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GUIDE FOR REDUCING VULNERABILITY DUE TO FLOODING OF ROADS

INSPECTION AND MAINTENANCE

DANISH ROAD INSTITUTE
REPORT 184 - 2010

INSPECTION AND MAINTENANCE

Guide for reducing vulnerability due to flooding of roads
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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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FORORD

Projekt SWAMP er en del af det ERA-NET ROAD initierede internationale forskningsprogram der går under navnet "Road Owners Getting to Grips with Climate Change". De 4 projekter der er med i programmet er finansieret i fællesskab af vejadministrationer fra følgende lande: Østrig, Danmark, Finland, Tyskland, Irland, Holland, Norge, Polen, Spain, Sverige og England.
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1. INTRODUCTION

Climate researchers predict significant changes in climate during the current century (SWAMP Report 2). This will have multiple effects on society. One such is that more troublesome floods may occur in many parts of Europe, in particular in central and northern Europe (e.g. Christensen and 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. Given the uncertainty of what to expect of the upcoming climate, it is difficult to give specific recommendations on how to change dimensioning, valid for all ERA-NET countries. Some countries have adopted a nationwide uniform modification of e.g. the design flood, while others have suggested a climate factor that varies with the geographical (or rather climatologically) region of the country (SWAMP Report 2, chapter 4).

In order to ensure an international perspective and learn from others, a questionnaire was sent out early in the SWAMP project to persons working with roads in eleven countries. Questions were for example asked about what were considered problematic parts of the drainage system, 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. The questions and results are presented in SWAMP Report 2. It was clear from the answers that inadequate maintenance was believed to be the main reason for road failures in connection to floods. Hence, proper management of existing structures may prove to be an equally important adaptation measure as renewal or upgrading of the existing systems.

The information in this report is based on literature described in some details in SWAMP Report 2, Chapter 2. The references used are listed at the end of the report. The content in this report has also been developed and discussed with Danish and Swedish maintenance professionals.

Changing the entire existing road network is very costly, and most likely not necessary. We believe that an awareness of the weak parts of the road network is the first and most important part of a climate adaptation strategy. The SWAMP Report 3 addresses the critical issue of finding the parts of the road network that are most vulnerable to flooding, using a geographical information system as basis. These parts are referred to as blue spots. We believe that most resources should at least initially be spent on relatively few blue spots. Additionally, one should perhaps think twice before rebuilding or upgrading structures. In many situations the worst socio-economic costs, which appear to be related to obstruction of traffic, may be avoided simply by using early-warning systems combined with effective communication to the road users.

The present report deals with the issue of how to limit the effects of flooding, or if possible avoid flooding, at the blue spots.

Given the variability of road and drainage system constructions, and the differences in geology and climate across national borders, a general European guide is at the moment not easily accomplished. This report aims to present the crucial issues to consider when creating national or even regional guidelines for inspections and maintenance. The suggestions are geared towards lowland areas that are relatively flat and mildly undulating landscapes, and do not explicitly cover steep, sloping areas.

In organising the content of the present report, we found it practical to distinguish between personnel that work mainly in an office environment and personnel that work mainly in the field. We assumed that the former group of people deals with planning and the latter with field operations suggested by the planners.

Chapter 2 gives guidance and instructions for engineers and people in charge of inspection, maintenance and repair. It can also be useful for decision makers responsible for renewal of the drainage system with the aim to reduce future flooding and damage of the road network.

Chapter 3 contains instructions on how to perform the work in the field in a systematic way over the season, and also how to prepare the road system before, during and after a heavy rain event.

2. CONSIDERATIONS FOR MANAGERS OF ROAD INFRASTRUCTURE

The aim of this guide is to suggest how to work with drainage systems at road locations vulnerable to flooding, also known as blue spots. This guide is written for blue spots on main link roads in the open landscape. It is not written for urban roads and local roads of less importance with low traffic volume. However, principles and methods described here can in an adapted form be usable for all types of roads.

Identification of blue spots with the GIS model is described in some detail in the SWAMP Report 3 (the Blue Spot Model). It is possible that several blue spots can be identified in a region or along a road stretch. Therefore, it is necessary to prioritise between the different locations. This can e.g. be done in the model by taking into account different precipitation scenarios (SWAMP Report 2).

When the prioritisation is complete, the investigation at a blue spot commences. The procedure typically comprises:

- Collection of background information
- Evaluation of the drainage system
- Routines for inspection and maintenance
- Introduction of early-warning systems (if suitable).

A blue spot is often already known from daily/yearly inspections of the road network. There is generally no difference how to treat such a location and a “blue spot” recognised by the GIS-model. Inspection, management and repair procedures are the same.

2.1 GATHERING OF BACKGROUND INFORMATION

When it is decided to examine a blue spot, it is important to have a full understanding of the problems before taking any actions. It is necessary to increase the knowledge about:

- the general physical conditions at the site
- the drainage system in particular
- previous events from logbooks or databases

and make use of

- results from blue spot calculations
- measured data from instrumentation

It is important to gather as much background knowledge as possible about the local situation. This information may be knowledge about the road, the existing drainage system, and the actual status of the construction. It is also important to look at the original hydrodynamic calculations and design of the drainage system.

Obviously, information about earlier flooding events and previous repair and maintenance issues from field logbooks or databases are vital. Repeated construction failures or high maintenance needs indicate a problem.

General knowledge

Table 2.1 gives examples of important background information to look for. A basic topographic map is perhaps the most essential information needed. It contains plenty of important information such as location and extent of local depressions, location of streams, lakes, ponds, swamps, land use (agriculture, forests, urban, etc.), and steepness of hills and slopes. Proper knowledge about historical behaviour of local streams, lakes and other water recipients is required. Special considerations may need to be taken if the blue spot is close to a source of drinking water supply. This may significantly restrict the number of viable options available to reduce flooding sensitivity.

It is also good to have knowledge about unstable slopes and soil types that are potentially susceptible to erosion and land sliding. Streaming water causes erosion with subsequent redeposit of sediments. Sedimentation of the suspended material occurs when speed of the streaming water slows down which may happen in lakes, ponds, culverts, inlets and outlets. This process causes clogging of pipes in other parts of the drainage system. Water stream erosion can also cause undermining and loss of material of the road pavement and side areas which are a vital part of the construction. Bridges are especially sensitive for this kind of erosion and undermining. Cracking, movement or total destruction of a construction is common if this happens.

Information about the road construction on the blue spot site is important. It can include road pavement design, drawings, construction year, traffic volume, road classification, bridges and culverts. The catchment area is the land area that collects the rainwater and transports the water to the blue spot area. The catchment area for a blue spot is in general calculated when using the Blue Spot Model (SWAMP Report 3).

Drainage system

It is often not obvious until a storm event that some part of the drainage system does not function properly. The only way to prevent this is to carry out regular inspections and maintenance. If a problem is identified, which is not easily corrected on site at the time of discovery, a hydrodynamic calculation can help to find the most crucial parts of the drainage system.

The dimensions of pipes and culverts have a large impact on the capacity of a drainage system. It is important that the system can handle the expected maximum level of water and that the pipes are clean from debris and sediments. Drainage design should be based on expected rainfall and weather in the local area.

It is also important to know the maximum amount of water that is allowed to be released to a recipient in order to prevent transfer of the problems downstream. The environmental aspect regarding polluted water should be considered.

Table 2.1. Examples of important background information.

General information	Overview plan of local area Topography Nearby streams, lakes, recipients Terrain and soil Landforms, unstable slopes, erosion Year of construction Road design Road classification Traffic volume Bridges Catchment areas
Drainage system	Type of drain system Design of pipes and culverts Retention pond (basin) Allowable water release to recipient Design rain fall, design flood

Learning from blue spot calculations

The blue spot identification and evaluation consists of three levels (see Table 2 in Report 3, the Blue Spot Model). A level 1 and 2 analysis can give information about where the most sensitive places for flooding are located, where in the terrain the large sub-catchments are (i.e. where does most water come from), and what type of drainage elements that must be considered to reduce the vulnerability to flooding.

The model can give information about how much water a blue spot catchment area have to handle due to a certain climate change scenario. Alternatively, it is possible to find downstream channels and ditches that are too narrow and have too small capacity. With this type of information, it is possible to adapt the drainage system to meet the new requirements. It is also possible to calculate the effect of sea level rise and water level rise in rivers.

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 invaluable 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 indicators in manholes, wells, ground water tubes, culverts, retentions ponds, streams and reservoirs
- Video cameras.

Logbooks and database

Based on interviews and the questionnaire (SWAMP Report 2) it is clear that information is not managed adequately. We therefore suggest that the information from the blue spot sites is integrated in a maintenance database together with construction details. This information is essential to understand the conditions at a blue spot. The importances to learn from previous flooding events are described in Doyle and Ketcheson (2007). A database makes the data accessible and searchable. Once established, the idea is to save notes and documentation of observations from every interesting event.

Examples of information:

- inspection notes, check list, photos of the situation and other comments made on site
- maintenance and repair work (details and schedules)
- damage to road and drainage
- flooding events
- improper dimensions.

2.2 EVALUATION OF THE DRAINAGE 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 of course necessary to consider the changing climate and if 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.

This may be necessary due to:

- Capacity problems - the risk of problems is large (e.g. damage, flooding)
- Upgrading and reconstruction - the road is going to be upgraded or re-built in order to meet higher requirements (e.g. more traffic, safer, faster and better transportation)
- Climate adaptation – upgrading and reconstruction due to changed climate.

Climate adaptation

In order to maintain the road standard it is important that road constructions are adapted to the foreseen climate situation. As mentioned earlier, many countries now recommend using a climate factor of some sort when designing new roads and drainage systems. As an example, the design flood is multiplied with the climate factor such that the design flood increases with e.g. 20%.

The system at the blue spot was likely constructed before climate change was much on the agenda, and therefore the hydrological foundation used, in terms of design flood or rain, was not in line with present recommendations. Even though culvert and pipe diameters are limited, it might still be possible that the dimensions are large enough to handle more water. Hence, a suggested investigation procedure is: find out the climate factor at the site, and check if the present system can handle the increase or if it needs to be upgraded.

The knowledge gathered during inspections and blue spot modelling is the base used to make decisions to rebuild drainage systems and reconstruct roads. Conclusions from regional climate modelling exercises indicate that the annual precipitation will increase in northern Europe, while it will decrease in central and southern Europe (Christensen and Christensen, 2003). In the same study it was found that despite the predicted annual decrease in precipitation in central Europe, both central and northern Europe are very likely to suffer from more extreme rainfall. Hence, the effects of climate change will differ from region to region. Nevertheless, it is possible to adapt the calculations in the Blue Spot Model to the local precipitation situation.

To be able to handle blue spots, it is important to use the available information derived from Blue Spot Model calculations. Questions that may be answered are; where in the sub-catchment is most water generated? Which streams or canals bring the water to the blue spot?

A good idea is to combine inspection and maintenance with weather forecasts. It gives possibilities to carry out necessary inspection and maintenance days/hours before a predicted heavy rain event. It gives the road authorities and managers a chance to have a functional drainage system and to avoid flooding during a rainstorm.

Existing drainage system

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

Existing road and drainage system are in some cases "worn down" and capacity has decreased. The system degrades with time because of ageing which results in blockage, crushed pipes, settlements of systems, and permanent sediments in pipes. Ditches and retention ponds loose capacity due to wildly growing vegetation and fill up with sediments. It is also common that the drainage characteristics change when an area is developed with more paved roads or changing land use. 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.

Before upgrading or renewal, it is important to evaluate the current condition of the existing drainage system. Available methods include systematic visual inspections, video techniques for down-pipe inspections, measurement of water stream and capacity, and automatic water level measurement. The main idea is to find the actual "capacity" of the system to compare it with the demands of the new drainage system.

Compared to the original design of the road and drainage system a new hydrological situation in the location may have been established due to development and urbanisation.

It may lead to:

- Higher peak flow and faster response time for rain water drainage. This is often due to a larger percentage of paved ground
- Changes to the rainwater catchment areas

In some cases, it may prove fruitful to study rain events over several years recorded by a nearby rain gauge station or perhaps establish one in the blue spot area. Instrumentation to measure groundwater levels is also a good idea.

Upgrading of drainage system

When it has been decided to upgrade or renew the drainage system, or perhaps reconstruct the existing road, it is important to consider the local hydraulic conditions during the design process. The systems consist of cross drainage, longitudinal drainage and road surface drainage. These systems should take into account a number of considerations like available space, present infrastructure, new road standard, lifetime and cost. The selection of drainage type and dimension will depend on various factors including topography, water levels (up- downstream), water amount, catchment area, climate condition, soil type, environmental factors (e.g. nature, animals, pollutions), and road construction. All this will affect the design of drainage system.

Important hydraulic parameters are velocity of flow, slope gradient, upstream water levels and downstream water levels. Water speed strongly affects the potential for erosion. Therefore, water speed has to be considered when designing and protecting the drainage system from erosion. It may be necessary to make arrangements to slow down the water and reduce the maximum amount of water that can enter the system.

Cross drainage, like culverts that narrow the water paths can sometimes produce higher water levels upstream, if the capacity is exceeded. This has to be considered to prevent structural damage upstream. Cross drainage may need to be widened in order to improve flow capacity. Downstream water levels can also be affected by the capacity of culverts and bridges. If large water volumes are allowed to flow through the culvert, it can cause flooding of dams and ponds further downstream.

Other considerations are tidal levels and storm surges, which can have a strong impact on water levels at coastal locations. The drainage system should be able to handle changes in sea level. How large sea level variations are acceptable depends on the regulation and local conditions. A general increase in sea level worldwide is expected due to global warming and subsequent melting of glaciers.

Generally, the ambient climate conditions have a large impact on the type of drainage that is selected. It is not possible within the scope of this report to go through all different climate scenarios and suggest design solutions.

2.3 ACTION PLAN FOR INSPECTION AND MAINTENANCE OF DRAINAGE SYSTEM

The ‘maintenance office’ is responsible for site work including overview of field work such as inspection, maintenance and repair. This means that guidelines for field personnel (see following chapter 3) have to be developed. These guidelines should include working practices for carrying out inspections and maintenance of blue spots along the roads. Work should be done safely, with respect to traffic and work procedure. Personnel should have appropriate training on how to perform the work in the best manner. Traffic can be very dangerous for people working on or close to roads. It is strongly advised that personnel have the right training for working in a busy traffic environment.

Instructions for maintenance people in the field

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 guide for field personnel in this report are suggestions that need to be developed and adapted to fit local conditions. This is recommended to be done in close collaboration with the field personnel in order to get the best understanding of the work required to be done.

2.4 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.

The effect of a storm having a certain intensity and duration depends on the conditions when it starts. Therefore, monitoring systems at blue spots are very useful in order to assess the severity of the situation. For example, if the water level in a culvert at the blue spot is high already when the weather warning is received, the storm will lead to greater problems at this blue spot than it would have if the water level was low. Information to road users about the probable upcoming situation is essential. If alternative and safe routes are available, traffic control offices should direct traffic to them as early as possible.

This is of great significance from a socio-economic perspective. Preparing the actual blue spot is also of great importance. Culverts, retention ponds or other parts of the drainage system must not be blocked or otherwise functionally impaired at the onset of the storm or flood. This is further explained in the next chapter which details actions at the sites. The early-warning system thus 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.

Hence, responsibilities for these actions need to be given, and an agreement must be in place between the road agency and the agencies or companies that deliver meteorological and hydrological forecasts.

3. MAINTENANCE AND INSPECTION ACTIVITIES

The focus of this chapter is to highlight the needed inspection and maintenance work of road drainage systems in locations, which are vulnerable to flooding (blue spots). Local conditions like environment, climate, road construction and type of drainage system dictate the activities that are necessary to perform to prevent flooding. It is not possible within the scope of this report to cover all situations. Therefore, the information is meant to be used as a base for development of new guidelines. A number of instructions for inspection and maintenance are listed in the tables 3.1, 3.2, 3.3 and 3.4. They can be selected and put together to fit local conditions. Some instructions are likely to have been missed and thus not listed and must be added to complete a guideline for specific blue spot locations.

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.

3.1 PLANS FOR INSPECTION AND MAINTENANCE

It is important to have a plan how to 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 inspections activities. Plans and programmes are based on information and details from logbooks. Especially, events of serious nature are important to be noted when creating a plan. We suggest that blue spot maps (SWAMP Report 3) are part of the inspection and maintenance plans. These maps are important when prioritising the work. In the following paragraph, inspection activities for each of the three main types of drainage elements are listed. Environmental issues are not the primary goal with this report, but may be linked to inspection and maintenance plans to prevent flooding.

It is proposed (Table 3.1) that inspection routines are performed annually and in connection with extreme weather situations, before events, during event and after events.

Table 3.1. 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 events 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

Annual inspection

The purpose with annual routine inspections and maintenance is to keep the drainage system in good condition. It is the cheapest and best way to avoid flooding and destruction of roads. Sensitive places may be inspected several times per year. Normally, it is done in springtime (at least in northern countries) after the winter events which may have done damage to the drainage system. Table 3.2, 3.3 and 3.4 give suggestions about what drainage element to inspect. It is essential to solve simple problems when they are discovered. The activities involve removal of debris, clogged materials (sediments and vegetation) and repair of damage. Documentation of failures should be carried out both before and after repair, preferably including photos.

Extreme weather inspection

Extra inspections and maintenance before an expected heavy rain event increase the chance to avoid flooding related problems. Debris and junk that block drainage pipes and culverts often cause local damming and flooding resulting in damages. It is therefore a good idea to clear the drainage system and side areas before an expected rain storm. Table 3.2, 3.3 and 3.4 give suggestions about what drainage element to inspect. During the rain storm it is normally too late to do any maintenance and repair work without risking the life of the field personnel. Inspections during extreme weather have usually the purpose to observe problems. The work may in worst case also include implementation of pre-planned emergency actions (sandbags, flood barriers, evacuation of people). Documentation with video and photos is very important during a flooding event because it may be used later to help to understand the situation. After an extreme weather event it is suggested to do a new inspection to look for possible damages on the road drainage system.

3.2 INSPECTION OF DRAINAGE SYSTEMS

It is important to inspect the drainage system regularly in order to find maintenance and repair needs. The primary goal is to propose necessary work activities on site to prevent drainage systems failure.

There are different types of road drainage systems. For main roads and highways, several parts of the drainage elements are important. The most obvious components are surface drainage and sub-surface drainage. The latter is often more difficult to inspect.

Inspection of three main types of drainage elements are described in some detail below:

- main catchment area and downstream recipient
- side area drainage
- road surface water drainage.

Below are listed suggestions for systematic inspections of all important drainage elements. Table 3.2, 3.3 and 3.4 are examples of inspection drainage system actions near a blue spot location. The importance of each inspection element depends on the actual blue spot and its local condition. It is also possible that some inspection elements are missing for a certain blue spot location. In general, inspections of blue spots are needed at different occasions as suggested in Table 3.1.

Inspection of the catchment area, down- and upstream water system
Table 3.2 suggests inspection activities in catchment areas and downstream water systems.

The catchment area collects and brings the water down to the blue spot location (the lowest point). The water follows natural and constructed systems of rivers, channels, and culverts down to the blue spot. If the water paths are blocked or too small to handle the water volume, the water will find new ways. When this happens, it is a risk that erosion, undermining, and destruction of roads occur.

The downstream systems are of special interest because they serve as the system, which brings the water away from the blue spot to a new recipient like a river or lake. The downstream drainage system may involve constructions for cleaning of the water (sedimentation, oil separation) or constructions to delay the water volumes (retention ponds or dams). It is important that these systems can handle the water volume to avoid flooding.

The suggested routines in Table 3.2 are not complete for all blue spots. Complementary routines may be necessary. The importance of each routine may vary depending on the local condition of the actual blue spot.

Table 3.2. Inspection sheet for the catchment area and downstream water system.

…………………………………...... (Name, Station) …………………		**………. (Insp. type, Year/Month/Day)**				
Drainage Element		**Inspection**	**Yearly**	**Before event**	**During event[1)]**	**After event**
Downstream a blue spot						
Retention pond	General condition	Water level	v	v	v	v
	Entrance of the pond	Erosion	v	v	v	v
		Sedimentation	v X	v X	v	v X
		Vegetation	v X	v X	v	v X
	Outflow of the pond	Erosion	v	v	v	v
		Sedimentation	v X	v X	v	v X
		Vegetation	v X	v X	v	v X
River, channel, ditch	General condition	Water level	v	v	v	v
		Erosion	v	v	v	v
		Sedimentation	v X	v X	v	v X
		Vegetation	v X	v X	v	v X
	Narrowing parts	Erosion	v	v	v	v
		Sedimentation	v X	v X	v	v X
	Stream	Flow speed	v	v	v	v
Long distance pipe	Construction	Function	v	-	-	v
		Damages	v	-	-	v
	Manhole	Clogging	v X	v X	v	v X
		Debris	v X	v X	v	v X
	Outlets	Clogging	v X	v X	v	v X
		Debris	v X	v X	v	v X
		Flow	v	v	v	v
	Pipe	Clogging (visual or video)	v X	v X	v	v X
		Debris	v X	v X	v	v X
		Root intrusion	v X	v X	v	v X
Pumping plant	Construction	Function test	v	v	-	v
	Inlet	Clogging	v X	v X	v	v X
		Debris	v X	v X	v	v X
Culvert	Entrance	Clogging	v X	v X	v	v X
		Debris	v X	v X	v	v X
	Construction	Damage	v	-	-	v
		Water level	v	v	v	v
Aqueduct	Entrance	Clogging	v X	v X	v	v X
		Debris	v X	v X	v	v X
	Construction	Damage	v	-	-	v
		Water level	v	v	v	v
Bridge	Foundation	Condition	v	-	-	v
		Water level	v	v	v	v
		Erosion	v	v	v	v
Lake	Outflow to lake	Condition	v	v	v	v
		Water level	v	v	v	v

……………………………………..… (Name, Station) ………………….			………. (Insp. type, Year/Month/Day)			
Drainage Element		**Inspection**	**Yearly**	**Before event**	**During event[1)]**	**After event**
Catchment area of a blue spot[2]						
River, channel, ditch	General condition	Stream, flow speed	v	v	v	v
		Erosion	v	v	v	v
		Sedimentation	v X	v X	v	v X
		Vegetation	v X	v X	v	v X
	Narrowing parts	Erosion	v	v	v	v
		Sedimentation	v X	v X	v	v X
		Water level	v	v	v	v
Culvert	Entrance	Clogging	v X	v X	v	v X
		Debris	v X	v X	v	v X
	Construction	Damage	v	-	-	v
		Water level	v	v	v	v
Aqueduct over stream	Entrance	Clogging	v X	v X	v X	v X
		Debris	v X	v X	v X	v X
	Entire construction	Damage	v	-	-	v
		Water level	v	v	v	v
Bridge over stream	Foundation	Condition	v	-	-	v
		Water level	v	v	v	v
		Erosion	v	v	v	v

v = Check

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

1) Important to document with photos

2) Constructions and water streams.

Inspection of the side area drainage

Table 3.3 suggests inspection activities for side area drainage. Side area drainage collects water that is coming from unpaved neighbouring areas along the road. A simple type of side area drainage consists of ditches on the sides of the road. Systems that are more sophisticated are; slope drainage of various types, cut off drain, collector pipes, galleries and spurs to stabilise the slopes. In some cases ground drain and especially side area drains can cause problem, in other cases they can be neglected.

These drainage systems can be problematic if they for example bring extra water in a short time to the blue spot location or if the water have nowhere to continue.

Complementary routines may be necessary. The importance of each routine may vary depending on the local condition of the actual blue spot.

Table 3.3. 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.

Inspection of the road water drainage installation

Table 3.4 contains inspection activities for road water drainage. The run off drainage system takes care of water coming from the road surface, and there are in general two ways to handle it:

1. Water flows over the pavement edge to an unpaved shoulder where it infiltrates the shoulder and percolates through the road layers and most

likely the subgrade until it reaches the groundwater. Groundwater in turn, may flow to a trench drain near and along the road, or the side area drainage as long as they actually drain groundwater. With a carefully selected combination of granular materials, or perhaps geotextiles, it is possible to divert the water directly to a trench drain

2. Kerb and gutter along the pavement edge catches and diverts the road water to gully pots and to drainage systems along the road.

In both cases there is focus on the drainage construction elements (kerb, gutter, pipes) and the used unbound material over and around drain pipes and trenches (granular materials, fine drains, etc.) and their function.

Complementary routines may be necessary. The importance of each routine may vary depending on the local condition of the actual blue spot.

Table 3.4. Inspection sheet for the road water drainage.

……………………………..…. (Name, Station) …………………		**………. (Insp. type, Year/Month/Day)**				
Drainage Element		**Inspection**	**Yearly**	**Before event**	**Under event[1)]**	**After event**
Road run off over shoulder						
Soft shoulder	Sufficient slope	Inclination	v	-	-	-
	Differ crown/shoulder	Too high/ to low	v	-	-	-
Ditch	Growth, vegetation	Cutting, clearing	v X	v X	-	-
	Debris	Remove	v X	v X	-	v X
	Mud in bottom	Remove	v X	v X	-	v X
		Water level	v	v	v	v
	Stone cist, culvert	Clog material	v	v X	-	v X
Embankment slope	Erosion	Visual	v	-	-	v
	Drainage spurs	Visual	v	v	v	v
Trench drain[2)]	Pipe and cover	Visual	v	v	v	v
	Manhole	Sediments	v	v X	v	v X
		Water level	v	v	v	v
Transverse drain[2)]	Entrance areas	Clog materials	v X	v X	-	v X
	Inlet	Clog materials	v X	v X	-	v X
	Outlet in ditch	Clog materials	v X	v X	-	v X
		Erosion	v	v	-	v
Swale[2)]	Functionality	Visual	v	v	-	v
Pumping plant	Functionality	Visual and test	v	v	-	v
	Inlet	Clog materials	v	v X	-	v X
………..(other)						

……………………………………..… (Name, Station) ………………….		………. (Insp. type, Year/Month/Day)				
Drainage Element		**Inspection**	**Yearly**	**Before event**	**Under event[1)]**	**After event**
Road run off to kerb and gutter						
Kerbs, asphalt bead	Functionality	Visually in order	v	v	-	v
Gutter[2)]	Entrance areas	Debris, sediments	v X	v X	v	v X
	Bottom	Debris, sediments	v X	v X	-	v X
Ditch	Growth, vegetation	Ned to cut	v	v	-	v
	Mud in bottom	Digging needed	v	-	-	v X
		Water level	v	v	v	v
	Stone cist, culvert	Clog material	v	v X	-	v X
Embankment slope	Erosion	Visually in order	v	-	-	v
	Drainage spurs	Visually in order	v	v	-	v
Trench drain[2)]	Pipe and cover	Visually in order	v	v	-	v
	Manhole	Sediments	v	v X	-	v X
		Water level	v	v	v	v
Transverse drains[2)]	Entrance areas	Clog materials	v X	v X	-	v X
	Inlet	Clog material	v X	v X	-	v X
	Outlet in ditch	Clog materials	v X	v X	-	v X
		Erosion	v	v	-	v
Swales[2)]	Functionality	Visual	v	v	-	v
Pumping plant	Functionality	Visual and test	v	v	-	v
	Inlet	Clog materials	v	v X	-	v X
………..(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.

3.3 MAINTENANCE AND REPAIR OF DRAIN SYSTEM

The idea with maintenance and repair is to restore or reach the intended function of the drainage system. In some cases this 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.

Road surface

The repair and maintenance of the road surface involves work to prevent water to enter the road pavement layers. If water enters the road pavement it is detrimental for the road construction. This type of damages should be taken care of and repaired as soon as possible. Sudden build up of hydrostatic pressure is causing damages as vehicles are passing. Other types of damages are freeze-thaw damages, and serious damages will occur if the moisture content is much too high for longer periods.

Maintenance and repair work:

- repair holes and cracks that permit water to enter the pavement structure
- correct slope from centre to the edge to drain water off the surface
- correct road surface to prevent water to accumulate in ponds.

Shoulders, slope and ditches

Ditches drain the road side area of groundwater, and transport it further in the drainage system. The ditch either infiltrates the water or transports it further in drainage system. In this process, it is important that the waterway is not blocked, forcing water to take new routes. It should not bring any debris that causes blockade further downstream. It is also important that the slopes do not have erosion problems. If shoulders and slopes have erosion or stability problems, it is important to find the reason (e.g. soil type or steepness). Stabilisation of the slope may be needed. Inlets and outlets must be secured from sedimentation to prevent to structural failures and blockages.

Maintenance and repair work:

- correct edges and irregularities that permit the water to flow off the road surface
- remove vegetation (but not completely because naked soil is sensitive to erosion)
- clean ditches and slopes from debris that can cause blockage
- stabilise sediment that cause clogging and erosion problem to culverts or pipes

- the slope inclination should be right (according to country regulation, normally 2:1 to 4:1).

Culverts, inlets, curb and gutters

Culverts and inlets are important structures that make it possible for water to reach the recipient and enter the pipe system respectively. A blocked culvert or inlet can cause flooding and severe damages to the road construction.
In urban drainage systems, it is common with curb and gutters systems that collect water from the pavement, and brings it to the inlets of the pipe system. Sediments and debris follows the water and can cause blockage and clogging in inlets and pipe system.

Maintenance and repair work:

- clean from debris and sedimentation
- repair broken pipes and culverts
- repair erosion problems.

Sub-surface drainage

Sub-surface drainage consists of granular pavement layers and pipe systems. Sub-surface drainage can be difficult to maintain, the focus should be on the function. The granular layers are generally not maintained they should have the design thickness and right material gradation. Drainage pipe system can be clogged. Blockage can be checked with a video camera devise.

Maintenance and repair work:

- clean from debris, sedimentation and root intrusions
- repair broken pipes and culverts
- not so much to maintain
- function should be confirmed.

4. CONCLUSIONS

Flooding of roads is damaging for the construction and dangerous to traffic. Climate change will cause more extreme weather, which increases the risk for flooding in several places. The main focus of this work has been to highlight systematic work with drainage systems in a location that is vulnerable to flooding of a road. The Blue Spot Model helps to finds the weakest and most vulnerable road sections with regards to flooding. The report describes how to perform.

Chapter 2 gives guidance and instructions for engineers and people in charge of inspection, maintenance and repair. It may also be useful for decision makers responsible for the renewal of the drainage system with the aim to reducing future flooding and damage of the road network.

Chapter 3 contains instructions how to perform inspection and maintenance work on site in a systematic way at the weakest locations over the season. It also contains how to prepare the road system before, during and after a heavy rain event. It includes inspection sheets for different drainage elements. Nevertheless, it is important to point out that the guidelines need to be developed and reworked to fit local conditions.

5. REFERENCES

Dawson, A., (Ed.). Water in Road Structures, Movements, Drainage and Effects, 2008. COST 351. Springer

Doyle, J.& Ketcheson, G. 2007: Lessons Learned from Management Response to Flood Damaged Roads in the Western Washington Cascades. p. 291-296, In: Furniss, M.; Clifton, C.; Ronnenberg, K. eds. 2007. Advancing the Fundamental Sciences: Proceedings of the Forest Service National Earth Sciences Conference, San Diego, CA, 18-22 October 2004. Gen. Tech. Rep. PNW-GTR-689. Portland, OR: U.S. Forest Service, Pacific Northwest Research Station. 577 p.

CEN EN 13508-2:2003 E: Conditions of drain and sewer systems outside buildings - Part 2: Visual inspection coding system. Belgien 2003

Christensen, J.H. and O.B. Christensen, 2003: Severe Summer Flooding in Europe, Nature, 421, 805-806.

Mayor, M. 2006: Stormwater Drainage Manual Coleman City of Columbus Division of Sewerage and Drainage, Department of Public Utilities, Director Cheryl Roberto, March 2006 Download at utilities.columbus.gov , pp316

Moritz, L. 2008: VVMB 310 Hydraulisk dimensionering, 2008:61 Swedish Road Administration. download at www.vv.se or vagverket.butiken@vv.se, pp 68

Saarenketo, T. 2007. Developing Drainage Guidelines for Maintenance Contracts - Results of a ROADEX III pilot project on the Rovaniemi Maintenance Area in Finland. Research Report.

Smith, D.E. 2006: Local Roads, Maintenance Workers' Manual. Center for Transportation Research and Education, Iowa State University. Report number TR-514, pp. 152

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.

Rapport / Report		
Nr. No.	Titel/Title	Forfatter/Author
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168	Øster Søgade 8 år med 2-lag drænasfalt	Jørn Raaberg Annette Neidel
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175	Paper Temperature influence on noise measurements EURONOISE 2009 - Edinburgh	Hans Bendtsen Qing Lu Erwin Kohler Bruce Rymer
176	Bituminous binders - Results of Danish Round Robins for CEN test methods from 2000-2009	Erik Nielsen
177	Ageing of bituminous binders	Erik Nielsen
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183	The Blue Spot Model Development of a screening method to assess flood risk on highways	Michael Larsen, DRI
184	Inspection and Maintenance Guide for reducing vulnerability due to flooding of roads	Fredrik Hellman, VTI, Sweden Knud A. Pihl, DRI Klas Hansson VTI, Sweden
185	Blue Spot Konceptet Metode til udpegning og håndtering af oversvømmelser på motorveje	Klas Hansson, VTI, Sweden Fredrik Hellman, VTI, Sweden Marianne Grauert, DRI Michael Larsen, DRI

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