SWAMP

The Blue Spot Concept

• methods to predict and handle flooding on highway systems in lowland areas

Summary Report 1

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Storm WAter prevention - Methods to Predict damage from the water stream in and near road pavements in lowland areas

Report 1 – The Blue Spot Concept

- **methods to predict and handle flooding on highway systems in lowland areas**

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List of Tables

List of Figures

Table of content

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

Climate researchers predict significant changes in climate over the current century. This will have multiple effects on society. One such is that more severe floods may occur in many parts of Europe, in particular in central and northern Europe (Christensen & Christensen, 2003). Flooding poses a great threat to roads, and may in severe cases lead to massive obstruction of traffic and damages to the road structures themselves. In many countries, design guidelines for new road related constructions have changed in response to the anticipated future climate. However, changing the entire existing road network is very costly, and likely not necessary.

The SWAMP project targets the critical issue of finding the most vulnerable parts of the road network, and how to prepare them for flooding. The uncertainties inherent in predictions of future climate are significant. The climate research community is convinced that there will be a change, but admits it is difficult to precisely quantify the changes in e.g. terms of magnitude and frequency of rainfall. However, floods have always occurred through history and always will. Hence, identifying and improving road sections vulnerable to flooding are of great value irrespective of the severity of climate change.

Areas close to roads that are prone to flooding are referred to as blue spots in the SWAMP project reports, corresponding to e.g. black spots denoting serious accidents on the road network. Given the vast distances covered by roads, an effective tool to assist in finding the weak sections would be very useful. Hence, the objectives of the SWAMP project were to 1) determine the structure and requirements of a model to find blue spots, 2) to produce guidelines on how to reduce vulnerability to flooding at blue spots. Notice that the creation of an actual computer model was not part of this project.

In order to ensure an international perspective and learn from others, a questionnaire was sent out early in the SWAMP project to persons who work with roads in eleven countries. Questions were asked about what are considered problematic parts of the drainage systems, experiences with flooding, whether guidelines for design and maintenance of road drainage systems existed, and if (and how) they have changed due to the climate issue. In addition, a literature review was carried out, as well as a directed study of climate change modelling and its outcomes and uncertainties.

Besides this summary (Report 1), the details of the project work packages are described in three separate reports covering:

- Report 2 – Background Report - literature, questionnaire and data collection for blue spot identification
- Report 3 - The Blue Spot Model – development of a screening method to assess flood risk on national roads and highway systems.
- Report 4 - Inspection and Maintenance - guide to reduce vulnerability due to flooding of roads.

This report will briefly summarise the findings of the last two reports and put them in a context.

2 The Blue Spot Concept

The blue spot concept is a chain of procedures that can be used by road owners, operators or consultants to systematically analyse, adapt and protect the road network with respect to flooding. It involves computer methods executed at office PCs, followed up by targeted field inspections and actions. The starting point is a screening method that can be used on the regional scale to find blue spots. Depending on the severity of possible conflicts between the blue spot and the road, the level of investigation can be expanded to analyse rain sensitivity of individual blue spots, or even an additional step to detailed numerical modelling of hydraulic processes. The last procedures of the blue spot concept are inspections at local selected sites, followed by the appropriate actions as suggested by the guide. These actions may e.g. include upgraded drainage systems or improved monitoring of water levels in streams.

The method of finding and analysing the blue spots (i.e. the Blue Spot Model) will be described in section 2.1, while the guide for action at the local site are described in chapter 3, 4 and 5.

The blue spot concept is intended for use at large and important roads in a non-urban setting.

2.1 The Blue Spot Model: Finding the blue spots

The first level can be described as a screening (Table 1, Figure 1), where all depressions in the map material are identified. This is done by allowing rain to fall on the model land surface while not allowing for infiltration into the ground or evaporation to the atmosphere. Hence, every drop of rain will flow along the land surface until it reaches a volume of free water collected in a depression. If these volumes are larger than $10m^3$ and close to a road, they are considered as threats and are included in the following analysis.

The second level is a calculation of rain sensitivity for each individual depression found in level 1. It is done by assuming no drainage from depressions and assuming impermeability of the catchment of 20, 40, 50, 60, 80 & 100%. In this way a risk map can be drawn showing the amount of precipitation needed to fill low-lying areas (Table 1, Figure 2).

The third level consist of a 1D-1D hydrodynamic model of surface reservoirs and depressions which is used to find pathways, catchments and ponds in a risk area. In this way calculation of both water flow on the surface and in the drainage systems is taken into account giving a more accurate calculation of flood risk (Table 1, Figure 3).

In addition, the risk of flooding due to sea level rise is mapped by incrementing the sea level and tracking how far inland the sea water reaches. Dykes act as barriers as long as the water level does not exceed the upper limit of the dyke.

The risk of flooding from water level rise in rivers can be calculated in the same way as the sea level rise. The water level in a river can be incremented to a given level and the water level rise can be tracked inland.

In general, at least a level 2 analysis is recommended for all blue spots.

Table 1. Level of analysis

LEVEL 1 – Screening using terrain analysis

• All the depressions are identified. Assuming a surface runoff of 100% in the catchment (i.e. no infiltration of rainwater into the soil), e.g. Zerger (2002). See Figure 1.

• Low-lying areas where there is danger of flooding due to rising sea levels are identified. Different levels of sea level are used. Dikes are included so that no flooding behind the dikes occurs unless water levels exceed their height. It takes no account of gradients in streams.

Figure 1. All depressions are identified assuming 100% catchment runoff and no drainage in the depression.

LEVEL 2 – Rain sensitivity for individual depressions

• Flow paths and catchment areas for each blue spot are calculated, e.g. Maksimović et. al. (2009).

• Simple calculation from contributing areas. "Risk map" with the amount of precipitation needed to fill low-lying areas. Assuming no drainage from depressions. Rain sensitivity analysis with impermeability of the catchment area of 20, 40, 50, 60, 80 & 100%. See Figure 2.

Figure 2. Top: Rain sensitivity analysis with impermeability in the catchment of 20%. Bottom: 100% impermeability.

LEVEL 3 - Hydrodynamic model of surface reservoirs and depressions

• Provides a time-variable flooding prediction

• 1D-1D Coupling between the surface (terrain, canals and ponds) and drainage systems (pipes), e.g. Boonya-aroonnet (2007), Jensen et. al. (2010).

• 2D-1D Coupling between surface and drainage systems e.g. Nielsen et. al. (2008), DHI (2009), Wallingford (2009), Domingo et. al. (2009). See Figure 3.

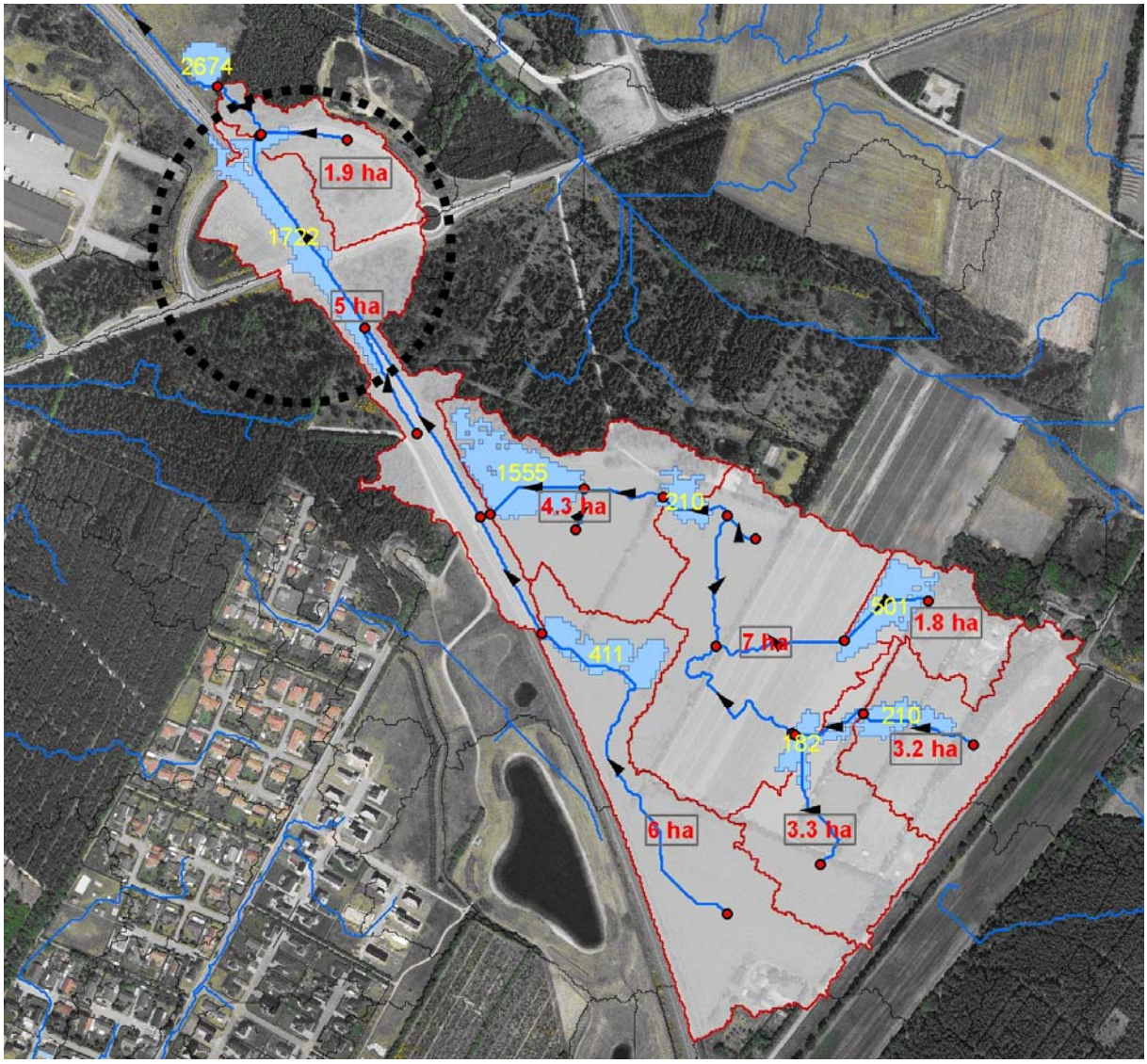

Figure 3. Pathways, catchments and ponds in a risk area are calculated by the use of 1D-1D and 1D-2D modelling.

2.2 Rain sensitivity of individual depressions

Normally, there will always be quite a large number of blue spots along or near a road stretch and a level 2 analysis is probably justified in most, if not all, cases. The level 2 analyses focuses on pointing out the most risky depressions.

Two depressions of similar geometry (volume and shape) do not need to pose the same problem. It is crucial to determine the catchment for every depression in order to estimate the volume of water available to fill the depression. A large catchment for a small depression means a greater risk than a small catchment for a large depression. Rainfall depth in millimetres needed to fill the depression up, can be calculated by dividing the depression volume with the area of the catchment. Depressions can be colourised according to the input of rain (Figure 4), e.g. depressions can be coloured in red if it should be explored further, because it takes less than 25 millimetres of rain to fill them up.

In conclusion, depressions near the road, which can be filled up by relatively moderate rainfall should be targeted first for inspection and pre-emptive measures.

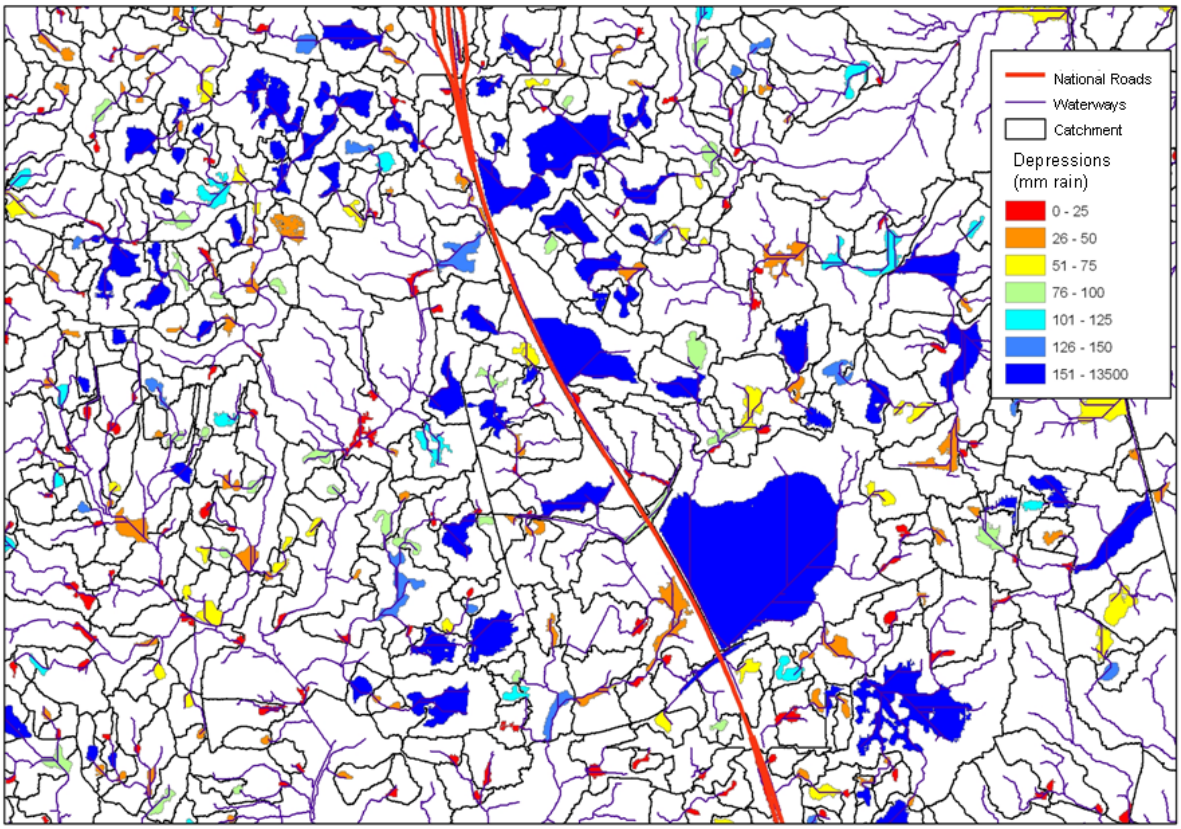

Figure 4. Flood risk illustrated by the precipitation needed to fill depressions.

2.3 Hydrodynamic model of surface reservoirs and depressions

The benefits of implementing level 3 analysis are that both the water flow on the surface and in the drainage systems is taken into account thus giving a more accurate calculation of flood risk. Level 3 is an excellent tool to use when looking for a solution, including more details about the systems (e.g. drainage and storage capacity) and when setting up emergency

plans.

In the demonstration example (introduced in section 2.4) a level 3 analysis using 1D-1D modelling was performed. Mike Urban (Mike Urban, DHI 2010) were used as the hydrodynamic 1D model. Water was routed between the blue spots by pathways identified in the digital terrain model. See Report 3 for details.

2.4 Demonstration example Denmark

The basis for calculating the areas at risk of flooding was laser scanned elevation data for a large part of Mid-Jutland (Figure 5). Grid data is available with a 1.6 m resolution (commonly used in Denmark) and a height accuracy of better than 10 cm at well-defined surfaces. The whole model contains 2.9 billion points, thus requiring a quite powerful personal computer by today's standards.

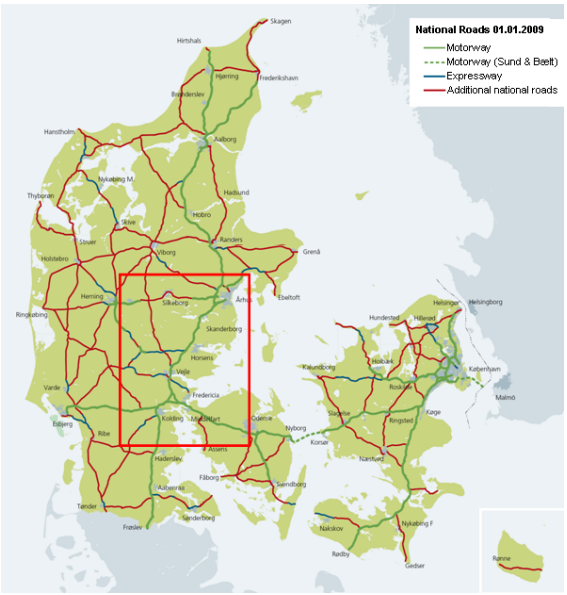

Figure 5. The study area (red square) has a total of 875 km of national roads. Total length of all national roads in Denmark (January 2009) was 3790 km.

The investigation in the demonstration example utilised software described in Report 3 (the Blue Spot Model). The result of the level 2 analysis is a map showing e.g. water depth above land after a rainfall (Figure 6). Clearly, there are plenty of depressions found near the roads, and one of them is magnified in Figure 7. Notice how the road underpass is entirely filled by deep water, completely blocking traffic on the highway. Clearly, this is a Blue Spot which need to be analysed further in order to come up with a solution that prevents this situation from happening, or at least preparing a plan for how to quickly restore it to dry status. Chapter 3, 4 and 5 contain guides for this work.

To correctly calculate water depths requires information about infiltration capacity that may be difficult to obtain, and that may vary in time. As an example, prolonged periods of rain before a heavy rain event, creates larger surface runoff and consequently more severe flooding. Nevertheless, its importance to blue spot prioritisation can be investigated by sensitivity analysis. The application of a level 3 analysis is also explored in Report 3.

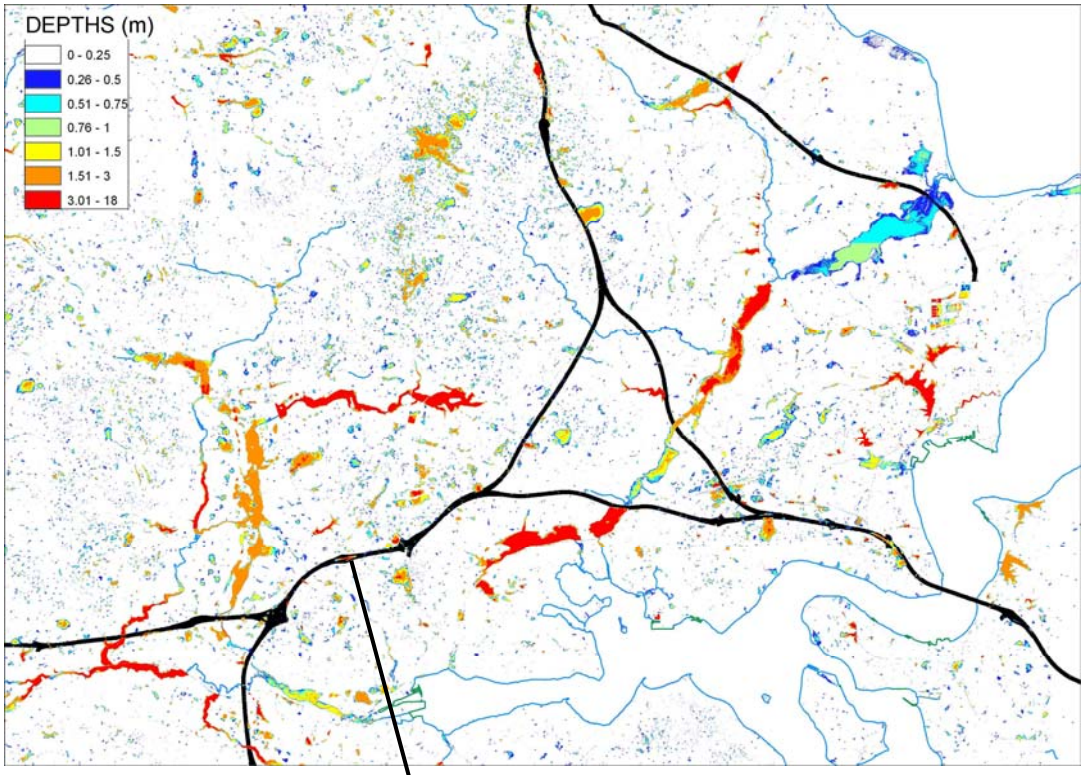

Figure 6. Examples of depressions, which have information about area, volume and depths.

Figure 7. A magnified blue spot with water depths above land surface.

3 Reducing Vulnerability to Flooding at a Blue Spot

The previous chapter describes how blue spots can be identified and analysed using a computer model, terrain information and appropriate software. In order to find out how to handle the situation at a single blue spot, site visits are required even though a level 3 analysis can give some ideas of where to look for problems. Here, information is presented about what parts of the road drainage system and surroundings that should be evaluated on a blue spot. The following two chapters (4 and 5) include condensed information from report 4 – Inspection and Maintenance which comprises two parts targeting office management and field activities respectively. The first focuses is on information retrieval, considerations of redesigning the drainage system, but also directions concerning which elements of the drainage system should be considered at a blue spot. The second focus is more practically oriented, and gives information about what to look for during a site inspection. The information is intended for use at large and important roads in a non-urban setting.

It can be used as a base for developing and planning new guidelines and routines to fit local conditions.

4 Considerations for Managers of Road Infrastructure

The management staff has the responsibility to organise inspections and maintenance in an appropriate way. We assume that they spend most of their time in an office setting, not carrying out much field work. They need to work with information retrieval, in order to evaluate if a redesign of existing drainage systems is necessary, and finally determine a blue spot specific action plan for inspections and maintenance. The information related activities to be done should focus on:

- Blue Spot Model simulations outcome
- Background information at the site
- The current drainage system
- Feasibility of monitoring (early-warning) systems
- Preservation of information in a database

Blue Spot Model simulations information

The level 2 analysis in the Blue Spot Model can give indications on how much more water one can expect at a site, and perhaps most importantly, what parts of the catchment provide most of the water reaching the blue spot. Hence, it gives good clues to where e.g. a retention pond should be placed to maximise its effect. In addition, Level 3 analysis using a hydraulic model can be very useful in evaluating the possible water stress at a blue spot, and investigating various ways to retain, or divert water.

Background information for the site

This includes for example maps showing topographic data, maps of streams, lakes, ponds, swamps, geology and land use. This information is of great value in the further analysis. If present, previous experiences with floods or at least high water levels near the site are very valuable. In addition, knowledge of slope stability issues and erosion problems are necessary to have before planning actions. Sedimentation of eroded particles causes clogging of pipes, culverts and ditches and erosion may in the worst case damage the road itself. Obviously, it is also important to find out how the road and drainage systems were originally built.

The current drainage system

It is important to know the current status of the drainage system. With time, the capacity decreases if not very well maintained. Still, one may expect an operational life time which is shorter than the average expected life time of a road. Hence, some older drainage systems should perhaps be replaced due to age. The dimensioning should be reviewed to find out if the expected effect of climate change is acceptable, or if the system should be upgraded. Some countries (like Denmark, UK, Ireland and Sweden) have introduced climate factors to adjust the design storms (see Report 1 and Report 2). One should also consider restrictions on how much water is allowed to be discharged from the road drainage system to the receiving stream, lake or sea. Such restrictions are perhaps more common in urban areas but may exist elsewhere too and are primarily pollution related.

Instrumentation at a blue spot site

In fortunate cases, the pinpointed blue spot is already instrumented, and ideally data has been logged for some time. Local weather stations together with e.g. water level measurements in a retention pond or culvert may give valuable information on how the system responds to specific weather conditions like heavy rain. Changes in the response over time also give good clues to when maintenance is needed. Monitoring systems may include:

- Local weather stations
- Water level sensors in manholes, wells, ground water tubes, culverts, retentions ponds, streams and reservoirs. Water level readings can be directly converted to water flow if a discharge curve is determined for the measurement site
- Video cameras

Information storage in databases

It was apparent both from the questionnaire and from interviews that information about road constructions and all things related are not generally stored in a proper way. It is not unusual that the construction is unknown and that no one knows what kind of drainage is used. This is quite disturbing and we strongly recommend that a database solution is created in which e.g. the following information can be stored:

- Inspection notes, check list, photos of the situation and other comments at site
- Information about maintenance and repair work
- Damage to road and drainage
- Flooding events
- Improper dimensions

4.1 Evaluation of the drainage systems

Existing drainage systems are usually designed and constructed based on previous precipitation events (statistics). These calculations are based on former experiences. Today's demand have focus on the future situation and especially take into account the scenarios of more intensive rain events according to climate change prediction for the actual region (or the local site if possible).

Road and drainage systems are in some cases worn down to such an extent that the original capacity for water transport is no longer reachable. The system degrades with time because of ageing with resulting blockage, crushed pipes, settlements of systems, and sedimentation in pipes. Ditches and canals lose capacity due to growth of vegetation and they fill up with sediments.

Another factor which is easily forgotten is that the drainage pattern changes when an area is developed with more paved roads or grounds or draining is changed due to farming.

All this must be considered when upgrading the drainage system. It is usually not a single point that needs to be upgraded but the whole chain in the system.

- Once the background information is gathered, it is time to consider if the drainage system needs to be upgraded or perhaps only renewed. When doing so, it is necessary to consider the changing climate and whether a specific adaptation to

climate change is required. If needed, reconstruction of road and drainage system gives possibilities to decrease the number of blue spots

4.2 Action plan for inspection and maintenance of drainage systems

The maintenance office is responsible for the work at site including overview of field work such as inspection, maintenance and repair. This means that guidelines for field personnel (see following chapter 5) have to be developed by the management office. We propose that the instructions should include:

- Inspection sheets and log book directions
- How to perform the job and what to do
- How to use equipment and machinery

The guideline for field personnel in this report are suggestions that need to be developed and reworked to fit local conditions.

4.3 Early-warning systems

At most blue spots, early-warning systems can be very useful. The purpose of such systems is to give the responsible persons some time to consider appropriate measures before the real problems start. The cause of the problem in this case is typically a storm with heavy rainfall, rapid and massive spring snowmelt or high river flow. Obviously, a close cooperation with meteorological and hydrological institutes is required in order to receive warnings about upcoming problems.

An early-warning system may comprise:

- A weather alert notification system
- Information and data retrieval from monitored blue spots
- Risk assessment based on weather alert and conditions at blue spot
- In case of severe risk, presentation of information to road users about alternative routes using e.g. signs, radio or suitable information technology
- Inspection and preparation of the blue spot for harsh conditions
- Arrangement of warning signs and lights with adequate information

5 Inspection and Maintenance Activities

It is essential that blue spot locations are inspected and maintained regularly to prevent flooding. The focus of this chapter is to highlight the needed inspection and maintenance work of road drainage systems outlined in Report 4 – Inspection and Maintenance. The chapter gives descriptions of necessary activities on a blue spot location.

It consists of:

- Plans for inspection and maintenance (including work during extreme weather events)
- Work sheets and instructions for inspection
- Suggestions for maintenance and repair

5.1 Plans for inspection and maintenance

It is important to have a plan how and when to carry out inspections. A blue spot inspection plan is normally created by the "management office". Field personnel are responsible for the performance of inspection activities. It is proposed (Table 2) that inspection routines are performed annually and in connection with extreme weather situations, before, during and after events.

Table 2 Frequency for the inspection depends on the local situation for the blue spot

Annual inspection	Annual main inspection of all drainage elements, normally in spring after the winter events which may have caused damage, faults and defects. Sensitive places ought to be inspected several times per year
Extreme weather inspection	**Before event** Inspections one or two days before an expected extreme weather event such as heavy rain which could cause flooding of road and neighbouring areas
	During event Inspections during extreme weather with the purpose of observing problems. It is not recommended to do repair and maintenance work during an event, due to safety reasons. The work may include implementation of pre-planned emergency actions (sandbags, flood barriers, evacuation of people)
	After event Few days after extreme weather for observation, clean up and repair

5.2 Inspection of drainage systems

The inspection is divided into blue spot catchment (i.e. the upstream part), the downstream recipient, the side area drainage, and the road water drainage. Suggested actions for this work are presented in Report 4: Inspection and Maintenance. It includes tables with different drainage elements, inspection frequency, what to look for, and proposed actions. One example is given here for side area drainage (Table 3).

Table 3 Inspection sheet for the side area drainage

…… (Name, Station) …… …… (Insp. type, Year/Month/Day)						
Drainage Element		**Inspection**	**Yearly**	**Before event**	**During event[1)]**	**After event**
Side area drainage (slopes and adjacent areas):						
Ditch	Growth, vegetation	Need to cut	v	-	-	-
	Debris	Need cleaning	v X	v X	v	v X
	Mud in bottom	Digging needed	v X	v	-	v X
		Check water level	v	v	v	v
Cut-off drains[2)]	Entire construction	Check functionality	v	v	-	v
	Outlet installation	Visually in order	v	v	-	v
	Manhole	Clean from sediments	v X	v X	v	v X
		Check water level	v	v	v	v
Galleries in slope[2)]	Entire construction	Functionality	v	-	-	v
	Outlet installation	Visually in order	v	-	-	v
	Manhole	Clean from sediments	v X	v X	v	v X
		Check water level		v	v	
Drainage spurs[2)]	Granular trenches	Functionality	v	-	-	v
	Drain below trenches	Visually in order	v	-	-	v
	Outlet installation	Visually in order	v	-	-	v
Californian drains[2)] or Collectors	Outlet installation	Visually in order	v	v	-	v
	Manhole	Sediments	v X	v X	v	v X
		Water level		v	v	
Pumping plant	Construction	Functionality test	v	v	-	v
	Inlet	Clogging and debris	v X	v X	v	v X
Trench drain[2)]	Pipe and cover	Visually in order	v	v	v	v
	Manhole	Sediments	v	v X	v	v X
		Water level	v	v	v	v
……. (other)						

v = Check

X = Remove materials (sediments, vegetation, other) immediately

1) Important to document with photos
2) Glossary and abbreviations can be found in Dawson (2008) Annex C, and explaining figures in chapter 13– Control of pavement Water and Pollution Prevention by José Santinho Faìsca et. al.

5.3 Maintenance and repair of drain systems

The idea with maintenance and repair is to restore the intended function of the drainage system. In some cases that includes a changed design after damages to avoid future problems. The maintenance activity follows the timing of inspection. Repair work is done when damages are discovered. The maintenance activity starts with the road surface and then moves towards road edges, sides and last the sub-surface drainage. Details are given in Report 4 - Inspection and Maintenance.

6 Concluding remarks

According to the questionnaire, maintenance rather than bad design is thought to be the reason for most flooding related problems. Supposedly, this means that the previous design guidelines regarding flooding have at least not led to under-dimensioned systems, which is encouraging and promising. They may of course be over-dimensioned though, which in most situations sounds bad, but may prove to be a good thing since this would mean that they are in a sense already adapted to climate change (i.e. there is already room for more water in the pipes).

Documentation of most information of interest (as the design of the road or drainage system) is more or less absent in many countries. Proper investigation and documentation of previous flooding events is invaluable, but mostly lacking. These are problems that should be addressed.

As a result of the uncertainties regarding the development of the future climate, road agencies have chosen different approaches to climate adaptation in different countries. Despite the uncertainties, most countries studied have presented recommendations associated with the design of new roads that are intended to adapt the roads to future climate. How to deal with the already existing road network is more unclear. It seems that for example drainage systems are always upgraded, never downgraded, despite predictions of drier conditions in some regions.

It is likely that climate researchers will be unable to provide society with definite and certain numbers of e.g. percent change of precipitation in a given region for a given decade or whatever the time scale might be. It is also likely that as models and theories develop, new and perhaps surprising results will emerge; particularly on the small regional, or even local scale. It is therefore necessary that road agencies remain as flexible as possible when preparing guidelines, follow the climate science development, and adjust design or maintenance guidelines accordingly.

Given the mentioned difficulties, it is important to proceed clever. The SWAMP project has presented a systematic approach to preparing the road network for floods. The method covers the entire chain of procedures, starting with the identification of weak spots (in this work referred to as blue spots) and ending with guidelines on how to reduce the risk for, or impact of, flooding at the local site. Hence, we suggest taking action at the spots that are identified as problematic, despite the magnitude of climate change. Some of the adaptation components are better monitoring at blue spots, combined with better information to road users.

An ongoing study that may be of great interest to road owners is the IPCC Special Report “Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation”. This Special Report will consider three types of extreme events: the ones for which climate change has or will amplify occurrence - as floods and droughts; the ones in which trends outside the domain of climate will increase exposure or vulnerability to climate-related extremes - for instance coastal development increasing exposure to storm surges; and new kinds of potentially hazardous events and conditions that may occur as a result of climate change - such as glacial lakes outburst. Key main topics to be assessed will be the frequency, intensity and duration of extreme events; vulnerability; and disaster risk reduction and climate change adaptation. The UN International Strategy for Disaster Reduction (ISDR) will participate in the preparation of the report which is planned to be released in 2011.

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Appendix 1. 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.