SWAMP

Background Report

- **literature, questionnaire and data collection for blue spot identification**

Report 2

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Report 2 – Background Report

- **literature, questionnaire and data collection for blue spot identification**

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1 Preface

The SWAMP project is part of an ERA-NET ROAD initiated transnational research programme called "Road Owners Getting to Grips with Climate Change". The four projects commissioned under this programme are funded jointly by the road administrations of Austria, Denmark, Finland, Germany, Ireland, Netherlands, Norway, Poland, Spain, Sweden and United Kingdom. The other three projects are:

IRWIN: Improved local Road WINter index to assess maintenance needs and adaptation costs in climate change scenarios

RIMAROCC: RIsk MAnagement for ROads in a Changing Climate

P2R2C2: Pavement Performance and Remediation Requirements following Climate Change

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1. Introduction

A lot of work is on-going in many European countries with regard to the impact of changing climate on roads and how to deal with the consequences either through mitigation or adaptation. And even though climate change predictions are very much in focus at present, it can still be a challenge for road administrations to prioritise mitigation actions, when several other things are on the agenda, e.g. lack of funding. We hope that by having examples of models and strategies to meet these challenges, it might be easier for road administrations to take the next step in preparing for future climate changes.

The background report focuses on information gathering, in order to support and create a reliable base for Report 3 "The Blue Spot Model" and Report 4 "Inspection and maintenance. All this data are not needed to be displayed in the respective reports, but the information and data is important knowledge to provide, and it is consequently displayed in this background report. The background report has been prepared for researchers and others interested in additional background material on the subject.

During the initial phase of a research project, search for relevant literature is an essential part of getting to know the area of interest. Whether research and published literature exist in the area of interest is never certain. Chapter 1 therefore explores the results of a literature search. It is presented as a state of the art review with a reference list at the end. Most of the literature is used in Chapter 4 of this report, Report 3 (the Blue Spot Model) and Report 4 (Inspection and maintenance). Literature not directly used in the reports, but with certain relevance, is referred to as related literature.

Chapter 3 is a list of abbreviations and definitions on some of the most used terms. It may be a good idea to read this list before reading the reports. The list will be shown as an appendix in every report.

Chapter 4 is an introduction to climate modelling. The study is made to understand the background of climate modelling, before we make recommendations for designing a Blue Spot Model. Four socio-economic scenarios and several emission scenarios are described by the Intergovernmental Panel on Climate Change in their Third Assessment Report. These scenarios all generate differences in the expected temperature and precipitation pattern, and we believe that they are important to consider when deciding input to the Blue Spot Model. The purpose is to make a good basis for deciding which parameters and scenarios are most suitable for the Blue Spot Model and how to use them in especially precipitation input. Furthermore, we have looked at the different countries in Europe to see how they handle the problem of deciding a climate change scenario to work with on a national level. The conclusion is that it is not really possible to recommend a certain scenario, and from a Blue Spot Model point of view, not really necessary to make a useful product. Consequently, the climate change research is not used directly in the Blue Spot Model, but is displayed here as important background information.

In chapter 5, we present the outcome of a questionnaire on flooding and drainage in Europe. The purpose of the questionnaire was to explore whether guidelines for maintenance and inspection of the drainage system exist and whether we can use them as an inspiration for more general guide for reducing vulnerability to flooding of roads. Another purpose was to collect and assemble experiences from experts working with various aspects of drainage systems, and thereby eventually flooding issues. The questionnaire was returned by seventeen respondents representing nine countries in northern Europe. The results support the idea that there is a need to be able to identify and prioritise road sections prone to flooding, since maintenance and funding apparently cannot cover the entire road network. Likewise, there is a need for a clear strategy, telling how to inspect and maintain in order to prevent flooding on the designated vulnerable road sections.

2. Literature

2.1 Introduction to the literature used in the reports

Search for literature

Literature within the area of water on roads, climate change modelling, GIS modelling and guidelines for maintenance and repair of roads has been searched for in all to us available scientific databases and common browsers. We have used keyword combinations from one to several words. Furthermore, we have looked through homepages to find relevant research projects and literature and distributed a questionnaire to ten countries. Seventeen experts on drainage have returned the questionnaire, telling us about already existing guidelines and research topics related to this study.

As is often the case with new research areas, hardly any relevant literature exists in the field of interest. Most of the described research in this search deals with water in road structures and the implications for bearing capacity and lifetime of the road, or the consequences for nature of water pollution by traffic during storm water runoff. Also a lot of work is done on modelling drainage capacities to different precipitation events. Consequently a lot of literature is found that is only related to the purpose of this study. Some of the most relevant of these are displayed in the literature list as *related literature*, but not looked into any further.

One of the reasons that we could not find a lot of relevant literature can be due to the language problem. If e.g. guidelines for personnel working in the field with drainage and flooding problems exist, they will most likely be in the local language and not published. This problem was thought to be solved by sending out the questionnaire, asking if guidelines exist. Two of the countries (Germany and Netherland) did send guidelines to us (see section 5.4.1 of this report). Netherlands refer to CEN EN standard for inspection and maintenance sewerage systems, and Germany uses a local German guideline (in German). Perhaps more of these types of documents exist as internal documents in road directorates and local municipalities. We believe that another reason is, that it is a new area of interest, especially the blue spot modelling, and therefore literature does not exist.

Choosing a climate change scenario

The objective for the literature study on climate change – scenarios, modelling and national practices – Chapter 4, was to decide on a scenario that would be suitable to use as a case in the Blue Spot Model and to gain a certain level of knowledge for the project about the climate change modelling dilemmas. The Blue Spot Model needs input about future precipitation and temperature patterns, and the need to decide on a scenario seemed necessary. Furthermore, if there appeared to be a consensus about which scenario is most suitable or probable, a recommendation for road owners could be made.

A great deal of literature is available on the subject, and the goal was to make a short objective resume only for use in the blue spot modelling concept.

The most important and influential literature regarding climate change modelling has been the IPCC (2000) Special Report on Emission Scenarios (SRES) which presents 40 scenarios depicting the future development of the world. They are organised in four storylines that relate to the four families of scenarios: A1, A2, B1, and B2, which were further divided into six scenario groups: A1FI (fossil fuel intensive), A1T (predominantly non-fossil fuel), A1B (balanced), A2, B1, and B2. For each scenario group an illustrative scenario was developed. The scenarios comprise the following steps: socio-economic scenarios, leading to emission scenarios, leading to atmospheric concentrations and radiative forcing, leading to altered conditions in climate models, which ultimately provide a means of studying the effects of the different scenarios through the use of more specific and detailed models suitable for e.g. road design. The article by Tol et. al. (2005) states, that the IPCC scenarios leave much to be desired, but are better than alternative emission scenarios. In 2008, Moss et. al. (2008) states that at an expert meeting, four representative concentration pathways (RCP) will be identified and later used to initiate climate model simulations. It is expected that the selected RCPs will replace the previous SRES scenarios. End users, like road owners, will be pleased to hear that near-term scenarios that cover the period to about 2035 will be developed, and that models that use them as input provide a higher spatial resolution.

The 2005 Hadley Centre article discusses the problem of uncertainties in climate models, concluding that all model predictions must be assumed to have the same unknown probability. Thereby no scenario can at the moment be recommended as the most reliable. The Hadley Centre article concludes that ”models give different predictions because they use different representations of the climate system, we are approaching this problem in the Hadley Centre by building large numbers of climate models, each having different but plausible representations of climate processes; so-called ‘physics ensembles’.”

This discussion on deciding a scenario is present in the press in Denmark at the moment, because municipalities ask for a general guideline from the state in order to plan future adaptation strategies better. But no one wishes to make that decision, since no one knows which scenario will become closest to the truth. Therefore, municipal planners must plan to be flexible to extensions, or plan for the worst case. That is very expensive, and the discussion will probably go on.

The article by Christensen et. al. (2007), describes the climate projections in Europe, stating the *likely* consequences in the future. These consequences, described as changes in temperature and precipitation in zones of Europe, are parameters we can use directly in the Blue Spot Model.

Modelling the blue spots in Geographic Information System (GIS)

Within the last twenty five years, models have focused on simulating drainage systems, surface runoff patterns and pollution. Also, models are made for urban areas, simulating pipes and sewers below mainly road pavements and houses. Recently, climate change has put focus on flooding as a major risk for both urban and rural areas, and consequently new research areas evolve. Domingo et. al. (accepted) recently presented a study, where a new 1D-2D model in rural areas is tested, where hydrology is important to see whether this model performs better than classical models for highly paved areas.

A transition from digital surface models (DSM) to high quality digital terrain models (DTM), removing houses, trees, cars etc. from the surface has meant a great deal for the ability to make better simulations. The focus of this study is to make a model for roads in the open country, and the DTM has been a valuable tool.

A key reference in this work is Nielsen et. al. (2008) which uses 1D-2D models to simulate drainage conditions in the sewer network coupled with overland flow. This turned out to be very useful in urban flood management. Two cases from Odense in Denmark are used to verify the model and conclude that the integrated 1D-2D model is suitable for developing strategies for minimising consequences of hazardous flooding. This is for instance done by cost-benefit analysis. Level three in the Blue Spot Model is based on the work by Nielsen et. al. (2008).

In Zerger (2001), the author introduces a way to map relative flood risk by using GIS and digital elevation models. The technique is made especially for flood risk managers and is evaluated for the risk management decision-making. The study is used especially in level one in the Blue Spot Model, where depressions in the terrain are found.

Boonya-aroonnet et. al. (2007) made an important contribution to the coupled DTM 1D-1D and 1D-2D modelling, by describing the process of a step by step development of a model. They describe thoroughly how the model is built and how the different layers are linked together. The basic principle of the model is used in the Blue Spot Model.

Finding experiences with guidelines

A questionnaire was sent out and it provided many useful comments on how the different countries in Northern Europe deal with maintenance and repair of drainage systems and whether they use national guidelines. A thorough study of this input can be found in Chapter 5. Of published literature, a handful of papers and books have served as a good inspiration to what a guideline could look like.

Smith (2006), published a manual that describes best roadway maintenance practices for Iowa’s local roads and streets, from the centre line to shoulders, ditches and drainage, with chapters on public relations, bridge maintenance, and snow and ice control. Chapter 5 is especially interesting for development of guide in the SWAMP project. It describes how to make good surface drainage, subsurface drainage and maintenance.

Saarenketo (2007) offers a report that includes guidelines for maintaining drainage, but also survey techniques, drainage classifications for paved and gravel roads, rehabilitation techniques, procurement policies and research update. Likewise, the European standard (CEN EN 13508-2:2003 E) describes conditions of drainage and sewer systems outside buildings, and provides a visual inspection coding system. The standard gives suggestions about visual inspection of sewer systems. It also contains references to other international standards.

By talking to Danish and Swedish personnel working with drainage on the roads, we experienced that most maintenance and repair is done ad hoc, as the problems occur. No system is made for registering observations and repairs. Doyle & Ketcheson (2007) describes the importance of learning from previous flooding events and adopts new designs to prevent flooding in the future. The author points out the importance of have log books and databases to learn from the past.

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Germany	www.gkss.de
Sweden	www.smhi.se
Denmark	www.klimatilpasning.dk www.dmi.dk www.klimaupdate.dk www.klima-basen.dk www.life-treasure.dk www.conwoy.ku.dk www.reroad.dk www.dhigroup.com
Norge	www.vegvesen.no/Fag/Fokusomrader/Forskning+og+utvikling /Klima+og+transport www.bioforsk.no
UK	www.ukclimateprojections.defra.gov.uk www.wallingfordsoftware.com www.ukcip.org.uk/index.php
Netherlands	www.climateresearchnetherlands.nl www.knmi.nl/index_en.htm www.wldelft.nll
USA	www.climate.dot.gov www.dot.ca.gov/hq/env/stormwater
Italy	www.grass.itc.it
Greenland	www.sermitsiaq.gl/klima

3. Abbreviations and definitions

Phrase	Description
A2	A2 is one of the six families of scenarios discussed in the IPCC Third Assessment Report (TAR) and Fourth Assessment Report (AR4). The families are A1FI, A1B, A1T, A2, B1, and B2. The A2 scenario family represents a differentiated world. Compared to the A1 storyline it is characterised by lower trade flows, relatively slow capital stock turnover, and slower technological change – among many others things.
AOGCM	Atmosphere-Ocean Global Climate Model
AR4	Assessment Report 4 by IPCC in 2007
ArcGIS	ArcGIS is an integrated collection of GIS software products that provides a standards-based platform for spatial analysis, data management, and mapping. ArcGIS is scalable and can be integrated with other enterprise systems such as work order management, business intelligence, and executive dashboards.
B2	B2 is one of the six families of scenarios discussed in the IPCC Third Assessment Report (TAR) and Fourth Assessment Report (AR4). The families are A1FI, A1B, A1T, A2, B1, and B2. The B2 scenario is one of increased concern for environmental and social sustainability compared to the A2 storyline.
Blue spot	A blue spot is a part of a road that is vulnerable to flooding, either by precipitation, catchment water or sea level rise. The term blue spot is self-made, inspired by “black spots” referring to places with many traffic accidents. The blue spot needs enough water to cause a dangerous situation for road users, more than a normal aquaplaning risk. The presence of a blue spot on the road can have a variety of reasons, e.g. road design, damage or underestimation of the drainage system, a saturated catchment, heavy rain etc. A blue spot can be identified by experienced personnel in the field or by GIS modelling. A 1D-2D model for blue spot identification has been developed, using different layers of information, e.g. a digital terrain map, geography, road maps, drainage systems etc. The model can, in a GIS map, show places on the road network, where a blue spot is likely to occur, e.g. under different precipitation intensities. There is likely to be a higher risk of blue spots in the future, if predictions for an increasing precipitation pattern come true.

CDS Chicago Design Storm	A storm whose magnitude, rate, and intensity do not exceed the design load for a storm drainage system or flood protection project.
Depression	A depression is a landform where an area is sunken or depressed below the surrounding area. Depressions will often be the first places that stow water.
DSM Digital Surface Model	Digital surface models (DSMs) are topographic maps of the earth's surface that provide a geometrically correct reference frame over which other data layers can be draped. In addition to the Digital Terrain Model (DTM), the DSM data includes buildings, vegetation and roads.
DTM Digital Terrain Model	Digital surface models (DSMs) are topographic maps of the earth's surface that provide a geometrically correct reference frame over which other data layers can be draped.
EMIC	Earth System Models of Intermediate Complexity
Emission scenario	Scenarios for emission of greenhouse gases. Examples include A1, A1B, A2 etc.
Ensemble	A group of parallel model simulations used for climate projections. Variation of the results across the ensemble members gives an estimate of uncertainty. Ensembles made with the same model, but different initial conditions only characterise the uncertainty associated with internal climate variability, whereas multi-model ensembles including simulations by several models also include the impact of model differences. Perturbed parameter ensembles, in which model parameters are varied in a systematic manner, aim to produce a more objective estimate of modelling uncertainty than is possible with traditional multi-model ensembles.
EU2C	The EU2C scenario, calculated by the Danish Meteorological Institute, is based on the EU objectives that the human induced global warming will not exceed 2 degree Celsius. The scenario is based on A2 and B2.
FAR	First Assessment Report: The first assessment made by IPCC in 1990
GCM	Global Climate Model or Global Circulation Model
GHG	Greenhouse Gas
GIS Geographic Information System	A geographic information system (GIS) allows you to view, understand, question, interpret, and visualise data in many ways that reveal relationships, patterns, and trends in the form of maps, globes, reports, and charts. GIS describes any information system that integrates, stores, edits, analyses, shares, and displays geographic information.

	In a more generic sense, GIS applications are tools that allow users to create interactive queries (user-created searches), analyse spatial information, edit data, maps, and present the results of all these operations.
Greenhouse gas	Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, the atmosphere itself, and by clouds. This property causes the greenhouse effect. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere. Moreover, there are a number of entirely human made greenhouse gases in the atmosphere, such as the halocarbons and other chlorine and bromine containing substances, dealt with under the Montreal Protocol. Beside CO_2, N_2O and CH_4, the Kyoto Protocol deals with the greenhouse gases sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs).
Grid cell	The geometric unit (often an area or a volume) in a numeric computer model.
IPCC	Intergovernmental Panel on Climate Change So far responsible for development of scenarios.
Lowland areas	A lowland area is characterised as any broad expanse of land with a general low level. The term is normally applied to the landward portion of the upward slope from sea level to continental highlands, to a region of depression in the interior of a mountainous region, or to any region in contrast to a highland. In these study examples of lowlands are Netherlands, Denmark, southern parts of Sweden, northern part of Germany and Poland and most of UK.
Manning number	Is a constant number for surface roughness and is used in a formula calculating the velocity of the water flow on different surfaces. The number varies between 130 – 20, where the high number refers to very smooth surface and thereby a high flow velocity, and the low number to a very rough surface.
Mike Urban	MIKE URBAN is an urban water modelling software made by Danish Hydrological Institute, and it is a complete integration of GIS and water modelling. MIKE URBAN covers all water in the city, including: • sewers - combined or separate systems or any combination of these • storm water drainage systems, including 2D overland flow • water distribution systems

MMD	Multi-model data set, same as PCMDI
PCMDI	Program for Climate Model Diagnosis and Intercomparison
RCM	Regional Climate Model
RCP	Representative concentration pathways
SAR	Second Assessment Report made by IPCC in 1996
SRES	Special Report on Emission Scenarios
TAR	Third Assessment Report made by IPCC in 2001
1D-1D modelling	1D-1D refers to 1D flow in pipes and to 1D flow in surface pathways and ponds. The hydrodynamic model is a model combining the surface and ponds runoff with the sub-surface runoff. This is done for grid nodes in the terrain and is calculated as water level for each node.
1D-2D modelling	1D-2D refers to 1D flow in pipes integrated with 2D surface flow simulation by taking the water level for each grid node in the 1D-1D modelling and visualising it in a GIS layer, showing the extent and the depth of the depression which gives the 2D in the surface modelling.

4 Climate change - scenarios, modelling and national practices

4.1 Climate modelling basics

4.1.1 Introduction

Climate is one of the more important components of road design. For instance, culvert diameters are selected by looking at design floods that in turn are the result of statistical analysis of historic data. Currently, the majority of the scientific community believes that a change in climate will occur over the coming century, or perhaps even longer into the future, which to a variable degree invalidates the current designs. Hence, existing structures may need to be adjusted, and new structures may need to consider different design rain or floods.

In order to adapt the road network to climate change, knowledge of how the climate will change is needed. The purpose of the work described in this chapter was therefore to find out where and how to obtain existing climate change data, what the predicted changes in climate are, what the main uncertainties are, and learn more about how the data is obtained in order to understand climate modelling. More specifically, we wanted to know what numbers to use as input to the Blue Spot Model (SWAMP Report 3) that singles out the road sections that are prone to flooding.

Climate modelling is a complicated process involving many steps, each with its own setup of models. Thus one should remember that modelling climate is not the same as simply running *one* computer model in order to reach *one* result, but rather a process in which a sequence of various models (not only computer models) is used. In every step, the output from the previous model is used as input for the following model. Consequently, the end result will be significantly affected by model choice and output along the way. The following paragraphs will briefly explain the current practice and the possible future practice, as well as the issue with time and spatial scales, in climate modelling. The various steps of the current practice will later be described in more detail, and a discussion of uncertainty ends the chapter.

4.1.1.1 The greenhouse effect

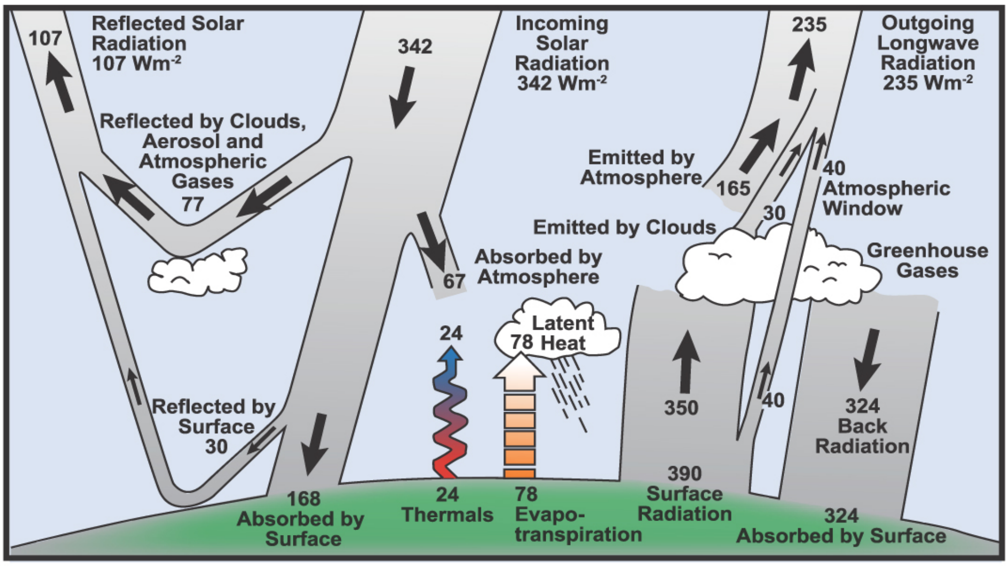

Figure 4.1 Estimate of the Earth's annual and global mean energy balance. On the long term, the amount of incoming solar radiation absorbed by the Earth and atmosphere is balanced by the Earth and atmosphere releasing the same amount of outgoing long wave radiation. About half of the incoming solar radiation is absorbed by the Earth's surface. This energy is transferred to the atmosphere by warming the air in contact with the surface (thermals), by evapotranspiration and by long wave radiation that is absorbed by clouds and greenhouse gases. The atmosphere in turn radiates long wave energy back to Earth as well as out to space.

It is important to differentiate between the essential natural greenhouse effect and the reinforced effect caused by human activities. Le Treut et. al. (2007), describes the greenhouse effect accordingly:

'The Sun powers Earth's climate, radiating energy at very short wavelengths, predominately in the visible or near-visible (e.g., ultraviolet) part of the spectrum. Roughly one-third of the solar energy that reaches the top of Earth's atmosphere is reflected directly back to space. The remaining two-thirds are absorbed by the surface and, to a lesser extent, by the atmosphere. To balance the absorbed incoming energy, the Earth must, on average, radiate the same amount of energy back to space. Because the Earth is much colder than the Sun, it radiates at much longer wavelengths, primarily in the infrared part of the spectrum (see Figure 4.1, Le Treut et. al., 2007). Much of this thermal radiation emitted by the land and ocean is absorbed by the atmosphere, including clouds, and reradiated back to Earth. This is called the greenhouse effect. Without the natural greenhouse effect, the average temperature at Earth's surface would be below the freezing point of water. Thus, Earth's natural greenhouse effect makes life as we know it possible.'

4.1.1.2 Current modelling practice

The climate modelling process starts with the well known socio-economic scenarios produced by the Intergovernmental Panel on Climate Change (IPCC). Anyone having the slightest interest in this topic is most likely familiar with abbreviations like A2 and B1 that denote socio-economic scenarios described by the IPCC in the Special Report on Emissions

Scenarios (SRES) from 2000. These scenarios describe the development of the world on the global scale, in terms of population, economic and technological development, fuel preferences, travel patterns and more. Given these scenarios, the anthropogenic emissions of various gases and particles can be estimated. As a result, the atmospheric concentrations of individual gases and particles change with time. Some of these (a.k.a. greenhouse gases) enhance the greenhouse effect while others reduce it. The greenhouse gases lead to a radiative forcing on the atmosphere, i.e. a certain increase in CO_2 concentration corresponds to a certain decrease in outgoing radiation from the earth-atmosphere system which would otherwise cool the planet. The consequences of such a forcing are studied using global climate models (GCMs). Global climate models calculate temperature, air pressure, wind velocity, relative humidity, precipitation and many other variables for the entire atmosphere, and sometimes the oceans. These values represent averages of large volumes, or individual points, and do not reflect the conditions on the land or road surface very well. Thus, a procedure called downscaling is often used to approach the local scale; the scale which is most interesting to owners and users of roads.

4.1.1.3 Future modelling practice

In 2006, the IPCC decided that it would not develop any new scenarios, but rather depend on the research community to do so. Through an expert meeting, four representative concentration pathways (RCP) will be identified and later used to initiate climate model simulations. It is expected that the selected RCPs will replace the previous SRES scenarios. End users, like road owners, will be pleased to hear that near-term scenarios that cover the period to about 2035 will be developed, and that these will have a higher spatial resolution (Moss et. al., 2008).

4.1.2 Socio-economic scenarios

These scenarios are often referred to as storylines, depicting different global socio-economic development. They form the basis for the climate change model chain, and are thus very important. So far, IPCC has presented the scenarios, having the nowadays familiar abbreviations A1, A2, B2 etc. When producing the scenarios, four categories are considered: world, economy, governance, and technology. Depending on the possible developments within these categories, a number of socio-economic scenarios are compiled (Figure 4.2).

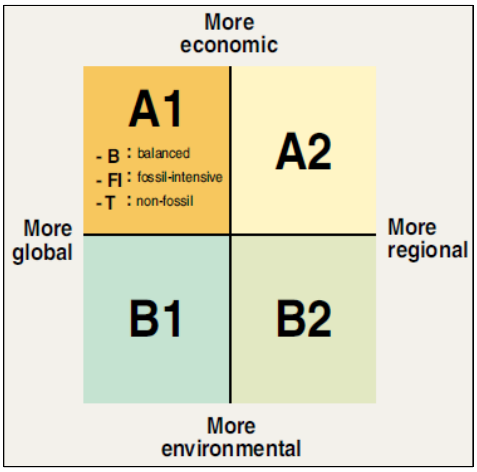

Figure 4.2 The socio-economic development paths presented by IPCC (2000).

As an example, the worst case scenario from a climate change impact perspective is described like this in the IPCC Third Assessment Report: “The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.” All scenarios should be considered equally sound (IPCC 2007). The SRES scenarios do not include additional climate initiatives, which mean that no IPCC scenario explicitly assumes implementation of the United Nations Framework Convention on Climate Change or the emissions targets of the Kyoto Protocol.

4.1.3 Emission scenarios

The greenhouse gas emission scenarios are derived from the socio-economic scenarios. The IPCC Special Report on Emission Scenarios (SRES) from year 2000 describes one procedure of generating these predictions. However, more scenarios have been developed since then by the research community (Figure 4.3).

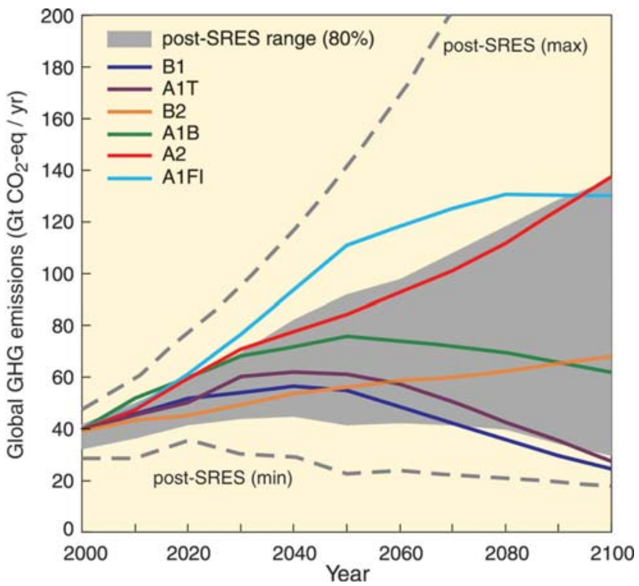

Figure 4.3. Global greenhouse gas emissions (in $GtCO_2$-eq per year) in the absence of additional climate policies: six illustrative SRES marker scenarios (coloured lines) and 80th percentile range of recent scenarios published since SRES (post-SRES) (gray shaded area). Dashed lines show the full range of post-SRES scenarios. The emissions include CO_2, CH_4, N_2O and F-gases (IPCC 2007).

4.1.4 Atmospheric concentrations and radiative forcing

Emissions of greenhouse gases and aerosols from the land surface sooner or later end up in the atmosphere, and therefore every emission scenario corresponds to an atmospheric concentrations scenario. When changing concentrations of gases and particles in the atmosphere, the radiation (energy) balance for the globe changes as well. In order to compare the effect of these atmospheric constituents, the concept of radiative forcing is used to translate atmospheric concentrations to effect per square meter, i.e. basically tuning the sunshine up or down. This effect in turn leads to changes in climate. Thus, radiative forcing is used to assess and compare the anthropogenic and natural drivers of climate change. Examples of the change in anthropogenic and natural radiative forcing components from 1750 to 2005 are shown in Figure 4.4.

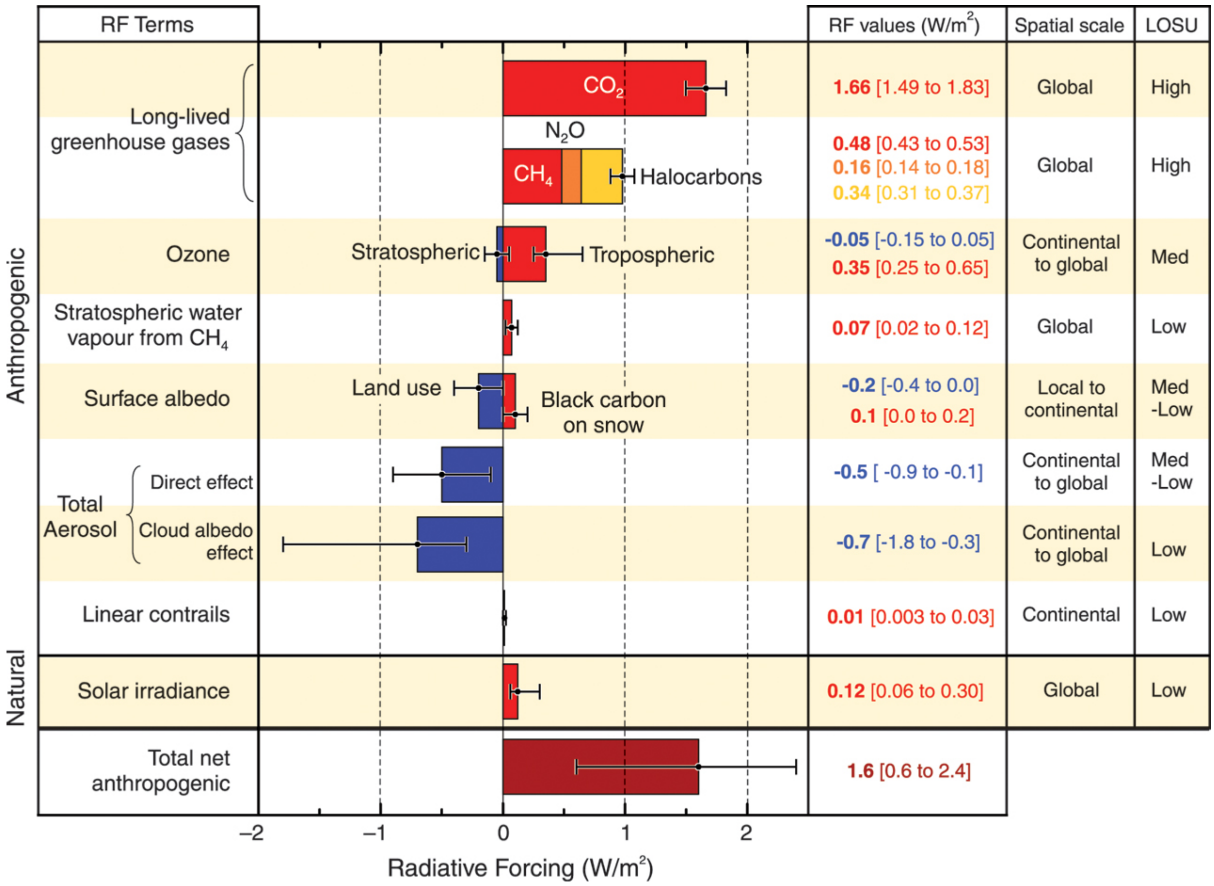

Figure 4.4. Global average radiative forcing (RF) in 2005 (best estimates and 5 to 95% uncertainty ranges) with respect to 1750 for CO_2, CH_4, N_2O and other important agents and mechanisms, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU) (IPCC, 2007).

4.1.5 Climate models

Given the complexity and magnitude involved when simulating the entire earth system, a large number of models have emerged, specialising in different parts of the "full" earth system. Climate projections are made on different spatial scales as we proceed along the climate modelling chain. The emission scenarios are created on the global scale, and the first step in climate projection applies to the same scale. However, many end-users are interested in very local effects, which is the case for the SWAMP project as well. In order to obtain local data, the global data needs to be downscaled, first to regional, and then to the local scale.

4.1.5.1 Dealing with scales - downscaling

In order to calculate the climate all over the globe, the earth must be divided into a number of small, connected volumes called grid cells. Considering that the side of a typical grid cell of a state-of-the-art global climate model is about 110 km, it is evident that not even the largest of roads is represented by the average value of such a cell. Hence, for this data to be more useful for end users wishing to adapt to future climate, the information must be resolved further in space such that the original grid cell is split into many smaller ones or in some way related to a point or object on the land surface. This process is referred to as downscaling.

Dynamic downscaling

In dynamic downscaling, models similar to GCMs are applied at a smaller spatial scale, hence increasing the spatial resolution. The boundary conditions are given by a coarser scale GCM model.

Statistical downscaling

In statistical downscaling, a relationship is sought between a variable at the sub grid level for a specific site or cell, and another variable (or several) at the coarser grid level. For example, there may be a relationship between the simulated temperature on the coarse grid at 90 m height, and the measured temperature in a specific measurement station on the ground. If such a relationship is found, the assumption is then made that this statistical relationship holds also when projecting temperature at this site or cell into the future.

4.1.5.2 Global scale modelling

Global climate models have evolved greatly over time, both by improving the descriptions of processes already included in the models, and by including additional processes. Some models include both ocean and atmosphere, others only atmosphere, and there are also simplified models. The more advanced models have established couplings between the atmosphere and the oceans. The atmosphere and ocean is divided into a large number of “boxes” (often called grid cells), as seen in Figure 4.5. The climate projections provide values of e.g. temperature in each of these boxes for every time step. The global models end up using very large grid cells, where sometimes only a few cells are used to represent entire nations. The reason for this is that the computational power required to make the calculations is huge, and it is simply not possible to utilise a finer spatial resolution. However, with time the spatial resolution has become increasingly higher as the computing capabilities have grown. To some extent, this development is hampered by the constant addition of more physical and chemical processes. Lakes, cities etc. do not explicitly show up on the global scale, and it is obvious that local weather near the ground cannot be reproduced accurately. Hence, the data from global climate models must be downscaled, such that they better take into consideration, and represent, the conditions near the ground. The first step in that process is to move from global to regional models.

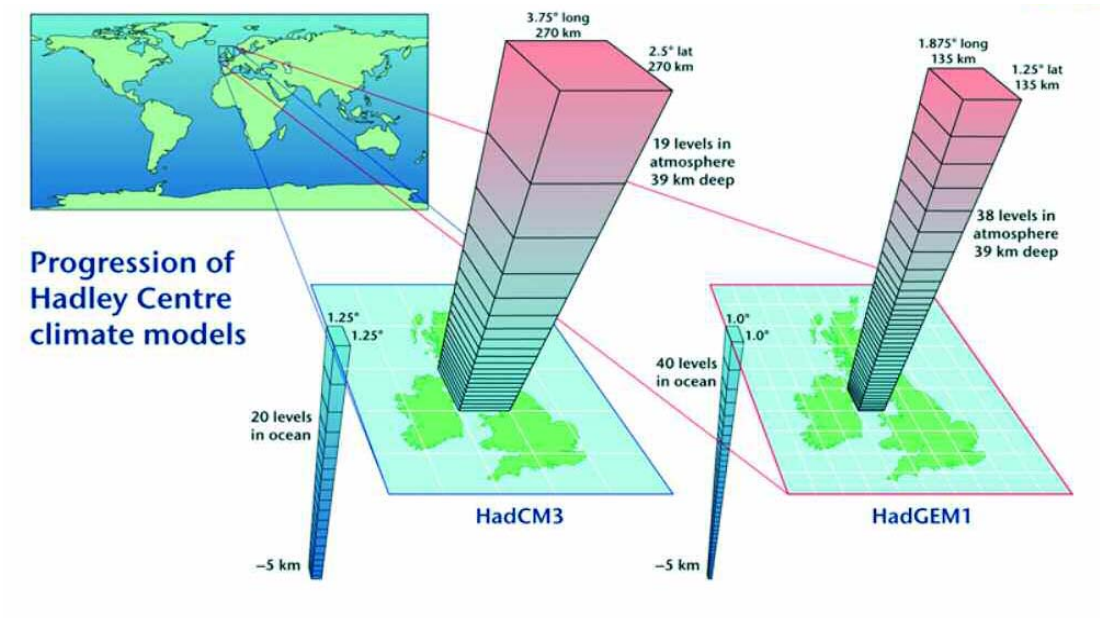

Figure 4.5. The spatial resolution in climate models increases with every model generation (Hadley Center, 2005).

4.1.5.3 Regional scale modelling

Global climate models generally have a resolution of about 300 km (getting smaller with time), and this is insufficient to calculate reliably the *impacts* of climate change. To achieve a higher resolution the global predictions are downscaled using Regional Climate Models (RCM), which have a resolution of 25 or 50 km, over a sub-global domain (Figure 4.6) which may be of the order 5000 km x 5000 km. The climatic predictions from the global climate models are used as driving variables for the regional model. For the example scales above, every square on the land surface in the global model is replaced by 36 (50 km resolution) or 144 (25 km resolution) small squares in the regional model. Regional climate models take better account of features such as mountains and coastlines, and give a much improved simulation of (and, hence, can be expected to give better predictions of) changes in extremes such as heavy rainfall events. The accuracy of RCM predictions is of course limited by the accuracy of the predictions from global models that serve as input to the RCMs. Regional climate models are often dynamic models like the GCMs; i.e. they can predict the development over time. Obviously, the spatial scale is still large, and further downscaling to the local scale is often useful.

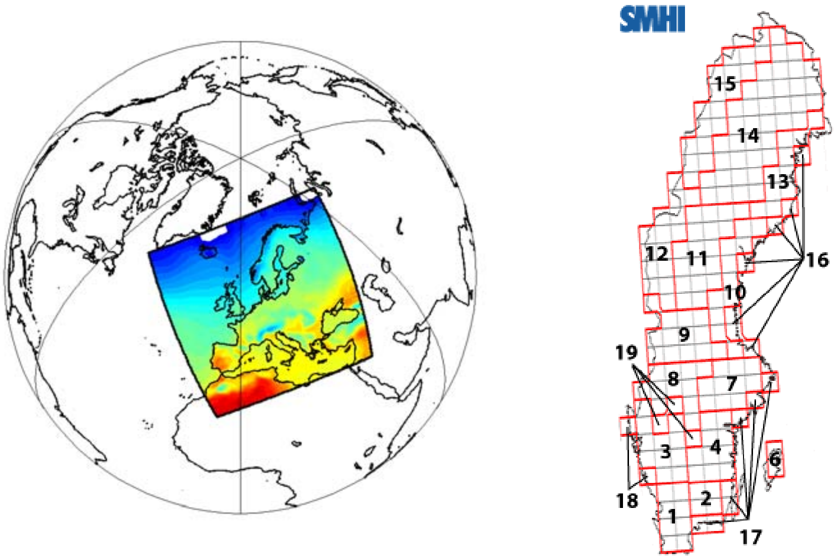

Figure 4.6 Regional climate models (RCM) cover specific regions of the earth, in this case Europe. The spatial resolution in such models is illustrated in the right figure of Sweden.

4.1.5.4 Local scale modelling

Local predictions may e.g. be obtained using statistical methods, or using Soil-Vegetation-Atmosphere-Transfer (SVAT) models. SVAT models are often referred to as land-surface schemes by meteorologists who by tradition are not that interested in the ground, and merely looked upon it as a boundary condition. SVAT models are developed by soil and plant researchers who in contrast tend to regard the atmosphere as a boundary condition. Hence, two (or more) disciplines meet at the interface between atmosphere and ground. The similar culture clash takes place between meteorologists and oceanographers. A large number of land surface schemes are used to transfer the regional information to the local scale, and one example is given in Figure 4.7. Here the climatic condition derived from the regional model is used to calculate flows of water, energy, and e.g. carbon between the land and the atmosphere. It is well known that these depend greatly on land use, soil type, and micro-meteorology and it is thus possible to consider climate effects on e.g. forested areas, agricultural land and even structures such as roads by altering material parameterisations in the model. Hence, this is the scale that is most interesting for the SWAMP project end-users.

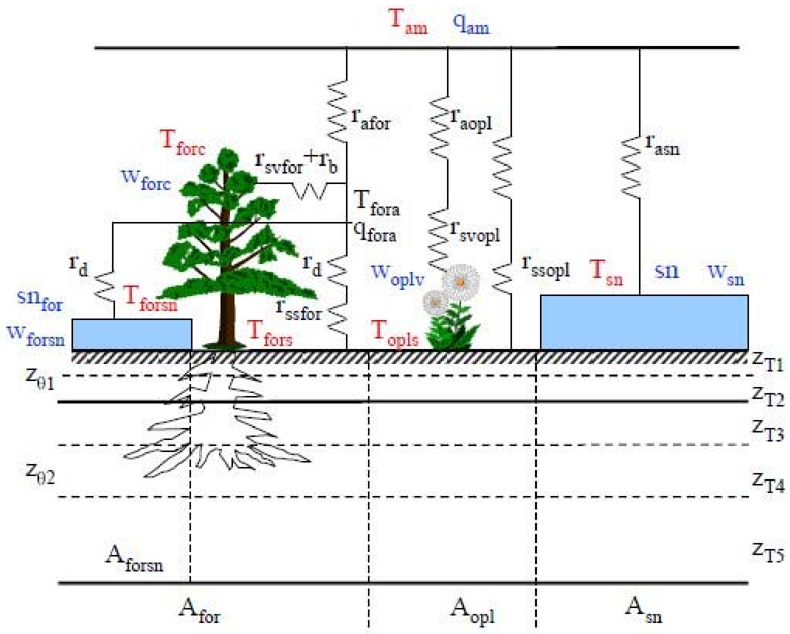

Figure 4.7. The land-surface scheme in RCA3 (SMHI). The land surface scheme is divided into three main tiles: forest, open land and snow on open land. Each individual tile is connected to the lowest atmospheric level via their corresponding aerodynamic resistances (rs). The lowest atmospheric level is about 90 m above the land surface.

4.2 Uncertainties in climate modelling

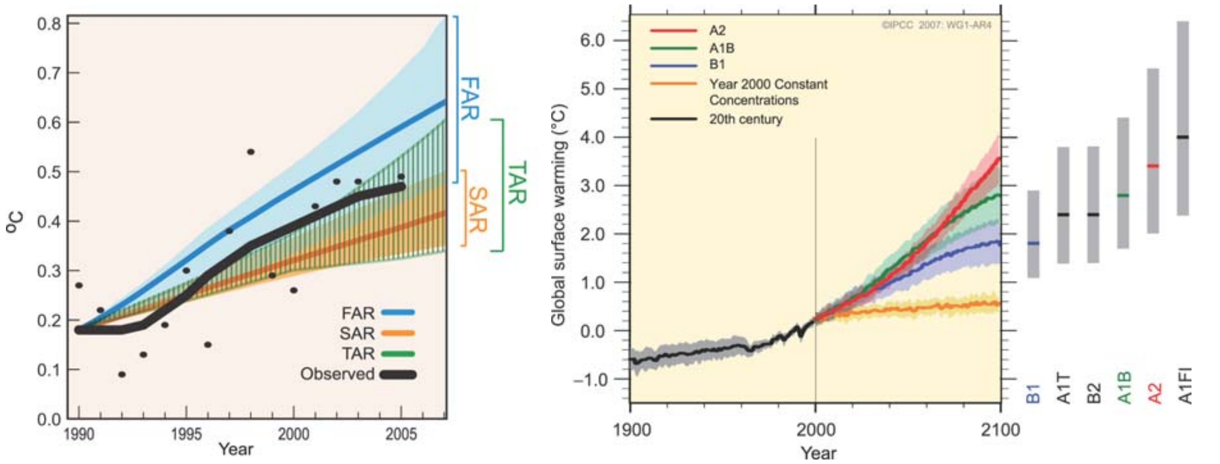

Figure 4.8 Left: Yearly global average surface temperature (Le Treut et. al., 2007), relative to the mean 1961 to 1990 values, and as projected in the FAR (IPCC, 1990), SAR (IPCC, 1996) and TAR (IPCC, 2001a). Right: Multi-model means of surface warming (relative to 1980–1999) for the scenarios A2, A1B and B1, shown as continuations of the 20th-century simulation (IPCC, 2007).

Given the complexity of climate modelling, as evidenced by the preceding presentation in this document, there are many sources of uncertainty, which altogether lead to a span in e.g. computed temperature. Kjellström (2009) lists the following key factors:

- Emission scenarios
- Choice of AOGCM
- Model formulations
- Resolution in space
- Initial conditions

In addition, different regional models will also be a source of uncertainty while temporal resolution is determined by spatial resolution and as such not considered being a separate factor. The impact of the first four factors can be elucidated using a modelling concept known as ensemble modelling. The idea behind, and scope of, ensemble modelling can be described like this (Hadley Centre, 2005):

“We have seen earlier that models give a wide range of predictions in global-mean quantities; the uncertainty at a smaller scale is even bigger. … Because we have no way of assigning the skill of each of the models, all of the predictions must be assumed to have the same (unknown) probability. This is obviously unhelpful to planners trying to adapt to climate change; hydrologists deciding on whether a new reservoir should be built to avoid summer water shortages, for example. If they plan for the smallest climate change then they could be caught out if predictions of greater change come about. On the other hand, if they spend large sums adapting to the highest predictions, these may be wasted if smaller predictions turn out to be more realistic. The reduction in uncertainty in predictions is unlikely to be rapid, depending as it does on hard-won improvements in our understanding of how the climate system works. Planners therefore wish to move away from the current situation of having a large number of different predictions of unknown credibility, to a situation where the probability of different outcomes (for example, percentage changes in summer rainfall) is known. They can then use these probabilistic predictions in risk assessments, to decide on the optimum adaptation strategy. Recognising that … models give different predictions because they use different representations of the climate system, we are approaching this problem in the Hadley Centre by building large numbers of climate models, each having different but plausible representations of climate processes; so-called ‘physics ensembles’.”

One explicit example of an ensemble in use is given by the SMHI climate change ensemble matrix, comprising 20 members (Table 4.1).

Ensembles like this one, allow researchers to better illustrate aspects of climate change and its dependence on:

- Emission scenario – most important in the 2nd half of the 21st century
- Model formulation – important both in the near and distant future
- Natural variability – most important in the nearest decades

As an example, the impact of AOGCM selection is given in Figure 4.9, which shows the twenty year return period precipitation for the control period 1961-1990 (CTL), and the change in percent for period 2071-2100 when using the six different AOGCMs of table 4.1, as well as the average of these simulations. Clearly, the results differ quite significantly in many regions of Europe simply by changing the AOGCM forcing data. The figure shows the effect during the summer months June, July, and August (JJA). The results can be looked upon from the opposite angle, i.e. the change in frequency of precipitation events rather than the amounts of rain. As an example, Figure 4.10 shows how often the rainfall which during the control period happened only once in twenty years, will happen 2071 to 2100 for summer and winter. The changes appear to be largest in central and northern Europe where the twenty year rain may happen as often as every five years in a few regions (Figure 4.10). This is of direct interest to road owners since many culverts, bridges and drainage systems are designed based on the concept of return period events and most likely need to be updated. It is evident from results like the one presented in Figure 4.10 that no general rule can nor should be applied all over Europe. It is important to consider geographical aspects, while national boundaries are of no importance.

Table 4.1. Simulations in the regional climate change ensemble at the Rossby Centre (Rossby Centre Newsletter May 2009).

No	**AOGCM** (Institute, country)		**Emission scenario**	**Horisontal resolution** (km)	**Reference**
1	Arpège (CNRM, France)		A1B	50	Déqué et al (1994), Royer et al (2002)
2	BCM (NERSC, Norway)		A1B	50	Déqué et al (1994), Bleck et al (1992)
3				25	
4	CCSM3 (NCAR, USA)		A2	50	Collins et al (2006)
5			A1B	50	
6			B2	50	
7	ECHAM4 (MPI-met, Germany)		A2	50	Roeckner et al (1999)
8			B2	50	
9	ECHAM5 (MPI-met, Germany)		A2	50	Roeckner et al (2006), Jungclaus et al (2006)
10			A1B	50	
11				50	
12				50	
13				25	
14				*12.5*	
15			B1	50	
16	HadCM3 (Hadley Centre, UK)	ref (Q0)	A1B	50	Gordon et al (2000)
17		low (Q3)		50	
18		high (Q16)		50	
19		low (Q3)		25	
20	*IPSL-CM4 (IPSL, France)*		*A1B*	*50*	*Hourdin et al (2006)*

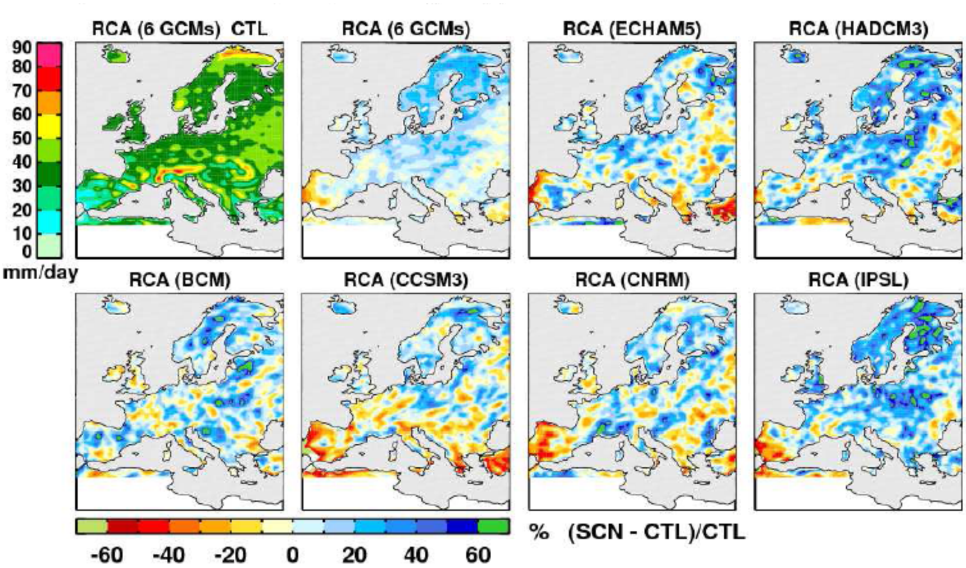

Figure 4.9 20-year return values of precipitation in summer in 2071-2100 as predicted using six AOGCMs and compared to the control period 1961-1990 (Kjellström, 2009).

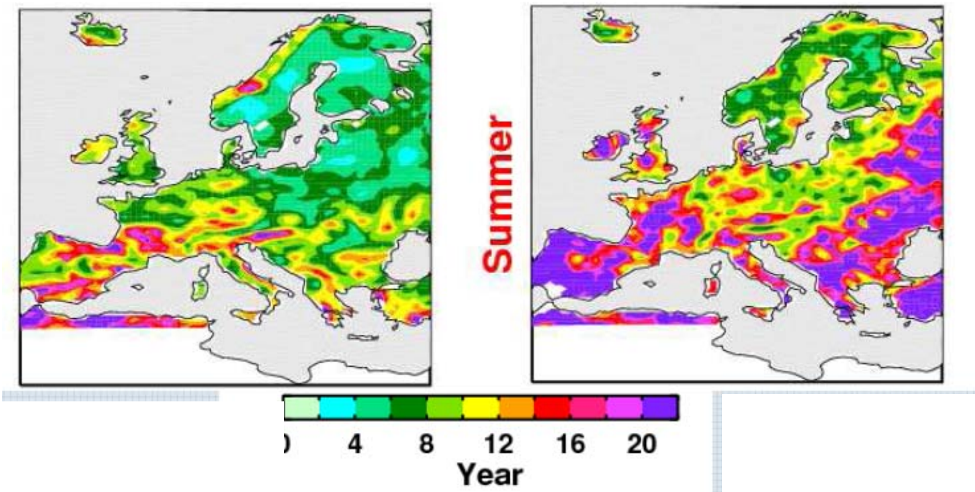

Figure 4.10 Change in extreme precipitation: how often will the 1961-1990 20 year return rainfall occur in the future (2071-2100)? (Kjellström, 2009).

4.2.1 Difficulties in short-term modelling and its relevance to climate prediction

Uncertainties regarding initial conditions are the primary reason why it is currently not possible to make short-term (< year 2040) predictions of climate. There are no given starting values, and the turnover times for oceans in particular are very long (many years). However, an effort will be made in the next years to adopt a strategy similar to the ones used in weather prognoses by measuring conditions in the atmosphere, hoping to approach the "true" initial values. Whether this procedure will work is at this point very uncertain. The effect of varying initial conditions (e.g. temperature in every computational grid cell of the computer model) is demonstrated for the average 2 m winter temperature in Figure 12, which exhibits differences up to 2-3 degrees in northern Finland and western Russia depending on starting condition alone for the period 2011-2040 as compared to the control period 1961-1990. As stated by Kjellström (2009), the variability caused by the uncertainty in initial conditions is of the same order of magnitude as the climate change signal at this short time scale, making it difficult to separate anthropogenic effects from natural variability.

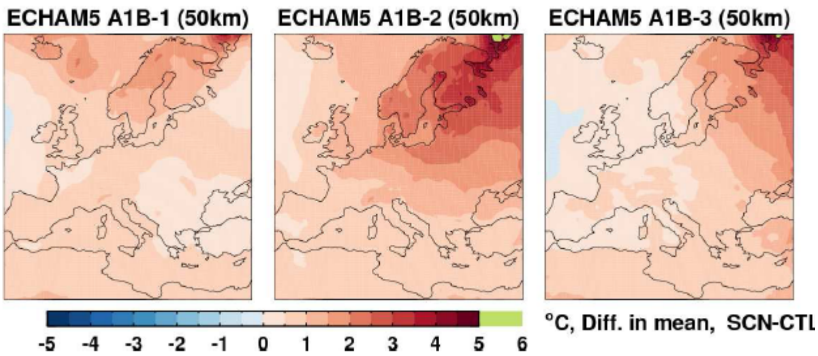

Figure 4.11 The mean change in 2 meter winter air temperature over Europe in 2011- 2040 when using different initial conditions in the RCA model using ECHAM5 data for scenario A1B on a 50km grid (Kjellström, 2009).

4.2.2 Summary of uncertainty issues

Apparently, “there is currently no consensus on the optimal way to divide computer resources among: finer numerical grids, which allow for better simulations; greater numbers of ensemble members, which allow for better statistical estimates of uncertainty; and inclusion of a more complete set of processes (e.g., carbon feedbacks, atmospheric chemistry interactions).”

Ensembles are used to assess and investigate uncertainties in climate modelling

- Long-term simulations (end of the century) are considered more reliable than short-term simulations (up to 2040) due to uncertainties in initial conditions and natural variability
- Results are more certain on the continental scale than on finer scales
- It appears that clouds, and particularly low clouds are a source of great uncertainty
- Rain is sometimes very local (much smaller geographical extent than the grid cell), and the average grid cell values produced by regional climate models is in these cases much too low (or high). Thus the magnitude of rain at extreme rain events may be underestimated.
- An attempt to predict the future climate is on the agenda. Scientists will try to measure initial conditions in the atmosphere and oceans in order to reduce the modelling uncertainty associated with unknown initial conditions. The similar approach is used when producing weather prognoses.

4.3 Short summary of climate projections for Europe

Annual mean temperatures in Europe are *likely* to increase more than the global mean. Seasonally, the largest warming is *likely* to be in northern Europe in winter and in the Mediterranean area in summer. Minimum winter temperatures are *likely* to increase more than the average in northern Europe. Maximum summer temperatures are *likely* to increase more than the average in southern and central Europe. Annual precipitation is *very likely* to increase in most of northern Europe and decrease in most of the Mediterranean area. In central Europe, precipitation is *likely* to increase in winter but decrease in summer. Extremes of daily precipitation are *very likely* to increase in northern Europe. The annual number of precipitation days is *very likely* to decrease in the Mediterranean area. Risk of summer drought is *likely* to increase in central Europe and in the Mediterranean area. The duration of the snow season is *very likely* to shorten, and snow depth is *likely* to decrease in most of Europe (Christensen et. al., 2007).

With regard to intense precipitation events it was concluded that it will very likely be a much larger increase in the frequency than in the magnitude of precipitation extremes over most land areas in northern Europe (Christensen et. al., 2007). This was designated very likely since the events were consistent across model projections; and empirical evidence show that there are generally higher precipitation extremes in warmer climates.

The decrease in precipitation together with enhanced evaporation in spring and early summer is very likely to lead to reduced summer soil moisture in the Mediterranean region and parts of central Europe. In northern Europe, where increased precipitation competes with earlier snowmelt and increased evaporation, the MMD models disagree on whether summer soil moisture will increase or decrease (Christensen et. al., 2007).

4.4 Using climate change information in practice – a few national examples

It is fair to say that a lot of work is going on in many European countries with regards to the changing climate and how to deal with the consequences either through mitigation or adaptation. As a result, the dimensioning of new infrastructure is adapted in various countries as given by this short list:

Sweden – a climate adaptation factor is to be used in hydraulic design of culverts and bridges that belong to large catchment areas. This factor varies between different parts of the country from 1 to 1.5, meaning that up to 50% larger dimensioning values should be used in e.g. the south-western parts of the country.

Denmark – in general Denmark advises agencies to consider three scenarios and their consequences: the before mentioned A2, B2 and an EU scenario called EU2C. Denmark has also changed drainage standards (unclear how).

UK and Ireland – have modified the dimensioning process such that in general one should increase the rainfall/flood by 20%.

Norway – work in progress at the time of the questionnaire sent out as part of the SWAMP project.

Netherlands – updating design rainstorm (work in progress during the time of the questionnaire)

Finland – the dimensioning in Finland is controlled by Finnish Environment Centres which perform the dimensioning. According to the respondent of the questionnaire, the width of bridges and the size of culverts have grown recently due to climate adaptation. It is unclear from the questionnaire by how much.

4.4.1 Comments on the selection of scenarios and their impact on road design

During the work with the material presented in this report, we have heard during interviews or presentations some interesting statements that reflect the current research position in autumn 2009, and may provide a feeling for what is to be expected for the future, as well as pointing out some problems regarding what society (planners/stakeholders) would like to know, and what researchers actually know.

- ”Stakeholders are ahead of science”, asking for something that no one knows (Martin Parry, Imperial College), Co-chair of "IPCC 4th Assessment Working Group on Climate Impacts, Adaptation and Vulnerability").

- No scenario is more likely than the other.
  ”If you ask for a specific scenario, you have not understood anything of what we have presented (Lars Bärring, SMHI)”. Currently, ensemble modelling is recommended.

- The short-term outlook (< 2040) is particularly difficult. On a direct question on what to recommend to stakeholders in terms of modifying dimensioning flow in hydraulics, the head of the SMHI Rossby Center for climate research (Colin Jones) said ”I honestly don’t know.”

- However, if a single scenario must be chosen, we notice that A1B is preferred in our companion ERA-NET project IRWIN, comprising experts in climate research: “As discussed in the *IRWIN First Inception Report*, it is impossible to know how much greenhouse gas our civilization will produce in the future, and so climate change simulations use hypothetical emissions scenarios from the IPCC Special Report on Emissions Scenarios (SRES). The climate change scenarios used in IRWIN assume the A1B emission scenario, which is considered a mid-range scenario in-terms-of 21st Century global warming. However, note that in the A1B scenario greenhouse gas emissions and global temperatures increase rapidly at first, but then emissions decline by 2100." (from IRWIN Inception Report Nr 2, June 2009)

4.5 How to obtain climate change information

Today, information is available, or is soon to become available, from many new national portals. A few examples are included in table 4.2.

Table 4.2. A selection of websites containing information about climate change and society

Country	Website
Germany	German Climate Service Center http://www.gkss.de
Sweden	http://www.smhi.se
Denmark	http://www.klimatilpasning.dk http://www.dmi.dk
UK	http://ukclimateprojections.defra.gov.uk/ http://www.ukcip.org.uk/index.php
Netherlands	http://www.climateresearchnetherlands.nl http://www.knmi.nl/index_en.html

4.6 Conclusions

Presently, experts on climate modelling cannot point out one scenario as more probable than the other, meaning that the SWAMP project team cannot from a climate modelling basis recommend a certain scenario to be used. As a result, neither can we recommend a certain change in e.g. design rain. Climate modellers use many scenario and model combinations to form ensembles in order to elucidate uncertainties. Even though the results vary considerably between ensemble members, trends and patterns have been found. One example is that extremes of daily precipitation are *very likely* to increase in northern Europe. This means that qualitative predictions are to some degree possible, but quantitative predictions are difficult. In this sense, "stakeholders are ahead of science" (Parry, 2009). We notice however, that many countries recommend or require a climate factor to be considered as a precautionary measure when building new roads.

Significant resources are spent on climate modelling, and the development is rapid. IPCC plan to present the results of their current work in 2012 and the scientific community constantly publish new results. The road owners must follow the development and be prepared for changing information.

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5 Results from the questionnaire about flooding and drainage

5.1 Introduction

One of the purposes of the SWAMP project was to provide an example for road authorities on how guidelines for preventing blue spots can be produced. We were therefore interested to know if guidelines exist in northern Europe with information about inspection and maintenance to prevent flooding. By sending a questionnaire we were aiming to collect the guidelines and other experiences with flooding of roads. The purpose was to use this information as inspiration and to learn what is considered to be necessary routines and precautions in different countries.

Another purpose was to collect and assemble experiences from experts working with various aspects of drainage systems, and flooding of roads.

All together the questions in the questionnaire were meant to answer the following

- Are there any guidelines?
- Are there any models or maps to predict flooding?
- How often do you inspect the drainage system?
- How often do you maintain the drainage system?
- What do you do to prevent flooding?
- What do you do after a flooding event?

Seventeen answers came back, representing eleven countries. A description of the methods is presented with the answers in the Appendix p. 45.

As the answers came back, it was obvious how difficult it is to make a questionnaire, especially in the beginning of a project. The questions were not always clear enough for the respondents, and consequently they sometimes gave contradictory answers, told us that they did not understand, or gave no answers at all.

So, the lesson learnt is that it is important to be exactly sure which questions you want to answer – not more than three or four. The design of the questionnaire should strictly follow the purpose. The best thing would be to make a multiple choice scheme to make sure that the answers are standardised and easier to interpret afterwards. Comments on the side are then possible.

The distribution of the questionnaire to people working with road drainage turned out fairly well, since seventeen answers came back. Still, it could be better. The SWAMP consortium had an excellent network in the members of the trans-national joint research programme "Road Owners Getting to Grips with Climate Change". The questionnaire was sent to the selected contact person in each country, and then distributed to persons with experiences in flooding and drainage systems. In addition it was sent to contact persons within the FEHRL collaboration. Steve Philips, Secretary-General of FEHRL kindly helped. The problem about this arrangement was that it is very difficult for the project group to follow up on the questionnaire, since the distribution chain is very long. We had no idea where some of the questionnaires have ended. The best thing would probably be to ask for names, and then send them directly, giving the project group the opportunity to follow up on 'missing' answers.

5.2 Discussion on some results

Guidelines in Europe

The results from the questionnaire suggest that most countries have some kind of written guidelines for inspection of national roads and bridges. There is however some confusion about the answers, since respondents from the same country gives contradictory answers. This can be due to the fact that they have different fields of responsibility, that districts within a country have different regulations and routines, or that the question was unclear.

In Denmark, they refer to a strategy document for maintenance and repair of drainage systems. This document suggests maintenance intervals for different kinds of drainage systems on four road categories. The roads are categorised according to traffic level. Repair is suggested to be organised in working campaigns. Normally, the drainage system is inspected and taken care of before a major road repair.

Likewise Germany has guidelines about inspection and maintenance of the storage and treating systems (Regional regulation from Straßenbau in Nordrhein-Westfalen). The document gives information about maintenance frequency and how it should be performed.

The Netherlands refer to guidelines for urban drainage systems and mostly work with the Dutch "Leidraad Riolering" (Sewerage Guideline NEN-EN 13508-2). It comprises four volumes and describes, among many other things, methods and recommendations for inspection, maintenance and hydraulic calculations.

In Ireland and Sweden they are presently working on national guidelines for inspection and maintenance. These are not available to us at the moment.

The conclusion from the questionnaire is that some guidelines exist, but they are very different, and treat different aspects of the road drainage system. There are no guidelines we can use as a direct inspiration for a blue spot maintenance and repair guideline.

Inspection frequency

The inspection frequencies for national roads are listed in Table 1 and 2. Five countries did not answer.

Bulgaria has a system where the roads are divided into different classes. Class 1 is inspected once a year, class 2 every 2nd year and class 3 every 3rd year. Norway inspects at least every 5th year, England with 1-10 year intervals and Finland at least every 10th year.

Bridges are inspected more frequently. 1-5 year intervals are apparently normal. In Norway the inspection is a part of regular function based maintenance, where the contractor has to inspect the drainage system and perform necessary works e.g. removing waste materials and debris, if needed.

Some respondents have answered that national roads and other roads are inspected when necessary. An inspection is normally a visual judgement, though; the use of new technology to find clogged pipes could improve the quality of the inspections.

Road verges, ditches, gullies and pipe systems were suggested to be the most important to inspect. Also culverts (cross-wise to road) including inlets/outlets and their erosion protection arrangements are important. It was also suggested that road networks with high traffic densities and roads with old drainage pipes are the most important. One respondent suggested that the use of new technology to find clogged pipes could improve quality of inspections.

The conclusion of the questionnaire is that most countries have inspection intervals, prescribed by some kind of national guidelines.

Table 5.1 Inspection frequencies of national roads

Denmark	Norway	England	Ireland	Finland	Bulgaria
When necessary	< 5 years	1-10 years	When necessary	10 years	1-3 years

Table 5.2 Inspection frequencies of bridges

Denmark	Norway	Germany	England	Ireland	Bulgaria
Yearly	Simple inspection every 1-2 years. Main inspection every 5-10 years	Observation 2/year Inspection every 3 years. Overhauling every 6 years.	Between 1-6 years	When necessary	Every 5-10 years

Maintenance frequency

The cause of flooding is often complex and is a combination of several factors. Still, from the answers it is obvious that clogging causes the most maintenance issues in the drainage system. Other explanations are root intrusion in pipes and vegetation growth and sedimentation in ditches. Most respondents state that cleaning of ditches and pipes will be done when needed. It is apparently not regulated at certain time intervals in most countries. The exception is the Netherlands where vegetation, pipes and drainage systems are cleared on a yearly basis in selected places and Bulgaria that has maintenance on regular basis, where the time intervals depend on the road class. The highest class has maintenance once a year.

The Netherlands, Germany and England suggest that gully pot cleaning is important in urban areas to prevent flooding.

The conclusion from the questionnaire is that cleaning of ditches and pipes are generally done when needed. It is apparently not regulated at certain time intervals in most countries.

Prevention of flooding by maintenance and design

It is suggested that cleaning and maintenance are the most important actions to perform to prevent flooding. This includes actions such as cleaning of culverts, removal of clogged material, debris, vegetation and sediments along road verges to allow for sideways drainage.

More than 2/3 of the respondents do not think that enough maintenance is done to prevent flooding. They suggest more funding, more maintenance, larger pipes and new guidelines. It is stated that flooding can never be completely prevented, but the probability can be reduced. The rest of the respondents do not struggle much with flooding problems, but one respondent answers, that in some cases maintenance of ditches and culverts should be done more frequently.

It is also problematic that maintenance sometimes is done only as a reaction to a flood event. The recommendations from the respondents are that more frequent inspections and more detailed inspection routines will help to prevent flooding. It is also important to identify areas prone to flooding and consider other design options for repair and reconstruction of sensitive road sections. It is also stated that registration by e.g. a data base system to store valuable data from inspections and repair work are important. There seems to be a need for a clear strategy to prevent flooding.

England, the Netherlands and Ireland have in their current hydrological design calculations already accounted for increased precipitation as a result of future climate changes.

The conclusions from the questionnaire is that

- It is important to identify areas prone to flooding and consider other design options for repair and reconstruction of vulnerable road sections.
- Maintenance is sometimes done only as a reaction to a flood event. There seems to be a need for a clear strategy to prevent flooding.
- Lack of funding is limiting for inspection and maintenance.

Repair after a flooding event

The most typical damages after a flooding event are clogging, erosion and replacement of pipes. Landslides are seldom seen, but they can flush a whole road section away, causing severe damage. It is also common among the respondents that a flooding event will not cause much damage to the road itself, except the fact that it is not possible to drive on it during the event.

Only 20% of the respondents are considering design alterations after a flooding event. The responsibility for design alterations is depending on the structure of the authorities within the country. Half of the respondents think that repair work can be done more effectively to prevent future problems. These answers might suggest that there is a need for better routines considering repair work.

The conclusion from the questionnaire is that repair work can be done more effectively to prevent future problems, suggesting that there is a need for better routines.

Future climate changes and mitigation of roads

The respondents generally believe that the expected climate change will have negative impact on road constructions. More intense rainfall is expected together with an increase in the annual amount of rain. In the Netherland they expect an increase of about 20%. In many of their municipalities they have plans to disconnect some areas from the urban drainage system and lead the water to local storage and infiltration facilities, in order to reduce risk of flooding. In Norway, Finland and Sweden, more rain in the winter season is expected. Some of the respondents think that there will be no major change during the next 20 to 30 years.

England, the Netherlands and Ireland have already in their current hydrological design calculations taken into account future climate changes (increased precipitation). About half of the respondents say that there are a group of people working with climate change issues in their organisation.

The conclusion from the questionnaire is that climate change is a question of concern in the respondent’s countries, but the initiative to act on it is not very clear.

5.3 Important conclusions

Based on the answers in the questionnaire it is possible to extract two important conclusions.

The questionnaire supports that

- There is a need to be able to identify and prioritise road sections prone to flooding, since maintenance and funding apparently cannot cover the entire road network.
- There is a need for a clear strategy, stating how to inspect and maintain the areas in question in order to prevent flooding on vulnerable road sections.

It is recommended that road authorities in the different countries address more attention to these questions. It is not only to meet future climate change but also to meet present maintenance and repair needs. This project suggests methods that can be the base in such work.

Report 3 “the Blue Spot Model” suggests a method that can be used to prioritise the most sensitive spots in the road network. It is important to keep the maintenance and repair costs low and to make work effort (maintenance and repair) in the right place.

Report 4 “Maintenance and Inspection” suggest how to work with drainage systems at road locations vulnerable to flooding. It gives guidance on how to perform inspection and maintenance work and also how to prepare the road system before, during and after a heavy rain event.

Appendix with questionnaire answers

1. Inspection, maintenance and repair of road draining systems

Question 1.1 to 1.10 deals with inspection and maintenance

Question 1.11 to 1.15 deals with repair issues

Question 1.16 and 1.17 deals with recommendations from the respondents

1.1. Do written inspection and maintenance guidelines exist for drainage systems, ditches, pipes etc. (new or old guidelines are both interesting):

For national roads?

For bridges?

Other roads and streets?

The result is illustrated in Figure 1. Ireland and Sweden are working on national guidelines for inspection and maintenance. At present, these are not available to us. Germany have sent a guideline (in German) about inspection and maintenance of the storage and treating systems (Regional regulation from Straßenbau in Nordrhein-Westfalen). The document gives information about maintenance frequency and how it should be performed. The Netherlands refer to guidelines for urban drainage systems. In the Netherlands, most urban drainage managers at municipalities (who are responsible for urban drainage management in our country) engineers work with the Dutch "Leidraad Riolering" (Sewerage Guideline NEN-EN 13508-2). It comprises 4 volumes and describes methods and recommendations for inspection, maintenance, hydraulic calculations, among many other things.

In Denmark they refer to a strategy document for maintenance and repair of drainage systems. The document suggests maintenance intervals for different kind of drainage systems on four road categories. The roads are categorised according to traffic level. Repair is suggested to be organised in working campaigns and before major repair of a road the drainage system is inspected and taken care of.

The other respondents from the different countries which have answered yes to this question have not specified what guideline they actually were thinking about.

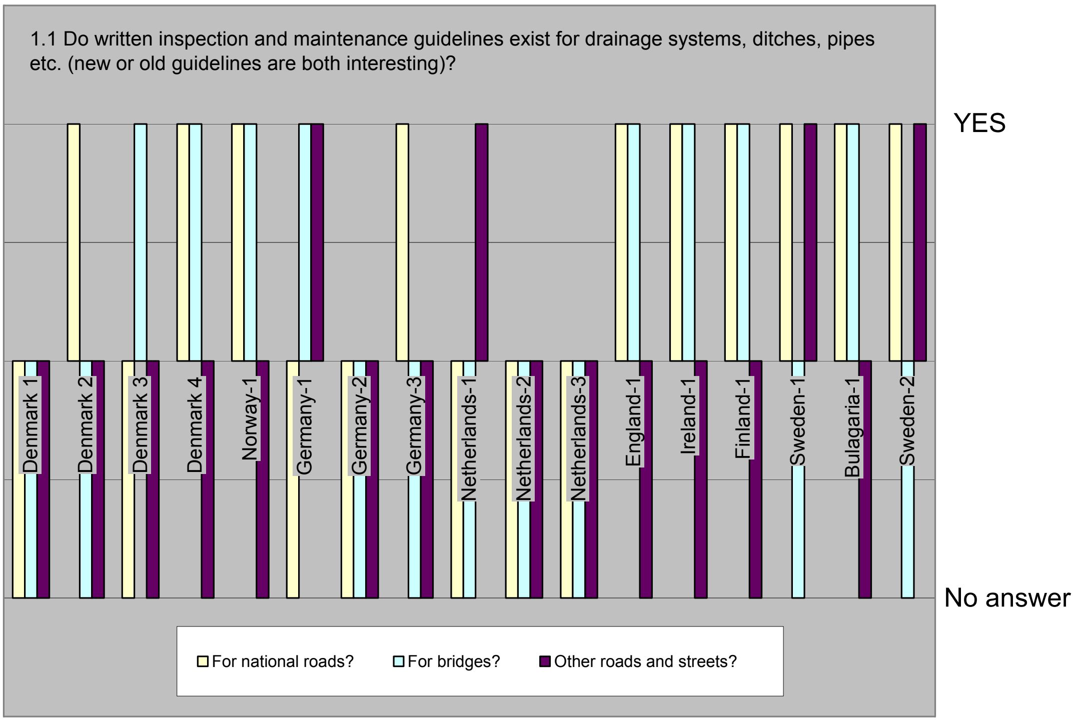

Figure 1. Comprises all answers from the respondents in the different countries. A positive value on the chart means yes and a negative value means that the question was not answered.

1.2 How frequently do you have drainage inspections of the following roads?

a) National roads? b) Bridges? c) Other roads and streets?

Most respondents have answered that national roads (a) and other roads (c) are inspected when necessary or in case of problems. Bulgaria seems to have system where the roads are divided into different classes. Class 1 is inspected once a year, class 2 every 2^{nd} year and class 3 every 3^{rd} year. Norway inspects at least every five years, England at one to ten year intervals, Finland at least every 10 years and the Netherlands check pipe systems every ten years.

Bridges (b) are inspected more frequently; one to five year intervals are apparently normal.

In Norway, the function control is a part of the regular function based maintenance, the contractor has to inspect the drainage and to perform necessary works as removing waste materials and debris, if needed. Special care should be taken if heavy rain and flood are predicted. In addition, the bridge drainage is inspected as a part of regular inspections, every year/second year (simple inspections) and every five to ten years (main inspections). Usually the bridge decks are drained by simple vertical tubes with no controlled system collection and treatment of water.

Germany checks gullies every two years.

1.3. Which parts of the drainage system are investigated during a typical inspection?

Generally, a visual inspection of culverts, ditches and the road side condition (shoulders, trenches etc.) is taking place. Old parts of a drainage system can also be subject for a certain inspection.

In Norway and Germany culverts (small and large), inlets/outlets including erosion protection are checked.

Comments countrywise below:

Denmark 1	Drain Well
Denmark 3	Various parts according to the actual problem
Denmark 4	We only inspect when we observe that there is a problem, such as flooding.
Norway	Regularly: culverts (small and large), inlets/outlets including erosion protection. More randomly: drainage pipes
Germany 1	inlets and outlets
Germany 2	For gullies: grid and manhole
Netherland 1	Parts of a certain age or project-based, to decide upon the need for rehabilitation
England	typically surface only, specialist inspections sub-surface
Ireland	Only visible sections
Finland	The Finnish Road Administration has a functionality demand in ditches. If they are not working properly, then they are checked.
Bulgaria	Culverts, ditches and the road side condition (shoulders, trenches etc.)
Sweden 1	our new guidelines will show
Sweden 2	ditches, culverts

1.4. What methods are used (e.g. TV inspection) to judge the functionality of the drainage systems during a typical inspection?

Most countries use visible inspection or in case of problems TV-inspection might be used.

Comments countrywise below:

Denmark 1	Manuel inspection
Denmark 3	Pressure flushing and TV inspection
Denmark 4	It depends on what type of drainage system we have to inspect, in pipes we use TV inspection and in open pipes we just go out there and have a look at the problem.
Norway	Existing roads: Visual inspection (mainly). For severe cases, TV inspection may be used (where possible). For new roads during construction: Visual inspection, but TV inspection is probably used to quite an extent, as part of the contractor's documentation of build quality and proper function.
Germany 1	Visual observation, sometimes TV inspection
Germany 2	optical inspection, TV camera only if necessary
Germany 3	Sichtkontrolle, -prüfung, Funktionskontrolle, TV
Netherland 1	CTTV inspection most common. Other methods: radar, manual, invert level measurement to check for subsidence
England	Surface walkover; CCTV for sub-surface
Ireland	Visual
Finland	If there are some problems (clogging) then TV inspection can be used.
Bulgaria	Visual inspection together with TV(video) inspection
Sweden 1	ocular and TV
Sweden 2	Visual

1.5. What is in your opinion the most important part of the road to inspect to prevent problems with flooding?

This question was answered very differently by the respondents. It is probably quite complex and can differ very much from case to case and from country to country. However, road verges, ditches, gullies and pipe system were suggested to be important. Also culverts (cross-wise to road) including inlets/outlets and their erosion protection arrangements are important.

In the Netherland storm water drainage system is important. It was also suggested that road networks with high traffic densities and roads with old drainage pipes are most important.

Comments countrywise below:

Denmark 1	Drain Well, road surface
Denmark 2	Nedløbsbrønde (Inlets downstream)
Denmark 3	Verges
Denmark 4	It must be the drain line in the verge or open pipes.
Norway	Existing roads: Most important to inspect culverts (cross-wise to road) including inlets/outlets and their erosion protection arrangements, drainage pipes (lengthwise to road), open ditches (with respect to sediments reducing the functions)
Germany 1	Very difficult to answer, because the whole system must be in function
Germany 2	gullies
Germany 3	Gewährleistung der Leistungsfähigkeit der Abläufe
Netherland 1	Of road network: Roads with high traffic densities, roads with old drainage pipes; of road structure: road surface levels to detect local depressions, gullies and gully pots to detect blockages of discharge devices
Netherland 3	Stormwater Drainage System
England	Interfaces between surface and sub-surface drainage, e.g. gullies
Ireland	Outlet
Bulgaria	Culverts' and ditches ' condition
Sweden 2	ditches, culverts

1.6. Would you like to include additional actions to your present inspection routine to improve it?

The respondents agreed quite well that more frequent inspections, more funding is needed. It is better to prevent problems. New methods to find problematic drainage are needed. It was also suggested to use geophysical methods like georadar.

Comments countrywise below:

Denmark 1	yes, frequency inspection of some pipes with TV
Denmark 3	Yes, inspections at regular intervals before problems occur
Denmark 4	It would be good if we have the funds to prevent flooding, instead of just take action ved we have flooding on the roads.
Norway	Yes, more frequent inspections, and/or more systematic and detailed inspection procedures. When in doubt, structural quality (strength and/or remaining service life) of the drainage system should also be assessed or checked
Germany 1	A systematically investigation of the pipes
Germany 2	No
Netherland 1	CCTV inspection results in terms of coding of observed damages have been proven to be unreliable + cannot detect blockages because pipes have to be empty. Reliable methods to detect blockages in pipes are required.
England	more funding for maintenance; enhanced standards
Bulgaria	Yes. Inspection of the drainage layers located under the road construction and by use of georadar
Sweden 1	our new guidelines will show

1.7. Which of the following cause most maintenance issues in drainage systems (pipes, ditches, culverts, dams, etc.); Clogging, Inadequate pipe diameter, Storage capacity or Other, please specify?

From the answers it is obvious that clogging causes the most maintenance issues in the drainage system (Figure 2). Other suggestions are root intrusion in pipes, which leads to blockage. For ditches, vegetation growth can be problematic and also sedimentation. Too little maintenance can cause maintenance problems.

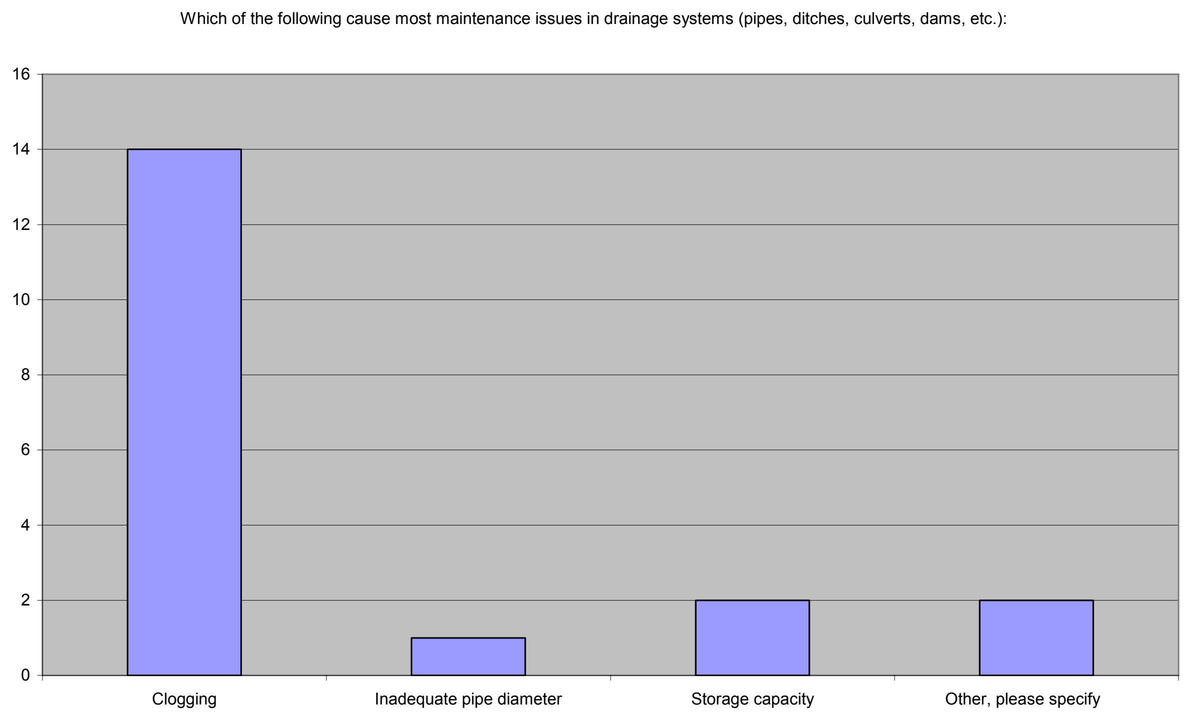

Figure 2. Shows the number of answers of Q 1.7. More than one answer possible.

1.8. With regards to maintenance, is cleaning of ditches and drainage pipes generally performed at regular intervals? How often is it done?

Most respondents state that cleaning of ditches and pipes will be done when needed. It is apparently not regulated at certain time intervals in most countries. The Netherland clear vegetation, pipes and drainage system on a yearly basis in selected places. In Finland drainage pipes are checked every year in springtime. Bulgaria has maintenance on a regular basis, the time intervals depend on road class. The highest class have maintenance once a year.

1.9. What is in your mind the most important maintenance action to be carried out to prevent flooding?

For this question most respondents answered that cleaning and maintenance is the most important. These actions include cleaning of culverts (removal of clogged material, debris), clearing of vegetation and sediments along road verge to allow for sideways drainage.

From the Netherland, Germany and England it is suggested that gully pot cleaning is important to prevent flooding (these are mostly used in urban areas; comment by the editor).

1.10. Is enough maintenance carried out to prevent flooding?

More than 2/3 of the respondents think that more can be done to prevent flooding (Figure 3). More funding, more maintenance, larger pipes and new guidelines are suggested to prevent flooding. Flooding cannot be completely prevented, but the probability can reduced. Flood consequences can be reduced by fast response to flood problems or by building emergency escapes for flood water on roads with high traffic densities

Some think that enough is being done. They comment that flooding is generally not a problem and that in special cases, the maintenance of ditches and culverts should be done more frequently.

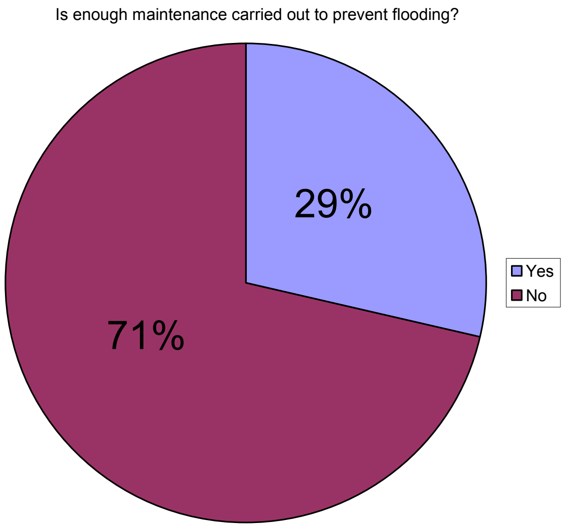

Figure 3. Answer from Q1.10.

Comments countrywise below:

Denmark 1	larger grants
Denmark 2	Larger pipes
Denmark 3	A maintenance schedule is needed
Norway	Probably not. It is assumed that many culverts etc are partly clogged, effectively reducing their capacity. The clogging will often be discovered only when the flooding takes place. It should be considered to do more frequent inspections, and preventive maintenance (cleaning etc), in vulnerable areas
Germany 1	Flooding of streets is not a general problem - only particular cases. The maintenance of the drainage system is important for water-protection.
Netherland 1	It is certainly not enough to prevent flooding completely: again, analysis of flood complaints shows that hundreds of people complain of urban flooding yearly and most of these complaints concern road flooding.

Netherland 3	Cleaning ditches and pipes
England	Greater frequency of maintenance, requiring increased funding
Ireland	More regular and targeted inspections
Finland	Enough maintenance is carried out.
Bulgaria	Providing enough budget for maintenance.
Sweden 1	Hopefully our new guidelines will show what and where.

1.11. What types of damages are most common after a flooding event?

A variety of different answers. Here are a collection of some comments. Clogging will often be the result of a flooding. Damage due to erosion occurs during severe flooding. Severe flooding may also bring culvert pipes etc out of their proper position, thereby causing risk for further damage and erosion. Economical damage due to lost travel time. Severe flooding incidents can lead to damage to infrastructure, but these are rare (in urban areas several flooding incidents per year, severe incidents that lead to damaged infrastructure once every 10 years or less). Damages in cellars and underground car parks are common after a flooding. Debris on the carriageway requiring cleaning. Property and land damage are common. Collapse of gravel roads and also paved roads. Damage in bridge cone (bracket). Damage on pavement. Erosion in bridge bank. Damages of the road construction layers. Over damping of the road construction layers. Washed away roads and culverts. There are no common type of damages.

Comments countrywise below:

Denmark 1	Traffic damages, damage on the embankment
Denmark 2	Erosion related damages on road
Denmark 3	Verge erosion and sand deposits in pipes
Denmark 4	There are no common type of damages.
Norway	Clogging will often be the result of a flooding, but should normally not be considered as a damage. Real damage to the erosion system for inlets/outlets often occurs during severe flooding. Severe flooding may also bring culvert pipes etc out of its proper position, thereby causing risk for further damage and erosion.
Germany 1	
Germany 2	flooding in cellars and underground car parks
Netherland 1	Economical damage due to lost travel time. Severe flooding incidents can lead to damage to infrastructure, but these are rare (in urban areas several flooding incidents per year, severe incidents that lead to damaged infrastructure once every 10 years or less).
England	Debris on the carriageway requiring cleaning
Ireland	Property and land damage
Finland	1) collapse of gravel roads and also paved roads 2) damages in bridge cone (bracket) 3) collapse of culverts 4) damages in pavement 5) erosion in bridge bank
Bulgaria	Damages of the road construction layers. Over damping of the road construction layers.
Sweden 2	washed away roads and culverts

1.12. After a flooding event, are design alterations of the drainage system typically considered? If so, by whom?

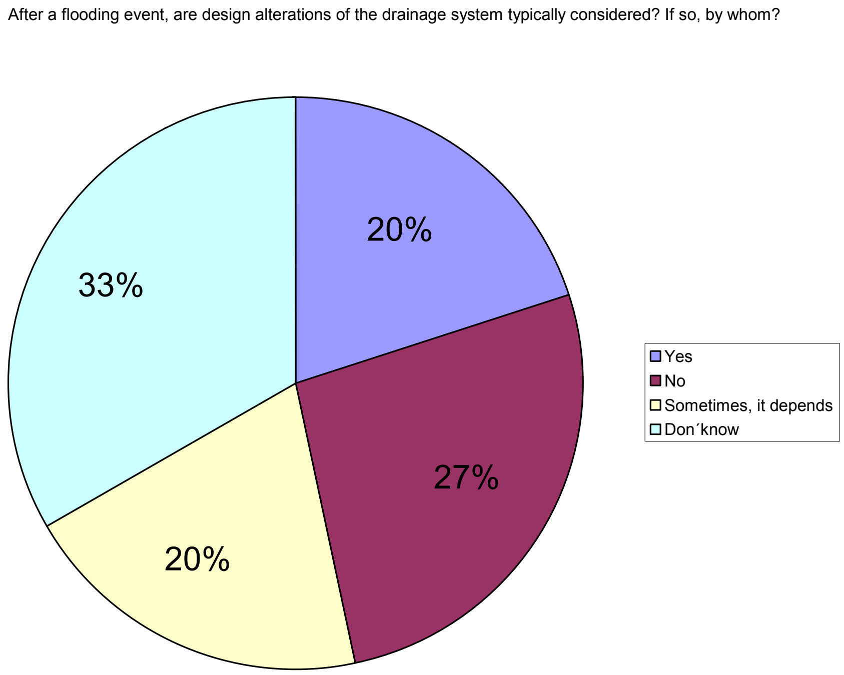

Figure 4. The result of Q 1.12.

Comments countrywise below:

Denmark 1	No
Denmark 2	dæksler skyller væk
Denmark 3	No
Denmark 4	After we discover a problem we try to increase the dimensions of the drainage system.
Norway	Flooding events are not necessarily reported in a satisfactory or systematic way. Events may be reported by the maintenance contractor, and/or by the road authorities' local inspector. Recommendations and design alterations due to flooding events may be suggested by both. Extensive design alterations is normally not included in the standard maintenance contracts, and has to be assessed and paid for individually.
Germany 2	Not generally, only in case of local or temporal concentration of flooding
Netherland 1	That depends entirely on the cause of flooding: if it is insufficient drainage capacity, capacity increase can be considered; if it clogging due to root intrusion or pipe subsidence repair actions are more likely.. Actions are taken by the responsible authority; for urban drainage systems this is the municipality, for surface water systems it is a surface water authority (water board).
England	No
Ireland	Yes. By the National Road Authority

Finland	No.
Bulgaria	Yes. National Road Infrastructure Agency/NRIA/
Sweden 2	by the local/regional road engineers and specialists

1.13. Will recommendations to prevent similar damage in the future be suggested after a severe flood? If so, who has the responsibility for this?

For results see Figure 5.

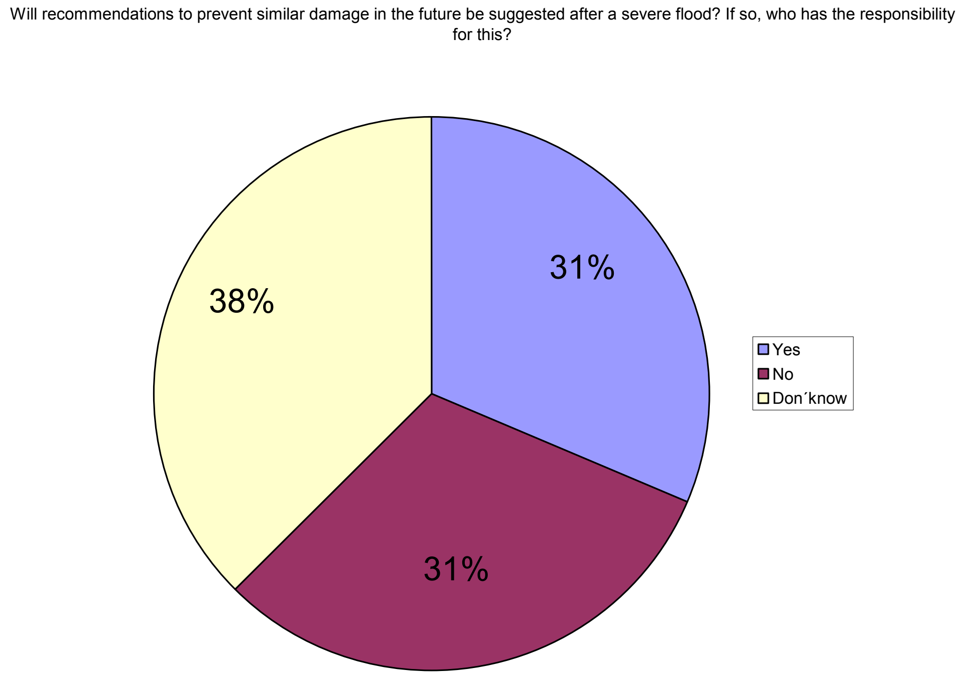

Figure 5. The result of Q 1.13.

Comments countrywise below:

Denmark 1	Yes the Government
Denmark 2	No
Denmark 3	No
Denmark 4	No, Severe flooding have so far only occurred as s result of poor maintenance, and repair solves the problems
Norway	See 1.12
Germany 2	yes, if applicable
Netherland 1	If the severe flood is caused by a heavy rainfall event, e.g. with a return period of 20 years or more, no changes are made to an urban drainage system since this is outside the design capacity.
England	No
Ireland	Yes. National Roads Authority
Finland	No
Bulgaria	Yes. NRIA is responsible for this
Sweden 2	probably, responsibility both locally and central in the maintenance rules

1.14. Do you use a specific guidance document or follow a specific routine when repairing?

Comments countrywise below:

Denmark 1	No
Denmark 2	Yes
Denmark 3	Danish Standards for construction of sewage systems
Denmark 4	No
Norway	To my knowledge there is no national guidance document or routine for repairing. Local guidance documents and/or specifications may exist. A lot of repair work is probably carried out on the basis of functional requirements and "good code of practice" and individual experience which have never been written down.
Germany 2	yes, for gullies
Netherland 1	Specialised contractors usually make a proposal; I'm not sure if there are general standards or guidelines.
England	Yes
Ireland	Have a guidance document but it is not specific
Finland	Yes, we follow instructions.
Bulgaria	No
Sweden 2	normally no, just the ordinary rules

1.15. Could repair be done more effectively or differently to prevent future problems?

For result, see Figure 6.

Some comments: More efficient repair could be done if better inspection techniques were available that can detect clogging. In the sense of reactive maintenance, repair actions could often be planned more efficiently. Yes, by careful design considerations. Repair can be done more effectively and differently to prevent future problems e.g. in bridge cones.

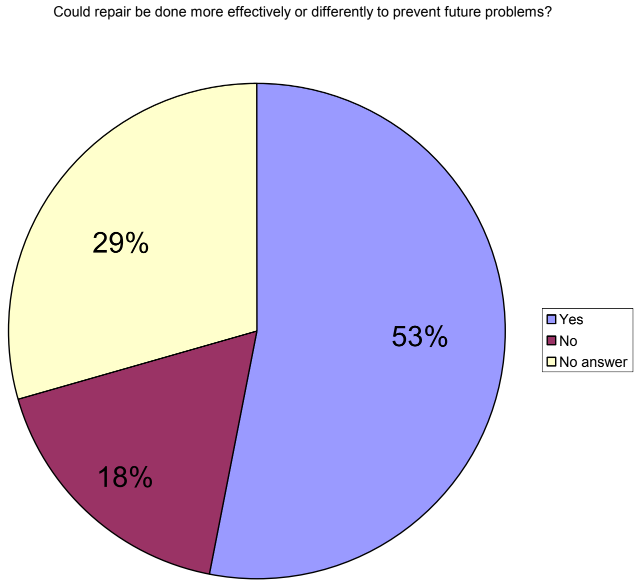

Figure 6. The result of Q 1.15.

1.16. What actions should be included in your ideal guideline with respect to inspection and maintenance?

Comments countrywise below:

Denmark 1	enough money to inspect and maintenance
Denmark 2	undersøgelser og registrering af systemet
Denmark 3	Drainage systems are generally constructed to handle 30% more than expected under severe weather conditions, and if the systems are inspected at regular intervals and any damage found by inspection is repaired at once, no further action is needed.
Denmark 4	I mean that open pipes must be re-establish in regular intervals.
Norway	More frequent and inspection, and more detailed inspection routines. Data from the inspection, including valuable information such as photos, should be stored in a data bank. (A data bank is in existence, but the amount and the quality of the information on drainage systems has not been assessed for the purpose of this questionnaire)
Germany 2	focus on demand-oriented cleaning of gullies

Netherland 1	To make a clear strategy choice: preventive maintenance, reactive maintenance or a combination of both.
England	More realistic standards, based on current practice
Ireland	1) Identify areas prone to flooding. 2) Methodology for inspection. 3) Design options for alterations and repair.
Bulgaria	Regular inspection and cleaning of the drainage system elements. Application of hydrophobic additives.
Sweden 2	A regular, frequent inspection (every year), and always ditches and culverts in top condition at spots where you can suspect flooding or other problems with drainage See also the Roadex project

1.17 Other comments about inspection, maintenance and repair?

Comments countrywise below:

Netherland 1	Availability of reliable inexpensive inspection techniques for detection of clogging (of pipes, gully pots and gully pot connections) could enhance efficiency of preventive maintenance.
England	Under funded
Ireland	Maintenance is only done as a reaction to a flood event.
Finland	Some kind of rail type can prevent water more than the others. This can have some meaning in the areas, where there is flooding e.g. every year.

2. Flooding of roads and models to predict flooding events in the future

Questions 2.1 to 2.11 deal with the respondents' experiences about flooding events

Questions 2.12 to 2.17 deals with the respondents' view of future climate changes and climate adoption of roads

Question 2.18 to 2.22 deal with how the work with climate adoption is organised.

2.1. How often do you experience flooding on roads schemes in your country/region?

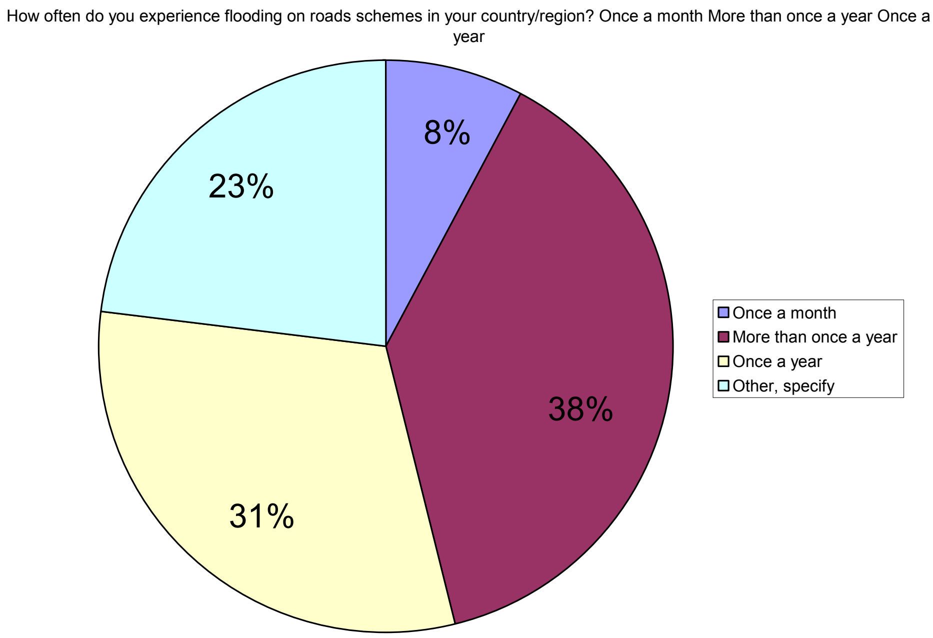

Figure 7. The result of Q 2.1.

Comments countrywise below:

Norway	It is not quite clear what is being asked for in this question.
Germany 1	Not flooding on roads, but other problems caused by heavy rains: 7 to 10 events a year
Sweden 2	Not every year but when the ice leaves the rivers, e.g. Torne River

2.2. On the national level, how often do you accept flooded roads depending on road type?

This question is not so well formulated therefore the answers differ depending on how you interpret it.

Comments countrywise below:

Denmark 2	Urban areas
Denmark 3	Never
Denmark 4	It's up to the staff who design the roads.
Norway	The design guidelines for new roads accepts that a given road is flooded once per 100 years, when it is possible to reroute the traffic to another road or detour. When there is no such possibility to move the traffic to another road, the design guideline accepts flooding once per 200 years. The design guidelines are currently being assessed in the perspective of possible climate changes and general safety issues.
Germany 2	once every 5 years
Germany 3	DIN EN 752
Netherland 1	Urban roads: once per year or per 2 years. Highways I think once in 20 years, but I'm not sure 10 year return period
England	1 in 5 years
Ireland	Rarely - once a year
Finland	I would say, that we don't accept flooded roads
Bulgaria	Do not understand completely this question
Sweden 2	We don't know yet, but our biggest roads can not be closed for more than a day. Small roads maybe a week. We are working out new guidelines for that as well.

2.3. What procedures do you adopt when conducting an inspection of a flooded road?

Comments countrywise below:

Denmark 2	Investigate were you have blockage
Denmark 3	It is assumed that flooding only occurs if then drainage system is damaged, i.e blocked at some point, and the aim of the inspection is to locate the blockade and initiate repair work
Denmark 4	Depends on what kind of drainage we have on the road.
Norway	Generally speaking, local authorities will do the necessary inspections, in cooperation with maintenance contractors, in order to secure the road and its surroundings against further damage, and the safety of road users. In severe cases the road may be closed until inspection results indicates that traffic may continue.
Germany 2	- Inspection of gullies and drainage pipes, calculation of hydraulic capacity
Germany 3	
Netherland 1	As far as I know, roads are not inspected when flooded. The flooding is solved (if possible) and the road is cleaned afterwards, if necessary.
Ireland	Inspect outlets and visible sections of drainage design - gullies etc.
Bulgaria	Cutting of drainage
Sweden 2	Mostly visual, sometimes geotechnical investigations

2.4. Is the cause of the flood investigated? If so is it often due to: Clogging. Inadequate pipe diameter, Storage capacity or Other

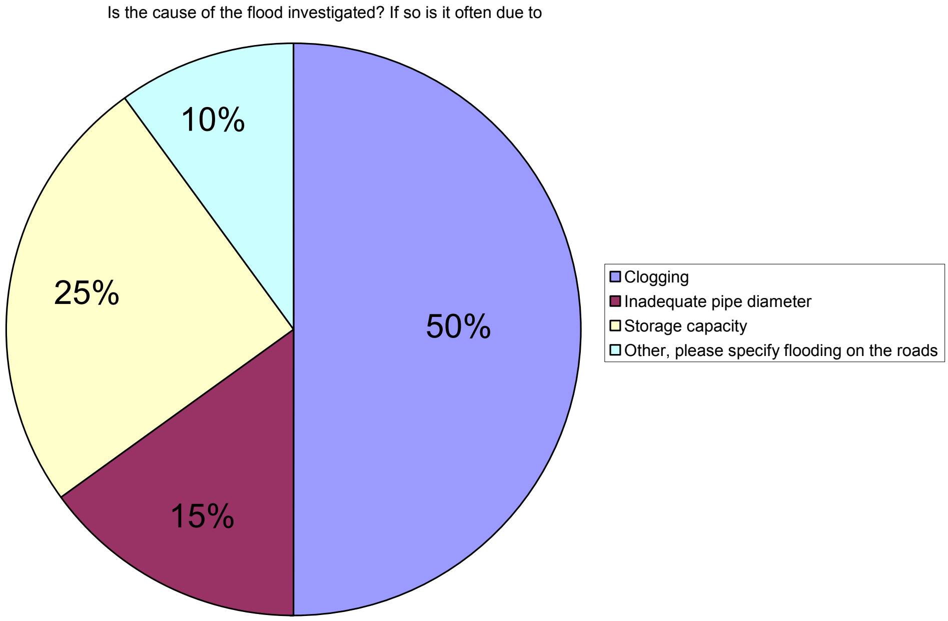

Figure 8. The result of Q 2.4.

Comments countrywise below:

Denmark 3	Defect sewage pumps
Norway	The cause of the flood may be a combination of several factors, and it is not always possible to point out a single factor. (Neglected maintenance and lack of cleaning or removal of debris in culverts or side ditches is believed to be a common cause for flooding.)

2.5. How is this information documented?

Comments countrywise below:

Denmark 1	Photo
Denmark 3	There is no central documentation
Denmark 4	We store the information about what kind of materials and equipment have been used to correct the damage.
Norway	Inspection reports from maintenance contractor, or from the road authorities' local inspector, or no documentation. (It is believed that a number of flooding takes place without being reported, or without systematic storing of the information.)
Germany 2	Systematic documentation of fire brigade actions due to flooding, systematic documentation of inspection and cleaning activities in GIS based operation system
Netherland 1	Flood causes are investigated only after severe flooding incidents. In the case I know responsible authorities (municipality, water board, fire brigade) would come together, exchange experience and suggest improvements to existing emergency procedures. Small incidents are generally not documented, other than in the form of complaints by citizens. Heavy rainfall, with a large return period is the cause and is considered
England	currently various databases; national register now implemented
Ireland	Informally by email or verbal communication
Bulgaria	In written statements

2.6. Are any of these drainage solutions more prone to flooding than others?

Swale with fin drains, Ditch and swales, Trench drain (Subsurface drainage only), Trench drain (Surface and subsurface drainage), Other, please specify

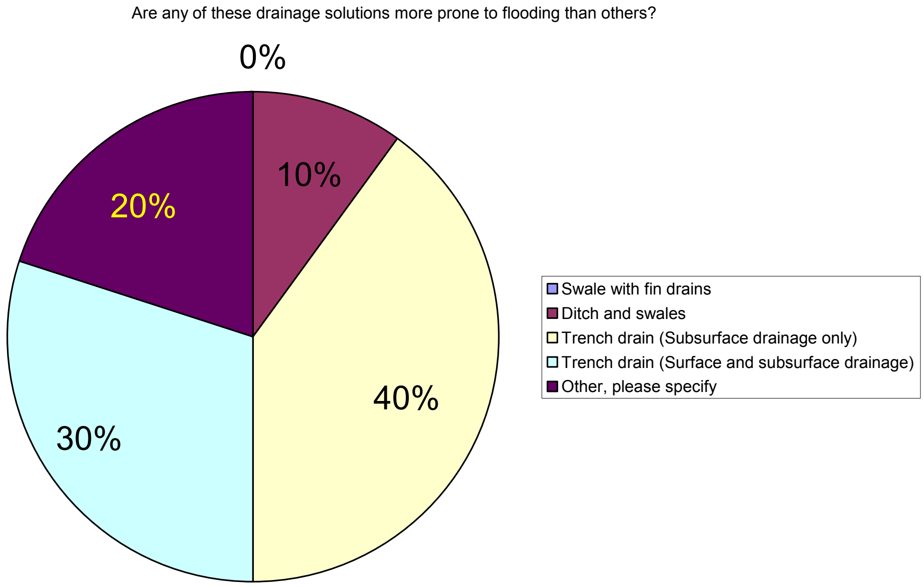

Figure 9. The result of Q 2.6.

Comments countrywise below:

Norway	This has not been assessed for the purpose of the questionnaire. It is doubtful if any information exists.
Netherland 3	Infiltration solutions
England	Gullies and chambers

2.7. Is flooding simply related to seasonal variations? (Related to thawing after winter or heavy rains in the summer or other causes that are generally expected)

Comments countrywise below:

Denmark 1	Yes, heavy rains
Denmark 2	Yes, Spring Winter
Denmark 3	No
Denmark 4	No
Norway	Yes, it is probably related to seasonal variations more than other factors. However, we have seen some cases where excessive flooding has occurred during heavy summer rain (any time in the summer) and even at other seasons (e.g. "winter rain"). Heavy rainfall and/or rainfall of long duration, in combination with ice- or snow-covered ground, or frozen ground, may lead to excessive flooding (high run-off coefficient, even > 1,0).
Germany 2	summer: heavy rainfalls causing overload of drainage pipes, autumn: leaves clogging gullies
Netherland 1	For urban systems, heavy rainfall is a recurrent cause; so is pipe clogging.
Netherland 3	Heavy rainstorms combined with inadequately designed/maintained locations
England	No
Ireland	Rainfall intensity
Finland	Yes, totally: thawing after winter, heavy rains and sealevel raise (caused by low air pressure and heavy westerly wind).
Bulgaria	Yes
Sweden 2	Yes mostly

2.8. In your experience, is flooding more common for some soils than others? Please indicate which ones.

Clay, Silt, Sand, Till, and Other

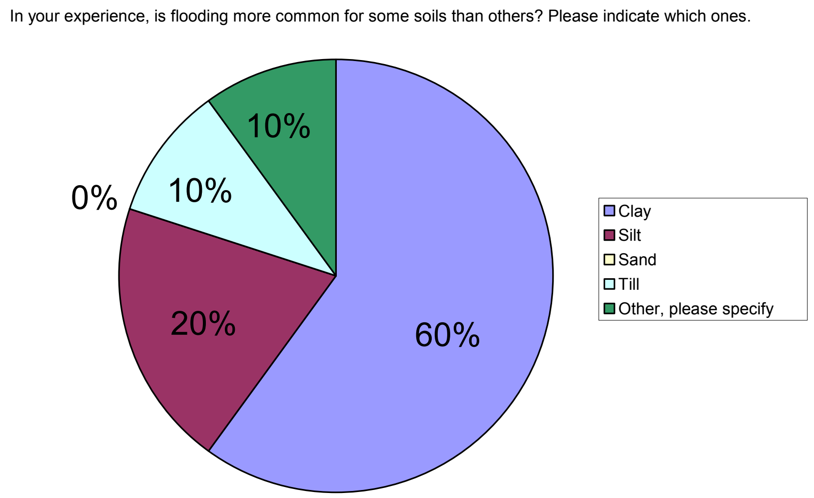

Figure 10. The result of Q 2.8.

2.9. We would like to know to what degree permeable pavements are used within your domain of operation. Attempt to provide the percentage of

a) Permeable pavement

b) Impermeable pavement (asphalt and concrete)

This question is hard to interpret as the respondents have responsibility in different types of fields.

Comments countrywise below:

Denmark 2	o Permeable pavement: 0% o Impermeable pavement 100%
Denmark 3	o Permeable pavement: 0% o Impermeable pavement 100%
Denmark 4	o Permeable pavement: 75% o Impermeable pavement: 25%
Norway	o Permeable pavement: Permeable pavements in terms of (porous) asphalt are only used to a very small extent in Norway. Permeable pavements in terms of gravel roads are still used to some extent on secondary and low-volume roads. [No percentages provided]

		o Impermeable pavement: Impermeable pavement (asphalt and concrete) Concrete roads are very few. Regular impermeable asphalt is the normal solution in Norway. [No percentages provided]
Germany 3		o Permeable pavement: o Impermeable pavement: Bankette werden in der Regel wasserdurchlässig ausgeführt. Oberflächen von Bundesautobahnen, Bundes- und Landesstraßen werden wasserundurchlässig ausgeführt.
Netherland 1		o Permeable pavement: Permeable pavement 80%; NB: this figure indicates an estimation of the percentage of brick roads. These are permeable to a limited degree. Special permeable pavements have been developed and are applied in new development areas and sometimes upon road reconstruction in existing areas. o Impermeable pavement: Impermeable pavement (asphalt and concrete) 20%
Netherland 2		o Permeable pavement: 90% o Impermeable pavement (asphalt and concrete) 10% Note: a clear definition of permeable pavement is not provided. In the Netherlands on the motorways the preferred wearing course is porous asphalt (now about 90% of our main road network is covered with PA. This , of course is laid on impermeable bas course materials. When the question is dealing with a totally permeable pavement the answer will be that 0% of the network has such a pavement
Netherland 3		o Permeable pavement: 85% o Impermeable pavement: 15%
England		o Permeable pavement: 0%, currently nil, plans to introduce o Impermeable pavement: 100%
Ireland		o Permeable pavement: Very little - not dealing with urban areas. o Impermeable pavement:
Finland		o Permeable pavement: 0% o Impermeable pavement: 100%
Bulgaria		o Permeable pavement: 0% o Impermeable pavement: 100%
Sweden 2		o Permeable pavement: 45% o Impermeable pavement: about 65 % of the state owned roads, the rest of these roads are gravel roads, some permeable asphalt exists

2.10. Is any sort of SUD (Sustainable Urban Drainage) commonly used? If so, please comment on solutions used.

Comments countrywise below:

Denmark 1	No
Denmark 3	No
Denmark 4	No
Norway	It is unclear (to me) what the SUD concept includes. In urban areas, the common solution is to use buried pipes for drainage of subsurface water and shallow ditches for surface water.
Germany 2	pilot projects within Urban Water Cycle Project (Interreg IIIb), implementation of a working group on storm water management
Netherland 1	Swales, infiltration ditches and special permeable pavements have been applied in urban developments since the 80s, more or less. There is discussion as to whether high traffic density roads can be connected to these facilities for the potential pollution of run-off from these roads.
Netherland 2	Hardly for National highways, increasing for urban areas higher on permeable soils > 2 m above groundwater level
England	Filter drains common, other types in use but less common
Ireland	Not common but becoming more common - swales and wetlands. Specifications for drainage design have recently been changed top allow further use of SUDS
Finland	SUD is not commonly used
Bulgaria	No
Sweden 2	Mostly state owned roads are outside urban areas

2.11. Describe an example where you have experienced an unusually large flooding event.

Comments countrywise below:

Denmark 1	flooding on the road surface. The verge/shoulder was cut down, and the pipe wells cleaned.
Denmark 2	Clogging, cleaning out pipes and gullies
Denmark 3	I never experienced flooding with road damage
Norway	An unusually large flooding event - at least it had a large and spectacular effect - took place in the autumn (October) of 1987 in a local district some 20 kilometres from Oslo, where the water level rose about 0,7 metres above what was predicted as a 100 years flood (forgive if I have missed some of the facts). The road section (a few hundred metres in length) was in an area with very soft ground, and it had been constructed as a super light embankment with EPS blocks (expanded polystyrene). When the water rose above its max predicted level, the road also rose, it was actually floating! (EPS weighs only 20 kg/m3). It was attempted to place a large number of loaded trucks to add weight and keep the road down, but they were too few and too late, so the road lifted and was damaged. After the flooding it had to be reconstructed.
Netherland 1	In 2002, a 100 mm storm hit an urban area in the city where I worked and was responsible for urban water management. About 20 ha of urban area flooded. Emergency teams from municipality, water board and fire brigade tried to help but could not do much more than to close heavily flooded roads and wait for the rain to stop. No road repair was undertaken afterwards; a study on the capacity of urban drainage and surface water systems was done and some local obstructions were removed. Nevertheless, a rainfall event of this size would still cause extensive flooding.
Netherland 2	Flooded road after heavy rainstorm, No action, No repair works
England	Summer 2007 - unprecedented rainfall intensity over regional catchment. Extensive network delays and road closures. Contingency plans put in place and roads opened as quickly as possible. Minimal repairs needed.
Ireland	M3 - Additional development in the area of the road scheme led to flooding in a section of the road. Flooding was reported, then inspected. Drainage design was changed - capacity increased.
Finland	In Kittilä and Ivalo area in 2005 due to spring run-off. 15 roads were blocked, some over a week. We repaired 17 bridge codes afterwards, replaced culverts, repaired roads and pavements, changed rail type (in one case). We made instructions about, how to act in flooding situation (what are contractors and road authorities responsible for).
Bulgaria	In August 2006. Cleaning of the rivers' beds along the roads. Building of new drainage system elements and support constructions.

2.12. Do you expect more negative impacts due to climate changes in the future?

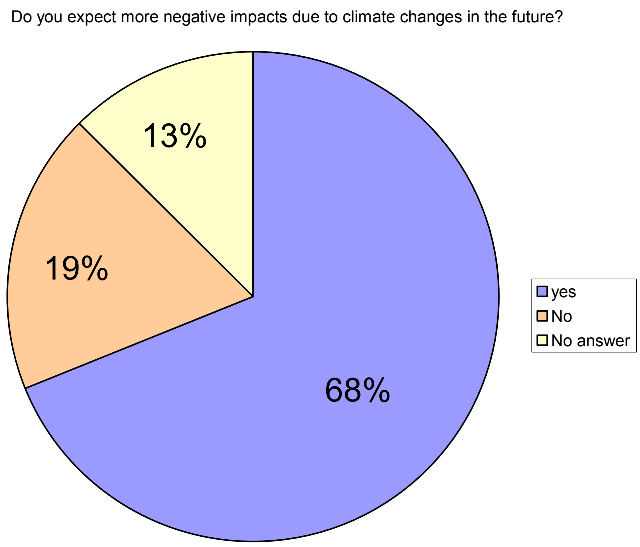

Figure 11. The result of Q 2.12.

Comments countrywise below:

Norway	Yes. Probably more heavy rains (will vary between the different parts of the country. Probably more events with rainfall in the "cold season" (combination with frozen ground and/or snow- and ice-covered ground), which can lead to sudden and severe floods.
Germany 3	Die nächsen 20 bis 30 Jahre keine signifikanten Änderungen.
Netherland 1	For urban drainage systems, the inspected increase in rainfall discharge due to climate change is in the order of 20%. Many municipalities have plans to disconnect areas from urban drainage systems and lead rainwater to local storage and infiltration facilities instead. These plans started out aiming at environmental improvement , but by reducing inflow towards urban drainage systems also reduce flood probability. Moreover, many urban areas have seen an increase in impervious surface area of 10 to 50%, sometimes even 100%. Where this increase has given rise to flooding, adaptations to the systems have often been made without causing severe increase in costs or disruptions of urban life. In a similar way it should not be much of a problem to accommodate an inflow increase of another 20%.
Netherland 3	Yes, more heavy rainstorms
Finland	Yes, in the long run.
Sweden 2	yes, more intense rain

2.13. What specific type of road damages do you expect to increase due to climate change?

Comments countrywise below:

Denmark 1	More flooding, and maybe more damage on the road embankment
Denmark 2	We need increased pipe diameter
Denmark 4	No specific type of damage.
Norway	Increased frequency of flooding events, and flooding events that are more severe than what we have been used to, may lead to more sediment transport and clogging of pipes and ditches, and more damage on erosion protection systems. It may also lead to more rock/mud/snow avalanches which hit the road, in places where we have not had it before.
Germany 3	Falls die Niedershlagsintensität zunimmt, dürften Erosionsschäden an Böschungen häufiger auftreten.
Netherland 1	As stated earlier, in urban areas I know of no examples of heavy damage to road infrastructure caused by flooding.
Netherland 3	Fatigue cracking of pavements due to more frequent periods of lower subsoil support
England	Increased structural damage across all assets
Ireland	Pavement degeneration
Finland	collapse of gravel and also paved roads due to flooding damages in pavements (freezing-thawing, also after flooding)
Bulgaria	Rutting due to of the summer temperatures; subsoil deformations
Sweden 2	roads washed away

2.14. Are roads and drainage systems, in your area, being changed to take account of climate change?

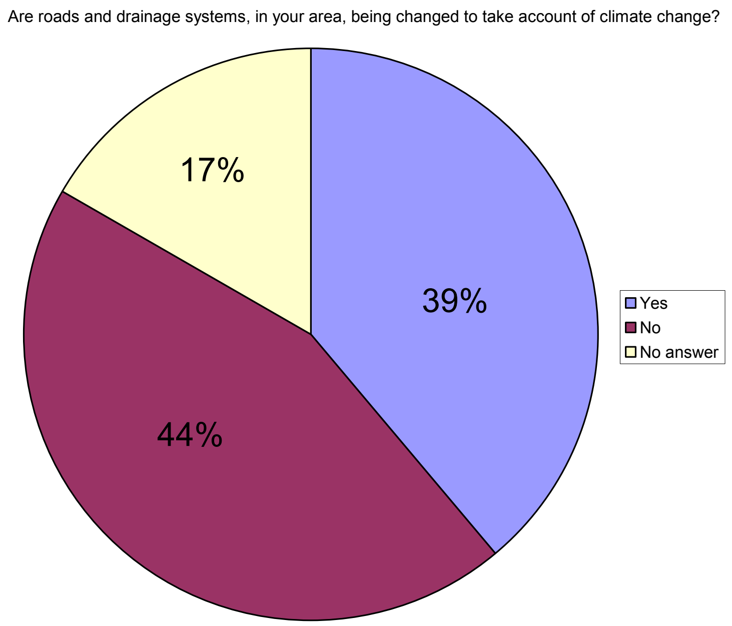

Figure 12. The result of Q 2.14.

Comments countrywise below:

Norway	The changes will probably be quite small and can only take place gradually. For new roads, which accounts only for a very small percentage of the road net, stricter guidelines are under consideration. For existing roads, the drainage system will be improved or enlarged only as necessary, following normal inspection and assessment of the need to improve it. However, stricter guidelines for inspection (which can reveal unknown problems) will be considered. In particularly vulnerable areas or areas with particulera areas, it will probably be necessary to assess the whole drainage system in terms of quality, durability and function in case of extreme rainfall, snow melting conditions etc.
Netherland 1	Exploratory studies are done to investigate what the potential impact of increased rainfall would be - by means of model simulations.
Netherland 2	We specify an updated once in 10 year design rainstorm
Ireland	A 20% increase in rainfall is used to design the drainage system - more use of vegetative features that have attenuation capacity - Increasing the size of attenuation ponds.
Finland	The width of bridges and the size of culverts has grown.
Bulgaria	Only in reconstructed road sections
Sweden 2	more focus on drainage system

2.15. Describe briefly how meteorology and hydrology are used in the present design of drainage systems. If changes are planned, please describe them as well.

Comments countrywise below:

Norway	**Meteorology**: The current design guidelines for new roads are mainly based on data about rainfall intensity (high resolution), and the use of the rational equation Q=CxIxA for the calculation of run-off. **Hydrology**: Direct measurements of run-off, mainly administered by the Norwegian Water Resources and Energy Directorate (NVE, www.nve.no), are used to some extent, mainly in connection with the design of bridges across rivers (need to determine the bridge deck level, and erosion protection of fundaments, etc. **Changes**: It is being considered to combine meteorology and hydrology, where hydrology can in some cases be used to calibrate results obtained by the rational equation.
Germany 3	Die hydraulischen Nachweise für die Entwässerung der Straßen werden mit Regenspenden nach KOSTRA-DWD-2000 (Deutscher Wetterdienst - Starkniederschlagshöhen für Deutschland 1951-2000) durchgeführt. Die Auswertugnen erfassten die Starkniederschlagshöhen im Zeitraum von 1951 bis 2000.
Netherland 1	For urban drainage systems, design storms are now used to design systems and check the capacity of existing systems. Design storms are artificially composed events, assumed to be representative of rainfall events of a certain return period based on rainfall statistics. Studies are being done to consider how design storms might be recomposed based on expected changes in rainfall characteristics. Climate predictions are too uncertain at this moment to make reliable adjustments to existing design storms. Sensitivity analyses are being done instead.
Netherland 3	The updated design rainstorm is based on recent meteorology studies
England	Design guidance includes climate change factors
Ireland	1 in 100 year storm event is used for attenuation design - 20% is added to rainfall. Drainage is designed based on 1 in 1year storm and tested for 5 year surcharge (size controlling factor.
Finland	The Finnish Road Administration gets the instructions to the width of bridges and size of culverts from The Finnish Environment Centres whose calculations are based on meteorology and hydrology information.

2.16. Do you have models or maps to predict where future flooding events are expected to occur?

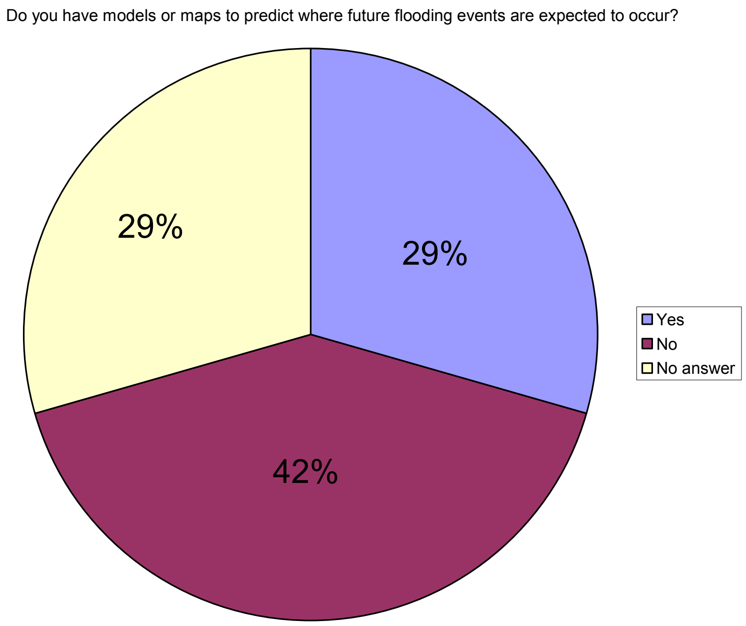

Figure 13. The result of Q 2.16.

Comments countrywise below:

Norway	The road authorities do not issue models or maps to predict future flooding events, but there is some cooperation with the NVE (see 2.15) and the meteorological authorities (www.met.no), in order to develop good prediction models which are also useful for road designers.
Germany 2	Hydrodynamic flow simulation model Hystem-Extran
Germany 3	Festgesetzte Überschwemmungsgebiete liegen im Kartenserver vor.
England	In preparation
Netherland 1	For urban drainage systems, often hydrodynamic sewer model have been made that can simulate flooding as a result of rainfall events.
Ireland	Office of Public works are responsible for identifying areas of historical flooding and areas prone to future flooding. This is not specifically focussed on national roads.
Finland	The Finnish Road Administration doesn’t have but The Finnish Environment Centres are preparing those maps (the EC Flooding Directive).

2.17. Where is this information stored?

Comments countrywise below:

Norway	The information and data on hydrology and meteorology will be stored by the involved authorities (see 2.15 and 2.16), and there will probably be possible to link up from the road authorities, consultants, contractors and others involved in road design and construction
Netherland 1	Geometrical data are stored in urban drainage system databases; simulation models are mostly stored in project files.
England	Various currently; will be national drainage data management system
Ireland	OPW website
Sweden 2	Information from the Swedish Meteorological Institute is used

2.18. Is there a special group of people in your organisation concerned with climate change issues?

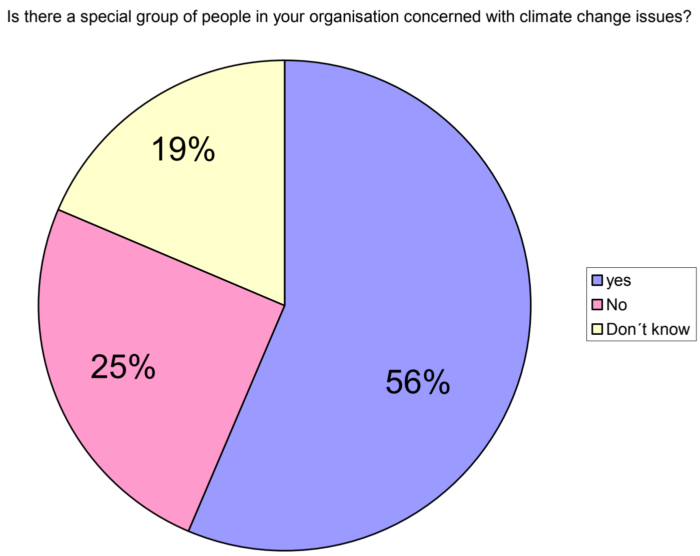

Figure 14. The result of Q 2.18.

Comments countrywise below:

Denmark 3	Vejteknisk Institut
Denmark 4	
Norway	Yes, there is a research programme, Climate and Transport. See www.vegvesen.no/klimaogtransport (Contact person/programme manager: Gordana Petkovic, gordana.petkovic@vegvesen.no)
Netherland 1	At TU Delft several research projects are running. In Breda, where I worked, there was a working group composed of about 10 employees from several departments, studying potential consequences of climate change.
Finland	Yes, in a way, it belongs to the Environmental Affairs Coordinators tasks.

2.19. Are you familiar with any research on impacts of climate change on drainage design and flooding being carried out for your country?

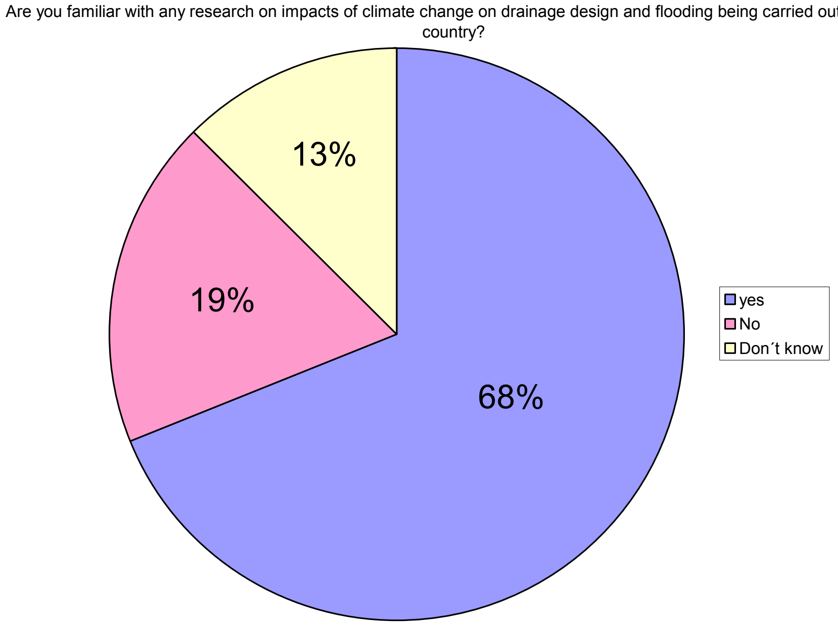

Figure 15. The result of Q 2.19.

Comments countrywise below:

Denmark 3	Vejteknisk Institut
Norway	Yes, there is a research programme, Climate and Transport. See www.vegvesen.no/klimaogtransport (Contact person/programme manager: Gordana Petkovic, gordana.petkovic@vegvesen.no)
Germany 3	z. B. KOSTRA-DWD-2000, KLIWA Bayern/Baden Württemberg (Klimaveränderung und Konsequenzen für die Wasserwirtschaft"
Netherland 1	Yes, there is even a national research program: Knowledge for Climate (kennis voor klimaat).
Ireland	Yes SWAMP
Finland	Dr Timo Saarenketo from Roadscanners has done some researchwork dealing with better drainage

2.20. Do you (or your organization) work in accordance with the EC Flooding Directive?

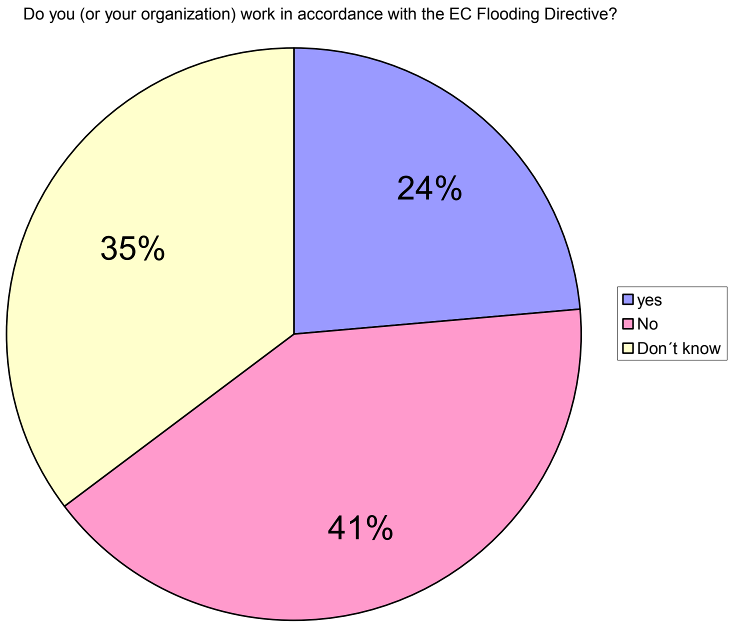

Figure 16. The result of Q 2.20.

Comments countrywise below:

Netherland 1	At the urban level, the flooding directive is not generally known, that is at least my impression.
Finland	No. The Finnish Environment Institute does.

2.21. Do you have an existing policy on prevention or on adaptations?

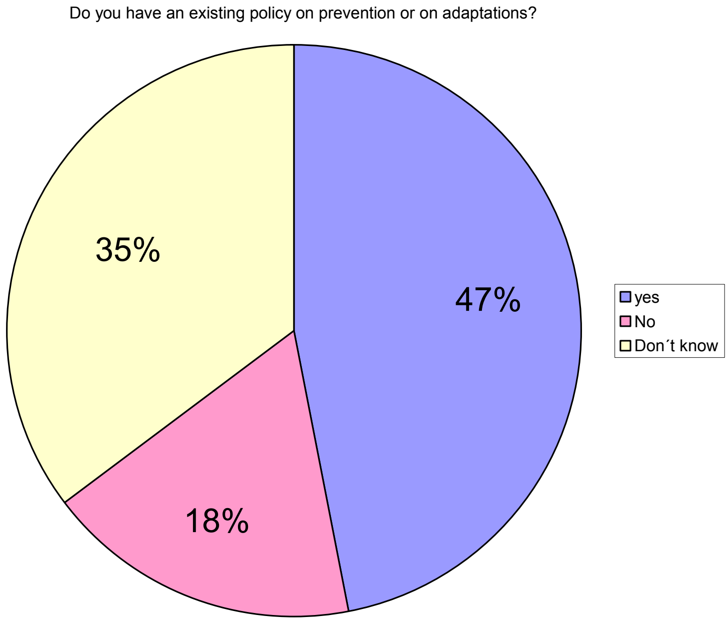

Figure 17. The result of Q 2.21.

Comments countrywise below:

Norway	Policies on prevention or adaptations are assessed continuously.
Netherland 1	Question is very general. If emergency plans are meant, these are available.
Netherland 3	We are working on a policy
Ireland	Yes OPW flood defence
Finland	Yes, The Ministry of Transport and Communications has.
Bulgaria	Yes but for this is the responsibility of The Ministry of the Extreme Situations

2.22. Is there an organisation assigned to identifying areas of flooding?

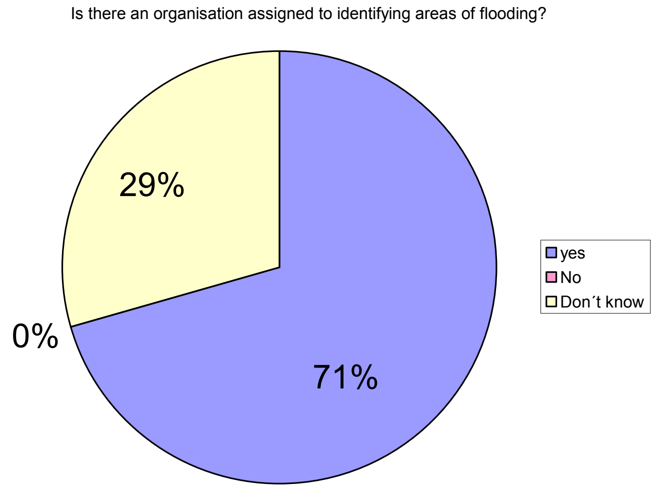

Figure 18. The result of Q 2.22.

Comments countrywise below:

Norway	The general authorities for identification and surveillance of areas of flooding is the NVE, see 2.15. For roads and their surroundings, such tasks are carried out by the public road authorities, in cooperation with NVE.
Germany 3	Untere Wasserbehörden
Netherland 1	no special organisation, part of urban water management tasks.
Netherland 3	Yes, investigating critical area's with high water and weak dikes
Ireland	OPW but not specifically on national roads
Finland	The Finnish Environment Institute and The Regional Environment Centres.
Sweden 2	We do it in our usual organisation