
3R	212	0,8
	205	0,9
	206	0,9
	202	0,9
Average:	*206,25*	*0,9*
3C	221	0,8
	212	0,8
	221	0,8
	230	0,7
Average:	*221*	*0,8*
3L	222	0,8
	201	0,9
	203	0,9
	224	0,8
Average:	*212,5*	*0,8*
Total roughness		**0,8**

SURFACE ROUGHNESS: SANDPATCH

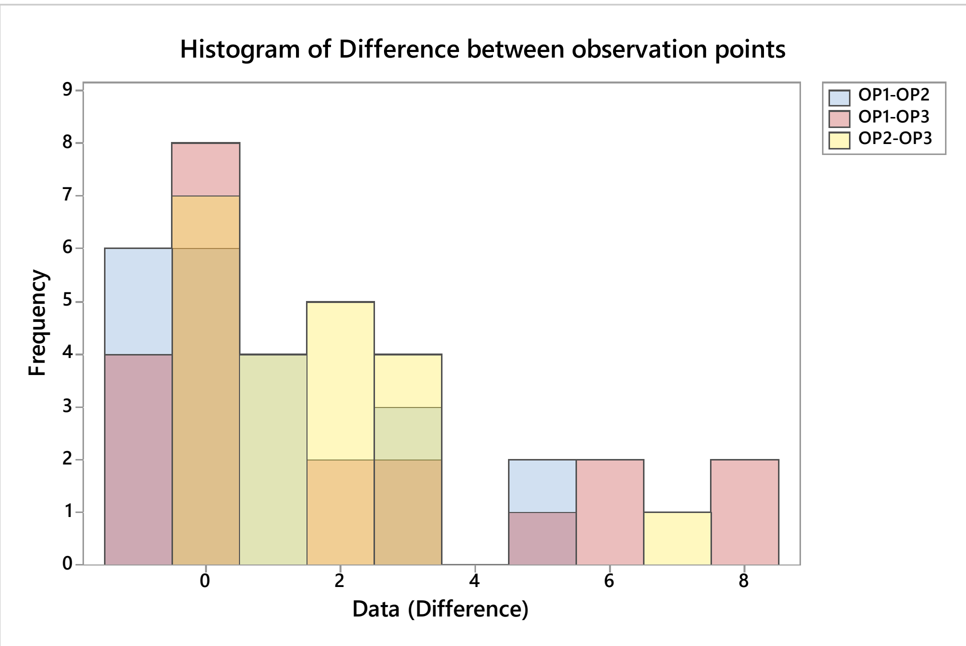


APPENDIX 5: RESULTS FROM MINITAB: TWO SAMPLE T-TEST

INPUT DATA FOR MEASURING AND OBSERVATION POINTS [Tf = -5 C°]

***Red numbers are neglected from the calculations in MiniTab**

1R	1C	1L	2R	2C	2L	3R	3C	3L	OP1	OP2	OP3
2,04	4,20	1,92	2,08	4,56	3,52	3,08	3,28	2,68	2,72	3,4	3
2,16	3,92	2,40	2,76	4,08	4,52	2,68	2,16	3,48	2,84	3,8	2,76
1,52	1,96	1,48	2,32	2,92	2,80	2,32	2,64	3,32	1,64	2,68	2,76
8,56	6,00	5,64	4,28	8,92	6,72	4,84	5,52	4,32	6,72	6,64	4,88
9,68	4,16	4,08	3,28	8,60	6,60	3,24	4,48	3,72	5,96	6,16	3,8
7,20	2,36	2,88	2,44	6,40	5,20	2,36	3,08	3,16	4,16	4,68	2,88
3,96	2,36	2,36	2,40	4,60	5,28	2,40	4,48	4,20	2,88	4,08	3,68
12,68	5,36	3,80	4,68	9,48	11,16	2,44	2,76	2,92	7,28	8,44	2,72
18,48	4,96	3,48	3,52	6,68	5,88	4,08	5,20	2,32	8,96	5,36	3,88
8,84	1,72	1,12	1,64	3,04	5,60	1,64	2,04	0,40	3,88	3,44	1,36
3,40	2,32	0,68	0,64	2,08	2,40	0,80	0,96	0,12	2,12	1,72	0,64
0,92	1,92	0,52	0,28	1,28	0,72	0,08	0,08	0,12	1,12	0,76	0,08
3,52	1,88	2,40	2,32	1,88	1,96	2,32	2,12	2,16	2,6	2,04	2,2
2,08	1,56	1,92	2,32	1,72	1,56	2,08	1,88	1,68	1,84	1,88	1,88
1,64	1,28	1,64	1,88	1,16	1,56	1,72	1,56	1,12	1,52	1,56	1,48
0,80	1,20	1,44	1,56	1,16	1,32	1,44	1,44	1,12	1,12	1,36	1,32
0,80	1,20	0,92	1,00	0,84	1,16	1,40	1,20	0,80	0,96	1	1,12
8,8	7,88	4,88	4,28	4,52	5,4	2,96	2,4	4,04	7,16	4,72	3,12
13,12	9,92	9,52	7,24	6,24	6,68	5,32	3,52	4,12	10,84	6,72	4,32
7,28	7,44	6,36	5,2	4,28	3,44	2,64	2,2	1,88	7,04	4,32	2,24
3,92	5,16	3,56	3,36	1,08	1,88	0,84	0,52	0,08	4,24	2,12	0,48



APPENDIX 5: RESULTS FROM MINITAB: TWO SAMPLE T-TEST

TWO-SAMPLE TWO-TAILED T-TEST BETWEEN OBSERVATION POINTS

Two-sample T for OP1 vs OP2

	N	Mean	StDev	SE Mean
OP1	21	5,20	3,57	0,78
OP2	21	4,56	2,67	0,58

Difference = μ (OP1) - μ (OP2)
Estimate for difference: 0,638
95% CI for difference: (-1,332; 2,609)
T-Test of difference = 0 (vs ≠): T-Value = 0,66 P-Value = 0,516 DF = 37

Two-sample T for OP1 vs OP3

	N	Mean	StDev	SE Mean
OP1	21	5,20	3,57	0,78
OP3	21	3,01	1,63	0,36

Difference = μ (OP1) - μ (OP3)
Estimate for difference: 2,186
95% CI for difference: (0,432; 3,940)
T-Test of difference = 0 (vs ≠): T-Value = 2,55 P-Value = 0,016 DF = 28

Two-sample T for OP2 vs OP3

	N	Mean	StDev	SE Mean
OP2	21	4,56	2,67	0,58
OP3	21	3,01	1,63	0,36

Difference = μ (OP2) - μ (OP3)
Estimate for difference: 1,548
95% CI for difference: (0,157; 2,938)
T-Test of difference = 0 (vs ≠): T-Value = 2,26 P-Value = 0,030 DF = 33

APPENDIX 5: RESULTS FROM MINITAB: TWO SAMPLE T-TEST

TWO-SAMPLE ONE-TAILED T-TEST BETWEEN OBSERVATION POINTS

Two-sample T for OP1 vs OP3

	N	Mean	StDev	SE Mean
OP1	21	5,20	3,57	0,78
OP3	21	3,01	1,63	0,36

Difference = μ (OP1) - μ (OP3)
Estimate for difference: 2,186
95% lower bound for difference: 0,729
T-Test of difference = 0 (vs >): T-Value = 2,55 P-Value = 0,008 DF = 28

Two-sample T for OP2 vs OP3

	N	Mean	StDev	SE Mean
OP2	21	4,56	2,67	0,58
OP3	21	3,01	1,63	0,36

Difference = μ (OP2) - μ (OP3)
Estimate for difference: 1,548
95% lower bound for difference: 0,391
T-Test of difference = 0 (vs >): T-Value = 2,26 P-Value = 0,015 DF = 33

Two-sample T for OP1 vs OP2

	N	Mean	StDev	SE Mean
OP1	21	5,20	3,57	0,78
OP2	21	4,56	2,67	0,58

Difference = μ (OP1) - μ (OP2)
Estimate for difference: 0,638
95% lower bound for difference: -1,003
T-Test of difference = 0 (vs >): T-Value = 0,66 P-Value = 0,258 DF = 37

Two-sample T for OP2 vs OP1

	N	Mean	StDev	SE Mean
OP2	21	4,56	2,67	0,58
OP1	21	5,20	3,57	0,78

Difference = μ (OP2) - μ (OP1)
Estimate for difference: -0,638
95% lower bound for difference: -2,279
T-Test of difference = 0 (vs >): T-Value = -0,66 P-Value = 0,742 DF = 3

APPENDIX 5: RESULTS FROM MINITAB: TWO SAMPLE T-TEST

TWO-SAMPLE TWO-TAILED T-TEST BETWEEN MEASURING POINTS

Two-sample T for 1R vs 1C

	N	Mean	StDev	SE Mean
1R	21	7,20	6,07	1,3
1C	21	4,67	3,11	0,68

Difference = μ (1R) - μ (1C)
Estimate for difference: 2,52
95% CI for difference: (-0,52; 5,57)
T-Test of difference = 0 (vs ≠): T-Value = 1,70 P-Value = 0,101 DF = 29

Two-sample T for 1R vs 1L

	N	Mean	StDev	SE Mean
1R	21	7,20	6,07	1,3
1L	21	3,73	2,73	0,59

Difference = μ (1R) - μ (1L)
Estimate for difference: 3,46
95% CI for difference: (0,48; 6,44)
T-Test of difference = 0 (vs ≠): T-Value = 2,39 P-Value = 0,024 DF = 27

Two-sample T for 1C vs 1L

	N	Mean	StDev	SE Mean
1C	21	4,67	3,11	0,68
1L	21	3,73	2,73	0,59

Difference = μ (1C) - μ (1L)
Estimate for difference: 0,941
95% CI for difference: (-0,884; 2,765)
T-Test of difference = 0 (vs ≠): T-Value = 1,04 P-Value = 0,303 DF = 39

Two-sample T for 2R vs 2C

	N	Mean	StDev	SE Mean
2R	21	3,53	2,05	0,45
2C	21	5,08	3,43	0,75

Difference = μ (2R) - μ (2C)
Estimate for difference: -1,546
95% CI for difference: (-3,321; 0,229)
T-Test of difference = 0 (vs ≠): T-Value = -1,77 P-Value = 0,086 DF = 32

APPENDIX 5: RESULTS FROM MINITAB: TWO SAMPLE T-TEST

Two-sample T for 2R vs 2L

	N	Mean	StDev	SE Mean
2R	21	3,53	2,05	0,45
2L	21	5,07	3,24	0,71

Difference = μ (2R) - μ (2L)
Estimate for difference: -1,540
95% CI for difference: (-3,241; 0,160)
T-Test of difference = 0 (vs ≠): T-Value = -1,84 P-Value = 0,074 DF = 33

Two-sample T for 2C vs 2L

	N	Mean	StDev	SE Mean
2C	21	5,08	3,43	0,75
2L	21	5,07	3,24	0,71

Difference = μ (2C) - μ (2L)
Estimate for difference: 0,01
95% CI for difference: (-2,08; 2,09)
T-Test of difference = 0 (vs ≠): T-Value = 0,01 P-Value = 0,996 DF = 39

Two-sample T for 3R vs 3C

	N	Mean	StDev	SE Mean
3R	21	3,01	1,59	0,35
3C	21	3,18	1,84	0,40

Difference = μ (3R) - μ (3C)
Estimate for difference: -0,171
95% CI for difference: (-1,241; 0,900)
T-Test of difference = 0 (vs ≠): T-Value = -0,32 P-Value = 0,749 DF = 39

Two-sample T for 3R vs 3L

	N	Mean	StDev	SE Mean
3R	21	3,01	1,59	0,35
3L	21	2,84	1,83	0,40

Difference = μ (3R) - μ (3L)
Estimate for difference: 0,167
95% CI for difference: (-0,903; 1,236)
T-Test of difference = 0 (vs ≠): T-Value = 0,32 P-Value = 0,754 DF = 39

APPENDIX 5: RESULTS FROM MINITAB: TWO SAMPLE T-TEST

Two-sample T for 3C vs 3L

	N	Mean	StDev	SE Mean
3C	21	3,18	1,84	0,40
3L	21	2,84	1,83	0,40

Difference = μ (3C) - μ (3L)
Estimate for difference: 0,337
95% CI for difference: (-0,807; 1,481)
T-Test of difference = 0 (vs ≠): T-Value = 0,60 P-Value = 0,554 DF = 39

Two-sample T for 1R vs 2R

	N	Mean	StDev	SE Mean
1R	21	7,20	6,07	1,3
2R	21	3,53	2,05	0,45

Difference = μ (1R) - μ (2R)
Estimate for difference: 3,67
95% CI for difference: (0,78; 6,55)
T-Test of difference = 0 (vs ≠): T-Value = 2,62 P-Value = 0,015 DF = 24

Two-sample T for 1R vs 3R

	N	Mean	StDev	SE Mean
1R	21	7,20	6,07	1,3
3R	21	3,01	1,59	0,35

Difference = μ (1R) - μ (3R)
Estimate for difference: 4,19
95% CI for difference: (1,35; 7,03)
T-Test of difference = 0 (vs ≠): T-Value = 3,06 P-Value = 0,006 DF = 22

Two-sample T for 2R vs 3R

	N	Mean	StDev	SE Mean
2R	21	3,53	2,05	0,45
3R	21	3,01	1,59	0,35

Difference = μ (2R) - μ (3R)
Estimate for difference: 0,525
95% CI for difference: (-0,620; 1,669)
T-Test of difference = 0 (vs ≠): T-Value = 0,93 P-Value = 0,359 DF = 37

APPENDIX 5: RESULTS FROM MINITAB: TWO SAMPLE T-TEST

Two-sample T for 1L vs 2L

	N	Mean	StDev	SE Mean
1L	21	3,73	2,73	0,59
2L	21	5,07	3,24	0,71

Difference = μ (1L) - μ (2L)
Estimate for difference: -1,338
95% CI for difference: (-3,208; 0,532)
T-Test of difference = 0 (vs ≠): T-Value = -1,45 P-Value = 0,156 DF = 38

Two-sample T for 1L vs 3L

	N	Mean	StDev	SE Mean
1L	21	3,73	2,73	0,59
3L	21	2,84	1,83	0,40

Difference = μ (1L) - μ (3L)
Estimate for difference: 0,894
95% CI for difference: (-0,562; 2,350)
T-Test of difference = 0 (vs ≠): T-Value = 1,25 P-Value = 0,221 DF = 34

Two-sample T for 2L vs 3L

	N	Mean	StDev	SE Mean
2L	21	5,07	3,24	0,71
3L	21	2,84	1,83	0,40

Difference = μ (2L) - μ (3L)
Estimate for difference: 2,232
95% CI for difference: (0,576; 3,887)
T-Test of difference = 0 (vs ≠): T-Value = 2,75 P-Value = 0,010 DF = 31

Two-sample T for 1C vs 2C

	N	Mean	StDev	SE Mean
1C	21	4,67	3,11	0,68
2C	21	5,08	3,43	0,75

Difference = μ (1C) - μ (2C)
Estimate for difference: -0,40
95% CI for difference: (-2,45; 1,64)
T-Test of difference = 0 (vs ≠): T-Value = -0,40 P-Value = 0,692 DF = 39

APPENDIX 5: RESULTS FROM MINITAB: TWO SAMPLE T-TEST

Two-sample T for 1C vs 3C

	N	Mean	StDev	SE Mean
1C	21	4,67	3,11	0,68
3C	21	3,18	1,84	0,40

Difference = μ (1C) - μ (3C)
Estimate for difference: 1,497
95% CI for difference: (-0,107; 3,101)
T-Test of difference = 0 (vs ≠): T-Value = 1,90 P-Value = 0,066 DF = 32

Two-sample T for 2C vs 3C

	N	Mean	StDev	SE Mean
2C	21	5,08	3,43	0,75
3C	21	3,18	1,84	0,40

Difference = μ (2C) - μ (3C)
Estimate for difference: 1,900
95% CI for difference: (0,167; 3,633)
T-Test of difference = 0 (vs ≠): T-Value = 2,24 P-Value = 0,033 DF = 30

APPENDIX 5: RESULTS FROM MINITAB: TWO SAMPLE T-TEST

TWO-SAMPLE ONE-TAILED T-TEST BETWEEN MEASURING POINTS

Two-sample T for 1R vs 1L

	N	Mean	StDev	SE Mean
1R	21	7,20	6,07	1,3
1L	21	3,73	2,73	0,59

Difference = μ (1R) - μ (1L)
Estimate for difference: 3,46
95% lower bound for difference: 0,99
T-Test of difference = 0 (vs >): T-Value = 2,39 P-Value = 0,012 DF = 27

Two-sample T for 1R vs 2R

	N	Mean	StDev	SE Mean
1R	21	7,20	6,07	1,3
2R	21	3,53	2,05	0,45

Difference = μ (1R) - μ (2R)
Estimate for difference: 3,67
95% lower bound for difference: 1,27
T-Test of difference = 0 (vs >): T-Value = 2,62 P-Value = 0,007 DF = 24

Two-sample T for 1R vs 3R

	N	Mean	StDev	SE Mean
1R	21	7,20	6,07	1,3
3R	21	3,01	1,59	0,35

Difference = μ (1R) - μ (3R)
Estimate for difference: 4,19
95% lower bound for difference: 1,84
T-Test of difference = 0 (vs >): T-Value = 3,06 P-Value = 0,003 DF = 22

Two-sample T for 2L vs 3L

	N	Mean	StDev	SE Mean
2L	21	5,07	3,24	0,71
3L	21	2,84	1,83	0,40

Difference = μ (2L) - μ (3L)
Estimate for difference: 2,232
95% lower bound for difference: 0,855
T-Test of difference = 0 (vs >): T-Value = 2,75 P-Value = 0,005 DF = 31

APPENDIX 5: RESULTS FROM MINITAB: TWO SAMPLE T-TEST

Two-sample T for 2C vs 3C

	N	Mean	StDev	SE Mean
2C	21	5,08	3,43	0,75
3C	21	3,18	1,84	0,40

Difference = μ (2C) - μ (3C)
Estimate for difference: 1,900
95% lower bound for difference: 0,460
T-Test of difference = 0 (vs >): T-Value = 2,24 P-Value = 0,016 DF = 30

APPENDIX 6: AVERAGE PERCENTAGES AND VALUES

DATASET FOR CALCULATION [Tf= -5°]

26.01.2017

Observation point 1	Time of day	Observation point 2	Time of day	Observation point 3	Time of day
2,72	09:30	3,4	09:45	3	09:55
2,84	10:30	3,8	10:41	2,76	10:52
1,64	14:30	2,68	14:36	2,76	14:43

22.02.2017

Observation point 1	Time of day	Observation point 2	Time of day	Observation point 3	Time of day
6,72	12:00	6,64	12:10	4,88	12:17
5,96	13:00	6,16	13:06	3,8	13:13
4,16	14:00	4,68	14:07	2,88	14:15
2,88	15:00	4,08	15:06	3,68	15:12

18.03.2017

Observation point 1	Time of day	Observation point 2	Time of day	Observation point 3	Time of day
7,28	10:30	8,44	10:42	2,72	10:53
8,96	11:10	5,36	11:17	3,88	11:23
3,88	12:00	3,44	12:06	1,36	12:14
2,12	13:00	1,72	13:06	0,64	13:14
1,12	14:00	0,76	14:07	0,08	14:13

28.03.2017

Observation point 1	Time of day	Observation point 2	Time of day	Observation point 3	Time of day
2,6	09:15	2,04	09:22	2,2	09:29
1,84	10:00	1,88	10:07	1,88	10:14
1,52	11:00	1,56	11:06	1,48	11:14
1,12	12:00	1,36	12:07	1,32	12:15
0,96	15:10	1	15:17	1,12	15:24

22.04.2017

Observation point 1	Time of day	Observation point 2	Time of day	Observation point 3	Time of day
7,16	14:16	4,72	14:09	3,12	14:00
10,84	15:34	6,72	15:22	4,32	15:15
7,04	16:28	4,32	16:23	2,24	16:15
4,24	17:29	2,12	17:22	0,48	17:15

APPENDIX 6: AVERAGE PERCENTAGES AND VALUES

AVERAGE PERCENTAGE OF DIFFERENCE

***Red numbers are neglected from the calculation of the average percentage**

[OP1-OP3]	([OP1-OP3]/OP3)*100%	[OP2-OP3]	([OP2-OP3]/OP3)*100%	[OP1-OP2]	([OP1-OP2]/OP2)*100%
26.01					
-0,3	-9,3	0,4	13,3	0,0	0,0
0,1	2,9	1,0	37,7	-1,0	-25,3
-1,12	-	-0,08	-	-1,04	-
	Average:		***Average:***		***Average:***
	-15,7		***16,0***		***-21,4***
22.02					
1,8	37,7	1,8	36,1	0,1	1,2
2,2	56,8	2,4	62,1	-0,2	-3,2
1,28	44,44444444	1,8	62,5	-0,52	-
-0,8	-21,7	0,4	10,9	-1,2	-29,4
	Average:		***Average:***		***Average:***
	29,3		***42,9***		***-10,6***
18.03					
4,6	167,6	5,7	210,3	-1,2	-13,7
5,08	130,9278351	1,48	38,1443299	3,6	67,1641791
2,5	185,3	2,1	152,9	0,4	12,8
1,5	231,3	1,1	168,8	0,4	23,3
1,04	1300	0,68	850	0,36	47,36842105
	Average:		***Average:***		***Average:***
	461,9		***302,5***		***37,6***
28.03					
0,4	18,2	-0,2	-7,3	0,6	27,5
0,0	-2,1	0,0	0,0	0,0	-2,1
0,04	2,702702703	0,08	5,405405405	-0,04	-
-0,2	-15,2	0,0	3,0	-0,2	-17,6
-0,2	-14,3	-0,1	-10,7	0,0	-4,0
	Average:		***Average:***		***Average:***
	-		***-1,91026091***		***0,222431886***
22.04					
4,04	129,4871795	1,6	51,28205128	2,4	51,69491525
6,5	150,9	2,4	55,6	4,1	61,3
4,8	214,3	2,1	92,9	2,7	63,0
3,76	783,3333333	1,64	341,6666667	2,12	100
	Average:		***Average:***		***Average:***
	382,8483245		***163,3597884***		***74,75749559***

Total [%]	***171,2443652***	**Total [%]**	***104,5664304***	**Total [%]**	***16,12542539***

APPENDIX 6: AVERAGE PERCENTAGES AND VALUES

AVERAGE VALUES FOR MEASURING POINTS [Tf= -5°]

Average Salt amount	Measuring point	Relative point 3.1
14,08433333	1.1	3,467908732
9,68	1.2	2,38345371
7,668666667	1.3	1,888214051
7,237333333	2.1	1,782009192
10,43866667	2.2	2,570256075
10,28866667	2.3	2,533322391
4,061333333	**3.1**	**1**
5,215	3.2	1,284061064
4,211666667	3.3	1,037015759