CEDR

Conférence Européenne des Directeurs des Routes

Conference of European Directors of Roads

WATCH

CEDR TRANSNATIONAL ROAD RESEARCH PROGRAMME

Call 2015

WATer management for road authorities in the face of climate CHange

Country Comparison Report

Oct 2018

CEDR Call2015: From desk to road

WATCH
WATer management for road authorities in the face of climate CHange

Country Comparison Report

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1 Introduction

1.1 The WATCH project

Many challenges exist in addressing intense rainfall events into proper design and maintenance of water management systems. These challenges exist both in the field of climate science itself, as well as in the translation of climate projections into proper design and maintenance of water management systems. The WATCH project addresses the most important high frequency causes of road flooding, caused by rainfall and run-off flooding in the area around the road, and heavy rain on the road itself. Objectives of the project are:

- Developing a manual to determine current and future resilience of the NRAs approach to water management, ensuring optimal maintenance planning and asset management.
- Providing easy access to climate data tailored to determining resilience and providing guidance on how to use these data, plus developing a simple tool to show climate analogues for rainfall extremes.
- Gaining insight in the application of SuDS (Sustainable Drainage Systems) for storage and cleaning of excess water.
- Gaining insight in the alternatives to the costly retrofitting of existing drainage systems.
- Enabling informed decision making on water management, supported by cost-benefit analysis.

1.2 Purpose of the country comparison report

The deliverables of the WATCH project need to be implementable by NRA's. As such, the deliverables should build on the current state of practice and approaches of NRA's related to water management and how they take climate change into account. Therefore this report provides an overview of existing water management and drainage approaches from guidelines that are used in the NRA's. The gained information will be used as input for the mentioned WATCH deliverables and if deemed necessary, information will be investigated in more detail. If this is the case, this information will be reported in the respective deliverable; no update of the country comparison will be made at the end of the project.

1.3 Scope

The project addresses the most important high frequency causes of road flooding that NRAs have identified in the CEDR report 'Adaptation to Climate Change': pluvial and run-off flooding in the area around the road, and heavy rain on the road itself (rain intensity).

Furthermore, the project will consider the drainage facilities that are designed and maintained by/for the NRA's with the purpose to enable a good water management of the road and as such a smooth and safe use of the road infrastructure. As such, both transmitting and storage of water are incorporated. Drainage facilities include storm water run-off systems, storm water management facilities, culverts, carrier pipes, attenuation ponds, wetlands and SuDS. Runoff from non-porous and porous pavements will also be taken into account, since the run-off is an integral part to ensure a proper water management system.

In this country comparison report, the water management assets are structured, according to the hazard that is posed on them. A distinction is made in 3 types of hazards:

- Precipitation on the road
    - Roads in fill (on embankment)
    - Roads in cut (excavated)
    - Tunnels
    - Bridges (not the bridge design itself, only the storm water system on the bridge will be taken into account)
    - Retention facilities
    - Treatment facilities
- Pluvial flooding (water besides the road)
    - Assets to prevent flooding (embankment height, water management system, dikes, etc.)
- Surface run-off flooding (water crossing the road)
    - Culverts

The countries coloured pink in the figure below have been investigated. They provide a good overview over different cultures and geographical characteristics.

Figure 1.1 investigated countries for the comparison are coloured pink

1.4 Structure of the report

Separate chapters are devoted to the different countries. After these country-chapters a chapter is devoted to the country comparison to identify similarities and differences.

2 Austria

2.1 Type of water management assets used

Purpose of this chapter is to get an overview about the type of assets that Austria has in its road network.

2.1.1 Precipitation on the road

Examples are given (see figures) for the types of assets existing in Austria:

- *Roads in fill (on embankment) / roads in cut (excavated) / bridges*
  There are no special drainage systems for road surface drainage in the event of a storm. The drainage systems are designed (pipe diameter, inlets, ditches) for extreme rainfall events.

- *Tunnels*
  There are no special drainage systems

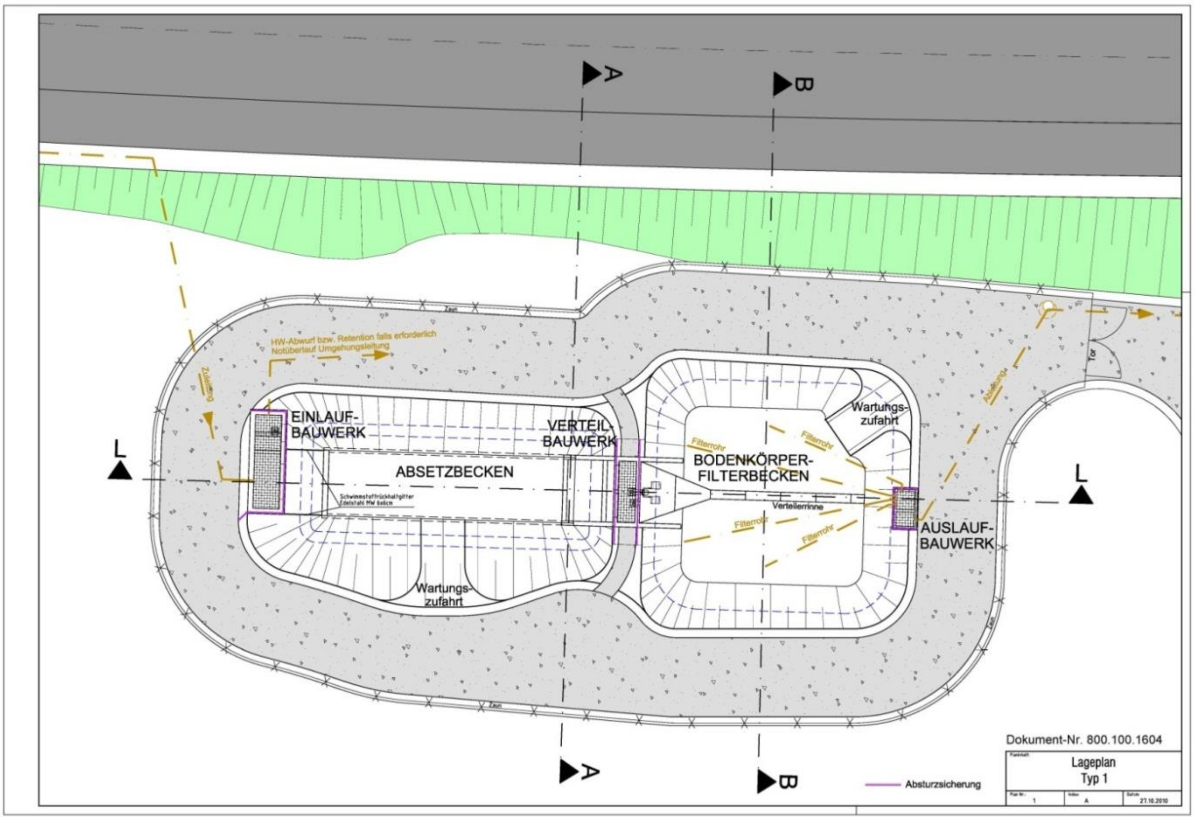
- *Retention facilities / Treatment facilities*

  There are different possibilities for retention. Most are integrated in surface water treatment plants. These facilities are designed to clean the surface water of the road. At the same time they keep the water back. Has the area a high flood hazard, flood retention basins are also used. The flood retention basins are build for a 100 year event.

Figure 2.1: Water treatment plant (sedimentation basin, infiltration basin)

Figure 2.2: Technical water treatment plant

Figure 2.3: Dam of a flood retention basin



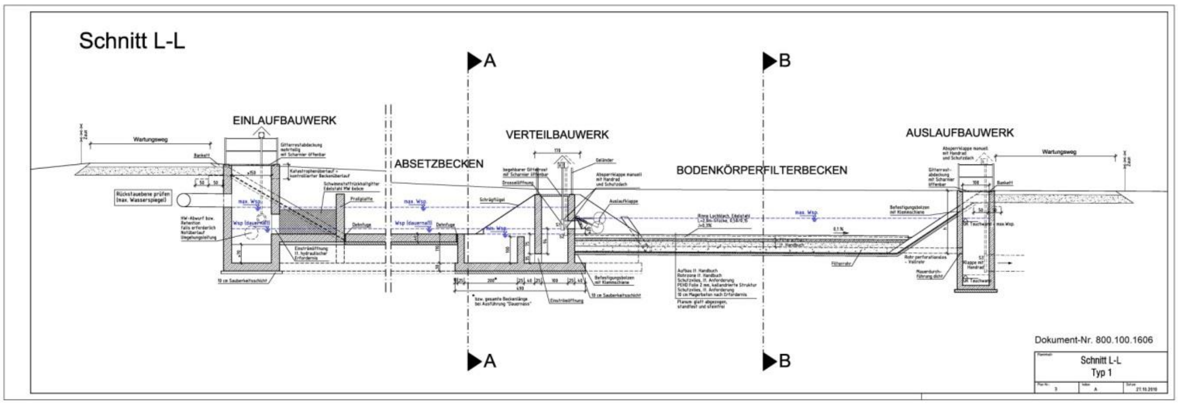


Figure 2.4: Scheme of a water treatment plant

Einlaufbauwerk = Inlet structure
Absetzbecken = Sedimentation basin
Verteilbauwerk = Water dividing structure
Bodenkörperfilterbecken = Ground filter basin
Auslaufbauwerk = Outlet structure
Wartungszufahrt = Maintenance access

2.1.2 Water besides the road (pluvial flooding)

Deflective dams or structures are being built in order to prevent the road from pluvial flooding.

2.1.3 Water crossing the road (run-off flooding)

Typical assets are concrete pipes and culverts, sometimes corrugated culverts.

Below examples of types of complementary assets (debris interceptors, rake) existing in Austria are given below (there are a lot of different types).

Figure 2.5: Bedload barrage, against mudflows

Figure 2.6: Bedload barrage, against mudflows

Figure 2.7: Ballast sedimentation basin, to protect pipes from spillage

Figure 2.8: Wild wood rake, to protect pipes and small bridges

Figure 2.9: Mudflow breaker, to reduce the energy of a flood with heavy stindes or high speed

Flood retention basins are also used.

2.2 Sources of climate data

2.2.1 Past climate

There is much information available in German and English at https://www.zamg.ac.at/cms/de/klima or https://www.zamg.ac.at/cms/en/climate

2.2.2 Current climate

Climate information is obtained with the internet application eHYD of the Ministry of Agriculture, Forestry, Environment and Water Management (http://ehyd.gv.at). Design precipitation events are based on the evaluation of precipitation data of measuring points of the last years, the values are given for a grid net with approx. 6 km * 6 km grid width for the precipitation duration of 5 minutes to 6 days and for return periods of 1 year to 100 years.

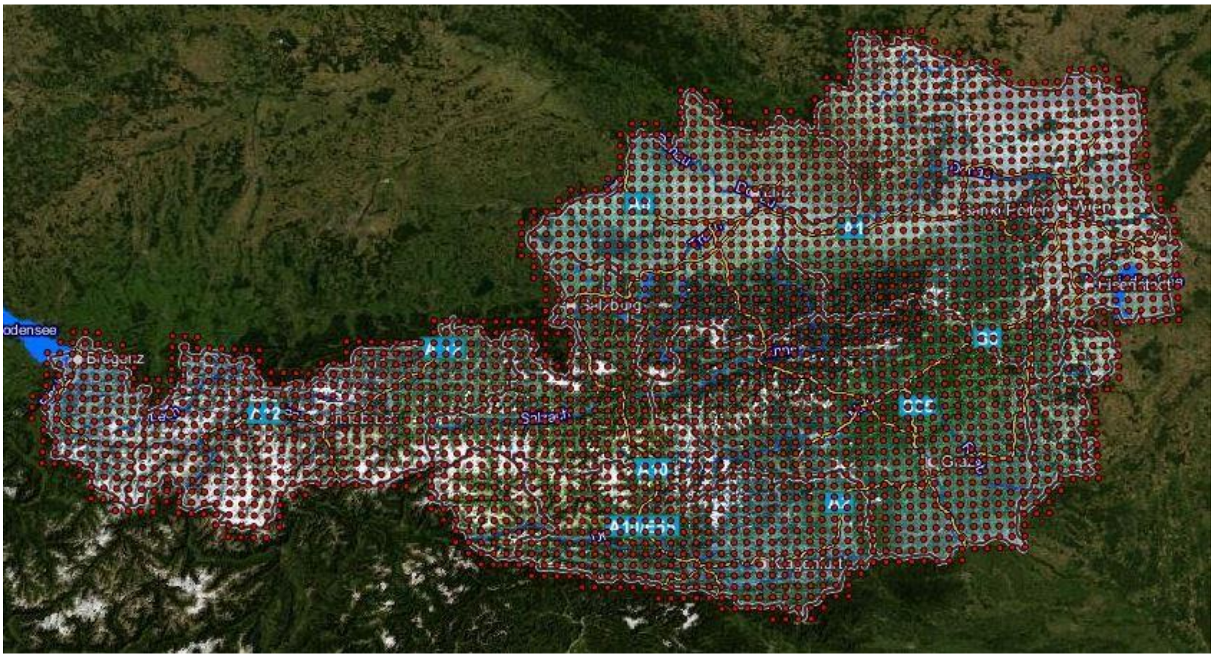


Figure 2.10: Internetapplication eHYD with 6 km * 6 km grid

Wiederkehrzeit (T) / Dauerstufe (D)	1	2	3	5	10	20	25	30	50	75	100
	7.8	*12.0*	*14.4*	*17.5*	*21.6*	*25.8*	*27.1*	*28.2*	*31.3*	*33.7*	*35.4*
5 Minuten	**7.5**	**10.9**	**12.8**	**15.3**	**18.6**	**22.0**	**23.0**	**23.9**	**26.4**	**28.3**	**29.7**
	7.1	*9.5*	*10.8*	*12.6*	*14.8*	*17.1*	*17.8*	*18.4*	*20.1*	*21.5*	*22.5*
	9.9	*15.3*	*18.4*	*22.4*	*27.9*	*33.3*	*35.0*	*36.4*	*40.4*	*43.6*	*45.9*
10 Minuten	**9.7**	**13.8**	**16.2**	**19.2**	**23.4**	**27.5**	**28.8**	**29.9**	**33.0**	**35.5**	**37.2**
	9.4	*12.1*	*13.7*	*15.8*	*18.5*	*21.2*	*22.1*	*22.9*	*24.9*	*26.6*	*27.8*
	11.4	*17.9*	*21.6*	*26.4*	*32.8*	*39.2*	*41.3*	*43.0*	*47.7*	*51.5*	*54.2*
15 Minuten	**11.2**	**16.0**	**18.8**	**22.3**	**27.1**	**31.8**	**33.4**	**34.7**	**38.1**	**41.0**	**43.0**
	11.0	*14.2*	*16.0*	*18.3*	*21.4*	*24.5*	*25.6*	*26.4*	*28.6*	*30.5*	*31.8*
	12.5	*19.7*	*23.9*	*29.2*	*36.3*	*43.5*	*45.8*	*47.7*	*52.9*	*57.1*	*60.1*
20 Minuten	**(12.4)**	**17.7**	**20.8**	**24.7**	**30.0**	**35.2**	**36.9**	**38.3**	**42.1**	**45.2**	**47.3**
	12.4	*15.9*	*17.9*	*20.5*	*24.0*	*27.4*	*28.6*	*29.4*	*31.9*	*34.0*	*35.4*
	14.4	*22.8*	*27.7*	*33.9*	*42.3*	*50.7*	*53.4*	*55.6*	*61.8*	*66.7*	*70.2*
30 Minuten	**14.6**	**20.6**	**24.1**	**28.5**	**34.6**	**40.6**	**42.6**	**44.2**	**48.7**	**52.2**	**54.7**
	**14.7*	*18.7*	*21.1*	*23.9*	*28.0*	*32.0*	*33.3*	*34.4*	*37.4*	*39.7*	*41.4*
	16.5	*26.3*	*32.0*	*39.3*	*49.1*	*58.9*	*62.0*	*64.6*	*71.8*	*77.6*	*81.6*
45 Minuten	**16.7**	**23.5**	**27.5**	**32.4**	**39.2**	**45.9**	**48.0**	**50.0**	**54.9**	**58.9**	**61.6**
	**16.8*	*21.3*	*23.9*	*27.0*	*31.4*	*35.8*	*37.1*	*38.5*	*41.7*	*44.2*	*45.9*
	18.2	*29.1*	*35.5*	*43.6*	*54.5*	*65.5*	*69.0*	*71.9*	*79.9*	*86.3*	*90.9*
60 Minuten	**(18.3)**	**25.6**	**30.0**	**35.2**	**42.5**	**49.8**	**52.1**	**54.1**	**59.5**	**63.6**	**66.6**
	**18.3*	*23.1*	*25.9*	*29.1*	*33.7*	*38.3*	*39.7*	*41.1*	*44.5*	*47.0*	*48.8*
	20.8	*33.6*	*41.1*	*50.5*	*63.3*	*76.1*	*80.2*	*83.5*	*93.0*	*100.4*	*105.8*
90 Minuten	**20.7**	**28.9**	**33.7**	**39.5**	**47.5**	**55.5**	**58.0**	**60.3**	**66.0**	**70.6**	**73.9**
	20.6	*25.8*	*28.8*	*32.2*	*36.9*	*41.7*	*43.1*	*44.7*	*48.0*	*50.7*	*52.6*

Figure 2.11: Internet application eHYD, table design precipitation (mm)

2.2.3 Future climate

Information is obtained from the publication “Climate scenarios for Austria – OEKS 15” of the Ministry of Agriculture, Forestry, Environment and Water Management, 2016 (https://www.bmlfuw.gv.at/umwelt/klimaschutz/klimapolitik_national/anpassungsstrategie/klimaszenarien.html):

The future precipitation shows a high spatial and temporal variability. The forecast for the precipitation are less reliable than for the temperature.

- Increase of the annual precipitation sum on average about 8,7 % (RCP8.5) for the period 2071-2100
- Increase of the maximum day precipitation on average about 16,2 % (RCP4.5) and 23,5 % (RCP8.5) for the period 2071-2100

2.3 Design approach and calculation methods

2.3.1 Precipitation on the road

2.3.1.1 Roads in fill / in cut / bridges

Reference: Guideline “RVS 03.08.65 - Constructive Details – Road Drainage”

The location of the storm drain systems depends on the cross slope of the road, but there are mostly two parallel channels (one in the central reserve and one at the low point of the road)

No requirements exist for the maximum thickness of the water film or for the allowable water spread on the pavements during normative precipitation events.

2.3.1.2 Tunnels

At the draining of the tunnels the mountain water and the tunnel road waters are collected separately and are drained out of the tunnels. (In older tunnels all waters are collected together)

2.3.1.3 Retention / treatment facilities

All waters including the groundwater should be kept clean and are to be protected in the context of the public interest and according to the regulations (Federal law concerning the water regulation - implementation Directive 80/68/EEC, Directive 2000/60/EC, Directive 2006/118/EC.

The dimensions and technical construction of water treatment plants are regulated in the guideline “Water protection on roads”. This guideline is binding for roads with more than 15.000 vehicles / day.

Today, the water treatment plants consist of sedimentation basins and infiltration basins. Depending on the local conditions, infiltration swales along the road could be built instead of the basins. State of the art is also the infiltration over the slope.

Different return periods of precipitation are normative in design, depending on the type of assets:

- pipes: 15 minutes of a rainfall, one to five years return period (depends on the possible impacts on the environment)
- infiltration swales: one year return period, duration up to 6 days precipitation event with a safety margin of e.g. 0,3 m
- sedimentation ponds: one year return period, duration up to 6 days precipitation event with a safety margin of e.g. 0,5 minfiltration ponds with discharge in surface water: one year return period, duration up to 6 days precipitation event with a safety margin of e.g. 0,5 m
- infiltration ponds with filtration in groundwater: five year return period, duration up to 6 days precipitation event with a safety margin of e.g. 0,5 m

As above mentioned the guideline is binding for roads with more than 15.000 vehicles / day. For roads with less than 15.000 vehicles / day the guideline is recommended.

The prevailing duration of precipitation in drainage design is for:

- pipes: 15 minutes of a rainfall
- ponds: decisive for dimension are longer rainfall events, e.g. 6 to 24 hours

The tables of the Internet application eHYD that are used correspond to IDF curves. For the dimension of the drainage system point data are used. For flooding areas see the Internet application HORA of the Ministry of Agriculture, Forestry, Environment and Water Management (http://www.hora.gv.at):

Figure 2.12: Internetapplication HORA: flooding area for 30, 100 and 200 return period

Information is available from the Hydrographic Services of the Federal States.

2.3.2 Water crossing the road (run-off flooding)

For bridges and culverts, the return period is 100 years (safety margin of e.g. 0,5 m). Precipitation duration depends on catchment area.

Prandtl-Colebrook formula is used to do the sizing.

2.4 Maintenance and operations approach

The maintenance strategy includes prevention and follow-up care after an event. In the case of prevention, the structures are constantly checked for their safety and functionality. Retention areas filled with material, pipes, etc. are cleaned.

We make constantly an evaluation of the influence of natural hazards on Austrian highways. The result is a Natural hazard indication plan. All areas in the plan with a high danger, are subjected to a detailed investigation. If the investigation shows that a measure is necessary, the measure will be implemented.

An event database for natural hazard is established.

In the case of an event, a close co-operation with the rescue forces and authorities is made.

ASFINAG use a Road weather forecast for planning and prevention. The forecasts are specifically created for the road operation.

2.5 How is climate change taken into account?

The increase of extreme rainfall events causes a higher maintenance requirement (higher sedimentation of solids in basins and ditches). No climate information for the future is used in design.

2.6 SuDS

See section 2.1 for examples of types of SuDS that are being used in Austria. The water treatment plant has 2 or 3 parts: Sedimentation Basin, Filtration Basin and if necessary a Flood retention basin. The same design standards as for new buildings are used.

No climate change is taken into account in the design of SuDS features. Operating manuals of manufacturers, Conditions of the Authority and Guidelines are used for the maintenance of SuDS systems.

2.7 Cost Benefit Analysis (CBA)

In Austria no CBA is done for water treatment of road run-off. As above mentioned the guideline “Water protection on roads” is binding on roads with more than 15.000 vehicles / day.

2.8 Summary

		precipitation on the road						water besides the road (pluvial flooding)	Water crossing the road
		Roads in fill (on embankment)	Roads in cut (excavated)	Tunnels	Bridges	Retention facilities	Treatment facilities	assets to prevent flooding	culverts
Design	Type of assets	pipes, inlets, ditches		no special drainage system	pipes, inlets, ditches	surface water treatment plants (retention, sedimentation, infiltration,), infiltration swale		flood retention basins deflective dam and structure	concrete pipes and culverts, bridges + complementary assets (bedload barrage, wild wood rake, mudflow breaker, flood retention basins)
	Which approach is used?	Guideline “RVS 03.08.65 - Constructive Details – Road Drainage” Location of the storm drain systems depends on the cross slope of the road, but mostly two parallel channels (one in the central reserve and one at the low point of the road)				All waters including the groundwater should be kept clean and are to be protected in the context of the public interest and according to the austrian regulations (Federal law)			
	What calculation methods are used?	refer to guideline “RVS 03.08.65 - Constructive Details – Road Drainage”				sedimentation and infiltration methods refer to guideline “Water protection on roads" for >15 000 vehicles/day			Prandtl-Colebrook formula
	What is the normative return period of precipitation in drainage design? Does this depend on specific road characteristics? (road importance, lifetime expectancy, cost, etc.)	1 to 5 years return period				1 year return period except infiltration ponds with filtration in groundwater : 5 years return period		100 years	100 years
	What is the prevailing duration of precipitation in drainage design?	15 min				up to 6 days			no prevailing duration , depends on catchment area
	How is climate change taken into account?	Not taken into account in design, but safety margins used in design							
	Do requirements exist for the maximum thickness of the water film on the pavements during normative precipitation events?	No						Not floodable for 1:100 years	Not floodable for 1:100 years
	Do requirements exist for the allowable water spread on the pavements during normative precipitation events?	No						Not floodable for 1:100 years	Not floodable for 1:100 years
Maintenance	Which approach is used?	prevention and follow-up care after an event + natural hazard indication plan (detailed investigation + natural hazard event database + close cooperation with the rescue forces and authorities + road weather forecast							
	Have you noticed a variation of your maintenance practices (frequencies, type of works…) that would be related to climate change?	Yes, The increase of extreme rainfall events causes a higher maintenance requirement (higher sedimentation of solids in basins and ditches).							

3 United Kingdom

3.1 *Type of water management assets used by NRA*

3.1.1 Precipitation on the road

3.1.1.1 Roads in fill (on embankment)

Different options can be used and guidance for selecting the appropriate option for various circumstances is provided in DMRB Volume 4, Section 2, Part 3:

- Kerbs and road gullies discharging to associated longitudinal carrier drains
- Surface Water Channels
- Grassed Surface Water Channels
- Over-the-edge drainage

3.1.1.2 Roads in cut (excavated)

Different options can be used and guidance for selecting the appropriate option for various circumstances is provided in DMRB Volume 4, Section 2, Part 3:

- Combined systems, where both surface water and sub-surface water are collected in the same pipe or using Grassed Surface Water Channel
- Narrow Filter with Sealed longitudinal drain
- Surface Water Channel with FIN or Narrow Filter Drain

3.1.1.3 Tunnels

Typically a kerb and gulley outfalling to a sump and a pumped system to discharge to appropriate watercourse.

3.1.1.4 Bridges

A combined kerb drainage system is typically used where the bridge deck length exceeds the gulley spacing requirements of HA102/00.

3.1.1.5 Retention facilities

The following facilities are used as appropriate:

- Dry Ponds/Detention Basin
- Wet Ponds/Retention Basins
- Infiltration basins
- Soakaways
- Wetlands
- Grassed channels
- Swales

3.1.1.6 Treatment facilities

Both Active and Passive systems are incorporated within the design. These following facilities are used either in combination or separately as appropriate:

- Wetlands/Pond
- Grassed channels/Swale
- Filter drain
- Infiltration basin
- Sediment trap
- Penstock/shut-off valve

- Oil/petrol interceptor

3.1.2 Water besides the road (pluvial flooding)

Interceptor ditches are the predominant form of collecting and conveying overland flow entering the site from outside the road boundary. These ditches are sized to accommodate the mean annual flow for a 75 year return period and are typically discharged directly to watercourses un-attenuated and un-treated.

3.1.3 Water crossing the road (run-off flooding)

Culverts are typically sized to accommodate the 1:100 year flood flow, with appropriate(typically 300mm) freeboard in accordance with CIRIA C689 culvert design guide. In Scotland a 1:200 year return period is more typical.

3.2 Sources of climate data

The rainfall data used in design is obtained from the National Meteorological Service.

3.3 Design approach and calculation methods

Road should not flood for the 1 in 100 year event. This is the case for all national roads.

All storm durations are simulated for the 1 in 1 year and 1 in 5 year return periods to ensure that the critical storm duration can be accommodated within the design as required by HD33/16. The Average Annual Rainfall data (SAAR) used in design is obtained from the National Meteorological Service.

DMRB TA 80/99 - Surface Drainage of Wide Carriageways provides guidance for drainage designs for four lane carriageways to limit depths of water during rain storms. It does not contain maximum allowable depths but rather indicates combinations of carriageway width, longitudinal gradient and crossfall that should be avoided if possible.

3.3.1 Precipitation on the road

3.3.1.1 Roads in fill and cut, tunnels and bridges

The Wallingford Procedure (www.hrwallingford.com) is the approach used to calculate run off.
Rainfall intensity is calculated according to the following equation:

$$I = 32.7(N - 0.4)^{0.223}(T - 0.4)^{0.565}(2\min M5)/T$$

I = mean rainfall intensity (mm/h) occurring in a storm of duration T (minutes) with a return period of N (years)

T = critical storm duration T (in minutes)

N = return period

2minM5 = the depth of rainfall (in mm) occurring at the particular geographical location in a storm with T= 2 minutes and N = 5 years.

According to DMRB HD 33/16, *"Longitudinal sealed carrier drains must be designed to accommodate a one-year storm in-bore without surcharge. The design must be checked against a five-year storm intensity to ensure that surcharge levels do not exceed the levels of chamber covers."* A similar set of criteria is also used for combined surface water and ground water drainage systems, with HD33/16 stating "*Combined surface water and ground water drains shall also be designed to accommodate a one-year storm in-bore without surcharge. A design check shall be carried out to establish that a five-year storm intensity will not cause chamber surcharge levels to rise above the formation level, or sub-formation level where a capping layer is present*"

Similarly, channels in the verge should be designed to just flow full for a storm with a return period of N = 1 year. Some surcharging is allowed to occur on to the adjacent hardstrip or hardshoulder during rarer storm events. This surcharged channel should be able to cater for a storm with a return period of N = 5 years without overflowing.

3.3.1.2 Retention facilities

According to DMRB HA 103/06 - Vegetated Drainage Systems for Highway Runoff*, "The capacity of the pond should normally be such as to retain an event with an annual probability of 1% for that catchment and discharge the water into the downstream watercourse at a rate that would occur in those rainfall conditions if no road were present".*

3.3.1.3 Treatment facilities

The design approach for selection of vegetated systems cannot be prescribed. Each situation must be considered individually as there are very many factors to be taken into account, ranging from the local landscape, geology, hydrology, climate and local river catchment and quality, to the actual or predicted traffic levels on the road, the risk of accidental spillages and the practicality of provision for maintenance.

3.3.2 Water besides the road (pluvial flooding)

Ditches are used for precipitation in the verge and runoff draining to the road from land outside the highway corridor. DMRB HA 106/04 "*Drainage of Runoff from Natural Catchments*" provides guidance on the design of these ditches.

Different methods are recommended for calculating run off depending on the catchment size:

- the IH 124 Method for catchments > $0.4km^2$
- the ADAS Method for catchments < $0.4km^2$

Ditches should preferably consist of earth channels lined with a native grass species in order to provide adequate resistance to flow erosion and provide treatment to the receiving water. The size of ditches can be calculated using Manning's resistance equation.

It is recommended that flow rates from natural catchments without defined watercourses should be assessed for design storms with a return period of 75 years.

3.3.3 Water crossing the road (run-off flooding)

According to CIRIA C689 (*Culvert design and operation guide*), broadly speaking there are two approaches to estimating design flows:

1. **Rainfall transformation methods based on runoff coefficients:** The approach involves modifying the rainfall using a runoff coefficient, multiplied by the catchment area, to derive either a direct estimate of the peak discharge or a flood hydrograph. There are various methods for doing this. Different methods are generally appropriate for different catchment types and areas.

2. **Statistical methods based on transfer of information from gauged flow data:** Uses measured discharge data from gauging stations and analyses it to get “flood frequency curve”.

The Flood estimation handbook (FEH) “statistical method” is the recommended approach for estimating a peak design flow in most rural river catchments (Institute of Hydrology, 1999). The FEH methods are not recommended in their original form for drained areas smaller than 50ha.

The culvert should be designed with capacity to accommodate flows which are anticipated to have between a 1% and 4% risk of occurring annually. Return periods from DMRB HA 107/04 are shown in the table below

1 in 100 years	Urban areas and villages
1 in 50 years	Agricultural land of high value and isolated properties
1 in 25 years	Agricultural land (minimum level of protection)

Design standards often used by practitioners are one per cent annual probability (100-year return period) in England and Wales, and 0.5 per cent annual probability (200-year return period) in Scotland.

3.4 Maintenance approach

Highways England has had Managing Agent Contractor (MAC) contracts running for a number of years now, where contractors are appointed to maintain all the Highways England roads within an area of the UK.

Other relevant points:

- Drainage is maintained by local authorities and sufficient access must be provided in design.
- Pipes are designed to be self-cleaning.
- During design of gullies, a maintenance factor ‘m’ is applied. The effect of reduced maintenance and accumulation of debris will be to reduce the hydraulic area and efficiency of the gully grating. This factor is included to allow for this effect.

No weather or climate data are used for maintenance purposes.

3.5 How is climate change taken into account?

No increase in maintenance frequencies that would be related to climate change is noticed. Climate change is allowed for by increasing design flows and rainfall intensities of the design storm by 20%.

3.6 SuDS

SuDS are being used by the NRA. *CIRIA C753 SuDS Manual* provides guidance on the planning, design, construction and maintenance of SuDS to assist with their effective implementation within both new and existing developments. This extensive manual has a section which examines the specific challenges in applying a SuDS approach to roads and highways. The DMRB design standards in relation to drainage design largely take on board the principles of SuDS Manual. Climate change is taken into account through application of the 20% increase for rainfall intensities when calculating the required capacity of the water management system.

3.7 CBA

No cba's are used to determine the requirements (return periods) on a strategic level or on an operational level (project specific).

The web based WebTAG project appraisal approach is used to select the appropriate solution for transport infrastructure.

WebTAG uses an environmental capital approach where a set of environmental resources are qualitatively assessed. Environmental resources include for example landscape, historic features, biodiversity and water, which can be interlinked. The appraisal can be used at any stage of the development of projects from options stage to detailed design appraisal.

However, the approach is generally to appraise the entire project and is not generally applied specifically to determine the appropriate drainage solution to use.

Climate change would be taken into account through application of the 20% increase for rainfall intensities when calculating the required capacity of the water management system.

Normally is the CBA performed by a consultant engineer in conjunction with the road authority.

3.8 Summary

UK		precipitation on the road						water besides the road (pluvial flooding)	Water crossing the road
		Roads in fill (on embankment)	Roads in cut (excavated)	Tunnels	Bridges	Retention facilities	Treatment facilities	assets to prevent flooding	culverts
Design	Type of assets	Kerbs and road gullies, Surface Water Channels, Grassed Surface Water Channels, Over-the-edge drainage.	Combined systems, Narrow Filter with Sealed longitudinal drain, Surface Water Channel with Narrow Filter Drain	kerb and gulley outfalling to a sump and a pumped system	Kerb drainage system	Dry Ponds/Detention Basin, Wet Ponds/Retention Basins, Infiltration basins, Soakaways, Wetlands, Grassed channels, Swales.	Wetlands, Grassed channels, Filter drain, Infiltration basin, Sediment trap, Penstock/shut-off valve, Oil/petrol interceptor	Ditches are used for precipitation in the verge and runoff draining to the road from land outside the highway corridor.	culverts
	Which approach is used?	The Wallingford Procedure (www.hrwallingford.com) is the approach used to calculate run off.				The capacity of the pond should normally be such as to retain an event with an annual probability of 1%	CIRIA C753 SuDS Manual provides guidance on the planning, design, construction and maintenance of SuDS	• the IH 124 Method for catchments > 0.4km2 • the ADAS Method for catchments . 0.4km2	Broadly speaking there are two generic approaches to estimating design flows: 1) Rainfall transformation methods based on runoff coefficients: The approach involves modifying the rainfall using a runoff coefficient, multiplied by the catchment area, to derive either a direct estimate of the peak discharge or a flood hydrograph. 2) Statistical methods based on transfer of information from gauged flow data: Uses measured discharge data and analyses it to get "flood frequency curve".
	What calculation methods are used?	$I = 32.7(N-0.4)^{0.223}(T-0.4)^{0.565}(2\min M5)/T$ Formula above is used to calculate the rainfall intensity and run off for design: I = mean rainfall intensity (mm/h) occurring in a storm of duration T (minutes) with a return period of N (years) T = critical storm duration T (in minutes) N = return period 2minM5 = the depth of rainfall (in mm) occurring at the particular geographical location in a storm with T= 2 minutes and N = 5 years.						The size of ditches is calculated using Manning's resistance equation.	
	What is the normative return period of precipitation in drainage design? Does this depend on specific road characteristics? (road importance, lifetime expectancy, cost, etc.)	HD33/16: "Combined surface water and ground water drains shall also be designed to accommodate a one-year storm in-bore without surcharge. A design check shall be carried out to establish that a five-year storm intensity will not cause chamber surcharge levels to rise above the formation level, or sub-formation level where a capping layer is present"				The capacity of the pond should normally be such as to retain an event with an annual probability of 1% and discharge the water into the downstream watercourse at a rate that would occur if no road were present.		It is recommended that flow rates from natural catchments without defined watercourses should be assessed for design storms with a return period of 75 years.	Design standards often used by practitioners are one per cent annual probability (100-year return period) in England and Wales, and 0.5 per cent annual probability (200-year return period) in Scotland.
	What is the prevailing duration of precipitation in drainage design?	All storm durations are simulated for the 1 in 1 year and 1 in 5 year return periods to ensure that the critical storm duration can be accommodated within the design as required by HD33/16.							
	How is climate change taken into account?	Climate change is allowed for by increasing design flows and rainfall intensities of the design storm by 20%.							
	Do requirements exist for the maximum thickness of the water film on the pavements during normative precipitation events?	"DMRB TA 80/99 - Surface Drainage of Wide Carriageways" provides guidance for drainage designs for four lane carriageways to limit depths of water during rain storms. It does not contain maximum allowable depths but rather indicates combinations of carriageway width, longitudinal gradient and crossfall that should be avoided if possible.				n/a	n/a	n/a	n/a
Maintenance	Which approach is used?	Highways England has had Managing Agent Contractor (MAC) contracts running for a number of years now, where contractors are appointed to maintain all the Highways England roads within an area of the UK.							
	Have you noticed an increase in maintenance frequencies that would be related to climate change?	No						No	No

4 France

4.1 Type of water management assets used by NRA

4.1.1 Precipitation on the road

The main water management assets for run-off water collection are the following (precast or cast in situ):

- Roads in fill (on embankment)
  - Storm water runoff systems for water collection:
    - Features : open facilities (easier maintenance)
    - Types : rectangular concrete channel, curb and slope ditch (regular discharging at slope base by curbs with regular openings and slope channels), slotted drain (with cleaning manholes)
  - Storm water runoff-systems for crossing:
    - Features : buried structures
    - Types : circular pipes, manholes and grate inlets
- Roads in cut (excavated)
  - Storm water runoff-systems for water collection:
    - Features : Surface facilities (easier maintenance)
    - Types : triangular channel, trapezoidal channel
    - Lining : grass, riprap, concrete
  - Storm water runoff-systems for crossing:
    - Features : buried structures, special attention at sag points
    - Types : circular pipes, manholes and grate inlets
- Tunnels (length < 300m)
  - Features: if possible storm drain system to be discharged before entering the tunnel in order not to mix run-off water and tunnel washing water
  - Type : slotted drain, pipes, pumps when needed, dedicated manhole to avoid fire spread
- Bridges
  - Features : Surface facilities (easier maintenance)
  - Types : curb inlet and gutter, grate inlet and pipes

The main water management assets for run-off water management (retention and/or treatment) are the following:

- Retention facilities
  - Types: longitudinal containment basin, longitudinal containment ditch, attenuation pond
  - Ancillary equipment : regulation manhole, safety weir,
- Treatment facilities
  - Types : longitudinal containment basin, longitudinal containment ditch, settling pond with dead volume, sand filter facility
  - Ancillary equipment : regulation manhole, safety weir, bypass

For each discharging points, the proposed facility can mix several functions (retention, containment of pollution from spillage, chronic pollution settlement). The final sizing takes into account the most disadvantageous function.

4.1.2 Water besides the road (pluvial flooding)

The main water management assets besides the road are trapezoidal ditches which collect pluvial run-off. The lining depends on the flow velocity.

Dikes or levees are linked to known floodable plains (linked to rivers) and are implemented in coordination with the crossing structures (refer to 4.1.3).

4.1.3 Water crossing the road (run-off flooding)

The main water management assets for water crossing the road are the following:

- Features :
  - hydraulic culverts implemented at each potential crossings points
  - inlet and outlet head structures (head walls and wing walls generally)
  - structures sometimes combined with environmental stakes (banks, natural waterbed if needed)
  - erosion protection at inlet and outlet (concrete slab, rock protection, gabion)
  - precast or cast in situ
- Shape : circular, rectangular, arch
- Material : mainly concrete for circular and rectangular, mainly metallic for arch

4.2 Sources of climate data

The climate data currently used for drainage design are based on statistical analysis of historical data (samples from rain gauges).
The agency which owns and sells these data is Météo-France (web site: https://publitheque.meteo.fr/okapi/accueil/okapiWebPubli/index.jsp)

Nevertheless data regarding future climate are also available from Météo-France on their website and there is a dedicated website for future climate: http://www.drias-climat.fr/

4.3 Design approach and calculation methods

4.3.1 Precipitation on the road

4.3.1.1 Roads in fill (on embankment) / Roads in cut (excavated) / Tunnels / Bridges

References:

- **Technical** guide – Roadway water management – Ministry of Ecology, Energy, Sustainable Development and Land Planning (MEEDDAT) - October 2006 – (Assainissement routier - Guide technique -SETRA) http://dtrf.setra.fr/

For longitudinal storm drain systems, the design approach is to provide superficial drainage systems (easier maintenance than buried systems) on each side of the road (except for super elevated road, surface drainage also provided in median area) before crossing the infrastructure towards the proposed outfall (with or without water management).

The lining of the network depends on the environmental sensitivity and especially the underground water that may be contaminated by pollutants.

The calculation method is based on the rational method (peak flow calculations) and the Manning-Strickler equation (conveyance calculations). There is no prevailing duration of precipitation in drainage design as the time of concentration is calculated at a regular step along the network (generally between 5 minutes and 1 hour).

The climate data used for the calculation is IDF curves (duration between 6 min to 24 hours – return period from 6 months to 100 years). The IDF curves are described thanks to the law of Montana: $i = a \times t^{-b}$

Where:

- i is the design rainfall intensity (mm/hr)
- t is the duration (minutes) of the rainfall event for a catchment area (time of concentration)
- a, b : adjustment factors

IDF curves are available for roughly 900 rain gauges within France.

The normative return period is 10 years. The storm drain system is sized (with a safety margin) for the maximum peak flow of a return period of 10 years. Then the designer must check that the run-off don't reach the driving lanes (hard shoulder floodable) for a return period of 25 years.

There is no allowable maximum thickness of the water film on the pavements during normative precipitation events but a cross slope of 2,5 % is usually implemented to evacuate run-off water as fast as possible.

4.3.1.2 Retention facilities / Treatment facilities

References:

- Technical guide – Roadway pollution – Water management facilities design - Ministry of Ecology, Energy, Sustainable Development and Land Planning (MEEDDAT) - August 2007 (Pollution d'origine routière - Conception des ouvrages de traitement des eaux - Guide technique) Where to find them : http://dtrf.setra.fr/
- European Water Framework Directive - Directive 2000/60/EC - http://www.rapportage.eaufrance.fr/

The run-off water management facilities are defined according to the vulnerability of outfalls. A range of 4 levels of vulnerability are defined within the guidelines and dedicated facilities are proposed for each level.

The calculation methods are the following according to the required function of the facility:

- Retention :
    - Volume size: The method consists in calculating, as a function of time, the difference between the run-off water precipitated on the ground and the discharged water evacuated by the regulation device ("méthode des pluies"). The normative return period is usually 10 years. Nevertheless, special regulations (urban areas, regional regulations, flood plains…) may ask for more.
    - Allowable discharging peak flow: its value depends on outfall regulation, regional regulation…
- Containment of pollution from spillage: In dry weather, it only consists in providing a dead volume to contain the volume of a tanker (around 50 m^3). During wet event, the available pond volume should match with the chosen rainy event to be contained: couple occurrency / duration (usually around 1 or 2 years – 1 or 2 hours). Moreover, the regulation device should enable the operator to close the regulation gate before the pollution reaches the outfall.
- Chronic pollution / routine run-off: The principle is to settle suspended solids which adsorb main road pollution. The minimum settling area is defined according to the Hazen law taken into account the peak flow to treat (usually corresponding to a return period of 6 months, 1 year or 2 years), the discharging peak flow and the required particles to treat (corresponding to a settling velocity). The polluted loads are calculated based on experiments conducted since 1992.

The climate data used for the calculation is IDF curves (reference to previous chapter for details) and average annual rainfall for polluted loads.

4.3.2 Water besides the road (pluvial flooding)

Trapezoidal ditches are typically implemented:

- at toe of embankments to collect pluvial flooding which may ruin embankments,
- at crest of cut to avoid run-off on the embankments.

In swamp/wet areas, these types of ditches are forbidden to avoid drying the soils.

In known floodable area (linked to watercourses), trapezoidal ditches are also implemented to collect run-off which is discharged within the crossing structure (refer to 4.3.3).

These ditches are not sized except for those which are implemented at the crest of cut embankments (return period of 100 years).

The hydrological calculation method is based on the rational method as the collected watersheds areas are usually low. There is no prevailing duration of precipitation (refer to previous chapter for details) in design as the time of concentration is calculated for each watershed.

The climate data used for the calculation is IDF curves.

The hydraulic calculation method is based on the Manning-Strickler equation.

4.3.3 Water crossing the road (run-off flooding)

References:

- Technical guide – Roadway water management – Ministry of Ecology, Energy, Sustainable Development and Land Planning (MEEDDAT) - October 2006 - (Assainissement routier - Guide technique -SETRA) http://dtrf.setra.fr/

The design approach for crossing structures is to provide a hydraulic facility at each low point in order to ensure the hydraulic transparency of the road (the road should not act as a dam but enable crossing of flows). The type of structure depends on the type of watercourse: natural or anthropic, perennial or intermittent…The hydraulic structure may be combined with environmental stakes.

The hydrological calculation method is based on the rational method and the Crupedix method for non-gauged watercourses and on statistical analysis for gauged site (rating curve).

The normative return period is 100 years (with a checking for exceptional events, 1,5xQ100). There is no prevailing duration of precipitation in design as the time of concentration is calculated for each watershed.

The hydraulic calculation method is based on the Manning-Strickler equation for preliminary design (uniform flow assumed) and on Bernoulli and energy equations for detailed design (gradually varied flow).

The climate data used for the calculation is IDF curves for non-gauged site.

4.4 Maintenance and operations approach

In France, a part of the motorway network is operated by private companies which have their own operation and maintenance approaches.

For the moment climate change is not taken into account in road maintenance and operations in France. The current guidelines do not address this topic.

4.4.1 Precipitation on the road

4.4.1.1 Roads in fill (on embankment) / Roads in cut (excavated) / bridges / tunnels

References:

- Technical guide – Roadway water management – Ministry of Ecology, Energy, Sustainable Development and Land Planning (MEEDDAT) - October 2006 - (Assainissement routier - Guide technique -SETRA) - http://dtrf.setra.fr/
- Guidelines – the routine maintenance of storm drain systems – Ministry of Ecology, Energy, Sustainable Development and Land Planning (MEEDDAT) - 1998 - (L'entretien courant de l'assainissement de la route – SETRA) http://dtrf.setra.fr/

The general approach is to prefer rustic open facilities which are easily maintained. For buried systems, manholes are regularly implemented for dredging or video survey when needed.

Usually, the routine maintenance is preventive: cleaning works (mowing, removal of silt, debris and vegetation…) and small repairs (masonry reset of invert…). The maintenance is mechanic and chemicals are forbidden.

Curative maintenance is done after extreme events.

During exceptional events, operators have emergency and rescue plans.

The operators may also subscribe to meteorological alerts from Météo-France.

4.4.1.2 Retention facilities / treatment facilities

References:

- Technical guide – Roadway pollution – Water management facilities design - Ministry of Ecology, Energy, Sustainable Development and Land Planning (MEEDDAT) - (Pollution d'origine routière - Conception des ouvrages de traitement des eaux - Guide technique) - August 2007 - Where to find them : http://dtrf.setra.fr/
- Guidelines – the routine maintenance of storm drain systems – Ministry of Ecology, Energy, Sustainable Development and Land Planning (MEEDDAT) - 1998 - (L'entretien courant de l'assainissement de la route – SETRA) - http://dtrf.setra.fr/

inspections (including operating of functional facilities), cleaning works (mowing, removal of silt, debris and vegetation…) and small repairs. The maintenance is mechanic and chemicals are forbidden. The maintenance frequency is adapted to the site and may evolve according to the inspections results.

Curative maintenance is done after extreme events or pollution from spillage.

4.4.2 Water besides the road (pluvial flooding)

Same principle as for retention and treatment facilities.

4.4.3 Water crossing the road (run-off flooding)

References:

- Technical guide – Roadway water management – Ministry of Ecology, Energy, Sustainable Development and Land Planning (MEEDDAT) - October 2006 - (Assainissement routier - Guide technique -SETRA) - http://dtrf.setra.fr/

Usually, the routine maintenance is preventive and annual: inspections, cleaning works (removal of silt, debris and vegetation…) and small repairs.

Curative maintenance is done after extreme events.

During exceptional events, operators have emergency and rescue plans.

The operators may also subscribe to meteorological alerts from Météo-France.

4.5 How is climate change taken into account?

For the moment climate change is not taken into account in road drainage design in France. The current guidelines do not address this topic.

Nevertheless, the government is fully aware of the need to take climate change into account, to anticipate and adapt to its effects. The national observatory on the effects of global warming (Observatoire national sur les effets du réchauffement climatique - ONERC) was created by law on 19th February 2001. These activities are mainly to collect and disseminate information, studies and research on risks associated to climate change and extreme climate events, to make recommendations on potential measures of prevention and adaptation in order to limit the risks associated to climate change.

http://www.developpement-durable.gouv.fr/-Impacts-et-adaptation-ONERC-.html

The government edited an adaptation plan for the effects of climate Change 2011 - 2015 which highlights the need for methodological tools to retain the most relevant projects. This plan is under revision.

http://www.developpement-durable.gouv.fr/Revision-du-plan-national-d,48074.html

The first action (achieved) was to define potential impacts of climate change on infrastructure and transport systems, on their design, maintenance and operation guidelines, and need for precision of climate projections. - http://www.cerema.fr/plan-national-d-adaptation-au-changement-a972.html

The third action (achieved) was to propose concepts related to risk analysis of climate events on infrastructure, systems and services of transport.

These actions are not linked to the climate change projections values themselves but to climate change qualitative impact.

4.5.1 Precipitation on the road

4.5.1.1 Roads in fill (on embankment) / Roads in cut (excavated) / Bridges / Tunnels

For the moment climate change is not taken into account in drainage design.

Nevertheless, safety margins exist because a large part of the storm drain systems is designed considering a maximum filling ratio for the design calculations (between 75% for rectangular gullies to 90% for triangular ditches).

4.5.1.2 Retention facilities / Treatment facilities

For the moment climate change is not taken into account in drainage design.

Nevertheless, for facilities with a spillway accurately sized, the consequence of the climate change has no impact on the facility itself but is only moved away (increase peak flow and / or pollution level).

4.5.2 Water besides the road (pluvial flooding)

Same principles at 4.5.1.1

4.5.3 Water crossing the road (run-off flooding)

For the moment climate change is not taken into account in drainage design.

Nevertheless, safety margins exist because a large part of the culverts is designed considering a maximum filling ratio for the design calculations (around 75%).

For high fill road, the water depth may increase significantly before reaching the traffic lanes creating artificial safety margin. Nevertheless, the impact of backwater has to be checked within the upstream area (flooding of housing, industrial areas or lower infrastructures).

Moreover, the culvert design is often checked for a rainfall event above the chosen design event (extreme peak flow equal to 1.5 to 1.8 times the design peak flow).

4.6 SuDS

References (not comprehensive):

- Alternatives solutions in drainage – choice, design, construction and maintenance - GRAIE – Y. Azzout et al., 1994
- The City and its drainage - MEDD – CERTU, 2003

  http://www.developpement-durable.gouv.fr/IMG/pdf/DGALN_Ville_assainissement_so.pdf
- Alternatives solutions to storm drain systems – key elements for implementation - CERTU, 1998, revision 2006
- www.adopta.free.fr
- www.graie.org

SuDS are mainly used for urban areas. They are used very rarely in roads because of narrow right-of-way and because treating chronic pollution/ pollution from spillage does not allow infiltration.

A few examples of freshwater species remediation exist but are only punctual initiatives.

SuDS can be used in service or rest areas (swales, ponds, soakaways, infiltration trenches, infiltration basins, pervious pavements…)

There are no design standards for SuDS especially dedicated for new roads, road widening or upgrade works.

4.7 Cost Benefit Analysis

References:

- The CBA (cost-benefit analysis): a decision-making aid for the management of floods - Guidelines for owners and their partners - European Center for Flood Risk Prevention (Centre Européen de Prévention du Risque Inondation – CEPRI) -2011
- Socio-economic evaluation of public investment – General department for strategy and foresight – 2013

- Adaptation plan for the effects of climate change 2011-2015 (PNACC) -Ministry of Ecology, Energy, Sustainable Development and Land Planning (MEEDDAT) - 2011

Regarding roads drainage, there are no CBA recommended for the moment.

Nevertheless within the PNACC and the dedicated form regarding roads infrastructures, the main methodological elements that can approximate a CBA approach (not explicitly cited) concern the need to provide methodological support to operators and to organize a network of correspondents to capitalize feedbacks.

Moreover, CBA is compulsory for flood prevention projects (Program of action for the prevention of flood risks - Programme d'action de prévention des risques liés aux inondations" – PAPI - 2011). In this specific case, the impact on the road system is only one impact studied.

Climate change is not taken into account in CBA because it is rather the CBA that is seen as a tool for appraising projects to adapt to climate change.

The CBA are performed by infrastructure operators, local authorities, government departments, but with the technical support of the government (referent network, methodological guide, etc.)

Guidelines and technical support of the government are available (CEREMA, ADEME, etc.) but not dedicated to road drainage.

4.8 Summary

France		precipitation on the road						water besides the road (pluvial flooding)	Water crossing the road
		Roads in fill (on embankment)	Roads in cut (excavated)	Tunnels	Bridges	Retention facilities	Treatment facilities	assets to prevent flooding	culverts
Design	Type of assets	rectangular concrete channel, curb and slope ditch, slotted drain ,circular pipes, manholes and grate inlets	triangular channel, trapezoidal channel, circular pipes, manholes and grate inlets	slotted drain, pipes, pumps, dedicated manhole to avoid fire spread	curb inlet and gutter, slotted drain	longitudinal containment basin, longitudinal containment ditch, attenuation pond	longitudinal containment basin, longitudinal containment ditch, settling pond with dead volume, sand filter facility	trapezoidal channels	circular pipes, rectangular box culvert, arch
	Which approach is used?	provide open drainage systems (easier maintenance than buried systems) on each side of the road (except for super elevated road, surface drainage also provided in median area) before crossing the infrastructure towards the proposed outfall (with or without water management).				facilities defined according to the vulnerability of outfalls (4 levels). Dedicated facilities for each level.		at toe of embankment and at crest of cut areas	provide a facility at each law point in order to ensure the transparency of the road
	What calculation methods are used?	rational method (peak flow calculations) + Manning-Strickler equation (conveyance calculations)				Difference between run-off water precipitated and discharged flow evacuated	containment for a duration event and an occurency + Hazen settling law	rational method + Manning-Strickler equation	Hydrology :rational method, Crupedix method for non gauged watercourses and statistical analysis for gauged site
	What is the normative return period of precipitation in drainage design? Does this depend on specific road characteristics? (road importance, lifetime expectancy, cost, etc.)	10 years + hard shoulder floodable for 25 years				10 years usually but may be different according to specific regulation	containment : usually around 1 or 2 years – 1 or 2 hours settlement :usually return period of 6 months, 1 year or 2 years	100 years	100 years (+ checking for exceptional events : 1,5 x Peak flow 1:100 years)
	What is the prevailing duration of precipitation in drainage design?	no prevailing duration as the time of concentration is calculated at a regular step along the network.				disadvantageous duration (usually around several hours)		no prevailing duration as the time of concentration is calculated for each watershed	
	How is climate change taken into account?	climate change not taken into account in drainage design guidelines. Nevertheless, safety margins exist due to the maximum filling ratio used in design.				climate change is not taken into account but always spillway for exceptional events	not taken into account	climate change not taken into account	climate change not taken into account in drainage design. Nevertheless, safety margins exist due to the maximum filling ratio used in design. Moreover design often checked for a extreme peak flow equal to 1.5 times the design peak flow
	Do requirements exist for the maximum thickness of the water film on the pavements during normative precipitation events?	No (but minimum cross slope of 2,5 %)				NA	NA	Not floodable for 1:100 years	Not floodable for 1:100 years
	Do requirements exist for the allowable water spread on the pavements during normative precipitation events?	storm drain system sized for the 10 year-return period + the run-off can't reach the driving lanes (hard shoulder floodable) for a return period of 25 years				NA	NA	Not floodable for 1:100 years	Not floodable for 1:100 years
Maintenance	Which approach is used?	preventive and curative / subscription to meteorological alerts / emergency and rescue plan						preventive and curative	preventive and curative / subscription to meteorological alerts / emergency and rescue plan
	Have you noticed a variation of your maintenance practices (frequencies, type of works...) that would be related to climate change?	No						No	No

5 Germany

5.1 *Type of water management assets used by NRA*

5.1.1 Precipitation on the road

The following technical facilities are regularly used for water management purposes in Germany:

- curbs;
- gutters;
- drains;
- sewers;
- pipes;
- ditches;
- culverts;
- retention ponds;
- settling ponds.

5.1.2 Water besides the road (pluvial flooding)

The following technical facilities are regularly used for water management purposes in Germany:

- road on embankment.

5.1.3 Water crossing the road (run-off flooding)

The following technical facilities are regularly used for water management purposes in Germany:

- culverts;
- pipes.

5.2 *Sources of climate data*

The German Meteorological Service (DWD) provides climate information to transport research institutes in Germany such as the Federal Highway Research Institute (BASt). The BASt uses this climate information to provide technical and scientific guidance to NRAs in Germany.

The DWD develops regional climate projections for Germany in close cooperation with weather services, research institutes, and scientific organizations worldwide. These climate projections are based on data from General Circulation Models (GCM) and Regional Climate Models (RCM). In previous research projects, the BASt has mainly used climate projections of two different RCMs provided by the DWD, which are COSMO-CLM and REMO. The DWD also provides historical data products on intense rainfall, with the KOSTRA atlas being the most important data product in this context.

Climate information (past, current, future) is provided by the German Meteorological Service (DWD). The DWD is part of the "BMVI-Expertennetzwerk", which is a national research network of transport research institutes and agencies of the Federal Ministry of Transport and Digital Infrastructure (BMVI). This research network addresses key challenges for the transport system in the 21st century, including the adaptation of transport infrastructures to climate change and extreme weather events. Further information about this research network is available at the website "http://www.bmvi-expertennetzwerk.de".

5.3 Design approach and calculation methods

The design of road drainage systems is regulated by the two following technical guidelines of the German Road and Transportation Research Association (FGSV):

1. RAS-Ew – Richtlinie für die Anlage von Straßen, Teil: Entwässerung
2. RiStWag – Richtlinie für bautechnische Maßnahmen an Straßen in Wasserschutzgebieten

There are also several technical guidelines of The German Association for Water, Wastewater and Waste (DWA) that need to be taken into account in the design of road drainage systems, including the guidelines entitled DWA-A 110, DWA-A 117, DWA-A 118, DWA-A 138, DWA-M 153, and DWA-M 178. These DWA guidelines in combination with the two guidelines of the FGSV contain important information about current design approaches and calculation methods. Furthermore, it is referred to the guideline DIN EN 752 "Drain and sewer systems outside buildings - Sewer system management", which is, just as the guideline ZTV Ew-StB, relevant to practical application in Germany.

5.4 Maintenance and operations approach

The maintenance approach to water management in Germany is usually both corrective and preventive. Learning from past events and rethinking of previous approaches according to practical experiences becomes increasingly important in maintenance. We would also like to draw your attention on the guideline H KWES of the German Road and Transportation Research Association (FGSV).

The management cycle in relation to the recovery from the impacts of hydrological extreme events on road infrastructures in Germany usually includes the following steps:

1. emergency response and road closure;
2. road clearance, provisional repair, and road reopening;
3. action planning;
4. maintenance and repair measures;
5. prevention (long-term).

5.5 How is climate change taken into account?

Reference:

Holldorb, C., Rumpel, F., Gerstengarbe, F.-H., Österle, H., Hoffmann, P. (2016): Analyse der Auswirkungen des Klimawandels auf den Straßenbetriebsdienst (KliBet). Berichte der Bundesanstalt für Straßenwesen, Verkehrstechnik, Heft V 270. Fachverlag NW, Bremen, 91 pp.

Climate change is generally considered to have an influence on road operation services in Germany. The impacts of extreme events such as intense rainfall, however, are still difficult to assess due to significant uncertainties (Holldorb et al., 2016).

The report, including an English summary, is available at the following website:

http://bast.opus.hbz-nrw.de/volltexte/2016/1748/pdf/V270_barrierefreie_Internet_PDF.pdf

The time horizon of climate change considerations in transport research and planning in Germany usually reaches from today or the recent past (reference period, see below) until the end of the 21st century. The reference period covers 30 years in most cases, but is not necessarily fixed to specific 30-year period. The period 1971-2000 is an example of a reference period used in previous projects of the Federal Highway Research Institute (BASt). In order to increase the reliability of climate projections, it is common practice today to create ensembles of several climate models, which helps to better reflect the range of potential modeling results. The uncertainties that still exist in the projection of future climate conditions are clearly communicated to data users and practitioners.

5.6 SuDS

Reliable answers couldn’t be given in this context (no specific expert knowledge in the field of SuDS).

5.7 Cost Benefit Analysis

Cost benefit analyses to promote best practices in terms of the technical performance, profitability, and environmental sustainability of water management systems play an important role in the planning, design, and maintenance of road infrastructures in Germany. This increasingly includes the consideration of climate change, its potential impacts, and measures for effective climate protection.

6 Ireland

In most cases Ireland adopts a similar approach to drainage design as the UK.

6.1 Type of water management assets used by NRA

6.1.1 Precipitation on the road

6.1.1.1 Roads in fill (on embankment)

Different options can be used and guidance for selecting the appropriate option for various circumstances is provided in Transport Infrastructure Ireland's (TII) DMRB Volume 4, Section 2, Part 3:

- Kerbs and road gullies discharging to associated longitudinal carrier drains.
- Surface Water Channels
- Over-the-edge drainage.

6.1.1.2 Roads in cut (excavated)

Different options can be used and guidance for selecting the appropriate option for various circumstances is provided in TII's DMRB Volume 4, Section 2, Part 3:

- Combined systems, where both surface water and sub-surface water are collected in the same pipe or using Grassed Surface Water Channel
- Filter drains
- Surface Water Channel with Sealed carrier pipe and separate Filter Drain

Cut off drains are used at the top of the cutting to prevent run off from adjacent lands entering the cutting.

6.1.1.3 Tunnels

Typically a kerb and gulley outfalling to a sump and a pumped system to discharge to appropriate watercourse

6.1.1.4 Bridges

A combined kerb drainage system is typically used where the bridge deck length exceeds the gulley spacing requirements of HA102/00.

6.1.1.5 Retention facilities

The following facilities are used as appropriate:

- Dry Ponds/Detention Basin
- Wet Ponds/Retention Basins
- Infiltration basins
- Soakaways
- Wetlands
- Grassed channels
- Swales

6.1.1.6 Treatment facilities

Both Active and Passive systems are incorporated within the design. These following facilities are used either in combination or separately as appropriate:

- Wetlands/Pond;
- Grassed channels/Swale;

- Filter drain;
- Infiltration basin;
- Sediment trap
- Penstock/shut-off valve
- Oil/petrol interceptor

6.1.2 Water besides the road (pluvial flooding)

Interceptor ditches are the predominant form of collecting and conveying overland flow entering the site from outside the road boundary. These ditches are sized to accommodate the mean annual flow for a 75 year return period and are typically discharged directly to watercourses un-attenuated and un-treated.

6.1.3 Water crossing the road (run-off flooding)

Culverts are typically sized to accommodate the 1:100 year flood flow, with appropriate(typically 300mm) freeboard in accordance with CIRIA C689 culvert design guide. Flow estimation methods vary dependent on the catchment characteristics. Office of Public Works (OPW) Section 50 approval is required for all structures crossing watercourses.

6.2 Sources of climate data

The rainfall data used in design is obtained from the National Meteorological Service.

6.3 Design approach and calculation methods

Road should not flood for the 1 in 100 year event. This is the case for all national roads.

All storm durations are simulated for the 1 in 1 year and 1 in 5 year return periods to ensure that the critical storm duration can be accommodated within the design as required by TII's HD33/15. The Average Annual Rainfall data (SAAR) used in design is obtained from the National Meteorological Service.

TII have published an Interim Advice Note (IAN 09/13) which is not part of the standard but which the road owner can specify as a requirement in the design of a new road. It states that *"A maximum water film depth of 2.5 mm shall apply to new single carriageway roads. On Motorways and Dual Carriageways, as the 2.5mm limit can be very difficult to achieve, a maximum value of 3.3 mm shall be adopted."*

Where a 2.5 mm or 3.3 mm water film depth cannot be achieved a departure from standard can be sought from the NRA to increase the water film depth, or where on a high speed road, for the inclusion of a rolling crown.

6.3.1 Precipitation on the road

6.3.1.1 Roads in fill and cut, tunnels and bridges

The Wallingford Procedure (www.hrwallingford.com) is the approach used to calculate run off.

Rainfall intensity is calculated according to the following equation:

$$I = 32.7(N - 0.4)^{0.223}(T - 0.4)^{0.565}(2\min M5)/T$$

I = mean rainfall intensity (mm/h) occurring in a storm of duration T (minutes) with a return period of N (years)

T = critical storm duration T (in minutes)

N = return period

2minM5 = the depth of rainfall (in mm) occurring at the particular geographical location in a storm with T= 2 minutes and N = 5 years.

According to TII's DMRB HD 33/15, *"Longitudinal sealed carrier drains must be designed to accommodate a one-year storm in-bore without surcharge. The design must be checked against a five-year storm intensity to ensure that surcharge levels do not exceed the levels of chamber covers."*

Similarly, channels in the verge should be designed to just flow full for a storm with a return period of N = 1 year. Some surcharging is allowed to occur on to the adjacent hardstrip or hardshoulder during rarer storm events. This surcharged channel should be able to cater for a storm with a return period of N = 5 years without overflowing.

6.3.1.2 Retention facilities

TII's DMRB HA 103/15 – "*Vegetated Drainage Systems for Road Runoff*" states that*, "the peak runoff rate from a proposed development should not be increased above the peak greenfield runoff rate for all storm events up to and including the 1 in 100 year storm event".*

The duration of the critical precipitation event which is used for attenuation design is typically in the range of 3 to 6 hours.

6.3.1.3 Treatment facilities

TII's DMRB Volume 4 Section 2 Part 1 TII HD 103/15:

The selection of vegetated systems cannot be prescribed. Each situation must be considered individually as there are very many factors to be taken into account, ranging from the local landscape, geology, hydrology, climate and local river catchment and quality, to the actual or predicted traffic levels on the road, the risk of accidental spillages and the practicality of provision for maintenance.

6.3.2 Water besides the road (pluvial flooding)

Ditches are used for precipitation in the verge and runoff draining to the road from land outside the highway corridor. TII's DMRB HD 106/15 "*Drainage of Runoff from Natural Catchments*" provides guidance on the design of these ditches.

Different methods are recommended for calculating run off depending on the catchment size:

- the IH 124 Method for catchments > $0.4km^2$
- the ADAS Method for catchments < $0.4km^2$

Ditches should preferably consist of earth channels lined with a native grass species in order to provide adequate resistance to flow erosion. The size of ditches can be calculated using Manning's resistance equation.

It is recommended that flow rates from natural catchments without defined watercourses should be assessed for design storms with a return period of 75 years.

6.3.3 Water crossing the road (run-off flooding)

As described by the UK CIRIA C689 Guidelines, there are two approaches to estimating design flows:

1. **Rainfall transformation methods based on runoff coefficients:** The approach involves modifying the rainfall using a runoff coefficient, multiplied by the catchment area, to derive either a direct estimate of the peak discharge or a flood hydrograph. There are various methods for doing this. Different methods are generally appropriate for different catchment types and areas.
2. **Statistical methods based on transfer of information from gauged flow data:** Uses measured discharge data from gauging stations and analyses it to get "flood frequency curve".

Culverts are designed with capacity to accommodate 1 in 100 year flows.

6.4 Maintenance approach

Historically there were poor levels of maintenance and issues were only resolved after extreme rainfall events highlighted an issue. However, this has improved on national roads in recent times.

Other relevant points:

- Drainage is maintained by local authorities and sufficient access must be provided in design.
- Pipes are designed to be self-cleaning.
- During design of gullies, a maintenance factor 'm' is applied. The effect of reduced maintenance and accumulation of debris will be to reduce the hydraulic area and efficiency of the gully grating. This factor is included to allow for this effect.
- Culverts with spans equal to or greater than 2 m are inspected as part of the TII's Eirspan bridge management system. Inspection intervals vary from one to six years depending on the age and condition of the structure.

No weather or climate data are used for maintenance purposes.

6.5 How is climate change taken into account?

No increase in maintenance frequencies that would be related to climate change is noticed. Climate change is allowed for by increasing design flows and rainfall intensities of the design storm by 20%.

6.6 SuDS

SuDS are being used by the NRA.The UK's *CIRIA C753 SuDS Manual* provides guidance on the planning, design, construction and maintenance of SuDS to assist with their effective implementation within both new and existing developments. This extensive manual has a section which examines the specific challenges in applying a SuDS approach to roads and highways. The TII's DMRB design standards in relation to drainage design largely take on board the principles of SuDS Manual. Climate change is taken into account through application of the 20% increase for rainfall intensities when calculating the required capacity of the water management system.

6.7 CBA

No cba's are used to determine the requirements (return periods) on a strategic level or on an operational level (project specific).

As part of the project appraisal process, Transport Infrastructure Ireland (TII) have developed Project Appraisal Guidelines. The Project Appraisal Balance Sheet (PABS) reports on all of the impacts of the project under the Government's five criteria. It contains a mixture of quantitative indicators and qualitative statements and provides a concise summary of all of the aspects and impacts of the project. The five criteria used are:

- Environment
- Safety
- Economy
- Accessibility
- Integration

The guidelines only require a CBA for projects with a capital expenditure of over €20m. For projects between €5m and €20m a Multi-Criteria Analysis (MCA) is required. The MCA establishes preferences between options by reference to an explicit set of objectives that the decision making body has identified, and for which measurable criteria have been established.

However, the approach is generally to appraise the entire project and is not generally applied specifically to determine the appropriate drainage solution to use.

Climate change is only taken in account by applying the 20% increase for rainfall intensities when calculating the required capacity of the water management system.

A consultant engineer and/or another specialist, where required, perform(s) the CBA.

6.8 Summary

Ireland		precipitation on the road						water besides the road (pluvial flooding)	Water crossing the road
		Roads in fill (on embankment)	Roads in cut (excavated)	Tunnels	Bridges	Retention facilities	Treatment facilities	assets to prevent flooding	culverts
Design	Type of assets	Kerbs and road gullies, Surface Water Channels, Over-the-edge drainage.	Combined systems, Filter Drain, Surface Water Channel with Sealed carrier pipe and separate Filter Drain	kerb and gulley outfalling to a sump and a pumped system	Kerb drainage system	Dry Ponds/Detention Basin, Wet Ponds/Retention Basins, Infiltration basins, Soakaways, Wetlands, Grassed channels, Swales.	Wetlands, Grassed channels, Filter drain, Infiltration basin, Sediment trap, Penstock/shut-off valve, Oil/petrol interceptor	Ditches are used for precipitation in the verge and runoff draining to the road from land outside the highway corridor.	culverts
	Which approach is used?	The Wallingford Procedure (www.hrwallingford.com) is the approach used to calculate run off.				the peak runoff rateshould not be increased above the peak greenfield runoff rate for all storm events up to and including the 1 in 100 year storm event	TII HD 103/15: The selection of vegetated systems cannot be prescribed. Each situation must be considered individually as there are very many factors to be taken into account.	• the IH 124 Method for catchments > 0.4km2 • the ADAS Method for catchments . 0.4km2	Broadly speaking there are two generic approaches to estimating design flows: 1) Rainfall transformation methods based on runoff coefficients: The approach involves modifying the rainfall using a runoff coefficient, multiplied by the catchment area, to derive either a direct estimate of the peak discharge or a flood hydrograph. 2) Statistical methods based on transfer of information from gauged flow data: Uses measured discharge data from gauging stations and analyses it to get "flood frequency curve".
	What calculation methods are used?	$I = 32.7(N-0.4)^{0.223}(T-0.4)^{0.565}(2\min M5)/T$ Formula above is used to calculate the rainfall intensity and run off for design: I = mean rainfall intensity (mm/h) occurring in a storm of duration T (minutes) with a return period of N (years) T = critical storm duration T (in minutes) N = return period 2minM5 = the depth of rainfall (in mm) occurring at the particular geographical location in a storm with T= 2 minutes and N = 5 years.						The size of ditches is calculated using Manning's resistance equation.	
	What is the normative return period of precipitation in drainage design? Does this depend on specific road characteristics? (road importance, lifetime expectancy, cost, etc.)	HD33/15: "Longitudinal sealed carrier drains must be designed to accommodate a one-year storm in-bore without surcharge. The design must be checked against a five-year storm intensity to ensure that surcharge levels do not exceed the levels of chamber covers."				The peak runoff rateshould not be increased above the peak greenfield runoff rate for all storm events up to and including the 1 in 100 year storm event		It is recommended that flow rates from natural catchments without defined watercourses should be assessed for design storms with a return period of 75 years.	Culverts are designed with capacity to accommodate 1 in 100 year flows.
	What is the prevailing duration of precipitation in drainage design?	All storm durations are simulated for the 1 in 1 year and 1 in 5 year return periods to ensure that the critical storm duration can be accommodated within the design.							
	How is climate change taken into account?	Climate change is allowed for by increasing design flows and rainfall intensities of the design storm by 20%.							
	Do requirements exist for the maximum thickness of the water film on the pavements during normative precipitation events?	A maximum water film depth of 2.5mm shall apply to new single carriageway roads. On Motorways and Dual Carriageways, as the 2.5mm limit can be very difficult to achieve, a maximum value of 3.3mm shall be adopted.				n/a	n/a	n/a	n/a
Maintenance	Which approach is used?	Historically there were poor levels of maintenance and issues were only resolved after extreme rainfall events highlighted an issue. However, this has improved on national roads in recent times.							
	Have you noticed an increase in maintenance frequencies that would be related to climate change?	No						No	No

7 Netherlands

7.1 Type of water management assets used by NRA

7.1.1 Precipitation on the road

In general, the order of preference for dealing with stormwater runoff from national roads and works is as follows:

1. discharge into the roadside verges (controlled infiltration into the soil):
   - drainage via the verges to a roadside ditch;
2. discharge into a surface water body:
   - drainage by gravity via gutters, drains and pipes into infiltration facilities (roadside ditches, retention ponds / tanks), which should not be connected directly on the water management system of the surrounding area (watercourses, sewerage), or into a facility for the collection and transportation of wastewater (other than polluted water);
   - drainage by gravity via gutters, drains and pipes into sewers and manholes with sewer outlet on a sewage pumping station (or sump). From the pumping station the rainwater will be transported through a discharge pipe to a water management system in the neighbourhood (watercourse, sewage system);
3. alternative discharge.

A storm water runoff-system (roadway gutters with sewerage etc.) will be only applied if the runoff is concentrated or obstructed (for example steep longitudinal slopes, wide roads, entrance ramps of tunnels and bridges, roads in cut, obstacles along the road, if there is a risk leaching) or when the run-off water has to meet strict environmental requirements (for example in a water extraction area). Ca. 10% of the national roads has water discharging or sewage systems (in the other 90% water infiltrates directly from the road in the road verge). If infiltration is not possible (roads in cut, tunnels bridges etc.) indirect discharging to surface water is applied through a retention facility. Retention ponds are often created nearby interchanges and tunnels.

The application of a storm water runoff-system in order to prevent soil and surface water contamination is not common. Also the environmental returns are missing for facilities like constructed wetlands. In practice, it appears that the quality of the runoff water strongly depends on the surface texture of the surfacing. In the Netherlands most (ca. 90 - 95%) motorways are constructed using porous pavement. If porous pavement is applied with corresponding maintenance measures, the environmental effects are negligible (also for vulnerable areas). For some specific locations additional measures are needed. Suitable methods of water treatment are infiltration, constructed wetlands and removal of coarse particles (sand trap). For roadside rest areas, non-porous pavements or a concrete pavement is applied and the rain water will be drained via sewers to oil traps/separators.

The discharge of stormwater runoff from bridges and tunnels on the surface water or a sandy soil are considered as point sources. This water exceeds the discharge standards in terms of PAHs and heavy metal concentrations.

The way of drainage of stormwater out of tunnels or roads in cut is as follows:

1. The most polluted water is discharged into the sewage system;
2. Cleaner water will be infiltrated into the soil in a controlled manner;

3. Clean water is discharged into a surface water body or into a facility for the collection and transportation of wastewater (other than polluted water).

7.1.2 Water besides the road (pluvial flooding)

In general, the roads are situated higher than the surface level (road on embankment). Also the road verges are canted towards the surrounding. Therefore, it isn't likely that flooding of the road or infiltration of water into the road foundation (due to water beside the road) will occur. For some specific situation measures have to be taken in order to prevent the road from pluvial flooding: the storm water runoff-system should catch the surface runoff of adjacent areas (also from melting snow) before it will hit the road. In case of a highway next to a river, a dike prevents the area from flooding. In case of tunnels or aqueducts in a polder a dike is used to prevent flooding of the polder.

7.1.3 Water crossing the road (run-off flooding)

In general surface runoff from the surrounding area is limited: for the most cases the water management is controlled. Culverts and drainage pipes are used in order to transport water from ditches, creeks etc.

7.2 Sources of climate data

Rijkswaterstaat (RWS) consults the Dutch national weather service KNMI in order to obtain climate data (current and future). Four scenarios are worked out in order to forecast the climate of the future (up to 2085): two scenarios of the global warming (moderate and warm) and two scenarios of the change in air current pattern (low and high). It is expected that the climate change in the Netherlands will develop within the boundaries of these four scenarios.

References:

- Extreme-neerslagcurven voor de 21e eeuw (MeteoConsult, 2006) https://staticresources.rijkswaterstaat.nl/binaries/Extreme-neerslagcurven%20voor%20de%2021e%20eeuw_tcm21-30628.pdf
- Statistiek van extreme neerslag voor korte neerslagduren (Buishand and Wijngaard, 2007) http://projects.knmi.nl/klimatologie/achtergrondinformatie/tr295.pdf
- KNMI'14 – Klimaatscenario's voor Nederland (2015) http://www.klimaatscenarios.nl/images/Brochure_KNMI14_NL.pdf
- Memo omgaan met transitie van KNMI'06 naar KNMI'14 scenario's (Rijkswaterstaat, 16 juni 2015) / Memo Schaling neerslagstatistiek korte duren obv Stowa (2015) en KNMI'14 - 20161214 (definitief)

7.3 Design approach and calculation methods

7.3.1 Precipitation on the road

7.3.1.1 General

In general, a proper design measure to ensure runoff and prevent water burden on the road is to construct road pavements with a transverse slope of 2.5 %. However it is questionable whether this slope angle also is a suitable requirement for very wide roads. The transverse slope of the roadside verge is 5% (standard). The verge should not drain towards the road. It should be noted that due to soft soil conditions and the accompanying consolidation it is difficult to maintain the transverse slope.

According to the Dutch Guidelines for Design of Motorways ROA (2014) it should be prevented that a water film layer with thickness larger than 2 a 3 mm develops during periods of heavy rain in order to prevent aquaplaning and splash / spray water.

A storm water runoff-system will be only applied if the runoff is concentrated or obstructed (for example if the longitudinal slope is steeper than 1% or if the road is wider than 11 m combined with a longitudinal slope steeper than 0.5%). The design of a storm water runoff-system has to be controlled with a dynamic calculation with histograms of the normative shower of rain and the discharge level as input. The normative shower of rain is determined by means of an IDF-curve (point data). The capacity of the storm water run-off system is calculated by following the curve to a period of 120 minutes. This implies that rainfall intensity is very high at the beginning of the calculation and then decreases until the 120 minutes is reached. The prevailing duration of precipitation in drainage design is unknown. Rijkswaterstaat realises that this approach isn't appropriate, since the rainfall intensity may vary over the period that is taken into account. In the calculation of the water discharge, account should be taken with the width and the length of the runoff area and the transverse and longitudinal slope of the road. The coefficient of runoff will depend on the road-surfacing type, however a coefficient of 1 is used in the calculation of the discharge. Water must not exceed the right (or left) road marking (no flooding of the lanes) during a normative shower.

The normative return period is linked to the consequences:

- For roads and bridges, where the water height can be physically impossible greater than 30 cm, the normative return period should be 10 years;
- For roads (in cut), where the water height can be greater than 30 cm, the normative return period should be 50 years;
- For tunnels and aqueducts the normative return period should be 250 years.

7.3.1.2 Tunnels

The following additional requirements hold for tunnels:

- The stormwater runoff system of the road sections upstream of both entrance ramps should drain in front of the entrance ramps (the water shouldn't drain to the entrance ramps).
- The stormwater runoff system of the entrance ramps should drain in front of the closed part of the tunnel (the water shouldn't drain into the closed part);
- No warps (transition between road sections with opposite slopes) should be created at the entrance ramps.
- The stormwater runoff system of the tunnel (entrance ramps and closed part) should facilitate that the stormwater will run off the road (gutters) and won't be able to flow back towards the road.
- The stormwater runoff system should drain the stromwater of each lane separately.

The stormwater runoff system of a tunnel has to fulfill two criteria. Next to calculations with the IDF-curves of Buishand en Wijngaard (2007) (adapted for climate change), the discharge capacity of a tunnel has to be calculated for a continuous rain intensity of at least 200 l/s per 10,000 m^2. In case the longitudinal slope is steeper than 4.5% or in case of a longitudinal slope combined with a large width, a steeper transverse slope (than 2.5%) is recommended.

7.3.1.3 Bridges

The following additional requirements hold for bridges:

- The stormwater runoff system of the road sections upstream of the bridge should drain in front of the transition to the bridge to the runoff system at the land abutment (the water shouldn't drain to the bridge).

- The stormwater runoff system of the road sections on the bridge should drain in front of the transition to the earth foundation to the runoff system at the land abutment. Next to a drain at the location of the land abutment, a second drain should be created at a distance of ca. 5 m behind the first drain (the first drain won't catch all the stromwater).
- The stormwater runoff system of the bridge should facilitate that the stormwater will run off the road (gutters) and won't be able to flow back towards the road.
- The stormwater runoff system should drain the stromwater of each lane separately.

7.3.1.4 Retention facilities

If infiltration is not possible indirect discharging to surface water through a retention facility is needed. As rule of thumb, 0.5 m^3 water retention is required for every 10 m^2 road.

7.3.2 Water besides the road (pluvial flooding)

In order to guarantee the functionality of the stormwater runoff system, the road verges should have a slope of 5%. The verge between the lanes should not drain towards the roads. The underlying soil of the verges has to be permeable (eventually additional drainage is required). The level of the verges should be lower than the draining layer of the road surfacing and the verges should serve as a snow storage.

7.3.3 Water crossing the road (run-off flooding)

Requirements for culverts are given by the water boards. Culverts can be designed according Handleiding Wegenbouw Ontwerp Hemelwaterafvoer (1988).

7.3.4 References

- Handleiding Wegenbouw - Ontwerp Hemelwaterafvoer (1988);
- Regenwaterafvoer deel II – Afvoergoten en putten (1988);
- ROA2014 – Richtlijn Ontwerp Autosnelwegen (2015);
- ROK 1.3 – Richtlijnen Ontwerpen Kunstwerken (2015);
- RTD1008 versie 2.0 – Eisen Hemelwaterafvoer van wegen en kunstwerken (2016).

7.4 Maintenance and operations approach

7.4.1 Precipitation on the road

In order to prevent the accumulation of suspended matter (sharps from tires) in the area, a set of measures is needed during the operational phase ('good housekeeping') [Kader Afstromend wegwater (2014)].

- Porous asphalt on the road shoulders (emergency lane) is cleaned twice a year in order to ensure the discharge of water, to reduce the risk of frost damage and to remove pollution.
- Excess soil from the road verges will be removed in order to ensure the discharge of water and to remove pollution. Also greenery maintenance has to be carried out at the road verges.
- Infiltration points (retention basins, sedimentation ditches, pump basements etc.), gutters (including cesspits and drains), grates against litter and roadside ditches have to be cleaned periodically. Stormwater runoff systems have to be design in such way that maintenance activities can be carried out easily.

Stormwater runoff systems have to be design in such way that they can be closed in case of a calamity. In case of flooding of a lane, that specific lane can be closed by matrix boards. No climate data is used for maintenance purposes.

7.4.2 Water besides the road (pluvial flooding)

In practice, it turns out that excess soil has to be removed from the road verges in order to ensure the discharge of water.

7.4.3 Water crossing the road (run-off flooding)

No maintenance has been carried out structurally / no maintenance approach exists at this moment for culverts.

7.5 How is climate change taken into account?

No variation of maintenance and operation practices that would be related to climate change has been noticed so far. Climate information for the future is used in design. The IDF-curves from Buishand and Wijngaard (2007) have been adapted for climate change and have to be used in design. Also new curves have been derived for the worst case climate scenario of the KNMI (Memo 2016). The year 2050 is used as time horizon. The reference periods that are used for the current climate are described in 7.3.1.1. (roads in fill and bridges 10 years; roads in cut 50 years and tunnels 250 years).

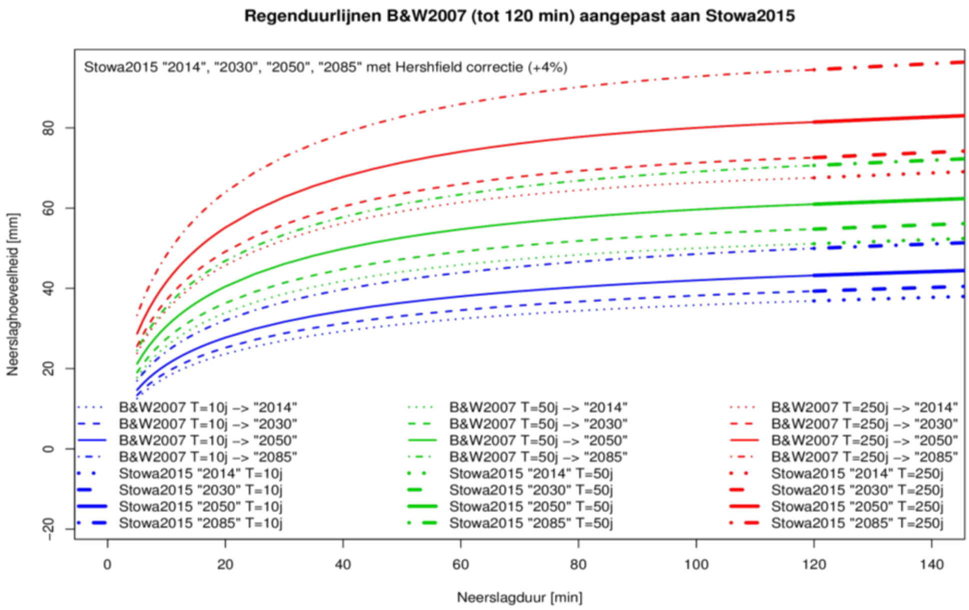


Figure 7.1 IDF-curves derived for the worst case climate scenario

7.6 SuDS

The combination of porous asphalt (PA) and infiltration of the stormwater runoff into the road verges and/or road side ditches is considered to be a sustainable drainage system. Circa 90 - 95% of the national roads are provided with PA. Research has demonstrated that only 20 - 30% of the stormwater will run off the road, where ca. 80% of the water will run off the road in case of non-porous asphalt. PA has a buffering effect on the stormwater runoff. Because the pollution mainly adheres to the suspended matter (sharps from tires), is PA, in combination with additional maintenance measures, a sufficient solution in order to prevent negative environmental effects by runoff. An advantage of infiltration in the road verges is that micropollution will be kept in the upper soil layer and partly biodegraded. Also retention ponds and constructed wetlands are considered to be sustainable drainage systems

7.7 Cost Benefit Analysis

On a strategic level, the return periods are linked to the consequences (expected level of damage/nuisance), however, no CBA's were used to determine these requirements:

- If little nuisance/loss is expected (aquaplaning/speed limit), because the water height can be impossible greater than 30 cm, the normative return period should be 10 years;
- If moderate nuisance/loss is expected (traffic disruption), because the water height can be greater than 30 cm, the normative return period should be 50 years;
- If severe nuisance/loss is expected (infrastructure damage) the normative return period should be 250 years.

In general CBA's aren't used to determine project specific requirements. Within the project specific requirements, CBA's/cost assessments can be used to determine the most desirable design solution (weighing of alternatives). This can be done by the contractor. CBA's will be used (in future) in order to make decisions whether climate adaptation and/or mitigation measures will be taken or not.

7.8 Summary

the Netherlands		precipitation on the road						water besides the road (pluvial flooding)	Water crossing the road
		Roads in fill (on embankment)	Roads in cut (excavated)	Tunnels	Bridges	Retention facilities	Treatment facilities	assets to prevent flooding	culverts
Design	Type of assets	storm water runoff systems (porous asphalt, gutters, sewers, pipes, open channels, slotted drains)	storm water runoff systems (porous asphalt, gutters, sewers, pipes, open channels, slotted drains)	gutters, sewers, pipes, pump basements, slotted drains	storm water runoff systems (gutters, sewers, pipes)	attenuation ponds, wetlands	wetlands, settling ponds,	levees, dikes, road on embankment	culverts
	Which approach is used?	Standard approach is to diverge water to the verges at which it infiltrates in the ground and flows to channels; only when water cannot freely flow to the road sides, a storm water run-off system is applied. A standard cross slope of 2,5% is applied	storm water run-off system is designed by combining longitudinal and cross slope in dynamic calculations			These assets are only used when a stormwater run-off system is in place, mostly in combination with the treatment facilities	Infiltration is the most preferable approach (in combination with the standard use of porous asphalt)	The road verges should have a slope of 5% and should be permeable or additional drainage is required. The verge should also be lower than the road surfacing.	Requirements are given by the water boards
	What calculation methods are used?	Dynamic calculation				Rule of thumb: 0.5 m^3 retention for every 10 m^2 road		no pre determined method is applied	
	What is the normative return period of precipitation in drainage design? Does this depend on specific road characteristics? (road importance, lifetime expectancy, cost, etc.)	10 years	50 years	250 years	10 years	3 years	3 years	not explicitly prescribed, most likely the same return periods will be used as for the drainage assets	
	What is the prevailing duration of precipitation in drainage design?	dynamic calculations are performed for durations from 5 - 120 minutes						dependent on the circumstances in terms of minutes to some hours	
	How is climate change taken into account?	IDF-curve + 30% which is the expected increase of extreme rainfall intensity in the worst case climate change scenario for the Netherlands						not explicitly prescribed, could be taken into account on project basis	
	Do requirements exist for the maximum thickness of the water film on the pavements during normative precipitation events?	2 a 3 mm				-	-	-	-
	Do requirements exist for the allowable water spread on the pavements during normative precipitation events?	Yes, water should not exceed the road markings				-	-	-	-
Maintenance	Which approach is used?	Preventive, inspections, cleaning porous asphalt, removing exccess soil from verges						preventive, cleaning, inspections	culverts tend to be poorly maintained but if so they are cleaned and debris is taken away
	Have you noticed a variation of your maintenance practices (frequencies, type of works…) that would be related to climate change?	No						No	No

8 Norway

8.1 Type of water management assets used by NRA

8.1.1 Precipitation on the road

- Roads in fill (on embankment)
  - Greatly determined by urban or rural roads and coastal and land-locked drainage system. Largely depends on the specific road and there are <u>no general policy in effect</u> that reflect how precipitation is taken into account. Also, relies largely on the prevailing geography, mountain, flatlands, soil characteristics, and local conditions.
- Roads in cut (excavated)
  - Depends on the specific road – again, <u>no overall standards and rules</u> that reflect how precipitation is taken into account.
    Pumps are largely the main remedy to transport water to higher levels. Recipients are unique to the specific road.
- Tunnels
  - Edge draining and pumps are in use to transport water in tunnels.
  - Particular environmental care is given to water from tunnels due to high levels of undesired particles and chemicals.

    Water is generally collected water beneath the road and pumped to a nearby recipient where water is environmentally managed.
- Bridges
  - No general policy is in effect on bridge drainage. Water is generally managed by edge-collecting to the drainage systems and pumped to retention systems where water is environmentally managed.
- Retention facilities and treatment facility
  - Retention systems are in the form of basins, where water is environmentally managed either by cleaning facilities/plants or by 'simple sedimentation'. Retention facilities are determined in capacity by the catchment area and prevailing geography.

8.1.2 Water besides the road (pluvial flooding)

Pluvial water/flooding is chiefly managed through elevated roads alongside culverts. Dikes are particularly in use in low laying areas and at coastal regions

8.1.3 Water crossing the road (run-off flooding)

Culverts are used to enable water to cross beneath roads. The dimensioning of the culverts is determined by hydraulic analyses, based on the design run-off. The design runoff is determined by hydrological analyses, the method being largely depending on the catchment area.

For highways, culverts are dimensioned to be able to cope with a 1 in 200 year return pattern. Smaller and less strategically important roads are dimensioned to be able to with a 1 in 50-100 year return pattern.

8.2 Sources of climate data

Climate data is obtained on a regional basis from the Norwegian Meteorological Institute. Data is particularly used for planning and design guidelines for runoff analyses. Additional information, including projections of the future climate, is available from the Norwegian Centre for Climate Services: www.klimaservicesenter.no.

8.3 Design approach and calculation methods

Specific, local circumstances are more determining on particular design and analyses than overall standards.

Generally, 1 in 200 year return patterns is the determining factor for design for major roads. 1 in 50-100 year for smaller roads. IDF curves are employed as guidelines for design.

Importance, geographical characteristics, traffic loading (ADT) and strategic level of a particular road are the dominant factors on design requirements.

8.3.1 Precipitation on the road

8.3.1.1 Roads in fill and cut, tunnels and bridges

- No specific road standard is in effect to distinguish between excavated and filled roads. Depends on local characteristics
- Motorway drainage systems are designed to manage a 1 in 200 year precipitation event.
- Drainage systems on motorways are designed to manage and drain surface water.
- Other types of roads are designed to manage a 1 in 50-100 year precipitation event.
- Extraordinary design requirements must be met when specific local circumstances entail additional considerations. These often come into play when constructing new infrastructure.

8.3.1.2 Retention facilities and treatment

Basins and reservoirs are used to collect water. Water is discharged into nearby lakes and ocean after cleaning processes of various types depending on local characteristics.

8.3.2 Water besides the road and water crossing (pluvial flooding)

Ditches and culverts are used as water management in this regard and are dimensioned in accordance with the catchment area to match the dimensioning of the respective roads from which water is drained

8.3.3 Water crossing the road (run-off flooding)

Culverts are used as water management in this regard and are dimensioned in accordance with the catchment area to match the dimensioning of the respective roads from which water is drained.

8.4 Maintenance approach

The Norwegian roads are maintained by local contractors. Main activities of maintenance are ensuring full capacity of existing drainage systems by vegetation cutting and/or removal, culvert and drainage cleaning, and tunnel inspections.

Contractors do use weather forecasts which can lead to more intensive maintenance. In addition, regional flood and landslide warnings are issued and followed.

8.5 How is climate change taken into account?

Maintenance is more demanding because of variations in weather. No increase in maintenance frequencies that would be related to climate change has been noticed.

No climate information for the future is used, however that may rely heavily on the particular staff responsible of the given road section. No standard is in function for future road management in this context. A requirement for more regular (annual) culvert inspection has however been implemented, but is not strictly followed.

8.6 SuDS

No SuDS are systematically being used by the NRA (not particularly). That being said, stern environmental considerations must be met when discharging water back into nature from the retention system through the given treatment type in function. Therefore SuDS are becoming more attractive in projects – often for other reasons than flood mitigation.

8.7 CBA

No cba's are routinely used to determine the requirements (return periods) on a strategic level or on an operational level (project specific). It's very difficult to provide an overall answer since it will always rely on local characteristics that will reveal potential, extraordinary economical considerations. No climate change is taken into account in cba's. If performed, the CBA is performed by an external advisor. What the available information is for performing the CBA depends on the specific case.

8.8 Summary

Norway		precipitation on the road						water besides the road (pluvial flooding)	Water crossing the road
		Roads in fill (on embankment)	Roads in cut (excavated)	Tunnels	Bridges	Retention facilities	Treatment facilities	assets to prevent flooding	culverts
Design	Type of assets	Greatly determined by urban or rural roads and coastal and land-locked drainage system. Largely depends on the specific road and there are no general policy in effect. Also, relies largely on the prevailing geography, mountain, flatlands, soil characteristics, and local conditions	Depends on the specific road – again, no overall standards and rules. Pumps are largely the main remedy to transport water to higher levels. Recipients are unique to the specific road	Edge draining and pumps are in use to transport water in tunnels. Particular environmental care is given to water from tunnels due to high levels of undesired particles and chemicals	No general policy is in effect on bridge drainage. Water is generally managed by edge-collecting to the drainage systems and pumped to retention systems where water is environmentally managed. to the sewer systems inside the bridge construction	Retention systems are in the form of basins, where water is environmentally managed either by cleaning facilities/plants or by 'simple sedimentation'	facilities/plants or 'simple sedimentation'	Dikes, dithches, culverts and pumps	Pipelines and smaller similar constructions
	Which approach is used?	Edge-collection of water and on-road drainage. All depends on the specific road and project.				Both retention facilities and treatment facilities are made and designed in acccordance with the specific project.		Culverst and pumps	Culvert and pumps
	What calculation methods are used?	Manning				Manning	Manning	Manning	Manning
	What is the normative return period of precipitation in drainage design? Does this depend on specific road characteristics? (road importance, lifetime expectancy, cost, etc.)	Motorway drainage systems are designed to manage a 1 in 200 year precipitation event. Other types of roads are designed to manage a 1 in 50-100 year precipitation event				Motorway - 200year, other roads 50-100 years		Motorway - 200year, other roads 50-100 years	
	What is the prevailing duration of precipitation in drainage design?	N/A				N/A	N/A	N/A	
	How is climate change taken into account?	May rely heavily on the particular staff responsible of the given road section. No standard is in function for future road management in this context A climate change strategy and associated action plan is implemented to support operations and constructions of roads				May rely heavily on the particular staff responsible of the given road section. No standard is in function for future road management in this context		May rely heavily on the particular staff responsible of the given road section. No standard is in function for future road management in this context	
	Do requirements exist for the maximum thickness of the water film on the pavements during normative precipitation events?	No				No	No	No	No
	Do requirements exist for the allowable water spread on the pavements during normative precipitation events?	No				N/A	N/A	N/A	N/A
Maintenance	Which approach is used?	Norwegian roads are maintained by local contractors. Main activities of maintenance are ensuring full capacity of existing drainage systems by vegetation cutting and/or removal, culvert and drainage cleaning, and tunnel inspections.						Norwegian roads are maintained by local contractors. Main activities of maintenance are ensuring full capacity of existing drainage systems by vegetation cutting and/or removal, culvert and drainage cleaning, and tunnel inspections.	
	Have you noticed a variation of your maintenance practices (frequencies, type of works…) that would be related to climate change?	Maintenance is more demanding because of variations in weather. A requirement for more regular (annual) culvert inspection has been implemented, but is not strictly followed.						No	No

9 Sweden

9.1 Type of water management assets used by NRA

9.1.1 Precipitation on the road

- Roads in fill (on embankment)
  - No overall standard is in place for roads on embankments. Typically, it will rest on the specific road, local geographical characteristics
  - Water on the roads from elevated roads is mainly collected in drainage systems through edge-collection, such as ditches
- Roads in cut (excavated)
  - No overall standard is in place for roads in cuts. Water management depends on the specific case.
  - Water from excavated roads is mainly pumped away into drainage systems
- Tunnels
  - Water in tunnels is pumped away to the nearest basin
- Bridges
  - Water is managed by edge-collection the bridge construction itself and led to a nearby retention system where water is environmentally managed and treated
- Retention facilities
  - Retention systems are in the form of basins, where water is environmentally managed and treated. Basin capacity is determined by the catchment area and geography. Analyses are conducted for each single basin
- Treatment facilities
  - Required water treatment is carried out in accordance to the respective recipient type. Typically, water is led to a nearby treatment facility of various types across the country

9.1.2 Water besides the road (pluvial flooding)

In Sweden, pluvial flooding is managed through dikes and road embankment. Dikes are maintained by vegetation removal and continuous capacity control. The specific frequency of maintenance is determined by in situ characteristics.

9.1.3 Water crossing the road (run-off flooding)

Culverts and minor bridge constructions are used to enable water to cross beneath roads. The dimensioning of the culverts is determined in size by the catchments area.

9.2 Sources of climate data

The source of the climate information which is used for the current and future climate is the Swedish Meteorological and hydrological Institute (http://www.smhi.se/en).

9.3 Design approach and calculation methods

No national-wide guidance is in effect on road design and water management. It is predominately carried out on local terms, governed by local characteristics.

Still, culverts are mostly dimensioned for a 1 in 50 year return pattern, sometimes up to 1 in 200 year return pattern at road stretches with particular needs and importance.

Furthermore, drainage systems are designed on CDS analyses and dimensioned to be able to cope with return patterns between 1 in 3 years to 1 in 20 years, depended in local characteristics on multiple factors

Currently, initiatives are ongoing for a national-wide guideline for water management design.

9.3.1 Precipitation on the road

9.3.1.1 Roads in fill and cut, tunnels and bridges

No specific guideline is in effect differentiating roads led through cuts or on embankments. It will solely be based on local analyses (see also 9.3).

9.3.1.2 Retention facilities

Retention systems consist of basins and reservoirs. Design in regards to size and capacity is determined by catchment area and local possibilities.

9.3.1.3 Treatment facilities

Water is mostly treated in the respective retention system where water must be stored for a minimum of 24h to allow microorganisms and sedimentation filtration to work.

9.3.2 Water besides the road (pluvial flooding)

Ditches are designed to keep roads ‘dry’ from pluvial flooding. Such dikes are typically installed at roads in low-laying areas and at coastal regions.

9.3.3 Water crossing the road (run-off flooding)

Culverts are employed in this context and are dimensioned in size as per local analyses for requirements to manage prevailing conditions.

9.4 Maintenance approach

Contractors maintain ditches and culverts to allow the drainage system(s) to uphold full capacity. The frequency of maintenance is specific for the specific road. No weather or climate data are used for maintenance purposes.

9.5 How is climate change taken into account?

No increase in maintenance frequencies that would be related to climate change has been noticed. Climate information for the future will be used: a climate change strategy and action plan for future road management is currently being implemented. No link is provided just but can soon be obtained.

9.6 SuDS

Each road project has an individual water treatment plan. Whether these, or some, can be defined as SuDS is unclear but some are very close. There is no distinct standard dictating a mandatory use of SuDS, however strict environmental considerations must be made for each project.

9.7 CBA

Generally, the larger the road project, the higher the need for a CBA to form the requirement for water management. CBA will depend more on the particular project in the context on whether a CBA is necessary on water management and who will conduct this analyses.

No cba's are used to determine the requirements (return periods) on a strategic level or on an operational level (project specific). It's very difficult to provide an overall answer since it will always rely on local characteristics that will reveal potential, extraordinary economic considerations. No climate change is taken into account in cba's. If performed, the CBA is performed by an external advisor alongside. What the available information is for performing the CBA depends on the specific case.

9.8 Summary

Sweden		precipitation on the road						water besides the road (pluvial flooding)	Water crossing the road
		Roads in fill (on embankment)	Roads in cut (excavated)	Tunnels	Bridges	Retention facilities	Treatment facilities	assets to prevent flooding	culverts
Design	Type of assets	No national-wide guidance is in effect on road design and water management. It is predominately carried out on local terms, governed by local characteristics. No specific guideline is in effect differentiating roads led through cuts or on embankments. It will solely be based on local analyses.	No specific guideline is in effect differentiating roads led through cuts or on embankments. It will solely be based on local analyses.	Water in tunnels is pumped away to the nearest basin	Water is managed by edge-collection the bridge construction itself and led to a nearby retention system where water is environmentally managed and treated to the sewer systems inside the bridge construction	Retention systems are in the form of basins, where water is environmentally managed and treated. Basin capacity is determined by the catchment area and geography. Analyses are conducted for each single basin	Required water treatment is carried out in accordance to the respective recipient type. Typically, water is led to a nearby treatment facility of various types across the country	Dikes, dithches, culverts and pumps	Culverts and minor bridges
	Which approach is used?	No specific guideline is in effect differentiating roads led through cuts or on embankments. Design based on local analyses and knowledge. Typically, edge-collection of water and on-road drainage.				No specific guideline is in effect differentiating roads led through cuts or on embankments. Design based on local analyses and knowledge. Typically, edge-collection of water and on-road drainage.		Culverst and pumps	Culvert and pumps
	What calculation methods are used?	IDF, drainage systems are designed on CDS analyses and dimensioned to be able to cope with return patterns between 1 in 3 years to 1 in 20 years, depended in local characteristics on multiple factors				N/A, depends on the specific project	N/A, depends on the specific project	Depends on the specific project	Depends on the specific project
	What is the normative return period of precipitation in drainage design? Does this depend on specific road characteristics? (road importance, lifetime expectancy, cost, etc.)	3-20 years dependend on the project						Culverts are mostly dimensioned for a 1 in 50 year return pattern, sometimes up to 1 in 200 year return pattern at road stretches with particular needs and importance.	
	What is the prevailing duration of precipitation in drainage design?	24h				24h		24h	
	How is climate change taken into account?	A climate change strategy and action plan for future road management is currently being implemented. No link is provided just but can soon be obtained.				A climate change strategy and action plan for future road management is currently being implemented. No link is provided just but can soon be obtained.			
	Do requirements exist for the maximum thickness of the water film on the pavements during normative precipitation events?	N/A				N/A	N/A	No	No
	Do requirements exist for the allowable water spread on the pavements during normative precipitation events?	No				N/A	N/A	No	no
Maintenance	Which approach is used?	Contractors maintain ditches and culverts to allow the drainage system(s) to uphold full capacity. The frequency of maintenance is specific for the specific road.				Retention systems consist of basins and reservoirs. Design in regards to size and capacity is	Water is mostly treated in the respective retention system where	No specific guideline is in effect differentiating roads led through cuts	No specific guideline is in effect differentiating roads led through cuts
	Have you noticed a variation of your maintenance practices (frequencies, type of works…) that would be related to climate change?	No						No	No

10 Denmark

10.1 Type of water management assets used by NRA

10.1.1 Precipitation on the road

- Roads in fill (on embankment)
    - Depends on the specific road (type); no overall policy is in effect in this context. Depends largely on the prevailing geography, i.e. topography and soil characteristics, and adjacent possibilities
    - Generally, precipitation from elevated roads is collected in sewer systems through drainage systems, ditches and culverts. All collected water is collected in closed systems (reservoirs and bassins)
- Roads in cut (excavated)
    - Depends on the specific road (type); no overall policy is in effect in this context.
    - Generally, water from excavated roads is collected in troughs through road-edge drainage, ultimately collected in closed systems (reservoirs and bassins)
- Tunnels
    - Gutters, sewers, pipes, pump basements
    - The Danish NRA does not manage large tunnels In minor tunnels water is managed by collecting all water beneath the road itself and led (pumped) to to a nearby basin where water is environmentally managed by 'simple sedimentation' driven by gravity.
- Bridges
    - Water is managed by edge-collecting (no water is 'allowed' to spill from the road on the bridge to infrastructure below) to the sewer systems inside the bridge construction itself and led to a nearby basin where water is environmentally managed by 'simple sedimentation' driven by gravity.
- Retention facilities
    - Retention systems are in the form of basins, where water is environmentally managed by 'simple sedimentation' driven by gravity. The basin size is determined in size by the catchment area and geography. Very strict environmental rules are in effect in Denmark that, for instance, dictate a maximum discharge out of the closed, controlled system of 1L/sec/hectare.
- Treatment facilities
    - Collected water is treated in the retention systems, predominately, by microorganisms through 'passive' treatment driven by gravity.

10.1.2 Water besides the road (pluvial flooding)

Pluvial water/flooding is chiefly managed through dikes that are maintained by vegetation removal and continuous capacity control. The specific frequency of maintenance is determined by in situ characteristics.

Dikes in low laying areas are kept under special supervision and controlled with all relevant and adjacent partners.

10.1.3 Water crossing the road (run-off flooding)

Culverts are used to enable water to cross beneath roads. The dimensioning of the culverts is determined in size by the catchments area. For highways, culverts are dimensioned to be able to cope with a 25 year return pattern, for other roads managed by the DRD, the dimensioning varies from 10 years to 25 years depended on geography and strategic importance of the specific road.

The management of the culverts are dictated by the Water Protocol, the specific rule set in this context.

10.2 Sources of climate data

Climate information is obtained from the Danish Meteorological Institute (www.dmi.dk) and the 'Spildevandskomiteen', a Danish engineering committee that has been in effect and acted as experts since the 1940s (https://universe.ida.dk/netvaerk/energi-miljoe-og-global-development/spildevandskomiteen/spildevandskomiteen/)

10.3 Design approach and calculation methods

For this chapter, only general comments can be made for Danish policies on design and calculations for roads. This is almost always due to specific requirements for specific planning and/or maintenance, dictated by factors such as environmental considerations, geographical restrictions, road strategic level, etc.

However, for almost all roads managed by the DRD, the following design is met to a minimum in regards to all types of water management systems:

- Motorways are designed to manage a 1 in 25 year precipitation event;
- Other types of roads are designed to manage a 1 in 10 year precipitation event.

10.3.1 Precipitation on the road

10.3.1.1 Roads in fill and cut, tunnels and bridges

The following design is met to a minimum in regards to all types of water management systems:

- Motorway drainage systems are designed to manage a 1 in 25 year precipitation event;
- Specifically, water systems on motorways are designed to manage and drain surface water up to 260L/sec/hectare, corresponding to a 1 in 25 year precipitation event over 10min;
- Other types of roads are designed to manage a 1 in 10 year precipitation event;
- Extraordinary design requirements must be met when specific local circumstances entail additional considerations. These often come into play when constructing new infrastructure.

10.3.1.2 Retention facilities

As written previously, retention systems are mostly in form of basins and reservoirs. The design of these is under the same policy as found in 10.3.1.1.

- Basins for motorways are designed in capacity and discharge to manage a 1 in 25 year precipitation event;
- Specifically, water systems on motorways are designed to manage and drain surface water up to 260L/sec/hectare, corresponding to a 1 in 25 year precipitation event over 10min;
- Other types of roads are designed to manage a 1 in 10 year precipitation event;

- Extraordinary design requirements must be met when specific local circumstances entail additional considerations. In the case of basins and reservoirs, such considerations are of environmental matters. These often come into play when constructing new infrastructure.

10.3.1.3 Treatment facilities

The DRD treat water collected from road surfaces and pluvial sources in retention facilities. Refer to 10.3.1.2.

10.3.2 Water besides the road (pluvial flooding)

Ditches are employed in this context and are dimensioned in size as found in 10.3.1.1.

10.3.3 Water crossing the road (run-off flooding)

Culverts are employed in this context and are dimensioned in size as found in 10.3.1.1.

10.4 Maintenance approach

Danish roads are designed to have no or as little maintenance needs as possible. Extra resources are spent when construction to eliminate or minimize maintenance needs during running and operation time.

Still, ditches culverts, etc. are maintained by contractors for the drainage system(s) to maintain full potential. The frequency of maintenance is determined from each respective site.

No weather or climate data are used for maintenance purposes, however, maintenance is seen upon as a very cost effective approach in terms of climate change since retrofitting and traffic disruption is hereby minimized.

10.5 How is climate change taken into account?

Roads are designed and build in accordance with the existing road standards. In these standards, climate change adaptation, e.g. in the form of installing drainage systems capable of managing more water than necessary in present time, is not written as a requirement. However, the Danish government, which the DRD is a part of, dictates that the climate scenario A1B of the IPCC report of 2007 must be used for operations of infrastructure. Furthermore, a climate change adaptation strategy and action plan is implemented and is currently set into effect.

Although, the policy now is to design drainage systems to be ‘more than plentiful in capacity’ relative to actual present-day necessities. Furthermore, the DRD does not see difficulties in water management on a more frequent basis than designed for concluded for the entire road system managed, just yet. Specific road stretches, though, have experiences more flooding scenarios over the past decade compared to historical data.

http://www.vejdirektoratet.dk/DA/viden_og_data/publikationer/Lists/Publikationer/Attachments/782/klimatilpasningsstrategi_eng_web.pdf

10.6 SuDS

SuDS are not explicitly mentioned as a requirement and as a design feature in road standards. Yet, existing basins and reservoirs meet some of the criteria found in the definition of SuDS.

Generally, the DRD are under very strict restrictions on discharge water quantity and quality since collected water is not led to a cleaning plant but cleaned and managed in retention systems.

10.7 CBA

Generally, CBA will depend on the particular case in the context on whether a CBA is necessary on water management and who will conduct this analyses.

No cba's are used to determine the requirements (return periods) on a strategic level or on an operational level (project specific). It's very difficult to provide an overall answer since it will always rely on local characteristics that will reveal potential, extraordinary economic considerations. No climate change is taken into account in cba's. If performed, the CBA is performed by an external advisor alongside DRD staff. What the available information is for performing the CBA depends on the specific case.

10.8 Summary

Denmark		precipitation on the road						water besides the road (pluvial flooding)	Water crossing the road
		Roads in fill (on embankment)	Roads in cut (excavated)	Tunnels	Bridges	Retention facilities	Treatment facilities	assets to prevent flooding	culverts
Design	Type of assets	Precipitation from elevated roads is predominately collected in sewer systems through drainage systems, ditches and culverts. All collected water is collected in closed systems (reservoirs and bassins)	Generally, water from excavated roads is collected in troughs through road-edge drainage, ultimately collected in closed systems (reservoirs and bassins)	Does not manage large tunnels In minor tunnels water is managed by collecting all water beneath the road itself and led (pumped) to to a nearby basin where water is environmentally managed by 'simple sedimentation' driven by gravity.	Water is managed by edge-collecting to the sewer systems inside the bridge construction	Retention systems are in the form of basins, where water is environmentally managed by 'simple sedimentation' driven by gravity.	Collected water is treated in the retention systems, predominately, by microorganisms through 'passive' treatment driven by gravity	Dikes, dithches, culverts and pumps	circular pipes, minor bridge constructions
	Which approach is used?	Edge-collection of water and on-road drainage. All depends on the specific road and project. Bridge: no water is 'allowed' to spill from the road on the bridge to infrastructure below				Retention and treatment facilities are handled and dimensioned in acccordance with the specific project. Very strict environmental rules are in effect in Denmark that, for instance, dictate a maximum discharge out of the closed, controlled system of 1L/sec/hectare		Culverst and pumps	Culvert and pumps
	What calculation methods are used?	Manning, CDS, and MIKE-flood				MIKE-analyses	Depends on the treatment type, project and local geography	MIKE-analyses	MIKE-flood
	What is the normative return period of precipitation in drainage design? Does this depend on specific road characteristics? (road importance, lifetime expectancy, cost, etc.)	All general remarks: Highway - 25year, other DRD roads 10 years				Highway - 25year, other DRD roads 10 years	Highway - 25year, other DRD roads 10 years	25 years based on 24h precipitation	Highway - 25year, other DRD roads 10 years
	What is the prevailing duration of precipitation in drainage design?	no prevailing duration as the time of concentration is calculated at a regular step along the network.				24h and 10min intensity		24h & 10min intensity	
	How is climate change taken into account?	Climate change is not an exclicit part of drainage design guidelines. A climate change strategy and associated action plan is implemented to support operations and constructions of roads							
	Do requirements exist for the maximum thickness of the water film on the pavements during normative precipitation events?	It doesn't				Not applicable	Not applicable	No	No
	Do requirements exist for the allowable water spread on the pavements during normative precipitation events?	No				Not applicable	Not applicable	No	no
Maintenance	Which approach is used?	Danish roads are designed to have no or as little maintenance needs as possible. Extra resources are spent when construction to eliminate or minimize maintenance needs during running and operation time. Still, ditches culverts, etc. are maintained by contractors for the drainage system(s) to maintain full potential. The frequency of maintenance is determined from each respective site.							
	Have you noticed a variation of your maintenance practices (frequencies, type of works…) that would be related to climate change?	No, however a database is in the makings to log future incidents to analyze trends in the future						No	No

11 Country comparison

In this chapter similarities and differences between the different countries are discussed. All input for this comparison originates from the different country chapters in previous chapters of this report. In addition to this, information was obtained during a workshop in which the state of practice in the different countries was discussed with participants from various countries in Europe. This workshop took place at February 6-7 2017 in the Netherlands at Deltares.

11.1 Type of water management assets used by NRA

It has become clear that there is a big variety of assets that are used for water management for roads. These differences are caused by several aspects:

- There seem to be different standard approaches for water management. For instance in the Netherlands the standard approach is to let the water drain into the berm and road side ditches, whereas for instance in France a drainage system is present alongside all important roads. A big difference between countries is identified in terms of requirements for treatment of the drainage water. This mainly is the consequence of the aspect below.
- Different topography and soil characteristics cause different approaches for water management. It is for instance clear that deflective dams in mountainous areas are not needed in low lying areas. Furthermore, the vegetation and permeability of the soil determines for a big extent the need for treatment of the drainage water. In the Netherlands the vegetation and sandy berms prove to be good filtration assets. In Karst areas with high permeability entrance of drainage water into these Karsts needs to be avoided and a closed drainage system with special treatment facilities are therefore needed.
- The terminology differs in between the countries. For the same type of assets different terms are mentioned. This is probably also caused due to translation of native terminology into the English language. In the paragraphs below the different assets are listed.

11.1.1 Precipitation on the road

Multiple assets are being used in order to manage the precipitation water on the road. The following assets are mentioned:

- <u>Roads in fill</u>
  - road side ditches (Austria, UK, France, the Netherlands, Ireland, Sweden, Denmark);
  - (grassed) channels (UK, France, Ireland);
  - kerbs and gullies (UK, France, Germany, Ireland);
  - (grate) inlets (Austria, France);
  - pipes / sewers (Austria, Germany, Denmark)
  - (slotted) drains (France, Germany);
  - manholes (France);
  - culverts (Germany, Denmark);

- Roads in cut
  - narrow filter drains (UK, Ireland);
  - gutters (France, Germany, the Netherlands);
  - pipes / sewers (Austria, Germany, the Netherlands);
  - manholes / (grate) inlets (France, the Netherlands);
  - pumps (Norway, the Netherlands, Sweden);
  - road-edge drainage (Denmark)

- Tunnels
  - kerb and gully (UK, Ireland);
  - slotted drains (France);
  - manholes (France, the Netherlands)
  - pipes / sewers (Austria, Germany, the Netherlands);
  - sump / basin (UK, the Netherlands, Ireland, Denmark);
  - pumps (UK, France, the Netherlands, Ireland, Norway, Denmark);
  - edge drainage (Norway, Sweden);

- Bridges
  - combined kerb drainage systems (UK, France, Ireland);
  - gutter (France, the Netherlands);
  - grate inlets and pipes (France);
  - edge-collection (Norway, Sweden, Denmark);
  - sewer system / pipes (Denmark, France);

- Retention facilities
  - dry / wet / attenuation / retention ponds (UK, France, Germany, the Netherlands, Ireland);
  - infiltration basins (Austria, UK, Ireland);
  - sedimentation basins (Norway, Sweden);
  - containment basins / ditches (France);
  - soakaways (UK, Ireland);
  - wetlands (UK, Ireland);
  - grassed channels (UK, Ireland);
  - swales (UK, Ireland);

- Treatment facilities
  - (constructed) wetlands and ponds (UK, Germany, the Netherlands, Ireland);

- infiltration basins (Austria, UK, the Netherlands, Ireland);
- sedimentation basins (Germany, Norway, Sweden, France);
- grassed channels / swales (UK, Ireland);
- infiltration into the verge (the Netherlands);
- filter drain (UK, Ireland);
- oil/petrol interceptor (UK, Ireland, the Netherlands)
- sediment/sand trap/filter (UK, France, the Netherlands, Ireland);
- containment basins / ditches (France);
- penstock / shut-off valve (UK, Ireland);
- cleaning facilities (Norway, Sweden).

11.1.2 Water besides the road (pluvial flooding)

The following assets preventing the road from pluvial flooding are mentioned:

- ditches (Ireland, UK, France, the Netherlands);
- dikes/levees (France, Norway, Sweden, the Netherlands, Denmark);
- road on embankment (the Netherlands, Sweden, Norway, Germany);
- deflective dams / structures (Austria).

11.1.3 Water crossing the road (run-off flooding)

The following assets for managing water crossing the road are mentioned:

- culverts / drainage pipes / minor bridge constructions (UK, France, Germany, Ireland, the Netherlands, Denmark, Sweden, Norway);
- bedload barrage / mudflow breaker (Austria);
- wild wood rake (Austria);
- ballast sedimentation basin / flood retention basin (Austria).

11.2 Sources of climate data

In general, the national road authorities obtain the climate data for the current and future climate from the national meteorological institutes (based on statistical analysis of historical data).

11.3 Design approach and calculation methods

In most countries standards and guidelines exist that thoroughly describe how road water management needs to be designed. In the northern countries Sweden and Norway however it appears that the design very much relies on specific, local circumstances in combination with the experience of the staff of local offices of the NRA, largely determined by local topographical circumstances and existence of tunnels.

Furthermore, in all countries return periods are used to make a design of the water management system given the characteristics of the specific road. In general, the more important or more vulnerable a road, the higher the return periods for the design that will be used. The requirements for return periods are thus dependent on two aspects:

- Criticality of the road

  The criticality of the road can be determined based on the importance of the road. In some countries this is just a label of the road (e.g. for Norway and Denmark local/other road versus motorway). In other countries this is described in terms of characteristics of the area (e.g. for Ireland and UK the differences between urban areas, agricultural lands of high value and isolated properties and agricultural land).

- Vulnerability of the road

  In other countries the return periods are determined, dependent on the vulnerability of the road. For instance, in the Netherlands the return period is low when water can freely drain to the surroundings and becomes higher when water is not able to freely drain causing nuisance for the users and operators of the road.

Normally, the return periods, given the specific characteristics, are the same for the whole country. In Ireland and the UK, on top of this, the road should always be designed to be able to cope the locally highest ever measured precipitation event. Also, when this event has a very high return period.

11.3.1 Precipitation on the road

It has become clear that the standard approach for drainage design in all countries is the use of dynamic calculations. Input regarding precipitation for those calculations is mostly in the form of IDF curves using point data. These can be both expressed in graphs (e.g. the Netherlands) as well as in formulas (e.g. Ireland or United Kingdom).

Requirements for drainage design are in all countries expressed in terms of return periods. It has not become clear whether these return periods are to be applied for a specific location or for the whole region or country. During the workshop and also during the interviews held for this country comparison report, it was seen that very often these two different return periods are mixed up. Probably return periods are in most countries meant to be applied for specific locations, but some people make the mistake of extrapolating this to the whole region. Often examples are provided like: we have seen a precipitation event with a return period of 200 years for a specific location, already 3 times in the region/country in the past 5 years. This reference can be used as a prove that events with high return periods may occur, but not in the sense that due to climate change these events are now occurring almost every year.

Country	Austria	UK/Ireland	France	Netherlands	Norway	Sweden	Denmark
Return period (years)	1 – 5	1 – 5	10 - 25	10 - 250	200	3 - 20	10-25

Table 11.1 Return periods that are required in different countries for design of storm water run-off

The requirements for return periods are generally well known. However, big differences between countries are observed. For roads in fill, for instance in Austria, the United Kingdom and Sweden (to some extent), return periods of 1 to 5 years are used. However, for Norway a return period of 200 years is reported as the standard requirement for motorways. The requirements of other countries are in between those values.

The prevailing duration of precipitation seems to be difficult to estimate. Dynamic calculations are made for several durations. However, in general it has become clear that the prevailing duration of precipitation for the design of pavements is in the order of 5 to 10 minutes and for the design of storm water management systems in the order of minutes to 6 hours.

In general no flooding of (a part of) the lanes may occur during a normative event. In France flooding of the hard shoulder may only occur for higher return period.

Requirements for the maximum water film thickness on the road are only explicitly mentioned in Ireland and the Netherlands and implicitly in France and UK by having requirements for the cross and longitudinal slopes of the road surface.

11.3.2 Water besides the road

It appears that the approach for water besides the road is comparable in most countries. Ditches are used in all countries for drainage of pluvial flooding water. On top of this the road can be put on an embankment and sometimes culverts or dikes are used as well. The manning equation is often used for calculation of the sizing of the ditches. Simple hydrological calculations for the catchment areas can be made as well. Precipitation input for these calculations is in the form of IDF curves. It has not become very clear whether point data or area data are used for development of the IDF curves. Most likely point data are used. Although this might not be completely accurate, it is probably sufficient since the size of catchments will generally be small.

Return periods have not been found or identified in all countries. Denmark uses a return period of 25 years whereas the UK/Ireland and France use a longer return period with respectively 75 and 100 years.

11.3.3 Water crossing the road (run-off flooding)

Two main approaches exist in all countries for calculation of design flows. These are:

- Use of gauge flow data in combination with (extreme value) statistics. This approach of course can only be used when streams are monitored, which is mostly the case in the larger streams/catchments.
- For non-monitored streams an estimation of the design flows is based on rainfall data that are transferred with the use of runoff coefficients (often the rational method is used). Sometimes hydrological modelling takes place.

Return periods generally are larger for this kind of flooding as compared to the other types of flooding. In most countries return periods are used of 100 to 200 years. In the UK, Sweden and Denmark also smaller return periods are used with a minimum of 25 years. Normally, the calculations are performed by the NRA's themselves (or at least under their responsibility). In the Netherlands however, the NRA's rely on the requirements that are obtained from the waterboards.

Country	Austria	UK	France	Ireland	Norway	Sweden	Denmark
Return period (years)	100	100-200	100	100	200	50-200	10-25

Table 11.2 Return periods that are required in different countries for run-off flooding

11.4 Maintenance and operations approach

Three maintenance approaches seem to be adopted by the NRA's:

- Preventive approach, by using periodic maintenance and minimizing maintenance needs with clever designs

In all countries, the national roads are periodically maintained, mainly by local contractors (periodically). The aim of this periodic maintenance is to ensure that the water management system is able to fulfil its job during high precipitation events. On top of this, storm water drainage systems are usually designed in such a way that the need for maintenance is minimized (for example self-cleaning pipes), that maintenance works can be easily performed and/or that some deterioration during use is taken into account already in the design.

Mentioned measures are:

- cleaning of infiltration points, gutters, grates, etc.
- cleaning of ditches / retention areas;
- cleaning of culverts;
- cleaning of porous asphalt at the shoulders;
- removing excess soil from the verges;
- greenery maintenance (vegetation cutting/removal);
- inspections (tunnels, culverts);

In Austria and Germany hazard mapping is explicitly mentioned as a way to focus specific actions on high risk locations. This includes also the learning from past events.

- Corrective approach, by acting during and inspections plus repairing after a flooding

  This approach is used in all countries. It however is generally understood that the preventive approach is most important and one should not rely on a corrective approach solely.

- Preparatory approach, by acting with operations and maintenance works shortly before flooding may occur, using meteorological forecasts

  This approach arose during the workshop. During exceptional events, operators have emergency and rescue plans and may also get alerts from meteorological institutes (France, the Netherlands, Austria). In the same time opportunities exist to use these forecasts as well for specific and focussed maintenance short before heavy precipitation events, in order to ensure the full capacity of the water management system. This approach however was not in use in any of the countries.

11.5 How is climate change taken into account?

Climate change is considered as an important aspect to consider for design and maintenance of water management systems for NRA's. It appears that the countries all have a slightly different approach to take climate change into account in the design:

- Ireland and the United Kingdom increase the design flows and rainfall intensities of the design storm by 20%, which is the expected annual change of rainfall due to climate change. The NRA's know it is not correct to use the same factor for short periods of rainfall but see right now no alternative since data are lacking.
- In the Netherlands, the worst case climate scenario is used with 2050 and 2085 as time horizons. Based on calculations for this scenario the rainfall intensity of the IDF curves for the current climate are increased with 21% and 41% respectively in order to take climate change into account.

- Germany adopts an ensemble approach to gain insight in the uncertainties for the future. No specific guidance is provided however on how to make choices given these uncertainties.
- Climate change is not explicitly taken into account at the moment in France, Norway (generally speaking), Sweden, Denmark and Austria. However, strategies/plans are currently being implemented or under revision for the most of these countries.

In general, no increase in maintenance frequencies that would be related to climate change has been noticed. Only Austria noticed a higher maintenance requirement due to the increase of extreme rainfall and Denmark noticed more flooding scenarios for specific road stretches over the past decade compared to historical data.

11.6 SuDS

SuDS, or Sustainable Drainage Systems, is an approach to drainage which has the objective of minimizing the impact that the surface water runoff from any development exerts on its environment by replicating, as closely as possible, the natural drainage from a site before a development is carried out. This applies to both the quality and quantity of the surface water runoff.

Examples of SuDS features are filter drains, Swales, Ponds, Subsurface tanks, Wetlands, Silt traps, Oversized pipes, Bioretention areas, Detention basins, Soakaways, Infiltration trenches, Infiltration basins, Pervious pavements, etcetera.

Ireland and United Kingdom make much use of SuDS in the water management of roads. Both countries have an extensive manual on planning, design, construction and maintenance of SuDS to assist with their effective implementation within both new and existing developments.

All other countries at first sight claim not to use SuDS. However, they all use SuDS features to some extent, mainly for the purpose of treatment and retention. France and Norway explicitly mention that infiltration of road discharge water into the ground is not allowed (for France, not allowed within sensitive and vulnerable groundwaters), which would make implementation of SuDS difficult.

The Netherlands, although they do not see it as implementation of SuDS features, seem to have the most extended implementation of SuDS throughout the national road network. Namely, their standard approach for roads with a combination of porous asphalt (PA) and infiltration of the stormwater runoff into the road verges and/or road side ditches can considered to be a sustainable drainage system. Circa 90 - 95% of the national roads are constructed with this approach.

11.7 Cost Benefit Analysis

Differentiation needs to be made regarding performing a Cost Benefit Analysis (CBA) on a strategic or on operational/project level.

- CBA at strategic level

  It has appeared that in none of the country's CBAs are performed on a strategic level to determine the requirements for water management systems. As seen before, the criticality or vulnerability of a road is considered in many countries to determine the return periods that need to be taken into account for design. However, no CBA is underlying the choices made in this respect. This is remarkable given the big variety in return periods that are used in the different countries. How can it be explained that in one country a return period of 200 years is standard procedure where in another country 5 years is the standard?

- CBA at operational level (project specific)

  Also on an operational level, CBAs are not used to determine or underpin the choices for specific design requirements. However, the use of CBAs on the project level is standard practice for selection of appropriate solutions. In most occasions a CBA is used for appraisal of the entire project and not specifically for drainage. Ireland and the Netherlands have a standardised approach for CBAs in projects using a multi criteria analysis.

  Climate change is taken into account in the CBAs in the same way as it is taken into account for design (in those countries that do consider climate change in the design phase). Only in the Netherlands it is mentioned that CBA's will be used (in future) in order to make decisions whether climate adaptation and/or mitigation measures will be taken or not.

In all countries, CBAs are performed by external consultants and contractors, sometimes in close cooperation with NRA staff.

11.8 Summary

All countries		precipitation on the road						water besides the road (pluvial flooding)	Water crossing the road
		Roads in fill (on embankment)	Roads in cut (excavated)	Tunnels	Bridges	Retention facilities	Treatment facilities	assets to prevent flooding	culverts
Design	Type of assets	road side ditches, (grassed) channels, kerbs and gullies, (grate) inlets , pipes / sewers, (slotted) drains, manholes, culverts	narrow filter drains, gutters, pipes / sewers, manholes / (grate) inlets, pumps, road-edge drainage	kerb and gully, slotted drains, manholes, pipes / sewers, sump / basin, pumps, edge drainage	combined kerb drainage systems, gutter, grate inlets and pipes, edge-collection, sewer system / pipes	dry / wet / attenuation / retention ponds, infiltration basins, sedimentation basins, containment basins / ditches, soakaways, wetlands, grassed channels, swales	wetlands and ponds, infiltration basins, sedimentation basins, grassed channels / swales, infiltration into the verge, filter drain, oil/petrol interceptor, sediment/sand trap/filter, containment basins / ditches, penstock / shut-off valve	ditches, dikes/levees, road on embankment, deflective dams / structures	culverts / drainage pipes / minor bridge constructions, bedload barrage / mudflow breaker, wild wood rake, ballast sedimentation basin / flood retention basin
	Which approach is used?	Detailed design guidelines exist in all countries except for Scandinavian countries where 'no general policies' are present. Differences exist in the allowance of infiltration of water into the ground and as a consequence differences exist in the standard approach of design of drainage assets.						Ditches are used for drainage of pluvial flooding water. The road can also be put on an embankment and sometimes culverts or dikes are used.	Two main approaches are: • Use of gauge flow data in combination with (extreme value) statistics. • For non-monitored streams an estimation of the design flows is based on rainfall data that are transferred with the use of runoff coefficients (often the rational method is used).
	What calculation methods are used?	In general, dynamic calculations are made for different time steps. Precipitation information is based on IDF curves. Often mentioned are the rational method and the Manning Strickler equation.						Manning and simple hydrological modeling	
	What is the normative return period of precipitation in drainage design? Does this depend on specific road characteristics? (road importance, lifetime expectancy, cost, etc.)	Requirements in normation are made in the form of return periods of precipitation events. These are either based on vulnerability or criticality of the road. The required return periods hugely vary between countries for the same situations.						Not all countries appear to have clear requirements, but if mentioned they lie between 25 and 100 years	Generally higher return periods than for other types of flooding.
	What is the prevailing duration of precipitation in drainage design?	The prevailing duration seems to be difficult to estimate. In general it has become clear that the prevailing duration of precipitation for the design of pavements is in the order of 5 to 10 minutes and for the design of storm water management systems in the order of minutes to 6 hours.						very much dependent on the characteristics of the site. In the order of hours to a couple of days.	
	How is climate change taken into account?	No standard approach has been identified. Ireland and the UK add 20% to the precipitation intensity based on expected annual changes in rainfall, the Netherlands use the expected change for daily rainfall as expected in the worst case climate scenario as known in 2012, Germany uses an ensemble approach, Denmark refers to IPCC, France/Sweden/Netherlands busy with general adaptation strategy							
	Do requirements exist for the maximum thickness of the water film on the pavements during normative precipitation events?	Only the Netherlands and Ireland have explicit requirements. France and UK have implicit requirements. The mentioned maximum water film thickness is 2.5 mm (2 a 3 mm). A transverse slope of 2.5% is applied.				-	-	-	-
	Do requirements exist for the allowable water spread on the pavements during normative precipitation events?	In most countries the design capacity is calculated using smaller return periods if compared to calculations with larger return periods to check whether the water reaches the driving lanes.				-	-	-	-
Maintenance	Which approach is used?	In all countries, the national roads are periodically maintained, mainly by local contractors (periodically). The aim of this periodic maintenance is to ensure that the water management system is able to fulfil its job during high precipitation events. On top of this, storm water drainage systems are usually designed in such a way that the need for maintenance is minimized (for example self-cleaning pipes), that maintenance works can be easily performed and/or that some deterioration during use is taken into account already in the design. A corrective approach is also used in all countries. It however is generally understood that the preventive approach is most important and one should not rely on a corrective approach solely.							
	Have you noticed a variation of your maintenance practices (frequencies, type of works…) that would be related to climate change?	In general, no increase in maintenance frequencies that would be related to climate change has been noticed. Only Austria noticed a higher maintenance requirement due to the increase of extreme rainfall and Denmark noticed more flooding scenarios for specific road stretches over the past decade compared to historical data.							

12 Conclusions

To conclude, the most remarkable findings are summarized in the list below.

- Type of assets: A big variety of assets for water management by NRA's exists. In the same time many similarities occur between countries.
- Guidelines / criteria:
  - Detailed design guidelines exist in all countries.
  - Requirements for water management design are made in the form of return periods of precipitation events. These are either based on vulnerability or criticality of the road.
  - The required return periods hugely vary between countries for the same situations. The requirements are not underlined with cost benefit assessments.
  - The prevailing duration of precipitation for design of drainage and storm water management systems is not very clear, since dynamic calculations are made for several durations. It is estimated that the prevailing durations vary between 5 to 10 minutes for drainage of pavements and in the order of minutes to 6 hours for the design of storm water management systems.
- Rainfall data and climate change:
  - Precipitation information into the design takes place using IDF curves, making use of mainly point data although this is not completely correct for modelling pluvial flooding and run-off.
  - National Meteorological institutes play a big role in getting climate data. Climate change data are also obtained from national institutes.
  - Climate change is not explicitly taken into account in most countries. Only Ireland, UK and the Netherlands consider climate change explicitly in the standards and use (with different backgrounds) a certain increase of precipitation intensity to accommodate climate change. In Germany an ensemble approach is used.
- Cost benefit analysis:
  - Cost benefit assessments are mainly used for identifying the best solutions on a project level. They do however most of the times not specifically address water management issues.
  - Cost benefit assessments for providing decision support on whether climate change adaptation measures need to be taken are not developed and implemented (yet, Netherlands in the near future).
- SuDS: SuDS are being applied in many countries in various forms and sizes as daily practice for treatment and retention purposes and are not recognized as a specific design feature, as compared to UK/Ireland where a specific detailed manual is developed for SuDS. SuDS are standard practice for storm water runoff in the Netherlands.
- Maintenance and climate change:
  - No increase in maintenance is seen over the past decades except for Austria and Denmark.

    - Maintenance generally takes place periodically and not specifically before an extreme weather event. Furthermore, maintenance is as much as possible avoided or reduced with a clever design.
- A good database with weather events and accidents is lacking in most countries in order to underpin whether climate change is having an effect already and to be used in a CBA.

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Appendix

The structure of all country chapters are based on the questions below.

A.1 Type of water management assets used by NRA

Purpose of this chapter is to get an overview about the type of assets that the NRA has in its road network.

A.1.1 Precipitation on the road

The following assets are pre-identified. A description should be provided about the assets that are used for the different circumstances within the NRA.

- *Roads in fill (on embankment)*
  - *Storm water runoff-systems (gutters, sewers, pipes)*
- *Roads in cut (excavated)*
  - *Storm water runoff-systems (gutters, sewers, pipes, pump basements)*
- *Tunnels*
  - *Gutters, sewers, pipes, pump basements*
- *Bridges*
  - *Storm water runoff-systems (gutters, sewers, pipes)*
- *Retention facilities*
  - *Attenuation ponds*
  - *wetlands*
- *Treatment facilities*
  - *wetlands*

A.1.2 Water besides the road (pluvial flooding)

The following assets are pre-identified. A description should be provided about the assets that are used for the different circumstances within the NRA.

- *Levees, including levees at entrances of tunnels under waterways*
- *Dikes*
- *Road on embankment*

A.1.3 Water crossing the road (run-off flooding)

The following assets are pre-identified. A description should be provided about the assets that are used for the different circumstances within the NRA.

- *Culverts*

A.2 Sources of climate data

This chapter is aiming at the origin of the climate data and not the climate data itself. These are covered in the following chapters (mainly 2.3). The following questions need to be answered in this chapter.

- *What is the source of the climate information you use for the current and future climate?*
- *Where do you get the climate information that you use for the current and future climate?*

References and/or links should be provided as complete as possible

A.3 Design approach and calculation methods

Purpose of this chapter is to get an overview of the design approach and calculation methods that are used. Right now the chapter is sub divided in several sub chapters for the different types of water management facilities. If approaches are similar for different facilities, sub-chapters can be combined into one.

References and/or links to guidelines etcetera should be provided as complete as possible.

Answers need to be provided on the following questions:

- *Which design approach is used?*
- *Which calculation methods are used?*
- *What is the normative return period of precipitation in drainage design? Does this depend on specific road characteristics? (road importance (of national roads), lifetime expectancy, cost, etc.)*
- *What is the prevailing duration of precipitation in drainage design?*
- *Which format of climate information is used?*
  - *eg. IDF curves*
  - *Are point data used or area-average data (point data could be very useful for rainfall on the road, but for flooding events the rainfall in a certain area may be more useful)*
- *Do requirements exist for the maximum thickness of the water film on the pavements during normative precipitation events?*
- *Do requirements exist for the allowable water spread (flooding of part of the lanes) on the pavements during normative precipitation events?*

A.3.1 Precipitation on the road

*** The questions should be answered for all following sub-chapters.***

Roads in fill (on embankment)

- *Storm water runoff-systems (gutters, sewers, pipes)*

Roads in cut (excavated)

- *Storm water runoff-systems (gutters, sewers, pipes, pump basements)*

Tunnels

- *Gutters, sewers, pipes, pump basements*

Bridges

- *Storm water runoff-systems (gutters, sewers, pipes)*

Retention facilities

- *Attenuation ponds, wetlands*

Treatment facilities

* *wetlands*

A.3.2 Water besides the road (pluvial flooding)

*** The questions should be answered for the possible assets like levees, dikes and roads on embankment.***

A.3.3 Water crossing the road (run-off flooding)

*** The questions should be answered for the possible assets, probably only culverts.***

A.4 Maintenance and operations approach

Purpose of this chapter is to get an overview of the maintenance approach that is being used. Right now the chapter is sub divided in several sub chapters for the different types of water management facilities. <u>If approaches are similar for different facilities, sub-chapters can be combined into one.</u>

References and/or links to guidelines etcetera should be provided as complete as possible.

Answers need to be provided on the following questions:

* *Which maintenance approach is used (preventive before extreme weather and corrective after extreme weather)?*
* *Which operational approach is used? How are extreme events managed?*
* *Are weather or climate data used for maintenance purposes?*

A.4.1 Precipitation on the road

*** The questions should be answered for all following sub-chapters.***

Roads in fill (on embankment)

* *Storm water runoff-systems (gutters, sewers, pipes, open channels, slotted drains)*

Roads in cut (excavated)

* *Storm water runoff-systems (gutters, sewers, pipes, open channels), pump basements*

Tunnels

* *Gutters, sewers, pipes, pump basements, slotted drains*

Bridges

* *Storm water runoff-systems (gutters, sewers, pipes)*

Retention facilities

* *Attenuation ponds, wetlands*

Treatment facilities

* *Wetlands, settling ponds*

A.4.2 Water besides the road (pluvial flooding)

*** The questions should be answered for the possible assets like levees, dikes and roads on embankment.***

A.4.3 Water crossing the road (run-off flooding)

*** The questions should be answered for the possible assets, probably only culverts.***

A.5 How is climate change taken into account?

Purpose of this chapter is to get an overview of the way climate change is taken into account (or maybe not) in design, maintenance and operations. Right now the chapter is sub divided in several sub chapters for the different types of water management facilities. <u>If approaches are similar for different facilities, sub-chapters can be combined into one.</u>

The following questions need to be answered:

- *Have you noticed a variation of maintenance and operation practices (frequencies, type of works…) that would be related to climate change?*
- *Is climate information for the future used in design? If yes,*
  - *What approach is used? same type of information used as for the current climate, just add a fixed percentage, or other approaches?*
  - *Which time horizon is used/what is a relevant time horizon?*
  - *What reference period is used for the current climate?*
  - *How do people deal with uncertainties?*

A.5.1 Precipitation on the road

*** The questions should be answered for all following sub-chapters.***

Roads in fill (on embankment)

- *Storm water runoff-systems (gutters, sewers, pipes, open channels, slotted drains)*

Roads in cut (excavated)

- *Storm water runoff-systems (gutters, sewers, pipes, slotted drains), pump basements*

Tunnels

- *Gutters, sewers, pipes, pump basements, slotted drains*

Bridges

- *Storm water runoff-systems (gutters, sewers, pipes)*

Retention facilities

- *Attenuation ponds, wetlands*

Treatment facilities

- *Wetlands, settling ponds*

A.5.2 Water besides the road (pluvial flooding)

*** The questions should be answered for the possible assets like levees, dikes and roads on embankment.***

A.5.3 Water crossing the road (run-off flooding)

*** The questions should be answered for the possible assets, probably only culverts.***

A.6 SuDS

The following questions need to be answered:

- *Are SuDS being used by the NRA?*
- *What design standards for SuDS (in terms of conveyance, treatment and storage) are used by the NRA for the construction of new roads?*
- *What design standards for SuDS (in terms of conveyance, treatment and storage) are used by the NRA in road improvement schemes (such as road widening and upgrade works)?*
- *How is climate change taken into account in the design of SuDS features – in terms of conveyance, treatment and storage?*
- *What standards and specifications are used by the NRA for the maintenance of SuDS systems?*

Reference is being made to extra information that John Paul provides regarding definition and demonstration of SuDS.

A.7 Cost Benefit Analysis

The following questions need to be answered:

- *On a strategic level, were CBA's used to determine the requirements (return periods)? How?*
- *On an operational level, are CBA's used to determine project specific requirements (return periods)? How?*
- *On an operational level, are CBA's/cost assessments used to determine the most desirable design solution? How?*
- *Is climate change taken into account in CBA's? How?*
- *Specifically related to SuDS: Is CBA performed to assess the appropriateness of:*
    - *SuDS for the design of new roads*
    - *SuDS retrofit on existing roads?*
    - *SuDS in the design of road improvement schemes (such as road widening and road upgrade works)?*
- *Who performs the CBA?*
- *What information is available for performing the CBA (e.g. serviceability, safety, network operation, financing, expenditure, environmental and societal considerations)?*