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WATCH

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Call 2015

WATer management for road authorities in the face of climate CHange

Manual

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Executive summary

The main objective of the WATCH[1] project consists in developing a manual to determine current and future resilience of the National Roads Authorities (NRAs) approach to water management, ensuring optimal maintenance planning and asset management.

Besides the present manual, the WATCH project provides five other reports and guidelines focusing on particular scopes:

- What is the current state of practice and approaches of NRAs related to water management and how they take climate change into account: “Country Comparison Report” (Bles et al., 2017)
- How to generate rainfall extremes for current and future climate: “Climate and climate change: protocol for use and generation of statistics on rainfall extremes” (Bessembinder et al., 2018).
- How to assess and increase resilience of Sustainable Drainage Systems (SuDS) in face of climate change: “Protocol for Adapting SuDS systems for Climate Change” (Rooney et al., 2018)
- How to assist the decision making process: “Socio-Economic Analysis Guidelines” (Tucker et al., 2018)
- How to implement and demonstrate the manual: “Case study” (Axelsen et al., 2018)

The present manual provides the over-arching guidelines integrating extracts of all the other deliverables mentioned above.

The present WATCH manual consists of two main sections;

- **Introductive chapters:** Provides the reader with useful background information for understanding the following parts of the manual
  - Chapter 1 presents the purpose, structure and how to use the manual
  - Chapter 2 introduces climate and climate change focusing on rainfall extremes
  - Chapter 3 reminds NRAs demands and existing guidelines that are the base of the present manual
  - Chapter 4 presents the current water management within Europe
- **Manual:** The WATCH manual is structured as follows:
  - The introduction provides in detail how to implement the methodology thanks to a decision tree
  - After a prerequisite aiming at defining the scope of the study, two levels of risk analysis are provided
  - Part A provides a method for a high level risk analysis in order to prioritize the roads assets and initiate an adaptation strategy
  - Part B describes a method for a detailed risk analysis in order to implement and plan adaptation measures
  - Additional criteria that could be incorporated in the standards.

[1] WATer management for road authorities in the face of climate CHange

The WATCH manual also provides an **excel sheet file of available measures**.

Glossary

This glossary is partly based on RIMAROCC[2] glossary [1]

Adaptation strategy: Initiatives and measures to reduce the vulnerability and/or consequences of natural and human systems to actual or expected climate change effects. Various types of adaptation exist, e.g. anticipatory and reactive; private and public; autonomous and planned.

Adaptive capacity: be prepared to take measures for the future. This means that there is some form of flexibility to change functions or assets over time, e.g. plan for the possibility to be able to change the drainage capacity in coming maintenance cycles.

Adsorption: Adsorption occurs when pollutants attach or bind to the surface of soil or aggregate particles. The actual process is complex but tends to be a combination of surface reactions grouped as sorption processes:

Adsorption	Pollutants bind to surface of soil / aggregate
Cation exchange	Attraction between cations and clay minerals
Chemisorption	Solute is incorporated in the structure of a soil / aggregate
Absorption	The solute diffuses into the soil / aggregate / organic matter.

Biodegradation: In addition to the physical and chemical processes, which may occur on and within a SUDS technique, biological treatment may also occur. Microbial communities may be established within the ground, using the oxygen within the free-draining materials and the nutrients supplied with the inflows, to degrade organic pollutants such as oils and grease. The level of activity of such bioremediation will be affected by the environmental conditions such as temperature and the supply of oxygen and nutrients. It also depends on the physical conditions within the ground such as the suitability of the materials for colonisation.

Change in acidity of runoff can either increase or decrease the adsorption of pollutants by construction materials or soils. Eventually the materials onto which pollutants adsorb will become will become saturated and thus this method of treatment will stop.

Climate change: Climate change refers to changes in the state of the climate that can be identified (e.g., using statistical tests) through changes in the mean and/or the variability of its properties, and which persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forces, or to persistent anthropogenic changes in the composition of the atmosphere or in land use.

Consequence: The negative effect, or effects, that can be expected if an asset or system is damaged, destroyed, or disrupted.

Consequence reduction: If an unwanted event occurs, measures can be taken in order to minimise the consequences. Examples are limitation of the spread of the disturbance to other areas, being prepared to take emergency measures (divert traffic), making assets less sensitive (promotion of winter tyres).

[2] RIsk MAnagement for ROads in a Changing Climate

Cost Benefit Analysis: A CBA is an evaluation approach that can be used for the Socio-Economic Analysis whereby the costs and benefits of all considered strategies can be quantified in monetary terms.

Cost Effectiveness Analysis: A CEA is an evaluation approach that can be used for the Socio-Economic Analysis whereby the relative costs and effects of different strategies are compared and the most cost effective option is identified for achieving a set of predefined objectives. It presents alternatives in order to identify the most appropriate option to achieve the most effective result at least cost.

Criticality level: Refers to the consequences of incorrect functioning of an asset. The more serious the expected direct and indirect effects of incorrect functioning, the higher the criticality level.

Exposure: Relates to the influences or stimuli that impact on a system. In a climate change context it captures the important weather events and patterns that affect the system, but can also represent broader influences, such as changes in related systems brought about by climate effects. Exposure represents the background climate conditions against which a system operates and any changes in those conditions.

Filtration and biofiltration: Pollutants that are conveyed in association with sediment may be filtered from percolating waters. This may occur through trapping within the soil or aggregate matrix, on plants or on geotextile layers within the construction. The location of any filtration will depend upon the internal structure of the particular SUDS technique, for example whether a geotextile layer is near the surface or at the subgrade in a previous surface.

Hazard: A potential source of harm; something with the potential to cause risk events and therefore adverse consequences.

Life Cycle Costing: A LCC Analysis is an evaluation approach that can be used for the Socio-Economic Analysis that considers the total cost of ownership of an asset(s) that will be incurred during its lifetime and includes acquisition costs, operation costs, maintenance costs and disposal costs. As such, an LCC analysis enables stakeholders to identify least cost alternative solutions over a long period of time.

Likelihood: Used to refer to the chance of something happening, whether defined, measured or determined objectively or subjectively, qualitatively or quantitatively, and described using general terms or mathematically (such as a probability or a frequency over a given time period).

Measure: unique action or act to reduce the vulnerability and/or consequences of natural and human systems to actual or expected climate change effects.

Mitigation: Activities designed to reduce or eliminate risks to persons or property or to lessen the actual or potential effects or consequences of an incident.

Multi Criteria Analysis: An MCA is an evaluation approach that can be used for the Socio-Economic Analysis if little or no quantitative information is available. As such, scores can simply be expressed in physical units or in qualitative terms

Nitrification: Ammonia and ammonium ions can be oxidised by bacteria in the ground to form nitrate, which is a highly soluble form of nitrogen. Nitrate is readily used as a nutrient by plants.

Photolysis: The breakdown of organic pollutants by exposure to ultra-violet light.

Precipitation (chemical process): This process is the most common mechanism for removing soluble metals. Precipitation involves chemical reactions between pollutants and the soil or aggregate that transform dissolved constituents to form a suspension of particles of insoluble precipitates. Metals are precipitated as hydroxides, sulphides, and carbonates depending on which precipitants are present and the pH level. Precipitation can remove most metals (arsenic, cadmium, chromium III, copper, iron, lead, mercury, nickel, zinc) and many anionic species (phosphates, sulphates, fluorides).

Recovery capacity: enhancing a quick return to the pre-disturbed situation, e.g. having pumps available to pump out water after flooding, insurance, well-trained people to help clean up and repair.

Resilient: A system is resilient when it can adapt to internal and external challenges by changing its method of operations while continuing to function. While elements of the original system are present there is a fundamental shift in core activities that reflects adapting to the new environment." (Ciara Rooney - Source: ww.activegarage.com/resilience-engineering-1-robust-resilient)

Resistance: Increasing the threshold before damage will occur, e.g. prevention by increasing the drainage capacity or by changing the pavement type.

Risk: A measure of potential harm that encompasses threat, vulnerability and consequence. Risk is often expressed in terms of a combination of the consequences of an event (including changes in circumstances) and the associated likelihood of occurrence.

Risk analysis: the use of available information to estimate the risk to individuals, populations, property or the environment, from hazards.

Risk evaluation: A process of comparing the estimated risk against given risk criteria to determine the significance of the risk.

Risk assessment: The overall process of risk identification, risk analysis and risk evaluation.

Risk management: the systematic application of management policies, procedures and practices to the tasks of identifying, analysing, assessing, mitigating and monitoring risk.

Risk scenario: In the present context, a scenario is a description of a future situation based on the present situation and knowledge, on the hypothesis of presumed evolution of some parameters from the present to the future, in order to evaluate consequences of unwanted events created by climate change. Each set of climate risk source, road vulnerabilities and consequences constitutes one scenario.

Road authority: The executive agency responsible for operating, maintaining and improving the road network. Administrative and operational functions may be delegated to other entities (contractors).

Robust: A system is robust when it can continue functioning in the presence of internal and external challenges without fundamental changes to the original system." (Ciara Rooney, Source: www.activegarage.com/resilience-engineering-1-robust-resilient)

Sedimentation: Sedimentation is one of the primary removal mechanisms in SUDS. Most pollution in runoff is attached to sediment particles and therefore removal of sediment results in a significant reduction in pollutant loads. Sedimentation is achieved by reducing flow velocities to a level at which the sediment particles fall out of suspension. Care has to be taken in design to minimise the risk of re-suspension when extreme rainfall events occur.

Socio-Economic Analysis: A tool or methodology, used in decision making, that analyses the advantages and disadvantages of the relationships between various strategies (design, rehabilitation etc.), and the stakeholders, including society, who would be impacted by those strategies.

SuDS: Sustainable Drainage Systems. The SUDS philosophy is to mimic the natural hydrological cycle by promoting; infiltration, evaporation, evapotranspiration, the harvesting of rainwater at source and the temporary storage of water (ponding), through the construction of a combination or series of components to form a ‘management train.

Threat: In the present context, an extreme climate event that could be detrimental to the infrastructure and/or its operation.

Uncertainty: Uncertainty is any departure from complete deterministic knowledge of the relevant system. Uncertainties can be due to imperfect knowledge (in the case of climate: about the climate system or about the socio-economic system causing the emission of greenhouse gasses) and/or it can be due to intrinsic variability (e.g. in the climate system).

Uptake by plants: In ponds and wetlands, uptake by plants is an important removal mechanism for nutrients (phosphorous and nitrogen). Metals can also be removed in this manner (although intermittent maintenance is required to remove the plants otherwise metals will be returned to the water when the plants die). Plants also create suitable conditions for deposition of metals, for example as sulphides in the root zone.

Volatilisation: Volatilisation comprises the transfer of a compound from solution in water to the soil atmosphere and then to the general atmosphere. The conversion to a gas or vapour occurs due to heat, reducing pressure, chemical reaction or a combination of these processes. The rate of volatilisation of a compound is controlled by a number of its properties and those of the surrounding soil. In SUDS schemes volatilisation is primarily concerned with organic compounds in petroleum products and pesticides.

Vulnerability: The extent to which a natural or social system is susceptible to sustaining damage [from climate change]. It is a function of the sensitivity of a system [to change in climate], adaptive capacity and the degree of exposure of the system to [climatic] hazards.

Vulnerabilities: In the present context, elements of the road system (infrastructure, traffic, environment, etc.) vulnerable to climate change.

INTRODUCTIVE CHAPTERS

1. Introduction

1.1. The WATCH project

European NRAs have recognized for a long time that climate change will have a significant effect on their assets and operations. Many challenges exist in addressing intense rainfall events and ensuring that proper design and maintenance of water management systems occurs. These challenges exist both in the field of climate science as well as in the translation of climate predictions into proper design and maintenance of water management systems.

The CEDR[3] funded WATCH project addresses the most important high frequency causes of road flooding, caused by pluvial and run-off flooding in the area around the road, and heavy rain on the road itself (rain intensity). The project considers the drainage facilities that are designed and maintained by/for the NRAs, and ensure adequate water management of the road and also a smooth and safe use of the road infrastructure. 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.

The project is developing a number of outputs of immediate benefit to NRAs, including:

- A country comparison report showing the state of practice of existing water management and drainage approaches at different NRAs.
- Guidelines to correctly interpret and apply relevant information extracted from climate projections and scenarios, to be used in road drainage and maintenance design.
- A simple tool that shows climate analogues for rainfall extremes in Europe.
- A protocol for adapting SuDS systems for climate change, with applications for roads across Europe.
- Guidelines for a Socio-Economic Analysis of adaptation and maintenance approaches for water management

These outputs are incorporated into a comprehensive manual (the present document) on how to determine the resilience of drainage systems and the consequences for inspection and maintenance as well as for the design and assessment of alternatives.

[3] Conference of European Directors of Roads

1.2. Scope of WATCH manual

While RIMAROCC [1] and ROADAPT[4] [2] (reference is made to chapter 3.2 for details on those 2 projects) addressed all the climatic threats to which road infrastructure is exposed, WATCH address the most important high frequency causes of road flooding that NRAs have identified in the CEDR report ‘Adaptation to Climate Change’-[5] and considers pluvial and run-off flooding in the area around the road, and heavy rain on the road itself (rain intensity).

The climate data protocol addresses extreme rainfall events with relatively short durations as they are the climate data relevant for water management facilities.

Similarly, while RIMAROCC [1] and ROADAPT [2] addressed all the infrastructures assets, WATCH only address water management facilities (reference is made to Chapter 1.4 for asset descriptions).

WATCH only addresses small and medium culverts and pipes. Bridge or river flood plain modelling are out of the scope (far beyond the only responsibility of road owners and no possible standardisation of the method). Culverts used as discharging structures for flood plains are also out of the scope.

The first WATCH audience are NRAs that aim at taking climate change into account in design and maintenance of water management assets. The WATCH manual gives them a how to do methodology.
Road contract designers and consultants are also a part of the WATCH audience as they design and implement road projects.

The methodology provided in the manual section focus on existing roads as it represents the primary area of water management challenges of NRAs since not many new road lines are planned across CEDR member countries.
Nevertheless, the manual provides recommendations for new roads within the introduction of the manual section as well as additional criteria that could be incorporated in the standards.

[4] Roads for today adapted for tomorrow

1.3. How to use the WATCH manual

The manual consists of two main sections;

- **Introductive chapters:** Provides the reader with useful background information for understanding the following parts of the manual.
  - Chapter 1 presents the purpose, structure and how to use the manual
  - Chapter 2 introduces climate and climate change focusing on rainfall extremes
  - Chapter 3 reminds NRAs demands and existing guidelines that are the base of the present manual
  - Chapter 4 presents the current water management within Europe
- **Manual:** The WATCH manual is structured as follows.
  - The introduction provides in detail how to implement the methodology thanks to a decision tree
  - After a prerequisite aiming at defining the scope of the study, two levels of risk analysis are provided
  - Part A provides a method for a high level risk analysis in order to prioritize the roads assets and initiate an adaptation strategy
  - Part B describes a method for a detailed risk analysis in order to implement and plan adaptation measures
  - Additional criteria that could be incorporated in the standards.

In parallel to this manual, five other guidelines are provided focusing on particular scopes of the WATCH project

- What is the current state of practice and approaches of NRAs related to water management and how they take climate change into account: “Country Comparison Report” (Bles et al., 2017) [16]
- How to generate rainfall extremes for current and future climate: “Climate and climate change: protocol for use and generation of statistics on rainfall extremes” (Bessembinder et al., 2018) [17]
- How to assess and increase resilience of SuDS in face of climate change: “Protocol for Adapting SuDS systems for Climate Change” (Rooney et al., 2018) [18]
- How to help decision making process: “Socio-Economic Analysis Guidelines” (Tucker et al., 2018) [19]
- How to implement the manual: “Case study” (Axelsen et al., 2018) [20]

The present manual provides the over-arching guidelines integrating extracts of all the other deliverables described before.

Summaries of the other deliverables are provided within the present manual with reference to them. Only parts needed to understand the overall method are mentioned. The user is referred to the deliverables for details.

1.4. *Assets concerned within the WATCH manual*

This chapter aims at presenting the concerned assets which are parts of an NRAs water management system. Reference is made to the country comparison report (Bles et al.,2017) [17] for more examples.

As within the country comparison report (Bles et al.,2017) [17], the water management assets are structured, according to the hazard that is posed on them: run-off flooding, precipitation on the road and pluvial flooding.

In that respect, they are split into four main types:

- Assets dealing with water crossing the road (run-off flooding)
- Assets dealing with precipitation on the road.
  This asset type is itself divided into two types according to whether it deals with
  - The conveyance aspect: how to collect precipitation on the road
  - The quantity and quality aspects: how to attenuate and treat the collected run-off
- Assets preventing pluvial flooding (water besides the road).

These assets include SuDS components.

1.4.1. Assets dealing with water crossing the road (run-off flooding)

The crossing structures, which deal with natural water crossing the road, are for example: culverts, drainage pipes, minor bridge constructions, bedload barrage, mudflow breaker and flood retention basins.

 @ Isabelle Lappe - Egis	 @ Isabelle Lappe - Egis
(a)	(b)

Figure 1: Crossing Structures : (a) Concrete Pipe, (b) Concrete Box Culvert

1.4.2. Assets dealing with precipitation on the road (conveyance field)

The assets dealing with precipitation on the road (conveyance field) are for example: roadside ditches, channels, kerbs and gullies, (grate) inlets, pipes, sewers, (slotted) drains, manholes, culverts, narrow filter drains, gutters, pumps, road-edge drainage, filter strips, swales and filter drains.

Regarding SuDS components (filter strips, swales, filter drains), reference is made to "Protocol for Adapting SuDS systems for Climate Change" (Rooney et al., 2018) [18] for details.

 @ Isabelle Lappe - Egis	 @ Marine Jaconelli - Egis
(a)	(b)
 @Protocol for Adapting SuDS systems for Climate Change" (Rooney et al., 2018) [19]	
(c)	

Figure 2: Storm drain system: (a) Concrete channel, (b) Rectangular concrete grating channel (c) swale

1.4.3. Assets dealing with precipitation on the road (quantity and quality aspects)

The assets dealing with precipitation on the road (quantity and quality aspects) are for example:

- Regarding retention: dry / wet / attenuation / retention ponds, infiltration basins, sedimentation basins, containment basins, soakaways, wetlands, grassed channels, swales and ponds
- Regarding treatment: (constructed) 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, bioretention areas, sand filters and wetlands

Regarding SuDS components (bioretention areas, sand filters, detention basins, infiltration basin, pond, and wetland), reference is made to Protocol for Adapting SuDS systems for Climate Change" (Rooney et al., 2018) [18] for details.

 @Country Comparison Report (Bles et. al, 2017) [16]	 @ Isabelle Lappe - Egis
(a)	(b)
 @Protocol for Adapting SuDS systems for Climate Change" (Rooney et al., 2018) [18]	
(c)	

Figure 3: Retention/treatment facilities: (a) water treatment plant (sedimentation and infiltration ponds), (b) Retention and sedimentation pond (c) wetland

1.4.4. Assets preventing pluvial flooding (water besides the road)

The assets preventing pluvial flooding (water besides the road) are for example: ditches, dikes/levees, road on embankment and deflective dams / structures.

These assets are considered separately to assets dealing with water crossing the road only when they are not linked to a crossing structure.

2. Climate and climate change: introduction and information on rainfall extremes

The information provided in this chapter is described more elaborately in the document "Climate and climate change: protocol for use and generation of statistics on rainfall extremes" (Bessembinder et al., 2018) [17]

2.1. Introduction to Climate and climate change

Climate is the average weather in a given area over a longer period of time. A description of a climate includes information on e.g. the average temperature in different seasons, rainfall, and sunshine. Also a description of the (probability of) extremes is often included. Climate change is any systematic and significant change in the long-term statistics of climate variables such as temperature, rainfall, air pressure, or wind sustained over several decades or longer. Climate change can be due to natural forcings (changes in solar emission or changes in the earth's orbit, natural internal processes of the climate system) or it can be human induced.

Meteorological institutes are obliged by the World Meteorological Organisation to make a new description of the climate of their country (and regions within the country) every 30 years. Currently the period 1961-1990 is used in several countries to describe the current climate, although many countries in Europe also make a new description every 10 years (after 1961-1990, the periods 1971-2000 and 1981-2010 were used).

Extremes of a climate are described with the help of statistics, or observed minimum and maximum values are reported. Even without climate change due to increased greenhouse gasses the climate would not be completely the same for each period of 30 years, due to internal variability and natural external forcings. To adequately describe the extremes that are rarer than e.g. once in 10 years ideally a period of more than 30 years is used.

By definition, extremes relevant for road design and maintenance are rare and, therefore, it is also more difficult to detect significant changes in extremes. However, for maximum rainfall intensity in heavy showers (mm/day) and extreme rainfall events (long periods, mm/5 days) it is likely over most mid-latitude land that these have increased in the past.

In Appendix 1, an overview of data on current and future rainfall extremes is given. The links and information in the WATCH Country Comparison Report (Bles et al., 2017) [16] are used as the basis and additional information is collected on the available statistics and available information on changes in extreme rainfall in the future. Some conclusions from the available information:

- Different reference periods with historical data are used in the various countries, and it is often difficult to find which historical period was used as the basis for the rainfall statistics
- Hardly ever rainfall statistics have been corrected for trends
- For most countries, only point statistics were found, whereas area statistics are needed for e.g. run-off estimation
- Information of climate (statistics, data sets) is not freely available in all countries, and data sets on short durations (less than 1 hour) are rare
- Some countries take into account climate change by adding a percentage, but often it is not possible to find how this percentage was determined and for what time horizon this should be used
- Hardly any of the climate change scenarios contain information on changes in short duration (less than one day) rainfall extremes.

2.2. Research on extreme rainfall in Europe

2.2.1. Methods for extreme rainfall statistics

The most used methods for generating extreme rainfall statistics are Peak over Threshold (POT) and Generalized Extreme Value (GEV). They may give more or less the same statistics. For very high return times (> 100 or >200 years) these methods may underestimate the extreme rainfall amounts.

In many regions increases in extreme rainfall amounts are observed (or the frequency increases) (figure 4). Not correcting for these trends may result in underestimation of extreme rainfall amounts for the "current" climate.

The temporal resolution of the basic data used for deriving the extreme rainfall statistics determines the rainfall amounts that will be obtained for the various return levels. Most extreme rainfall statistics found for the countries in this study are based on station data (point statistics). These give the probability to exceed a certain amount of rainfall for a certain point.

In regions with hardly any regional differences in rainfall extremes Areal Reduction Factors can be derived from high spatial and temporal resolution data. However, in most countries there are clear regional differences in rainfall statistics. In these cases the areal statistics have to be derived separately for each location.

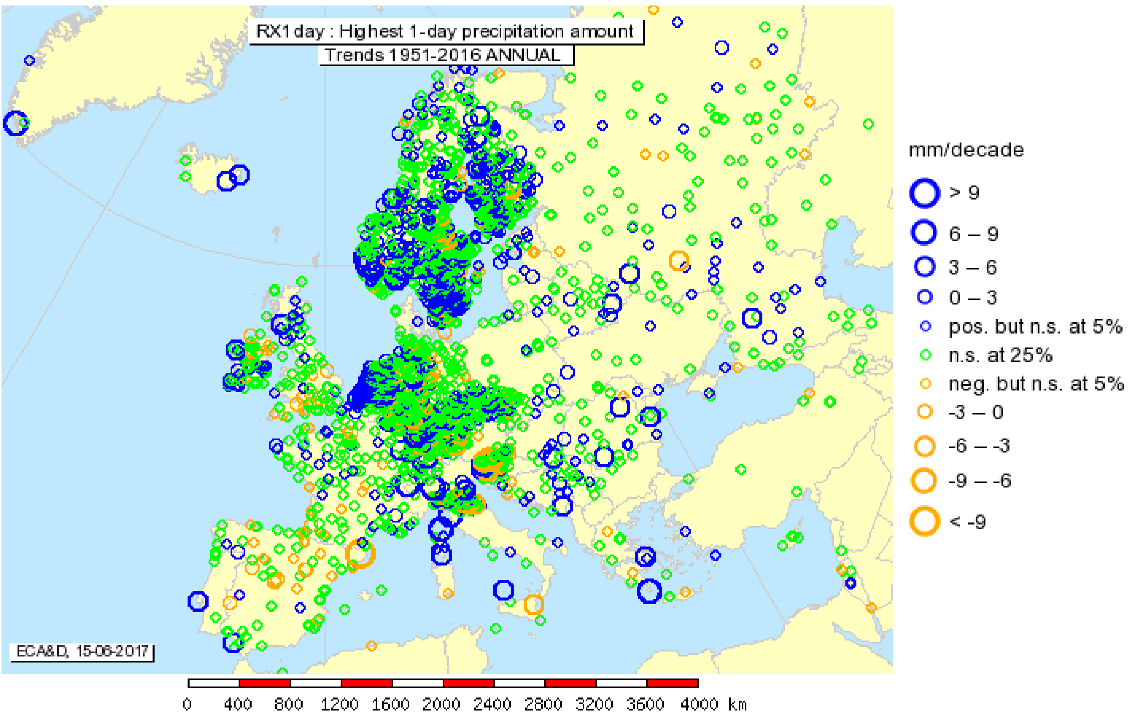

Figure 4: Trend in highest daily rainfall amount per year over the period 1951-2016 from the ECA&D[5] website (generated June 2017).

[5] European Climate Assessment & Dataset project

2.2.2. Scientific research on extreme (short duration) rainfall

Research on observations show that in several countries the rainfall extremes on hourly basis increase stronger with temperature increase than the rainfall extremes on daily basis. For higher temperatures increases of up to 14% per ˚C for hourly extremes. The turning point is approximately at a daily average temperature of 10-14 ˚C or an average dew point temperature of 6-10 ˚C. Increases in rainfall extremes can be better explained when using dew point temperature than when using temperature, since dew point temperature directly measures moisture instead of the maximum water holding capacity (as with temperature).

Most currently available climate models have too coarse spatial resolutions and are unable to represent local convective processes dynamically. Especially at higher temperatures they may underestimate the short duration rainfall extremes. Due to the limited number of climate studies undertaken at convection-permitting scales, it is still not possible to draw broader conclusions from these models on how sub daily rainfall will change under future climate change. But, there is reasonably support that changes in sub-daily extremes could be as large as 14 % per degree temperature increase.

Information on changes in the future for the short duration rainfall extremes is often missing in countries. Therefore, scaling with available data such as temperature can be used.

Based on the above information it seems most appropriate to use a scaling method whereby changes in rainfall extremes are set proportional to the change in dew point temperature.

2.2.3. Dealing with uncertainties

When deciding how to take climate change into account, keep the following aspects in mind:

- What is the life cycle of the asset one is working on? Determine the time horizon to take into account.
- Does one wants to be prepared for the worst case or a more average situation? Determine which projection or range of projections for the future to take into account.

3. Water management for roads in the face of climate change

3.1. *NRAs demands*

NRAs have recognized for a long time that climate change will have a significant effect on their assets and operations. In the current call specifically the challenges related to water management are addressed. This is logical since the damage caused by floods and rain to infrastructure assets amounts to €600 million annually, making it by far the dominant weather impact [21].

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 predictions into proper design and maintenance of water management systems.

The key problems for road owners and operators relating to successful water management resulting from climate change challenges include:

- Applying downscaled climate models to drainage design elements
- Examination of Sustainable Urban Drainage Systems on national road schemes and sensitivity to climate change
- How are climate analogues used for drainage design to decide on drainage alternatives? What methods are available and when are they of use or applicable in other countries
- How are model parameters to be used in a maintenance guide?
- How can the model parameters be incorporated into the NRAs standards for drainage design?

3.2. *Existing guidelines*

This chapter aims at describing the existing guidelines and basis of works for the WATCH project (non exhaustive list).

3.2.1. THE RIMAROCC framework

In the ERA NET ROAD[6] call (2008) “Road owners getting to grips with climate change” the topic of climate change and the way road authorities should deal with it was raised. RIMAROCC (Bles et al., 2010) [1] was one of the results of that call, providing a risk management based framework for decision support for road owners dealing with climate change. Seven general steps help road owners and operators in identifying, analysing, prioritizing, evaluating and mitigating climate change risks.

[6] Coordination and Implementation of Road Research in Europe

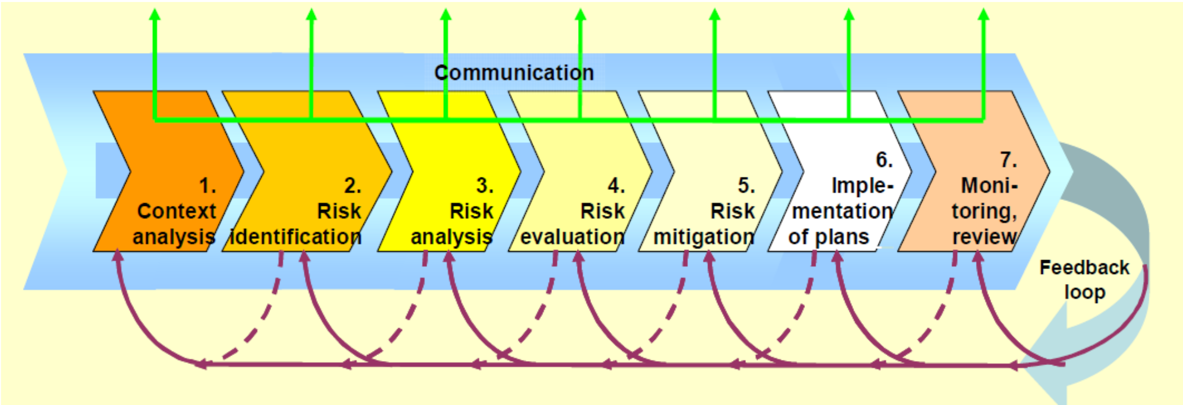

Figure 5: The RIMAROCC framework

The RIMAROCC framework consists of seven key steps and 22 sub-steps. For a detailed description of the different steps a reference is made to the RIMAROCC guidebook (Bles et al., 2010) [1].

3.2.2. The ROADAPT guidelines

The ROADAPT project [2] is part of the CEDR Call 2012 'Road owners adapting to climate change' in which is stated that one of the most important tasks of the road owners is the prioritization of measures in order to maximize availability with reasonable costs. This includes a risk based approach addressing causes, effects and consequences of weather related events to identify the top risk that need to be taken action on with mitigating measures.

ROADAPT aims at a further development of the RIMAROCC framework into practical and useful methods for road owners and road operators. Output of the ROADAPT project is one ROADAPT-RIMAROCC integrating guideline containing different parts (Figure 6):

- A. Guideline on the use of climate change projections
- B. Guideline on the application of a QuickScan on climate change risks for roads
- C. Guideline on how to perform a detailed vulnerability assessment
- D. Guideline on how to perform a socio economic impact assessment
- E. Guideline on how to come to an adaptation strategy

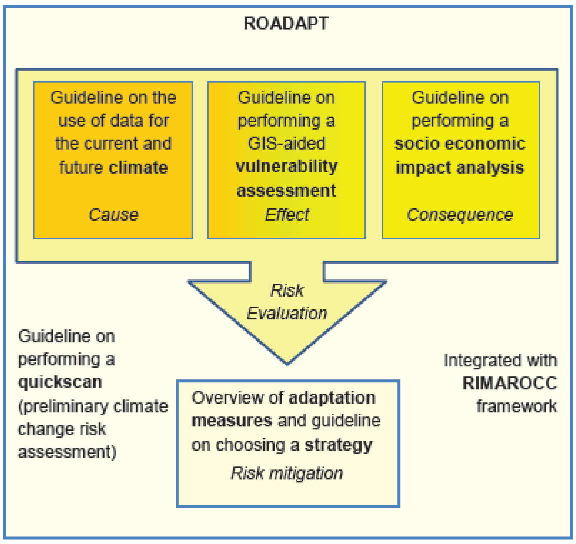

Figure 6: Contents of the ROADAPT guidelines

3.2.3. The SWAMP[7] guidelines

The SWAMP project [3] is part of an ERA-NET ROAD initiated transnational research programme called "Road Owners Getting to Grips with Climate Change".

The SWAMP project targets the critical issue of finding the most vulnerable parts of the road network, and how to prepare them for flooding.

Areas close to roads that are prone to flooding are referred to as blue spots in the SWAMP project reports, corresponding to e.g. black spots denoting serious accidents on the road network. The objectives of the SWAMP project were to determine the structure and requirements of a model to find blue spots, and produce guidelines on how to reduce vulnerability to flooding at blue spots.

[7] Storm Water prevention - Methods to Predict damage from the water stream in and near road pavements in lowland areas

4. Current European water management protocols

The information provided in this chapter is described more elaborately in the document "Country comparison report" (Bles et al., 2018) [16].

4.1. Country comparison

In this chapter, similarities and differences between the different countries presented in the figure below are discussed. All input for this comparison originates from country analyses for which interviews and a literature study were used. 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 office.

Figure 7: Investigated countries for the comparison are coloured pink

4.1.1. 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.

Reference is made to country comparison report (Bles et al., 2017) [16] for a list of the different assets.

4.1.2. Sources of climate data

In general, the NRAs obtain the climate data for the current and future climate from the National Meteorological Institutes (based on statistical analysis of historical data).

The following conclusions come from Bessembinder et al., 2018 [17]

- Different reference periods with historical data are used in the various countries, and it is often difficult to find which historical period was used as the basis for the rainfall statistics and Intensity/duration/Frequency (IDF) curves. With a changing climate it becomes more important to be clear about the basic or reference period.
- For the generation of rainfall statistics often long time series of rainfall are needed. These time series may contain trends. In most statistics it is assumed that the past climate is static. In the Netherlands the statistics were corrected for the observed trend in rainfall extremes. In Sweden and also in the Netherlands for the short rainfall durations (up to a few hours) only a relatively short and recent period is used where no trend can be detected. To get enough data for the statistics, data from a large number of stations is “pooled together”. This can only be done in regions with no clear regional differences in rainfall extremes. In some countries it is indicated that extremes increase, but that it was still assumed that there were no changes over the period used (methods for correcting for the trend only have been developed recently). E.g. this is done for Ireland, and it is indicated that therefore the statistics/IDF-curves may underestimate the rainfall extremes.
- There is a large difference between countries in the availability of data on rainfall: observational data sets aren’t available freely in all countries, data sets on short durations (less than 1 hour) are rare, statistical information on rainfall extremes is available freely in some countries and in others a fee has to be paid, in some countries gridded products are made from the stations data in others not. in some

countries rainfall radar data at high resolution is available and/or high resolution (temporal and spatial) climate modelling results are available.

- When countries take into account climate change, they may use different methods. In most cases a percentage is added to take into account climate change. Regularly, it is not mentioned explicitly whether this percentage has to be added to the rainfall amounts for certain return times or whether this percentage is used for the derived impact (e.g. run-off), and often it is not possible to find how this percentage was determined and for what time horizon this should be used. It would be very useful to make this more explicit, since that makes the users aware of how up-to-date the percentages are. It would also make clear when these percentages should be adjusted or up-dated (when a different life cycle for the assets is used or when new scientific information or climate scenarios become available).

4.1.3. 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.

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 count 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 count for specific locations, but many 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 1: Return periods that are required in different countries for design of storm water run-off (precipitation on the road)

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.

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.

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 NRAs themselves (or at least under their responsibility). In the Netherlands however, the NRAs 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 2: Return periods that are required in different countries for run-off flooding

4.1.4. Maintenance and operations approach

Three maintenance approaches seem to be adopted by the NRAs:

- 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.
  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 al.erts 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.

4.1.5. 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 NRAs. 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 NRAs 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 the 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.

4.1.6. Sustainable Drainage Systems

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.

4.1.7. 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.

4.1.8. 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.							

Table 3: Summary of water management and climate change throughout Europe

4.2. Conclusions

The most remarkable findings are summarized in the list below.

- Type of assets: A big variety of assets for water management by NRAs exists. In the same time many similarities occur between countries.

- Guidelines / criteria:

    - Detailed design guidelines exist in all countries except for Scandinavian countries where 'no general policies' are present and works are predominately carried out on local terms, governed by local characteristics.

    - 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 CBAs.

    - 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:

    - CBAs 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.

    - CBAs 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.

MANUAL

Introduction

The following methodology focus on existing roads as it represents the primary area of water management challenges of NRAs.

For new roads, recommendations are provided in the chapter "Proposition of additional criteria to be incorporated in standards".

According to the NRAs demands, the scale of the study, the complexity of the area and the knowledge of the assets, two methods are proposed:

- Part A – High level risk analysis / prioritization of the road assets / adaptation strategies
  Part A is a screening method aiming at highlighting the vulnerable assets.
  Part A:
    - is appropriate for section or network scales,
    - enables a comparative analyse of the structures,
    - does not need detailed data (especially topographical data)
    - does not involve calculations (hydrology or hydraulic)

- Part B - Detailed risk evaluation / adaptation measures and strategies
  Part B is a detailed method for assessing current and future resilience of assets. This assessment aims at defining and planning adaptation measures.
  Part B:
    - is appropriate for a single structure / a particular storm drain system
    - is appropriate for a structure defined as high priority from the high level risk analysis method or already known as highly vulnerable,
    - enables a detailed socio-economic analysis for decision making
    - needs detailed data
    - needs hydrological and hydraulic calculations.

The user can use Part A or Part B analysis approach independently of each other depending on the specific application. **However, typically Part A High level analysis is carried out initially, and subsequently usually followed by a Part B analysis.**

The WATCH decision tree (figure 8) provides how to implement the various parts:

- If the vulnerable assets have already been identified, the user can go straight to the part B approach
- If not, a prerequisite (reference stage) needs to be established in order to define the studied area and the scope of the study. To do so, the user should carry out a first assessment of existing knowledge of water management assets and climate change
    - For large spatial extent accompanied by a low knowledge of assets, the user should proceed on part A following by part B
    - If the vulnerable assets are known, the user can go straight to the part B approach.

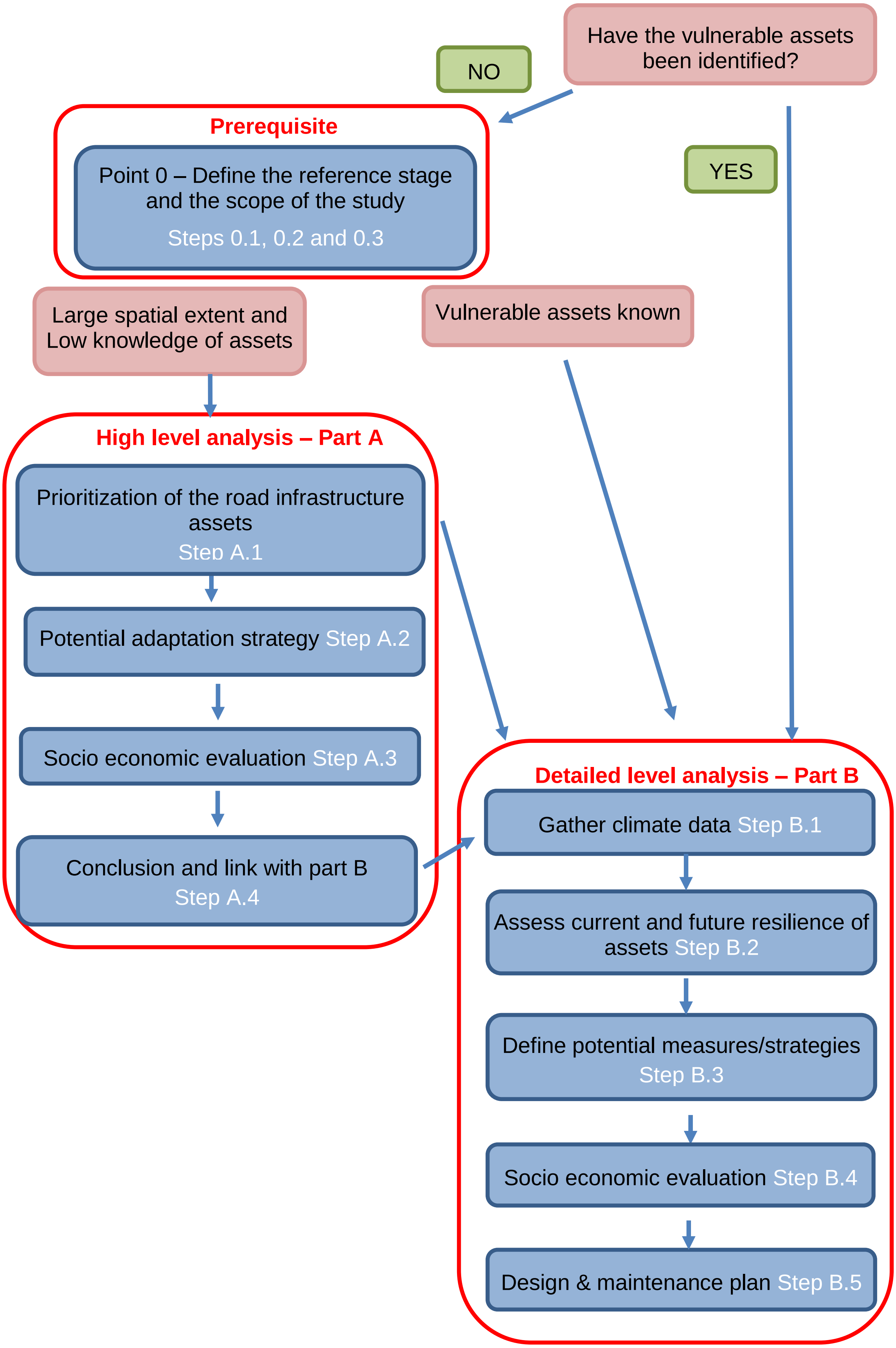

Figure 8: WATCH decision tree

The following table provides an overview of the steps and sub-steps for each part of the manual.

Part	Steps	Sub-steps
0 Prerequisite		
	0.1 Define the studied area and the scope	
	0.2 Existing knowledge on water management related to climate change	
	0.3 Conclusion and link with risk analysis	
A High level risk analysis / prioritization of the road assets / adaptation strategies		
	A.1 High level risk analysis / prioritization of the road assets	
		A.1.1 Selection of the most relevant criteria
		A.1.2 Evaluation / scoring of the criteria
		A.1.3 Weighting of the criteria
		A.1.4 Aggregating the weighted criteria for prioritizing the road assets
	A.2 Defining adaptation strategies	
	A.3 Performing a socio-economic analysis	
	A.4 Conclusion and link with part B	
B Detailed risk evaluation / adaptation measures and strategies		
	B.1 Gathering required climate data	
	B.2 Determining current and future resilience of assets	
		B.2.1 Asset inventories
		B.2.2 Defining hydrological data
		B.2.3 Determining asset functioning
		B.2.4 Asset risk evaluation in the context of the infrastructure
		B.2.5 Integration in a Road Asset management System
	B.3 Defining possible measures/strategies	
	B.4 Performing a socio-economic analysis	
	B.5 Finalisation of applicable/appropriate strategy	
		B.5.1 Identifying the best strategy
		B.5.2 Action planning
		B.5.3 Implement action plan
		B.5.4 Monitoring, review and capitalisation

Table 4: Overview of WATCH steps and sub-steps

The steps and sub-steps are structured as follows:
a) Objectives – describes the objectives
b) Output – describes the outcome
c) Method – presents the recommended methods or procedures
d) Data collection – describes what data is needed
e) Examples – each (sub)-step is provided with an example to improve readability.

Prerequisite – Point 0 – reference stage

01. Step 1 – Define the studied area and the scope

a) Objectives

The goal of this step is to define the studied area and the scope of the study.

b) Output

The output will be a description and/or a map of the studied area accompanied by the elements that enabled to define the scope and the objectives.

c) Method

Defining the studied area and the scope is a choice that needs to be made by the NRA.

It could be a consistent analysis in a long-term perspective in order to elaborate an action plan on the scale of a whole network or territory or a short-term decision on critical points.

It could come from questions asked by the management, workshops organised within the NRA, questions raised by an adjacent project, recent flooding event, etcetera.

The method can be based on:

- ROADAPT-Quickscan-part B-step1.1 [2]
- RIMAROCC – steps 1.1 and 1.2 [1]

The following sub-step 02 will also help to confirm the scope of the study.

d) Data collection

The data collection should take into account political or management concerns, operational feedbacks, recent extreme rainfall event report, etcetera.

e) Example

The example originates from the WATCH - case study [20]. Only main results are provided here. Reference is made to the case study report for details.

Regarding the context of water management in general at the Danish Road Directorate (DRD), reference is made to:

- Chapter 2.1 The DRD and water management
- Chapter 2.2 Process models
- Chapter 2.3 The Case Study Road

The study area is the M10 road (see figure below), leading into the greater area of Copenhagen. The M10 has been subject to construction over a longer period and can thereby be regarded as updated in terms of capacity and dimensioning of present water management systems along the entire stretch.

Applying the WATCH model will enable further insight into whether the current state and capacity of the water management on M10 can be considered adequately resilient to ensure safety and mobility as planned.

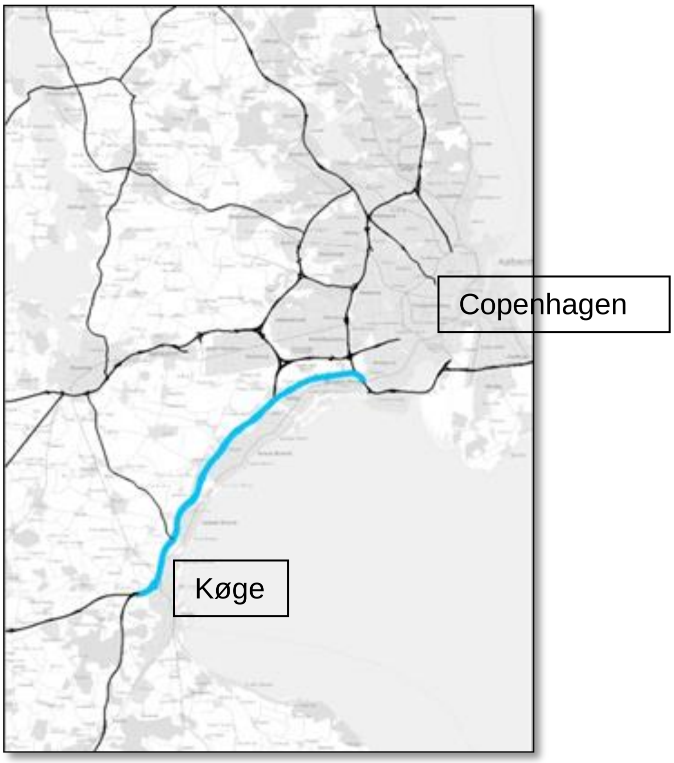

Figure 9: Location of M10 (marked blue), Denmark

02. Step 2 – Assess existing knowledge on water management related to climate change

a) Objectives

The goal of this step is to identify if global assessments related to drainage asset and/or climate change already exist within the studied area.

It enables to have a first knowledge of the studied area and the existing assets and to define the objectives of the study in order to implement part A and/or part B of the manual.

All existing studies are useful even if these are not only dealing with drainage assets and climate change.

If no such assessment exist, it is recommended to perform a risk assessment.

b) Output

The output is a report regarding existing assets and existing or newly risk assessments done.

The report should highlight data related to water management and climate change.

c) Method

If existing studies are identified, the method is to gather the elements in order to emphasize the knowledge related to water management and climate change.

For performing new global assessments, references are made to (non exhaustive list):

- QuickScan from ROADAPT [2],
- ROADAPT Part C (vulnerability assessment) [2],
- SWAMP - Blue Spot Concept - Possible methods to predict and handle flooding on highway systems in lowland areas [3],
- Any other risk assessment.

d) Data collection

Data related to drainage assets and climate change impact are gathered from (not exhaustive list):

- Desk study
  - From NRAs (existing studies, existing monitoring, etcetera)
  - Existing studies (flood studies, design studies)
  - Workshops
- Survey: Site visit / Interviews (residents, associations, administrations, etcetera)

Then extract interesting data/analysis regarding water management assets and climate change.

The following elements could be useful:

- Asset data:
  - Number of assets
  - Types/features of assets
  - Construction year
  - State of maintenance
  - Expected remaining lifetime of assets
- Hazard data:
  - Hazard maps
  - Vulnerability maps
  - Risk maps

- Climate change:
    - Was climate change considered in the design of the assets in the study region (see also table below and appendix 1)? If yes, what change was taken into account?
    - Is an increase of extreme rainfall expected during the life cycle?
    - What are the expected effects on related hazards (qualitatively) if extreme rainfall will increase?

Country	Rainfall durations	Return times	Climate change[8]
Austria	15 min up to 6 days	1 to 100 years	Not used for design
Denmark	?[9]	10-25 years	Danish government dictates scenario A1B (IPCC, 2007) must be used for operations of infrastructure. Climate change adaptation strategy and action plan is currently set into effect
France	6 min to 24 hours (or 48 hours)	1 to 100 years	Not used for road drainage design, but often checked if asset can manage factor 1.5/1.8 of peak flow + safety margins
Germany	?	?	Recognized that climate change may have impact, but not taken into account explicitly due to difficulty to quantity impact
Ireland	2 min up to 6 hours	1 to 100 years	+ 20 % for design flows and rainfall intensities
Netherlands	10 to 120 min	10 to 250 years	% based on climate scenario with largest increase for around 2050 (+30%)
Norway	10 min to 24 hours	50 to 200 years	By multiplying the design water flow by a climate factor, factors up to 40% based on location and catchment size
Sweden	?	3 to 200 years	Currently not taken into account, but climate change strategy and action plan for future road management is currently being implemented
United Kingdom	2 min up to ?	1 to 100 years (200 years for Scotland)	+ 20 % for design flows and rainfall intensities

Table 5: Used return times and rainfall duration in various countries and used approaches to take climate change into account for road design, (Bessembinder et al., 2018) [17].

[8] Hardly ever it is mentioned for which time horizon (or length of life cycles) the percentages increase in extreme rainfall for road design have to be applied.
[9] ? = could not be found with the information from the WATCH country comparison report, or complete document could not be found and read through internet.

e) Example

The example originates from the WATCH - case study [20]. Only main results are provided here. Reference is made to the case study report for details.

The water management assets along M10 have recently been updated, if needed, in relation to a lane-widening process newly undergone. Therefore, the knowledge of existing assets of water management is considered high and the mentioned update has been carried out in accordance with road standards which indirectly are conducted as risk analyses since the standard have built-in buffers.

In regards to climate change knowledge and awareness, the Danish Road Directorate has developed and incorporated a specific strategy on climate change adaptation, which thereby attest an acknowledgement that a changing climate will entail a consequence and risk towards road management as currently known. This is considered particularly consequential within management of water and especially precipitation.

As an example of integrated risk analysis, the CEDR SWAMP project [3] resulted in a Blue Spot model, which was subsequently custom tailored to analyses risk of flooding on Danish roads with Danish data input. The blue spot analysis is now an implemented risk analysis tool and is a part of the process model. **Studies have showed no blue spots on M10.**

As a limitation of the blue spot model, this approach concentrated solely on precipitation and thereby indirectly focused on the adequacy of pumps and retention systems coping with pluvial flooding. A more comprehensive risk analysis with another approach, yet more simple in approach, the QuickScan approach was applied as case study during the ROADAPT project [2]. The QuickScan approach provides a methodology which assesses main risks that can be related to extreme weather occurrences. As approach, the objective of the QuickScan is to gather all data and information by congregating relevant knowledge from experts and practitioners who have historical knowledge on the respective road of subject.

During the ROADAPT case study, the M10 did indeed show to have a particular area of risk. This is illustrated in the figure below, taken from the ROADAPT case study [2].

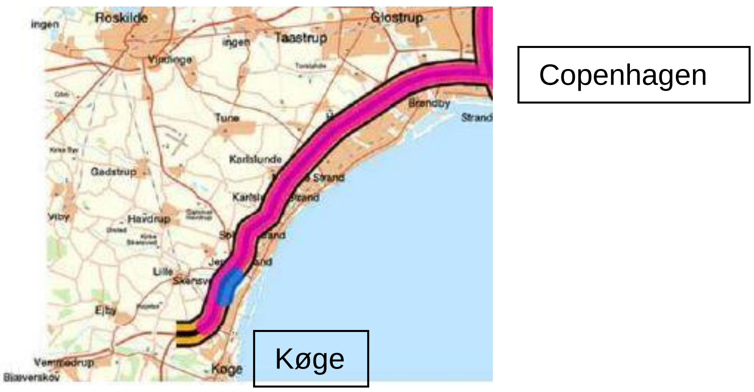

Figure 10: The M10 motorway in Denmark; the blue marking represents a vulnerable road stretch to flooding due to low capacity of stormwater runoff [2]

The road stretch which was identified as vulnerable was appointed on more factors then merely precipitation, namely including more risk factors such as crossing streams, weakening of road embankment, inundation from coastal regions and groundwater rise. This is further elaborated in the final ROADAPT report [2]

Applying the ROADAPT QuickScan approach on M10 showed to be fruitful and a risk was identified, and the results were published and disseminated through the final report. The result, however, was not incorporated in the tendering processes as a particular stretch or spot of interest for the later lane-widening on M10.

03. Step 3 – Conclusion and link with risk analysis

a) Objectives

The goal of this step is to conclude on which approach should be carried out: High level (part A then part B) or detailed level risk analysis (part B).

b) Output

The output is a report defining what will be the following steps.

c) Method

Generally, the scale of the analysis involves a particular approach:

- For a large scale study (territorial, network), it seems more interesting to begin with a high level analysis (part A) in order to define vulnerable assets or vulnerable stretches of road (if it hasn't been done before during a global risk assessment). This analysis is followed by a detailed level analysis (part B) in order to define an action plan (heavy works to implement on high risk assets and general measures for the rest of the water management assets)
- For a small scale study (section, structure), it seems more interesting to go straight to a high level analysis (part B).

If the previous step 0.2 concluded that vulnerable assets are known or that the studied area is homogeneous and of a low spatial extent, the critical assets should be assessed using detailed level risk analysis (Part B).

If the studied area shows a large spatial extent and few knowledge on asset, the user should proceed on high level analysis (part A).

d) Data collection

No additional data collection are needed in this step as it is only a conclusion of the previous steps 0.1 and 0.2.

e) Example

The example originates from the WATCH - case study [20]. Only main results are provided here. Reference is made to the case study report for details.

As stated in step 0.2, no blue spots were highlighted on M10 and only one area is meant to be a vulnerable stretch to flooding according to ROADAPT Quickscan.

Therefore, according to the WATCH decision tree, a possible next step could be to perform a detailed level analysis (part B of the manual) on the only stretch recognized as vulnerable (flooding due to low capacity of storm water runoff).

Nevertheless, it could be also interesting to perform a high level analysis (part A of the manual) to focus on storm water drainage assets and confirm or infirm the vulnerable assets. Indeed, the ROADAPT Quickscan [2] also stated that some risks were considered difficult to mark on maps based only on experience and the maps. The participants agreed that a more accurate and detailed identification of risk locations can be done.

A - High level risk analysis / prioritization of the road assets / adaptation strategies

A.0 Introduction

Usually, for NRAs the only requirements for water management assets are provided in terms of return periods that they should be able to cope with, sometimes in relation to some form of criticality (related to the consequences in the high level analysis). Due to climate change, many existing assets however will not comply with these standards. If the standards are taken literally, measures need to be taken for all assets in order to comply again with the current requirements and to be adapted towards future climate change. However, this will be very costly. Therefore, we propose a risk based analysis to identify those assets that have a higher priority for measures compared to other assets. This high level risk based analysis uses besides the threat and vulnerability (return period of the threat compared with the sizing of the asset) also the other risk ingredient being consequence of failure.

The goal of this part is to prioritize the road assets according to the risk level in order to:

- define a global strategy,
- launch detailed risk analysis and socio-economic analysis on high priority facilities (part B of the manual)

This analysis has to be done for each type of assets (reference is made to introductive chapter 1.4 for details):

- Assets dealing with water crossing the road (run-off flooding)
- Assets dealing with precipitation on the road (conveyance field)
- Assets dealing with precipitation on the road (quantity and quality aspects)
- Assets preventing pluvial flooding (water besides the road)

This part is divided into 4 main steps:

- A1 Global risk analysis / prioritization of the road assets
- A2 Defining adaptation strategies
- A3 Performing a socio-economic analysis
- A4 Conclusion and link with part B

A.1 Step 1 – High level risk analysis / prioritization of the road assets

A.1.0 Introduction

The high-level risk analysis aims at screening the water management assets in order to highlight those to be analysed further in part B.

The screening should be based on the definition of the risk that is a function of threat, vulnerabilities and consequences [1].

Three levels of analysis are proposed:

- asset types level: This method aims at defining the type of assets (crossing structures, longitudinal drainage…) which requires urgent analysis
- asset level or asset-class level: This method aims at prioritizing assets that will need further analysis.
  The 'asset-class' level can be chosen when the level of detail required for the asset types is perceived being too high. The water management assets can be classified in sub groups, based on:
    - extrinsic site factors (e.g. topography, land use, road network redundancy, economic importance),
    - infrastructure intrinsic factors (e.g. age of assets, number of driving lanes, traffic) and
    - hazard level (if this isn't homogeneous over the project).

  The asset-class level is interesting in a very homogeneous area where the assets are easily comparable.

It can be interesting to perform firstly an analysis on asset type level in order to know which asset type should be studied in priority followed by an analysis on this critical asset type.

Whatever the level, the proposed method is divided into four sub-steps:

- A1.1 Selection of the most relevant criteria for the risk analysis
- A1.2 Evaluation of the criteria
- A1.3 Weighting of the criteria according to their relative importance
- A1.4 Aggregating the weighted criteria for prioritizing the road assets

A.1.1 Sub-step 1.1 – Selection of the most relevant criteria

a) Objectives

The goal of this sub-step is to select the most relevant criteria.

b) Output

The output is a table showing the chosen criteria.

c) Method

The relevant criteria are chosen to describe the three components defining the risk [1]:

- Threat
- Vulnerabilities.
  This component should be split into intrinsic and extrinsic factors.

The intrinsic factors of vulnerabilities represent the elements which have an impact on the hydraulic functioning of the asset: sizing return period, state of maintenance, road features, low point…
The extrinsic factors of vulnerabilities are related to the socio-economic context: traffic volumes, road network redundancy….

- Consequences: The consequences represent the effects of the unwanted threat (modified due to climate change) on the asset, the infrastructure and the environment: impact on safety, costs…

The criteria need to be chosen in order to be discriminative. Indeed, the choice of the criteria should be done in view to differentiate the assets thanks to the notation in the following sub-step.

For the asset level and considering current and future climate, the criteria that seem interesting are provided in the following tale:

<table>
<tr><th rowspan="3">Asset category</th><th colspan="4">Risk component</th></tr>
<tr><th rowspan="2">Threat</th><th colspan="2">Vulnerability</th><th rowspan="2">Consequences</th></tr>
<tr><th>Intrinsic factor</th><th>Extrinsic factor</th></tr>
<tr><td>Assets dealing with water crossing the road (run-off flooding)</td><td rowspan="4">- Hazard
- Likelihood
- Exposure</td><td>- Sizing return period
- Age of the structure
- State of maintenance
- Fill height</td><td>- Traffic volumes
- Road network redundancy
- Economic importance</td><td rowspan="4">- Maintenance & Serviceability Issues (i.e. repair costs)
- Environmental costs
- Societal Impacts & Requirements (effect, costs)
- Safety Constraints & Impacts</td></tr>
<tr><td>Assets dealing with precipitation on the road (conveyance field)</td><td>- Location of the storm drain system (high vulnerability for system in cut, low points, counter slope area, safety structures, low profile, profile in cut…)
- Structure state of maintenance</td><td>- Traffic volumes
- Road network redundancy
- Economic importance
- Environmental constraints (sensitive ground water, water extraction area…)</td></tr>
<tr><td>Assets dealing with precipitation on the road (quantity and quality aspects)</td><td>- Facilities in Fill
- Existence of emergency spillway or weir
- Structure State of maintenance</td><td>- Traffic volumes
- Economic importance
- Environmental constraints (sensitive receiving water…)</td></tr>
<tr><td>Assets preventing pluvial flooding (water besides the road)</td><td>- Natural low point close to the road without crossing structure
- Fill height</td><td>- Traffic volumes
- Road network redundancy
- Economic importance
- Environmental/surroundings constraints (urban area, sensitive natural area…)</td></tr>
</table>

Table 6: Proposition of relevant criteria

It is highly recommended to verify that the chosen criteria are not redundant.

Obviously, the user can add other criteria or modify some criteria as needed.

d) Data collection

The data collection is done thanks to (non exhaustive list):

- Desk study
  - From NRAs (existing database, drawings, as-built drawings, inspection documents)
  - Existing studies (flood studies, design study)
  - Workshops within the NRA
- Survey
  - Site visit (dimensions, protection, pictures)
  - Interviews (residents, associations, administrations)

e) Example

The two examples described below and within the whole step A.1 originate from the WATCH - case study [20]. Only main results are provided here. Reference is made to the case study report for details.

Two approaches were used in the case study: a screening inspired by the ROADAPT QuickScan methodology to identify asset type at risk (asset type level) and a screening based on the WATCH manual-methodology to identify the most vulnerable assets (assets level).

<u>Screening using the ROADAPT QuickScan method</u>

At this asset type level, the two chosen criteria are:

- Likelihood of failure
- Consequence of failure

<u>Screening based on the WATCH manual-methodology</u>

At this asset level, the chosen criteria for assets dealing with water crossing the road are the following:

- Threat:
    - Hazard : extreme rainfall values
    - Likelihood
    - Exposure
- Vulnerabilities:
    - Intrinsic factors:
        - Sizing return period
        - Age of the structure
    - Extrinsic factors:
        - Traffic volumes
        - Road network redundancy
- Consequences:
    - Maintenance & Serviceability Issues (i.e. repair costs);
    - Environmental costs;
    - Societal Impacts & Requirements (effect, costs); - linked to the economic importance of the area (could be also in extrinsic factors but is redundant)
    - Safety Constraints & Impacts – linked to the road features and fill height (could be also in extrinsic factors but is redundant)

A.1.2 Sub-step 1.2 – Evaluation / scoring of the criteria

a) Objectives

The goal of this sub-step is to score the criteria for current and future(s) stage(s).

b) Output

The output is a table summarising the score of the criteria for each case studied.

c) Method

The step begins by defining the cases to study:

- Current stage
- Future(s) stage(s):
    - Establish a horizon to study. It could be according to road longevity, concession duration, scope of the study
    - Define climate scenarios to study (2 or 3 scenarios)

Then for each cases, each criterion (defined in sub-step A.1.1) may be scored according to 4 classes: Low (1), Medium (2), High (3), Very High (4) that may be define qualitatively (maintenance, economic importance…) or semi-quantitatively (fill height, traffic volumes…)

The qualitative or semi-quantitative scoring depends on evaluation methodology adopted and concerned criteria.

The scoring can be done by gathering experience and expertise from relevant staff within the NRA, desk study and surveys from designers or consultants, etcetera.

For the threat evaluation, it is not necessary to have very detailed information about the current and future climate. It is enough to have a qualitative idea about the current climate and its impacts and whether extreme rainfall will increase in the future and what are the impacts.

d) Data collection

The data collection method depends on evaluation methodology adopted and concerned criteria. As mentioned before, the evaluation can be done by gathering experience and expertise from relevant staff within the NRA, desk study and surveys from designers or consultants, etcetera.

e) Example

As stated before, the two examples described below and within the whole step A.1 originate from the WATCH - case study [20].

<u>Screening using the ROADAPT QuickScan method</u>

Determining the degree of likelihood and consequence for risk analysis, experience and expertise from relevant staff was gathered to identify vital factors to include. These were as follows

- Historical data, knowledge and experience of the M10 in regards to vulnerability towards extreme weather occurrences
- Capacity, state, and age of assets
- Use of climate data in the road standards
- Evaluation on imperviousness in the catchment area

These factors were used to cooperatively assess the likelihood in the global risk analysis to provide a holistic view on the current probability of particular water related challenges on the M10.

Assessing the consequence of the respective failure of the identified assets in the global risk analyses is evaluated by including experience and expertise from relevant staff to appoint essential factors to incorporate. These factors are as follows

- Annual average daily traffic (AADT)
- Road strategic importance
- Age of road
- Age of assets

Assessing consequence relates to the affect for the traffic flow and road safety in case of asset failure and the associated cost implication to repair or replacement of the given asset.

Taking climate change into account, the scoring is both conducted for the present day scenario and how the climate in the year 2030 will affect the risk assessments of the water management assets.

The scores for likelihood and consequence are as defined below. All are in relation to what the specific asset is dimensioned for and all scores are set by evaluating and taking into account the current state of resiliency.

Score	Frequency	Explanation
4	*Very likely*	*More frequent than every 5 years*
3	*Can occur*	*More frequent then every 10 years*
2	*Seldom*	*As dimensioned for*
1	*Very seldom*	*Less frequent than dimensioned for*

Table 7: Illustration of likelihood scores

Score	Degree	
4	*Catastrophic*	*Causing significant material damage and/or human injury / fatalities*
3	*Very significant*	*Substantial traffic disruption and potential overload of adjoining roads*
2	*Noteworthy*	*As dimensioned for*
1	*Insignificant*	*No remarkable consequence assessed*

Table 8: Illustration of consequence scores

The scores from the risk assessment of failure are illustrated in the table below

		Present day		Climate 2030	
ID	**Asset**	**Likelihood**	**Consequence**	**Likelihood**	**Consequence**
1	Retention systems	1	2	2	2
2	Culverts	1	3	2	3
3	Pumps	2	2	3	2

Table 9: Illustration of the risk assessment score for the present day climate and, as assessed, in 2030 provided an as is-strategy is chosen where no actions are taken to adapt the culverts to a changing climate

Screening based on the WATCH manual-methodology

The following figure proposes thresholds to score the criteria.

				1.2.1 Elements to score the criteria				
Risk component		**Relevant criteria**	**Comments**	**Low impact (1)**	**medium impact (2)**	**high impact (3)**	**very high impact (4)**	**Comments**
Threat		Hazard : extreme rainfall events		improvement (decrease of extreme rainfall events)	stability	highly aggravation	very high aggravation	
		Likelihood		very seldom Less frequent than dimensionned for	seldom As dimensionned for	can occur More frequent than every 10 years	very likely More frequent than every 5 years	
		Exposure		very minor exposure (very low duration < hours and very local event)	minor exposure (low duration < 1 days and local event)	moderate exposure (moderate duration < 1 week and regional event)	high exposure (long duration > weeks and large event)	
Vulnerability	**Intrinsic factor of vulnerability**	Sizing return period		> 50 yrs	25 yrs	10 yrs	<10 yrs	
		Structure age		< 10 yr	10-25 years	25-50 years	> 50 yrs	
	Extrinsic factor of vulnerability	Traffic volumes		< 1 000 veh/j	1000 to 10 000 veh/j	10 000 to 50 000	> 50 000 veh/j	to adapt according to the area
		Road network redundancy		several other road available	equal road available	one smaller road available	no other road available	
Consequences		Maintenance & Serviceability Issues (i.e. repair costs)	Directs costs for maintenance and repair costs	less than 25 k€	between 25 and 100 k€	between 100 and 500 k€	above 500 k€	Direct costs
		Environmental costs : flooding of an agricultural land, floating debris…	Impact on the surroundings environment	no vulnerable area upstream	medium vulnerable area upstream (natural area)	high vulnerable area upstream (agricultural area)	very vulnerable area upstream (industrial area with possible pollution due to flooding)	Indirect costs
		Societal Impacts & Requirements (effect, costs) : flooding of a urban area, operation organisation image…	Impact on social surroundings (urban area, road network, reputation…) linked to the economic importance of the area	no vulnerable area upstream	medium vulnerable area upstream (natural, agricultural area) or very flat area	High vulnerable area upstream (urban area upstream, low road upstream)	very vulnerable area upstream (urban area, industrial area with possible pollution due to flooding….)	Indirect costs
		Safety Constraints & Impacts	linked to fill height above the culvert	Insignificant: No remarquable consequence assessed fill height > 2 m	Noteworthy As dimensioned for fill height : 80 cm to 2 m	Very significant: Substantial traffic disruption and potential overload of adjoining roads Fill height : 50 cm to 80 cm	Catastrophic Causing significant material damage and/or human injury / fatalities fill height :< 50 cm or low point in the vicinity	Direct costs

Table 10: Example of thresholds to score the criteria

The table below is an example of evaluation for 4 culverts and future stage: horizon 2030 + scenario A1B-IPCC. Left of the double line the scores for the current situation are shown and right of the double line the scores for the future are provided. This has been done for horizon 2030 and the scenario A1B-IPCC.The blue areas show the differences between current and future stage.

Risk component		Relevant criteria	Current climate: Culvert 1	Culvert 2	Culvert 3	Culvert 4	Future climate: Culvert 1	Culvert 2	Culvert 3	Culvert 4	Comments
Threat		Hazard : extreme rainfall events	2	2	2	2	2	2	2	2	
		Likelihood	1	1	1	1	2	2	2	2	climate change
		Exposure	1	1	1	1	1	1	1	1	
Total threat (1-4)			**1.33**	**1.33**	**1.33**	**1.33**	**1.67**	**1.67**	**1.67**	**1.67**	
Vulnerability	Intrinsic factor of vulnerability	Sizing return period	2	2	2	2	2	2	2	2	
		Structure age	1	1	1	1	2	2	2	2	increase of age of assets
	Extrinsic factor of vulnerability	Traffic volumes	4	4	4	4	4	4	4	4	
		Road network redundancy	3	3	3	3	3	3	3	3	
Total vulnerability (1-4)			**2.50**	**2.50**	**2.50**	**2.50**	**2.75**	**2.75**	**2.75**	**2.75**	
Consequences		Maintenance & Serviceability Issues (i.e. repair costs)	2	2	2	2	2	2	2	2	
		Environmental costs : flooding of an agricultural land, floating debris...	1	1	1	1	1	4	1	1	construction of an industrial area for example
		Societal Impacts & Requirements (effect, costs) : flooding of a urban area, operation organisation image...	1	1	3	1	1	1	3	3	construction of a urban area for example
		Safety Constraints & Impacts	3	3	3	3	3	3	3	3	
Total consequences (1-4)			**1.75**	**1.75**	**2.25**	**1.75**	**1.75**	**2.50**	**2.25**	**2.25**	

Table 11: Example of scoring

The scoring of the vulnerability is high due to the important traffic volumes of the M10. As the M10 is quite homogeneous especially regarding threat and vulnerability, the scoring variation is due to the consequences criteria.

A.1.3 Sub-step 1.3 – Weighting of the criteria

a) Objectives

The goal is to weight the risk components.

b) Output

The output is a table showing the chosen weighting of the risk components.

c) Method

Weighting the risk components according to the following factors, by order of importance:

- Significance of the risk component. Low threat level will result in low risk level, whatever the vulnerabilities. Similarly, without any vulnerability at stake, even very high threat will not generate high risks.
- Capacity of acting on the risk component. A risk component is given a higher weight than another one if it is easier to address it.
- Level of knowledge and uncertainties related to the risk components. For example, climate changes are subject to high uncertainties. As to the other risk components, the vulnerabilities may be relatively well identified, but the consequences may not have been really fully assessed.

The weighting exercise is rather subjective, and it is proposed to submit the weighting choices to a panel of experts and/or stakeholders in the territory under consideration.

Another possibility is to do a sensitivity analysis on weighting if the expert panel is not available.

d) Example

The following table provides the weighting retained for the screening based on the WATCH manual-methodology (WATCH - case study [20])

	sub-step 1.3 weighting of the criteria				
	significance	Capacity of acting	knowledge	global weighting	Proposed weighting
Threat	High	Low	Medium	Medium	0
Vulnerability	High	High	High	High	30%
Consequences	Low	Medium	Low	Low	-30%

Table 12: Example of weighting

A.1.4 Sub-step 1.4 – Aggregating the weighted criteria for prioritizing the road assets

a) Objectives

The goal is to aggregate the weighted criteria for prioritizing the road assets.

b) Output

The output is a final screening/ranking of the assets.

c) Method

<u>Aggregating the criteria</u>

The final score for each element is the arithmetic mean of the three risk components (threat, vulnerability, consequence).

Two sets of values may be tested:

- 1.Using the risk component scores without weighting them (i.e. giving the same importance to each risk component);

- 2. Using the weighted risk component scores

Testing two sets of values will show if the final ranking changes or not. This is a sensitivity test allowing checking if the ranking is stable and robust. The classification obtained is more or less robust, and therefore the level of uncertainty about the results is higher or lower.

The elements having the highest scores are those deserving first priority for climate change adaptation.

<u>**Prioritizing the road assets**</u>

The total scoring for each studied type of assets split them into three subgroups: low, medium, high.

It is up to the panel of experts (or / and decision-makers) to determine the thresholds of acceptability (or at least to validate them, on the proposal of the Consultant).

The arithmetic mean may be enough to define the thresholds but risk matrix or triangle chart can also be useful for helping the panel of experts to choose or validate threshold values between low, medium and high risk levels.

It is also possible to define a redhibitory criterion that necessarily leads to unacceptable level: total absence of maintenance, sizing below 10 year return period…

The assets classified as high risk will be further detailed in part B in order to define adaptation measures. Of course, the user may decide to also further studied additional assets defined as medium if needed.

At that stage, the user can carry on with adaptation strategies or proceed to part B for detailed risk evaluation of the concerned assets.

d) Data collection

The main data are those gathered from the previous sub-steps (A.1.1, A.1.2 and A.1.3)

e) Example

As stated before, the two examples described below and within the whole step A.1 originate from the WATCH - case study [20].

<u>Screening using the ROADAPT QuickScan method</u>

Placing the scores obtained in sub-step A.1.2 in a matrix, as shown in figure below, it is evident that no assets are placed in the top-right part of the figure where immediate actions towards enhancing resilience are considered essential for current and future safety and mobility on M10.

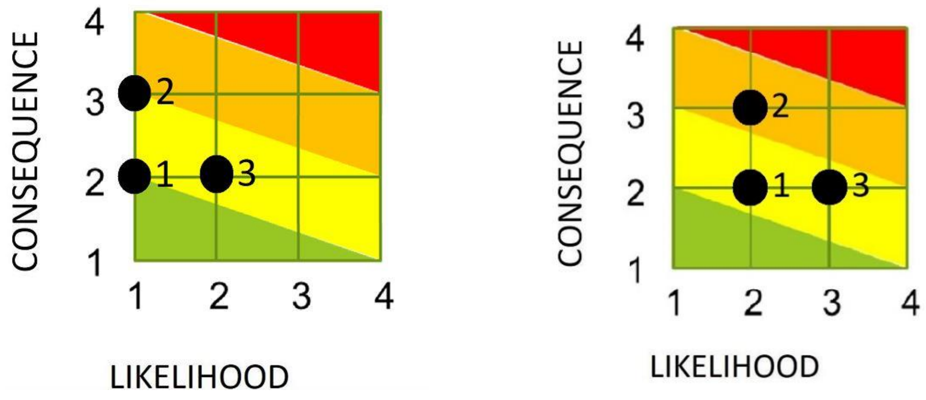

Figure 11: Illustration of risk scores placed in a matrix. 1 = Retention systems, 2 = Culverts, 3 = Pumps. Left: the risk assessment of the present day climate scenario. Right: illustration on how the climate change, as assessed, in 2030 will affect the risk assessments of the water management assets of an as is-strategy is chosen where no actions are taken to adapt the culverts to a changing climate.

The reason for the relatively low scores is chiefly driven by relatively low scores in likelihood. A key driver for these relatively low scores in likelihood is the recent lane-widening construction which has resulted in new or updated assets and road construction and a recent assessment of construction needs to meet the water management criteria as mentioned in 1.2 on the entire stretch.

An exception for this general statement is pumps. The reason for this is that pumps are generally considered more vulnerable to failure since they can fail on account of more factors than culverts and retention systems, e.g. flooding-related, electricity shortcut, debris-related complications and more complex maintenance requirements.

On the other side, consequence is scored comparatively higher in the risk assessment.

The main drivers for this are, firstly, the age of the road and assets and, secondly, the high number in AADT. Culverts are given the highest score in consequence since this water management asset is regarded as causing the most substantial and immediate impact of road flooding if the asset should fail. The consequence of an asset failure leading to reduced safety and mobility, or even a complete stand-still, largely affects the society in various ways and will therefore inherently manifest in relatively high consequence scores.

As a result of the risk scores, culverts are identified as the asset type which needs first and foremost attention when adapting to climate change and will therefore be the focus asset for the further case study.

Screening based on the WATCH manual-methodology

For culverts as regarded as a crossing structure (water crossing the road), the retained acceptability scale is the following.

Acceptability levels		
Acceptability level = Low = below 2 for each criteria	Acceptability level = Important = 2 to 3 for each criteria	Acceptability level = Unacceptable =3 to 4 for each criteria

Table 13: Example of acceptability levels

Triangle charts are used as a risk acceptability matrix:

- The risk envelope is between 3 and 4 for each criterion: the risk can be considered unacceptable and retro-fitting is compulsory (new sizing of the culvert)
- The risk envelope is between 2 and 3 for each criterion: the risk can be considered important and rehabilitation is needed (reinforcement of the structure, erosion protection, etc.) but without requiring a reconstruction
- The risk envelope is below 2 for each criterion: no specific intervention is required.

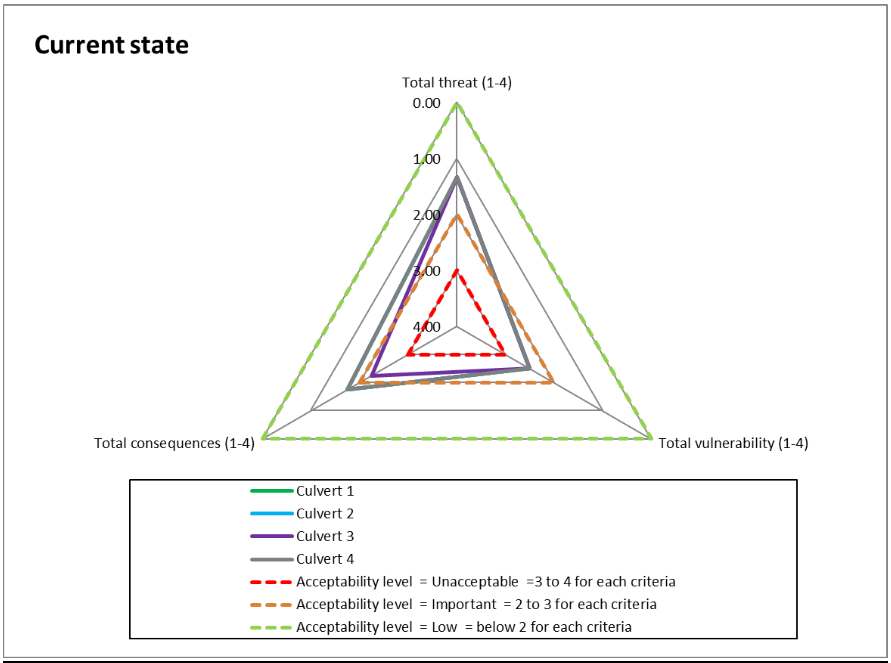

Figure 12: Example of risk matrix for current stage:

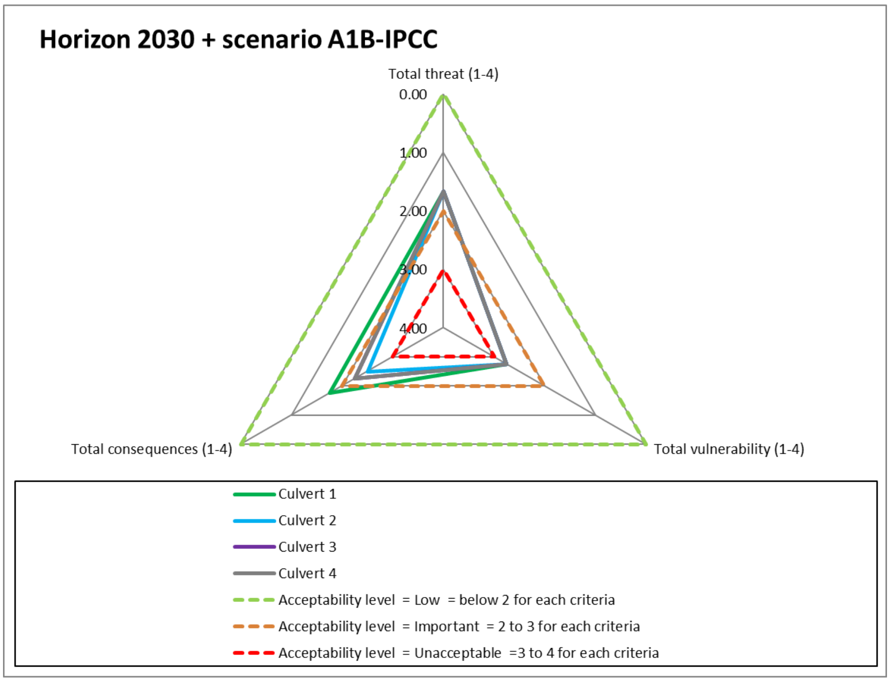

Figure 13: Example of risk matrix for future stage = horizon 2030 + scenario A1B-IPCC

The envelopes are asymmetrical for all the culverts, thus arithmetic mean of the three risk criteria (possibly weighted) is used to decide in which risk category to put it.

	Case 1 = current state				Case 2 = horizon 2030 + scenario A1B-IPCC			
Risk component	**Culvert 1**	**Culvert 2**	**Culvert 3**	**Culvert 4**	**Culvert 1**	**Culvert 2**	**Culvert 3**	**Culvert 4**
sub-step 1.4 Aggregating the								
Average without weigthing	**1.86**	**1.86**	**2.03**	**1.86**	**2.06**	**2.31**	**2.22**	**2.22**
Average with weigthing	**1.94**	**1.94**	**2.05**	**1.94**	**2.16**	**2.33**	**2.27**	**2.27**

Table 14: Illustration of categorization of risk criteria for various cases

For the current state, almost all the culverts are classified in the low acceptability level.

For the future stage, the scoring increases due to the increase of the threat, the rise of age of the assets and the potential developments near the road. All the culverts exceed the limit between low and important acceptability levels.

For this homogeneous road and quite small area, this global level analysis do not allow to clearly screen the culverts. In order to have a clearer view of the risks and according to the importance of this sketch of road (high scores related to traffic volumes and no equal alternative roads), the culverts should be studied at a more detailed level (part B of the manual).

A.2 Step 2 – Defining adaptation strategies

a) Objectives

The goal of this part is to define adaptation strategies according to the previous high level risk assessment.

b) Output

The output is water management strategy.

c) Method

For each type of assets, the previous step A.1 defined three risk levels: Low, Medium and High.

The general adaptation strategies proposed are the following, for each level:

- High level : measures are compulsory to decrease the impact of climate change and/or the consequences of it
- Medium level: adaptation measures possible according to available budget, context
- Low level: no compulsory measures / only accompanying or organisational measures such as monitoring/asset management.

For existing infrastructure and high risk level assets:

- If damages only on traffic, **develop contingency plans for being better prepared to manage emergency situations (improving resilience**). This is a "reactive" strategy especially relevant for risks showing more impact on traffic than on infrastructure
- If integrity on whole infrastructure at stake, **no-regret strategy** may be preferred (measures are already needed even without climate change) such as retrofit investments and strengthening infrastructure. When the integrity of the whole infrastructure is at stake and strengthened maintenance may not be enough, it may be necessary to plan investments for strengthening the infrastructure itself.

For existing infrastructure and medium risk assets, **strengthening preventive maintenance and inspection and monitoring** may be implemented.

For new road and new project, **safety margin strategy** can be an option.

d) Data collection – Available strategies

Within this part A related to the high level risk assessment, robust strategies are appropriate in the context of high uncertainties regarding rainfall extreme events and considering that they can be necessary even without climate change (no-regret strategies).

Also reversible and flexible strategies are highly recommended in the context of high uncertainties.

As developed in the ROADAPT QuickScan method [2], "*three types of measures are especially worth mentioning:*

- ***Research to reduce uncertainty and/or monitoring to answer:*** *is this a risk now and/ or is the climate changing so that this will become a risk in the future? In this strategy, it is assumed that risk knowledge has first to be improved before taking specific actions. This may result in better understanding of the current safety margin which provides insight weather the reliability is higher (or lower) than the demanded reliability.*

- ***Do minimum*** *(traffic management, business as usual). In this strategy, it is assumed that the risk can be managed through the current procedures, and in particular through traffic management (information of drivers, traffic restrictions).*

- ***Application of adaptation measures****. Several strategies are possible within this type of measures.*
    - *Update operation procedures to take account of the impact of climate change*
    - *Develop contingency plans for being better prepared to manage emergency situations (improving resilience). This is a "reactive" strategy*
    - *Strengthening preventive maintenance. This is a "proactive" strategy mainly aimed at avoiding major damage to the infrastructure*
    - *Retro-fit investments / strengthening infrastructure. When the integrity of the whole infrastructure is at stake and strengthened maintenance may not be enough, it may be necessary to plan investments for strengthening the infrastructure itself."*

Referring to ROADAPT Guideline part E - Selection of adaptation measures and strategies for mitigation [2], the following policy matrix proposes also different adaptation strategies.

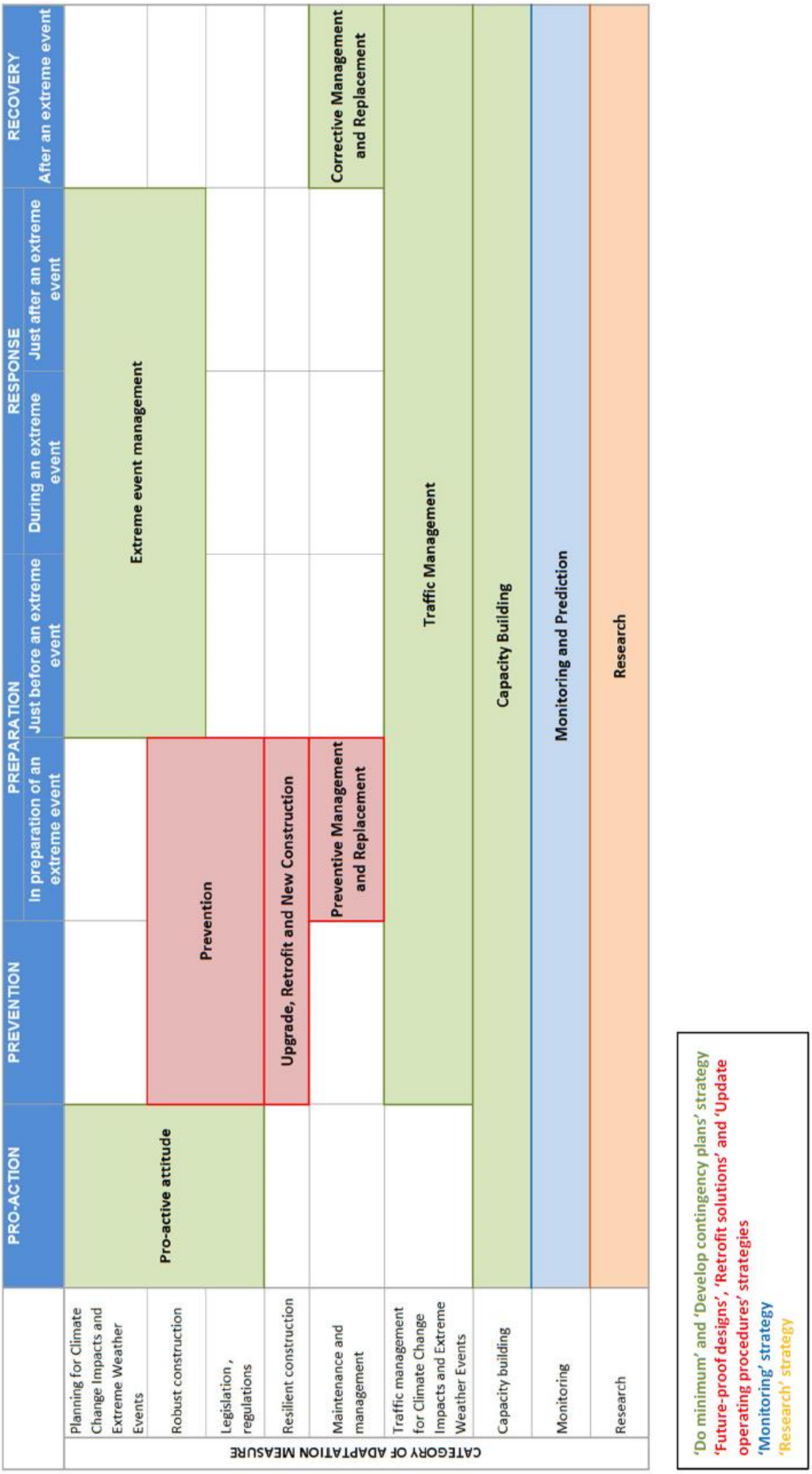

Figure 14: Policy matrix of ROADAPT

Different adaptation strategies can also be found in [7]:

- Wait and see (towards abandoning certain roads)
- Strengthening the preventive maintenance strategy
- Proactive hardening strategy
- Reactive hardening strategy
- Selection and scheduling of new investment strategy
- Modal and intermodal redundancy development strategy

e) Example

The example comes from the WATCH -case study [20].

Based on the preceding risk analysis, mitigating consequences can be conducted in various approaches, and most be assessed in relation to a status quo. The following points are the main arguments in this regard.

Firstly, a strategy of maintaining a current state, also referred to as an as is scenario, is important to include as a benchmark for mitigating measures. A status quo involves an acceptance of the current state and capacity of the water asset and thereby, implicitly, an acceptance of a high risk of flooding. On M10, the consequences of flooding is, as previously mentioned, assessed as particularly high due to the high number in AADT and strategic level.

A key argument of such strategy relies on a low associated, short-term cost of which resources can be allocated elsewhere to other regards of road management.

Secondly, a mitigating strategy of providing and/or redirecting more resource to update the water asset to enhance climate change robustness is identified and defined as a key strategy to follow and implement. The resource required to do so will require substantial input in form of additional analysis, labour, construction and material. Yet, for a road as M10, the heavy use, shown in AADT and strategic importance will cause a relative short break even time for such investment. The analysis will furthermore identify optimum basis for a prioritization of the asset of subject can be conducted.

As a final and third strategy to choose, revising or circumventing the current service criteria and strategy can be applied to manage the available resources, e.g. for single water assets or on a local scale. Such strategy is regarding as short-term, both in terms of resource management, e.g. on a single-year scale, and to live up to the current service criteria of handling flood risks.

A.3 Step 3 – Performing a socio-economic analysis

The information provided in this chapter is described more elaborately in the document "Socio-Economic Analysis Guidelines" (Tucker et al., 2018) [19]

a) Objectives

The objective of the Socio-Economic Analysis in Part A is to identify the best adaptation strategy, from step A.2, for an individual road drainage asset or sub-groups of drainage asset types that have been identified as a high priority asset or sub group of assets identified in step A.1.

In effect, the analysis at this level serves as a screening process aimed at highlighting vulnerable assets.

b) Method

The Socio-Economic Analysis framework developed as part of the WATCH project is shown in Figure 15. The framework is split into two phases, a Preliminary Assessment phase and Evaluation phase respectively and application of the framework involves addressing each step in the process sequentially. Further detail on the two phases and the steps within each phase can be found in Tucker *et. al* (2018) [19]

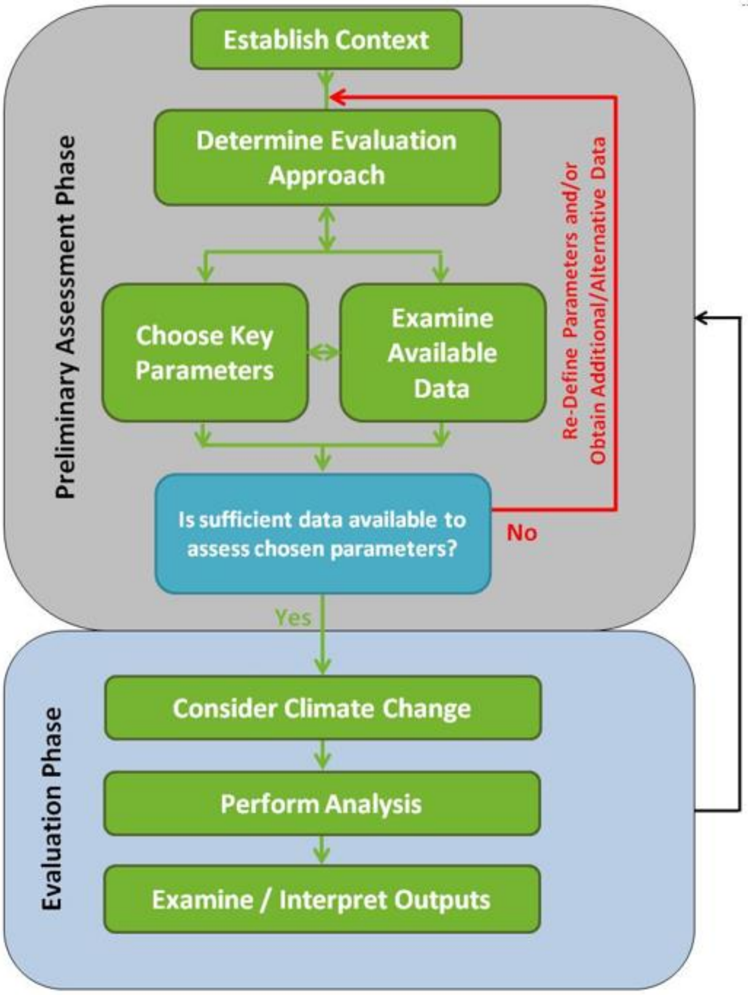

Figure 15: WATCH Socio-Economic Framework

At this level of analysis, an SEA is carried out to evaluate the best adaptation strategy for an individual asset or sub group of assets.

Typically (but not always) a Multi Criteria Analysis (MCA) evaluation approach is most suitable for this level of analysis as it is typically used for creating consensus building among stakeholders to create a common understanding between various disciplines and can be used when little or no quantitative information is available (though an MCA can include calculated or quantitative data). Note – other possible evaluation methods are described in Tucker *et. al* (2018) [19].

The assessment should be based on a set of key or hyper parameters. While any number of key parameters can be assessed for the Part A analysis the following items should be considered as a minimum;

- Maintenance & Serviceability Issues;
- Environmental issues;
- Societal Impacts & Requirements;
- Safety Constraints & Impacts;

This will require using global cost estimates of measures (e.g. construction and maintenance cost per km of storm water system). The cost estimates may be compared to the benefits, which will be aggregated at project level, because most benefits are related to the downtime of the infrastructure, i.e. the reliability of travel time. In the case of the Maintenance & Serviceability Issues parameter, for example, cost estimates in this case should consider for example;

- Cost of replacement parts/materials;
- Labour Costs (no. of people, day/night rates);
- Equipment costs;
- Costs for traffic management measures;

c) Data Collection

The source of data will depend on the parameter being assessed, but typically data can be should be collected in the following means or from the following sources;

- From previous similar projects;
- Desk study;
- Existing studies;
- Climatologists, meteorologists
- Environmentalists

d) Examples

Reference is made to WATCH - case study, chapter 2.3.4 [20] for more details.

Based on the qualitative ranking system chosen for the costs and impacts, the scores from the MCA analysis are tabulated in table 15 and table 16. A positive score indicates the impact has benefits or a lower impact for the DRD (e.g. less cost or increased safety). A negative score means the measure has disadvantages or a higher impact for the DRD (e.g. higher cost or decreased safety)

Strategy	Maintenance & Serviceability Issues	Environmental Issues	Societal Impacts & Requirements	Safety Constraints & Impacts	Averaged Total
As is (current state)	-2	-1	-2	-1	-1.5
Allocate Additional Resources for updating (Enlarge Culvert)	+1	+1	+1	+2	1.25
Updating or bypassing the strategy for service level	0	-1	-2	-1	-1

Table 15: MCA Analysis – Averaging of Key Parameters

Strategy	Direct Cost	Averaged Parameters	Climate Change Impact	Total
As is (current state)	+2	-1.5	-1	-0.5
Allocate Additional Resources for updating (Enlarge Culvert)	-2	+1.25	+1	**+0.25**
Updating or bypassing the strategy for service level	+1	-1	-1	-1

Table 16: MCA Analysis – Final scores

In conclusion through the MCA analysis, with the highest score of +0.25, it can be seen that enlarging the inadequate culvert is the optimum solution to be examined further in the detailed analysis.

A.4 Step 4 – Conclusion and link with part B

a) Objectives

The goal of this part is to define how to continue the process according to the scope of the study.

Typically, Part A High level analysis is carried out initially, and subsequently usually followed by a Part B analysis.

b) Output

A decision should be made whether or not to carry on the process with part B.

In case of implementing part B, structures to be studied are to be defined.

c) Method

As explained before, Part A is a screening method aiming at highlighting the vulnerable assets and defining a global adaption strategy.

Part B is a detailed method (involving calculations) for assessing current and future resilience of assets defined as highly vulnerable within part A. This assessment aims at defining and planning adaptation measures.

As a reminder, Part B:

- is appropriate for a single structure / a particular storm drain system
- is appropriate for a structure defined as high priority from the high level risk analysis method or already known as highly vulnerable,
- enables a detailed socio-economic analysis for decision making
- needs detailed data
- needs hydrological and hydraulic calculations.

If the scope of the study defined in the prerequisite stage was only to have a first idea on a global adaptation strategy, the user can finish the process here.

If part A highlighted vulnerable structures or vulnerable areas, the user should carry on part B to have a detailed assessment of high-risk assets and define a detailed adaptation plan.

d) Data collection

The main data are the results of the previous sub-steps (A.1, A.2 and A.3)

e) Example

Reference is made to WATCH - case study, chapter 5.5 [20].

From the high level assessment part A it has become clear that culverts are the assets with the highest risk profile. Conducting an MCA learned, that it is probably worthwhile to invest in updating of the inadequate culvert.

Going through the high level part A of the WATCH manual, the ROADAPT QuickScan was employed as approach for risk analysis which showed that culverts proved to be of highest risk of the water management assets of interest, both for the present day climate and for the future climate (2030).

Therefore, culverts were placed into the high level socioeconomic analyses where the multi criteria analysis (MCA) was chosen as the most fitting economic analysis form. The objective of the socioeconomic analysis was to identify the best strategy and action to enhance culvert resiliency and thereby enhance further decision making. This was carried out by identifying various strategies to act on the identified risk and directly compare these.

Conducting the MCA, it was learned that allocating resource for updating culverts which were identified as inadequate (in risk of caused too frequent flooding occurrences) was the most fruitful strategy to pursue and to take action on.

As a conclusion, the results of the high level part A analyses, it was considered necessary to elaborate further in the detailed part B of the WATCH manual to gain further insight on the single culvert risk, identifying suited strategies and measures and to gain a more detailed socioeconomic perspective. All, to ultimately enhance basis for optimum decision making.

B - Detailed risk evaluation / adaptation measures and strategies

B.0 Introduction

Part B is dedicated for assets defined as high priority from the high level risk evaluation or already known as of high risk.

Part B is divided into 5 steps:

- Step B.1 - Gathering required climate data
- Step B.2 - Determining current and future resilience of assets
- Step B.3 - Defining possible measures/strategies
- Step B.4 - Performing a socio-economic analysis
- Step B.5 - Finalising of applicable/appropriate strategy

B.1 Step 1 – Gathering required climate data

a) Objectives

The goals of this step is to:

- Define which data are needed and available for the concerned asset according to the country standard
- Gather useful climate data or adapt existing data in order to be able to assess the hydrological and hydraulic data to be studied (current and future(s))

b) Output

The outputs are the climate data (current and future) to be used for the following steps.

c) Method and data collection

The protocols for climate data are described in detail and with background information in Bessembinder et al. (2018) [17]. This document also gives many examples to help you use and interpret the available climate data. Part of this document is included here only.

Current climate

The protocol for extreme rainfall information for the current climate consists of the steps described in the figure below. These steps will be explained in the text.

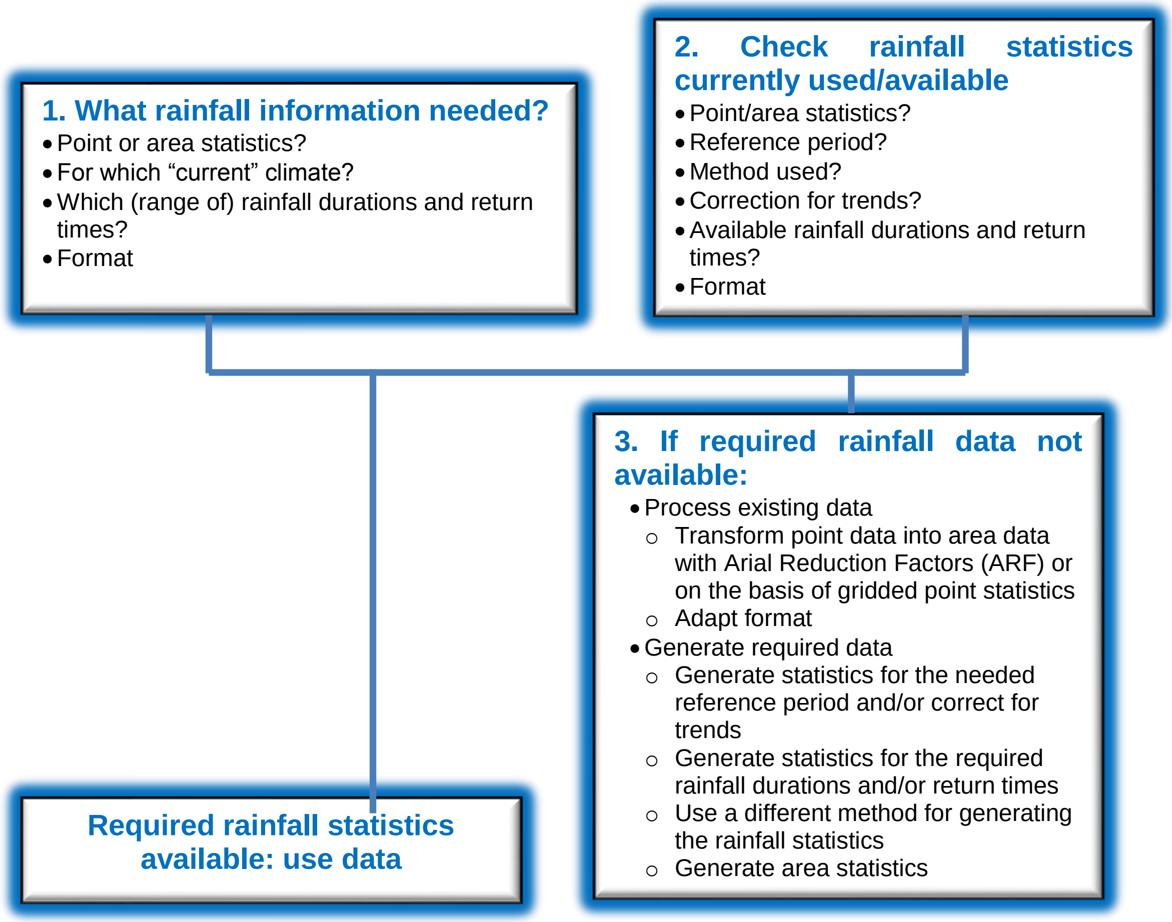

Figure 16: Procedure for data on extreme rainfall for the current climate

Current Climate, step 1 What extreme rainfall statistics do you need?

Before starting, look what information on extreme rainfall is needed. Consider the following aspects:

- Are point or area statistics needed?
- What is considered the current climate? This can be the climate described with the available extreme rainfall statistics / Intensity-Duration-Frequency (IDF) curves, Depth-Duration-Frequency (DDF) curves, but it can also be specified that the climate of e.g. the past 30 years should be used, or the climate around e.g. 2015. Due to the trend in extreme rainfall observed in many regions, there is a risk that the available statistics underestimate the current climate that you may have in mind.
- What rainfall durations or range of rainfall durations are needed? For water on the road often short durations (<1 hour) are needed, but in the case of run off longer durations (> 1 hour) could be more relevant.
- What return times are needed? This depends on the norms for roads in the country one is working.
- Which format of the data is needed? Information on the probability of rainfall extremes can be presented in the form of tables, IDF-curves, DDF-curves, formulas where one has to fill in the desired rainfall duration and return time to get the corresponding rainfall, etc. Often they can be transformed into each other. According to the country standard and the calculation method for assessing peak flows/ hydrographs, the user should define which data are needed.

Current Climate, step 2 and 3 Check and adjust extreme rainfall statistics

It is often difficult to find all the information mentioned in the Figure 16 if one is not an expert. Therefore, for the countries in the WATCH country comparison report, most information is summarized in tables in Appendix 1.

When you can not find all relevant information contact an expert (the producer of the statistics/IDF-curves or someone at your national metoffice, or a specialised meteorological or engineering consultant).

Below the various points that should be checked (**step 2**) are mentioned. In the case the required information is not available, it has to be generated or available data has to be adjusted (**step 3**).

- Is the information for points or for areas? Most statistics are calculated for points/locations. Sometimes point statistics can be transformed into area statistics with the help of general Areal Reduction Factors. Otherwise area statistics have to be derived from gridded point data/statistics derived from radar observations or rom a high density rainfall observation network.
- What is the reference period used for calculating the extreme rainfall statistics/IDF/DDF-curves ? If the available extreme rainfall statistics do not describe the required period, than new extreme rainfall statistics have to be generated.

  For the longer return times sufficiently long time series are needed (or in some situations data from various stations can be pooled) and possibly the statistics have to be corrected for trends in the observed data.
- What method is used for the statistics? Various methods exist to generate extreme rainfall statistics. It is also important to know what were the temporal resolution of the basic data and the quality of the simulation.

- Was there a correction for the trend in the basic data used for the statistics? New techniques have become available to correct for trends in observational data. First indications about trends in extreme rainfall can be obtained from reports on the current climate from the Meteorological institute in your country and from the ECA&D website under "indices of extremes" (http://www.ecad.eu/indicesextremes/index.php).

  If the available extreme rainfall statistics do not describe the required "current" climate, because there is a clear trend in the observed data, than the statistics should be generated again, but with a non-stationary method (does not assume that the climate is stable). Methods and tools are available for this (e.g. http://amir.eng.uci.edu/neva.php). It is advised to check the results always with experts, e.g. from your national Meteorological Institute.

- Which are available rainfall duration and return times? Since the temporal resolution of the basic data for the very short durations and for the longer durations may be different, not always the same type of information may be available for all rainfall durations. Sometimes estimates for missing rainfall durations or return times can be made by simple extrapolation of existing statistics. However, be careful with too much extrapolation. Sometimes for very long return times it may be better to use different statistical distributions. Be also careful with extrapolation to the very short rainfall durations

- What format is available? The required information on extreme rainfall is often available in the form of tables, IDF curves or formulas.

Future climate

The protocol for extreme rainfall information for the future climate consists of the steps described in the figure below. These steps will be explained in the text.

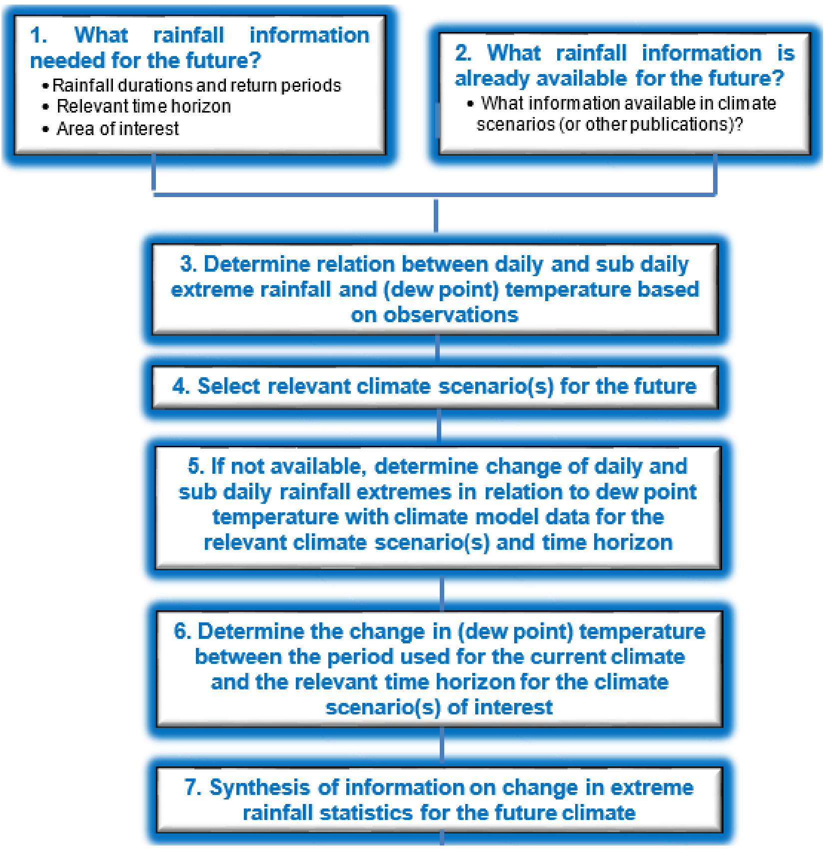

Figure 17: Schematized approach to estimate possible changes in subdaily and daily rainfall extremes in the future.

Future Climate, step 1 What rainfall information needed for the future?

In most cases the same or very similar information is needed for the future as was used for the current climate. Therefore, most information is already collected during step 1 in the protocol for the current climate. The following things deserve special interest:

- The relevant time horizon can be determined on the basis of the design life, expected life cycle or standards set by the NRA.
- The climate may not change every where in a country in the same way.

Future climate, step 2 What rainfall information is already available for the future?

In Appendix 1 an overview is available on what information is available on rainfall extremes in the climate scenarios in a number of European countries. Most climate models cannot simulate correctly the small scale (convective) extreme rainfall events. Therefore, climate scenarios often do not contain information on short duration rainfall extremes. Scaling with available data such as temperature can be used. This will be explained in later steps.

Future climate, step 3 Determine relation between rainfall extremes and (dew point) temperature in observations.

If the required information on rainfall extremes is found directly in projections in your country (step 2), you can use these extremes and skip this step 3.

In most countries, this information is not available. In that case, information from climate models and observations can be used to estimate the range of possible changes in the future (largely based on the approach of Lenderink & Attema (2015), figure 18) [9].

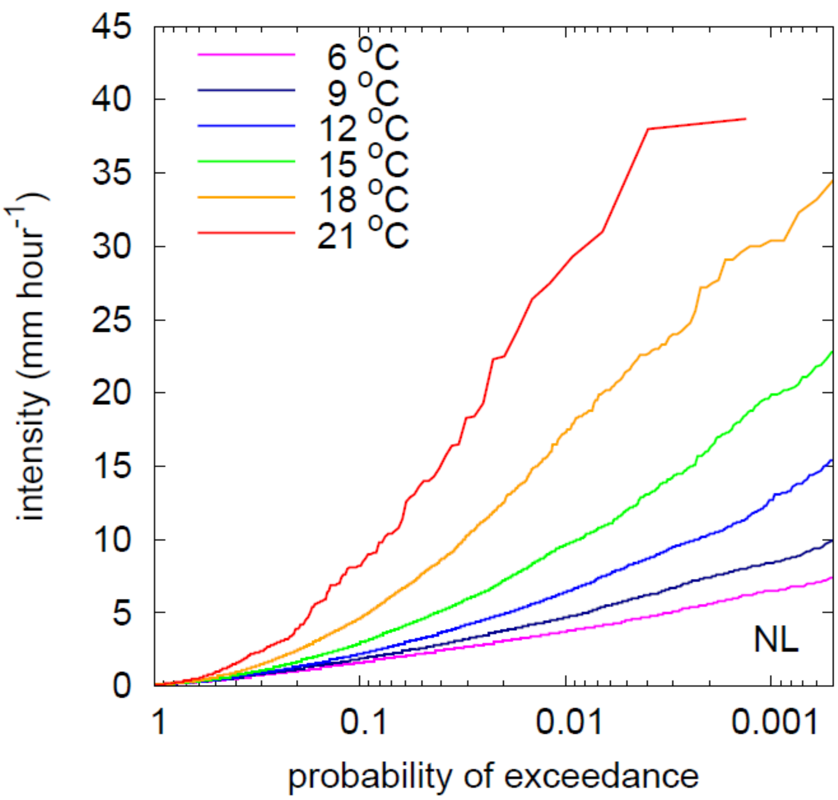

Figure 18: Probability of exceedance of rainfall extremes (‘intensity’ in mm per hour) at various average daily dew point temperatures at 27 stations in the Netherlands (Lenderink et al., 2011) in the period 1995-2010 (0.01 is once in 100 hours with rainfall within a certain temperature bin, etc.).

First the relation between rainfall extremes and (dew point) temperature in observations is determined.

The information needed for this analysis:

- Time series on temperature (daily and sub daily values)
- Time series on dew point temperature (or relative humidity[10]; daily and sub daily values)
- Time series on rainfall (daily values and sub daily values)

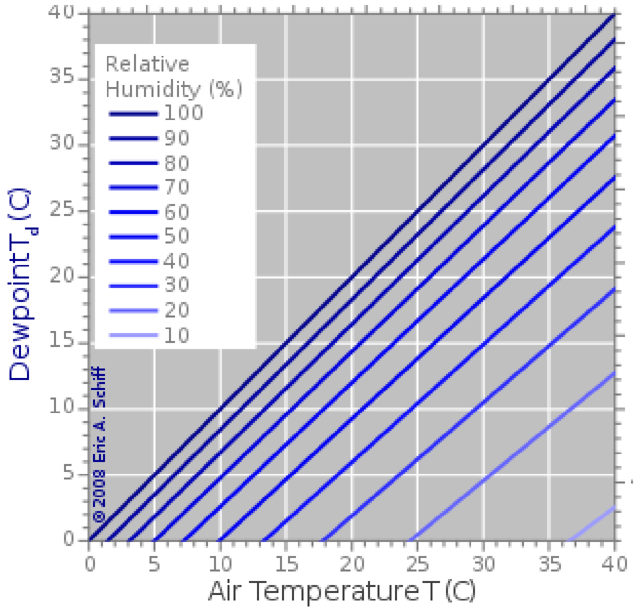

Figure 19: Dew point temperature as a relation of air temperature and relative humidity.

If information on relative humidity is not available, the analysis can also be performed with air temperature, although the relation between temperature and extreme rainfall is probably not as clear.

If the time series on extreme rainfall are not available one can assume as a first estimate for the north-western and northern part of Europe that the relations found by e.g. Lenderink & Attema (2015) also apply for your region of interest. The increase of about 14 % increase per °C (dew point) temperature increase can then be used as the upper limit of the change in short duration extreme rainfall above certain temperatures. For the southern and south eastern part of Europe the relations may apply, although especially when summers become dryer the air may not contain enough moisture.

Future climate, step 4 Select the relevant climate scenario(s) for the future

The potential changes in extreme rainfall do not have to be determined for all available climate scenarios or projections in your country, but only for the one or ones relevant for you.

Which scenario(s) are relevant, depends on the approach/strategy you use.

Future climate, step 5 Determine relation between rainfall extremes and (dew point) temperature in climate models

If the required information on rainfall extremes is found directly in projections in your country (step 2), you can use these extremes and skip this step 5.

[10] Dew point temperatures can be calculated from temperature and relative humidity data.

If not, use the correlation with (dew point) temperature as described in the approach of Lenderink & Attema (2015) [9].

If information on relative humidity is not available or not easy to get, the analysis can also be performed with air temperature, although the relation between temperature and extreme rainfall is probably not as clear.

If one has no possibility or limited possibility to analyse the climate model data, one can also as a first estimate assume for this step that the change in daily extremes also applies to sub-daily extremes (see also Lenderink & Attema (2015) [9] for relations in climate models). This is only possible when information on daily extremes is available in the climate scenarios.

Realize that the average rainfall can decrease in a season in the future, but at the same time extreme rainfall may increase in that season.

Future climate, step 6 Determine the change in (dew point) temperature over the relevant period

If the required information on rainfall extremes (with correct time horizon and reference period!) is found directly in projections in your country (step 2), you can use these extremes and skip this step.

If not, the change in (dew point) temperature over the period of interest will be determined.

Future climate, step 7 Synthesis of information for extreme rainfall statistics for the future climate

In this step 7 the information from steps 3 to 6 is combined to get the (range of) potential change in the rainfall extremes, similar to the approach described by Lenderink & Attema (2015) [9].

To get the range of possible change in extreme rainfall compared to the rainfall statistics that are used now for the “current” climate (point statistics):

- Lower limit: multiply the lowest % change per °C change in (dew point) temperature with the expected change in (dew point) temperature over the period of interest (step 6), but take into account the (dew point) temperatures throughout the year). The lowest percentage is often obtained from step 5, from the climate models, but not always;

- Upper limit: multiply the highest % change per °C change in (dew point) temperature with the expected change in (dew point) temperature over the period of interest (step 6), but take into account the (dew point) temperatures throughout the year). For the short duration extreme rainfall the highest percentage is often obtained from step 3, from the observations, but not always.

Since the temperatures may be higher or lower in one country from another, the percentage change may not be the same for all countries. It always useful to discuss the range that you want to use with a climate expert.

Information on changes in rainfall durations shorter than 1 hour is generally not available from climate models, and often limited information is available from observations. Therefore it is assumed that the range of change for hourly rainfall extremes can also be applied to sub hourly rainfall durations. If observational data for sub-hourly rainfall durations are available it can be checked whether this assumption is correct.

In the case there is information available on rainfall statistics for the future or on factors to use for the future, one can also check whether this information is in line with expected temperature changes.

d) Example

For examples, reference is made to Bessembinder et al. (2018) [17].

B.2 Step 2 – Determining current and future resilience of assets

B.2.0 Introduction

The goal of this step is to define the current and future(s) resilience of assets. The analysis is done thanks to five sub-steps:

- B.2.1 Assets inventories (including site constraints)
- B.2.2 Defining hydrological data (current and future(s) stage(s))
- B.2.3 Determining asset functioning
- B.2.4 Asset risk evaluation in the context of the infrastructure,
- B.2.5 Integration in a Road Asset Management System (RAMS)

As all the previous sub-steps are linked and interdependent, it is recommended to perform a global reading of this step before going into calculations details. Indeed, the hydraulic formulas chosen for assessing functioning of the asset (step B.2.3) involves which data are needed.

B.2.1 Sub-step 2.1 – Asset inventories

a) Objectives

This sub-step aims at gathering useful assets data in order to be able to assess their resilience.

b) Output

The output is a database or tables compiling assets and site data (access file, GIS file…)

c) Method

The typical required data (reference is made to table 17 below) concerns the structure itself as well as related elements such as road features and adjacent environment (receiving waters, outfall data…).

They can be gathered from (non exhaustive list):

- Desk study
  - From NRAs: existing database, drawings, as-built drawings, inspection documents, design reports, inspection and monitoring results, maintenance records, records of pas events
  - Existing studies: flood studies, design study
- Survey
  - Site visit: dimensions, protection, pictures
  - Topographical survey: the asset itself and the infrastructure
  - Interviews: residents, associations, administrations.

For data collection, it is highly recommended to use template forms, which enable coherent and similar data. These templates are to be defined by the NRAs.

Obviously, the data detail level will affect the level of detail of the risk evaluation. Thus, the more the asset is characterised, the more relevant is the analysis.

d) Data collection

The typical data to collect are the following. Obviously, the user have to adapt the needed data to the study and the context (standard, geographical…).

Asset category	Structural data				Receiving environment / outfall features	Road features	Adjacent assets at stake	Existing documents related to the facility
	Type of asset / function of asset	Features	Immediate upstream and downstream facilities	Watershed features				
Assets dealing with water crossing the road (run-off flooding)	culvert, pipe….	reference, location, date of construction, shape, dimensions, length, longitudinal gradient, material, number of barrel, state of maintenance, type of tehcnical fill, type of fill material….	inlet and outlet features, erosion protections, upstream retention if existing, upstream and downstream channel features, state of maintenance….	total drained area, mean slope, type of actual cover, run-off coefficients, peak flows if known…	/	minimum road level, road width…	downstream structures (dimensions, gradient…) vulnerable areas in the vicinity of the site : urban or industrial area, environemental areas, others transport infrastructures…	existing studies, standards used, design criteria…
Assets dealing with precipitation on the road (conveyance field)	Longitudinal drainage within dedicated storm drain system, over-the-edge drainage, infiltration along the road….	reference, location, date of construction, type of structure, shapes, dimensions, length, longitudinal gradient, material, state of maintenance….	/		stream (quality, quantity…) underground water (quality, quantity, infiltration rate, permeability…) existing storm drain system (size, quality, quantity…)	road in cut, road in fill, width, fill height…	downstream structures (dimensions, gradient…) vulnerable areas in the vicinity of the site : urban or industrial area, environmental areas, others transport infrastructures, underground water table…	
Assets dealing with precipitation on the road (quantity and quality aspects)	Facilities for Retention ? Infiltration ? Treatment ? With design criteria	reference, location, date of construction, type of structure, dimensions, appertunant facilities (regulation device, safety weir…), lining, state of maintenance….			water quality, peak flows (mean and dryweather flows)	road in cut, road in fill, width, fill height…	downstream structures (dimensions, gradient…) vulnerable areas in the vicinity of the site : urban or industrial area, environmental areas, others transport infrastructures…	
Assets preventing pluvial flooding (water besides the road)	Ditches, levees, road on embankment, deflective dams	reference, location, date of construction, dimensions, material, state of maintenance…			/	minimum road level, road width…	downstream structures (dimensions, gradient…) vulnerable areas in the vicinity of the site : urban or industrial area, environemental areas, others transport infrastructures…	

Table 17: Typical data for asset inventories

B.2.2 *Sub-step 2.2 – Defining hydrological data*

a) Objectives

The goal of this step is to define required hydrological values (for current and future(s) stage(s)) in order to be used for the next sub-step (B.2.3 asset functioning).

For the conveyance aspects, the typical hydrological data are mainly peak flows range or hydrographs related to extreme runoff.

For quality aspects, it can be rainfall amounts for different durations.

b) Output

The outputs are table or document gathering hydrological data according to the standard used.

c) Method

The following method comes from Bessembinder et al., 2018 [17].

Current stage

On the basis of the rainfall statistics defined in step B.1, extreme runoff can be estimated.

Within the context of this project for road design and maintenance, we are concerned mainly with runoff related to water alongside the roads (related to road ditches), as well as culverts under the roads. There are two main approaches for estimating extreme runoff for road design and maintenance:

- When runoff data based on a water level gauge is available, estimates can be made based on recorded runoff extremes. This approach is most precise, and is preferred. Typically, these data are available for larger drainage areas and in more urban locations. The approaches used here are commonly referred to as extreme value analysis, to estimate the required design dimensions. These methods are standard practice, and are not further discussed here.

- When no runoff records are available, methods are available to estimate runoff. This is typical for smaller catchments, and rural locations.
  Runoff estimation methods for this second purpose, commonly applied in different European countries, are listed in table below (and in appendix 1)

Country	Asset	Design standard	Runoff calculation methods
Austria	Culverts	100 year return period (duration depends on catchment area).	Prandtl-Colebrook
United Kingdom	Ditches	75 year return period	IH 124 Method for catchments > 0.4 km^2 ADAS Method for catchments < 0.4 km^2
	Culverts	For catchment areas >50ha and 100 year return period in England and Wales, and 200 year return period in Scotland.	Rainfall transformation methods based on runoff coefficients Method from the Flood estimation handbook (Institute of Hydrology, 1999) for drained areas > 50 ha.
France	Ditches	Ditches are sized for those implemented at crest of cut embankments (return period 100 yr.	Rational method based on IDF curves. Hydraulic calculation: Manning-Strickler equation.
	Culverts	Return period 100 years (plus check 1.5*Q100). There is no prevailing duration of precipitation in design as the time of concentration is calculated for each watershed.	Hydrology: rational method and Crupedix method and IDF curves for non-gauged catchments; Hydraulics: Manning-Strickler equation (preliminary design); Bernoulli and energy equations (detailed design).
Ireland	Ditches	Mean annual runoff for 75 year return period.	IH 124 Method for catchments > 0.4km2 ADAS Method for catchments < 0.4km2
	Culverts	Annual peak runoff for 100 year return period, plus (typically 300mm) freeboard (UK CIRIA C689 culvert design guide).	Rainfall transformation methods based on runoff coefficients
Nether-lands	Ditches	Roads in fill and bridges 10 years; roads in cut 50 years; tunnels 250 years	No information
	Culverts	Requirements for culverts are given by the water boards.	Requirements for culverts are given by the water boards.
Norway	Ditches	For existing structures often no information available about the design method or design capacity 200 year return period (highways). 50-100 year return period (other roads).	Rational method and IDF curves. Revised guidelines (coming up soon) include several other methods, distinguish between catchment characteristics.
	Culverts	Annual peak runoff for 100 yr return period, plus (typically 300mm) freeboard (UK CIRIA C689 culvert design guide).	IDF curves No further information
Sweden	Culverts	50 year return period, in some cases 200 year return period.	No information
Denmark	Culverts	25 year return period (highways); 10 to 25 years return period for other roads.	No information

Table 18: Methods for extreme runoff estimation, and commonly applied design standards (source: Bessembinder et al., 2018 [17]).

What is clear from this table is that many countries have adopted their own methods for runoff estimation when no runoff gauge data is available for estimation of extreme runoff. However, most use very similar approaches, based on observed rainfall (extremes), and catchment characteristics (see table). Most methods also use IDF curves as key input, to determine design storms, or at least rainfall values based on IDF curves for the relevant return periods and rainfall durations, required for the design.

Future stage

For estimating future runoff extremes, the estimates from the two methods described above can be transformed.

- With the estimation methods that are using rainfall data as input, use can be made of the projected change in extreme rainfall and corresponding revised IDF curves.
- The method using observed runoff data to estimate runoff extremes, needs to make assumptions about the relation between rainfall change and runoff change. In many European countries, such assumptions about changes in extreme runoff are made. For instance, in the UK and Ireland, 20% increase in design runoff conditions is applied to observed (or estimated) discharges. However, such changes are dependant not only on rainfall intensity changes, but also changes in rainfall regimes, changes in soil moisture conditions and evaporation that may alter catchment response, especially in larger gauged catchments.

Assuming that all additional rainfall is translated into runoff is a “conservative” estimate. This rule is a first order approach only, and should be applied with caution, as local conditions may require alternative changes to be taken into account. For instance, in larger catchments where time of concentration is long, soil conditions allow infiltration, and in larger catchments (larger than ~0.5 km^2), applying an analysis using empirical functions (see above) is worthwhile, to avoid an overly conservative design.

To get an idea how people deal with the estimated future rainfall extremes that you expect for your region, one can use the Climate analogues tool to find regions where your estimated rainfall extremes occur already. The tool is described in Bessembinder et al. (2018).

The following figure shows analogues stations for the future value you are expected (all criteria defined, in this example, average value of 59 mm/day)

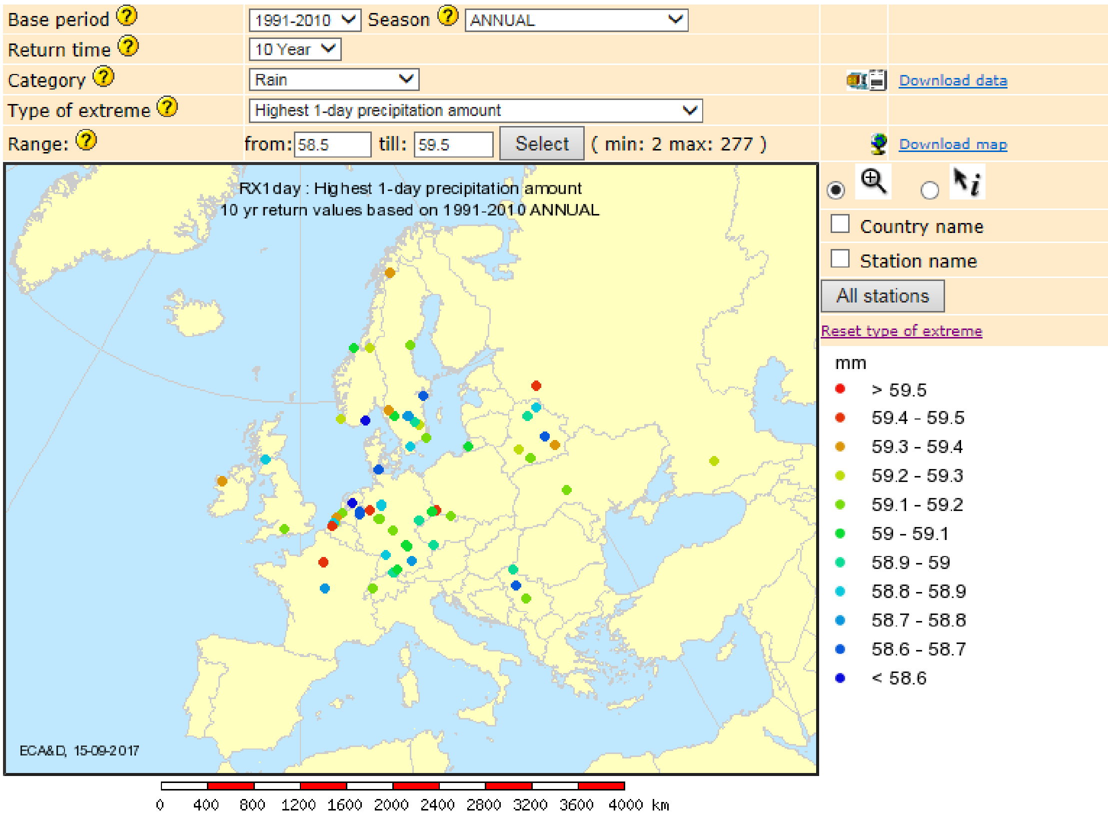

Figure 20: Example of stations put up as analogues for the future that have currently more or less the same rainfall statistics (e.g.in the Netherlands) as in Denmark (reference station near Copenhagen).

d) Data collection

Use the data gathered in previous sub-steps related to climate data (sub-step B.1) and the asset (sub-step B.2.1).

e) Example

The example below deals with culvert design (assets dealing with water crossing the road) and is an extract of Bessembinder et al. (2018) [17].

Typically, required hydrological data are peak flows to be calculated for current and future(s) stage(s).

Current stage

The basic steps involved in an analysis for culvert design are listed here below. Typically, for culverts draining small catchments, a calculation will be made using empirically derived functions, to calculate design runoff that need to be accommodated.

These steps include:

- Derive the IDF curve using methods described in par. 4.2 of Bessembinder et al. (2018) [17]
- Determine the required return period and corresponding rainfall intensity; for most culverts this is the 50, 100 or 200 year runoff).
- Calculate the design runoff using the empirical formula (some factors are added for safety). Most methods use several parameters, which can include:
    - Catchment surface area;
    - Parameter for soil characteristics (infiltration);
    - Time of concentration, which is derived empirically from catchment length and slope.

Future stage

As already mentioned, two alternative methods exist to estimate runoff extremes. These were based either on actual observed discharge records, or estimation methods based on rainfall and catchment characteristics.

For estimating future runoff extremes, the estimates from these two methods can be transformed.

With the estimation methods that are using rainfall data as input, use can be made of the projected change in extreme rainfall, as explained previously in step B.1 and corresponding revised IDF curves. The basic steps involved in such an analysis are the same than above.

The method using observed runoff data to estimate runoff extremes needs to make assumptions about the relation between rainfall change and runoff change.

As a general rule, it is advised to apply a percentage increase in design rainfall, per degree centigrade projected warming. If no information is available on the change of daily or hourly rainfall the protocol can be used to make an estimate of this based on observations and climate model results. This additional rainfall, derived from an IDF curve, can be translated to additional runoff for the known catchment size.

This is a conservative estimate, assuming that all additional rainfall is translated to runoff. This rule is a first order approach only, and should be applied with caution, as local conditions may require alternative changes to be taken into account.

B.2.3 Sub-step 2.3 – Determining asset functioning

a) Objectives

For each type of asset, the goal of this step is to determine the functioning of the asset for current and future(s) stage(s).

For assets dealing with water crossing the road (run-off flooding) and assets preventing pluvial flooding (water besides the road), this sub-step should assess the hydraulic and structural functioning of the asset (flow regime, water level elevations, flood features…)

For assets dealing with precipitation on the road (conveyance field), the goal depends on the drainage approach. For conveyance systems such as storm drain systems, the sub-step aims at assessing the functioning of the conveyance system (water elevation, potential flooding of lane…). For over-the edge drainage system, the infiltration and flooding functioning of the area need to be analysed.

For assets dealing with precipitation on the road (quantity and quality aspects), the goal is to define the asset efficiencies related manily to peak flow attenuation and/or water treatment.

b) Output

The typical outputs for each type of assets are provided in the table below.

Asset type	Typical outputs for asset functioning
Assets dealing with water crossing the road (run-off flooding)	Stage-discharge curves, performance curves, Hydrographs, flooding / infiltration map…. Indicating (list not exhaustive): flow types, water depths, velocities, shear stress, submersion duration….
Assets dealing with precipitation on the road (conveyance field)	Analysis presenting the functioning of the system: variable according to the type of drainage system and the chosen calculation methods
Assets dealing with precipitation on the road (quantity and quality aspects)	Storage, quality, infiltration efficiencies….
Assets preventing pluvial flooding (water besides the road)	Hydraulic functioning of the area

Table 19: Typical outputs for asset functioning

c) Method

Typical methods for each type of assets are proposed below. Obviously, the method has to be adapted according to the standard used.

Assets dealing with water crossing the road (run-off flooding)

Assumption: the studied structure is considered clean (regular maintenance done). The methodology is appropriate considering that regular maintenance is done. Any failure in the maintenance will increase the risk.

Two aspects should be addressed:

- Hydraulic functioning
- Infrastructure longevity

Then operation thresholds can be defined in order to classify the asset functioning.

Hydraulic analysis:

The hydraulic analysis consists in defining the functioning of the asset for a range of peak flows or hydrographs.

The data to assess could be (but not exhaustive): flow regime, water levels (upstream, within and downstream of the asset), velocity, shear stress, submersion duration, etcetera.

Some particularities should be taken into account on a case-by-case analysis:

- Downstream conditions: limiting structure for example (downstream impact), varying sea level, etcetera
- Upstream natural or artificial retention : could be analysed knowing the depth-area curve
- Diversion in another structure : potential lateral discharge

Asset or infrastructure longevity (structural strength):

The structural assessment consists in defining the critical parameters regarding asset longevity and structural strength. It could be by analysing fill type, fill material, asset material, age of the asset, flow velocities, duration of submersion, etcetera.

Define operation thresholds

The operation thresholds (usually according to the upstream water level) could be as follow:

- Normal operation level: corresponds to design functioning of the asset
- Degraded operation level: corresponds to degraded functioning of the asset (degradation of the culvert conveyance) - it depends on the characteristics of the structure and is identified by calculation.
- Breach level: corresponds to the failure limit of the asset (ruin of the structure, degradation of the fill materials) - it depends on the characteristics of the structure and the characteristics of the infrastructure.

Assets dealing with precipitation on the road (conveyance field)

Assumption: the storm drain system is considered clean (regular maintenance done). The methodology is appropriate considering that regular maintenance is done. Any failure in the maintenance will increase the risk.

Hydraulic analysis

It seems logical to carry out the study by watershed defined by an outfall or a discharging point. Numerous methods exists and has to be chosen according to the available data, study allowable time and retained modelling tools.

The table below lists some potential methods (not exhaustive)

Method	Description	Comments
Calculation of lengths of saturation	Construction of abacus for different longitudinal slopes / road features / rainfall events	Indicates when the system reaches its maximum capacity
Capacity calculations	Analyse at each critical point (location of change of structure, sudden change of slope, low points, system in cut…) : calculation of peak flows and comparison with the maximum conveyance of the structure	
Hydraulic software analysis	Mathematical modelling along the network	Need detailed data and mathematic tool
Blue spot model – Ref [3]	Screening method to assess flood risk on national roads and highway systems	need detailed data and mathematic tool

Table 20: Possible methods to assess functioning of assets dealing with precipitation on the road (conveyance field)

Some particularities should be taken into account on a case-by-case analysis:

- Downstream condition such as stream, underground water table, existing storm drain system
- Over the edge run-off in storm drain system in fill but without safety barriers
- In cut with safety barriers, also consider water depth on shoulders and lanes
- If crossing pipes, reference is made to crossing structure methodology

Assets dealing with precipitation on the road (quantity and quality aspects)

Quantity aspects

Firstly, the effective storage capacity of the facility is determined. This calculation could be done for several assumptions:

- The facility itself considering a freeboard (depth of filling ratio).
- The facility completely full.
- The facility with the spillway in action.
- The facility with extra-capacity if in cut configuration.

Infiltration has to be taken into account if needed.

Quality aspects

The efficiency of the facility is calculated. These calculations could be done for different type of pollution: accidental pollution, chronic pollution, etcetera.

Diagnosis

The diagnosis of the facility is carried out by comparing the available volumes or efficiency to the needed volumes or efficiency. As for culverts, operation thresholds could be defined.

If there is a spillway accurately sized, the consequence of the threat has no impact on the facility itself but is only moved away (increase peak flow, pollution level) if nothing more is done.

The following figure (extract from Rooney et al., 2018 [18]) can be used to define operation thresholds regarding quantity (attenuation volumes) and quality (water treatment parameters).

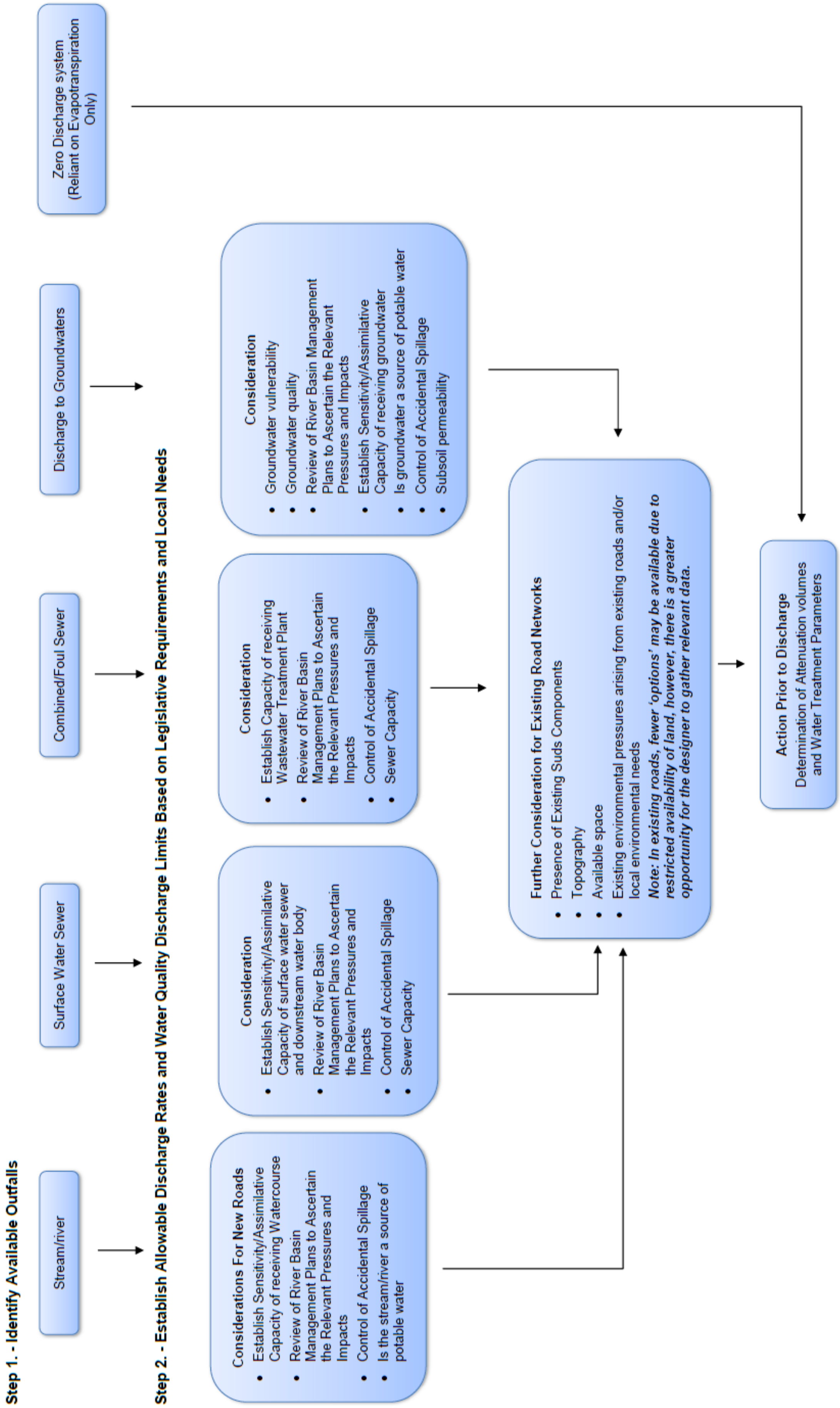

Figure 21: Extract of SuDS protocol

Assets preventing pluvial flooding (water besides the road)

Several calculation methods exist:

- Blue spot analysis – [3]
- Hydraulic modelling software mapping
- Retention/infiltration calculations.

The data to assess could be (but not exhaustive): flow types, water depths, velocities, submersion duration, shear stress, etcetera.

Some particularities should be taken into account on a case by case analysis:

- Infiltration,
- natural or artificial retention
- Diversion in another watershed : potential lateral discharge

d) Data collection

The needed data are those gathered in previous sub-steps related to the asset inventories (B.2.1) and hydrological calculations (B.2.2).

e) Example

The following example concerns with assets dealing with water crossing the road (run-off flooding).

More examples for the other asset types can be found in appendix 2.

Hydraulic functioning

For concrete culverts, operation thresholds in France are:

- Normal operation level: upstream water level below 1.2xD (120% of D) or 1.2xH (120% of H) D and H respectively represent the diameter or rise of the structure.
- Degraded operation level: limit of free-surface flow
- Breach level: upstream water level above 1.5xD or 1.5xH

Many tools or softwares exist to analyse water gradeline within culverts. The following example is based on the use of HY-8 (free tool provided by the Federal Highway Administration- USA).

The figure below shows the needed data filled for a rectangular concrete box.

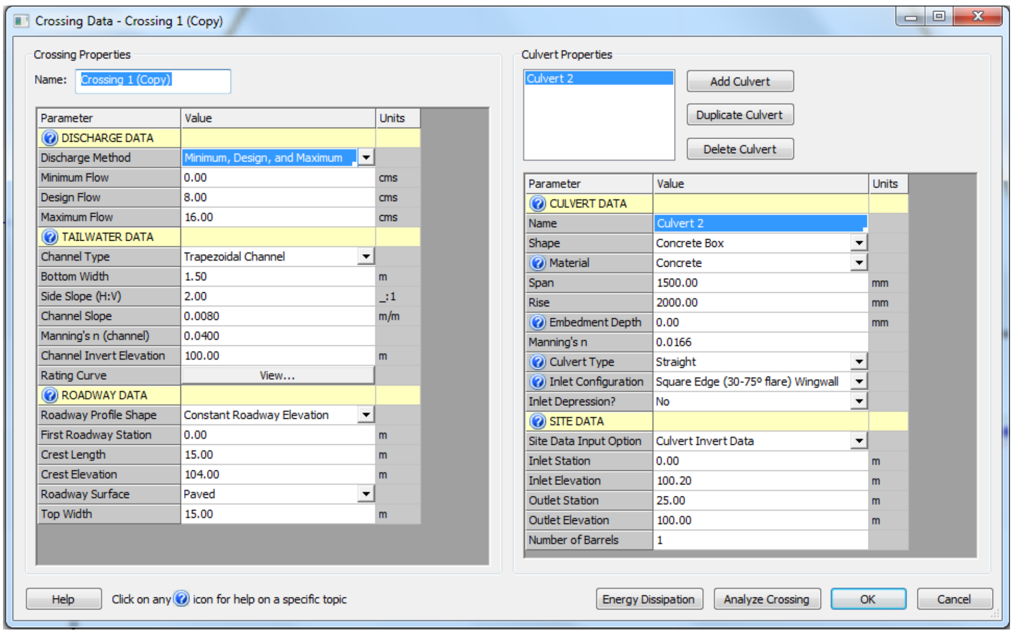

Figure 22: HY-8 data for culvert

The figure below shows the performance curve of the asset defined before. This curve enables to define the headwater elevation according to the peak flow.

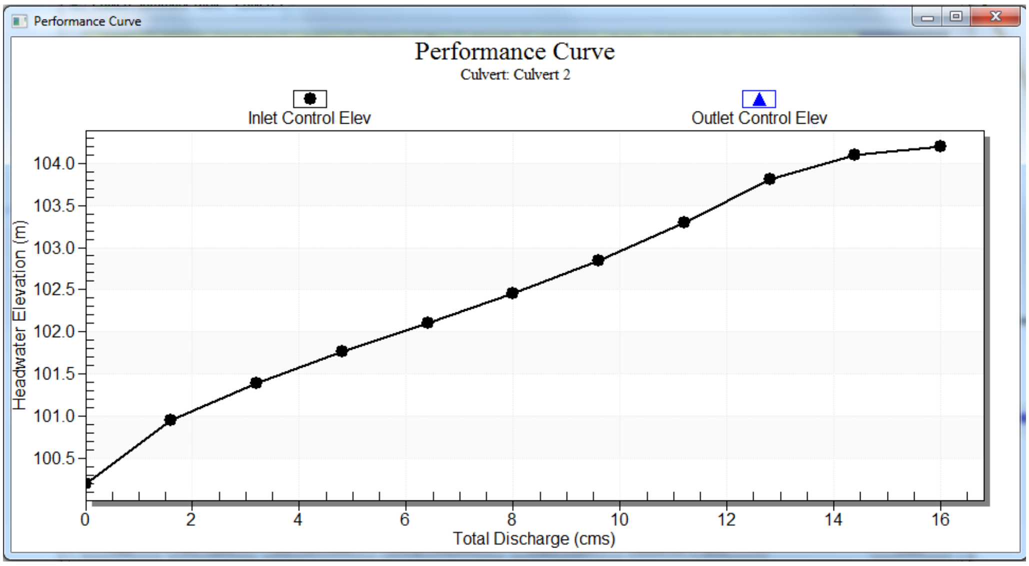

Figure 23: HY-8 performance curve

The figure below shows the detailed results.

Culvert Summary Table - Culvert 2

Total Discharge (cms)	Culvert Discharge (cms)	Headwater Elevation (m)	Inlet Control Depth(m)	Outlet Control Depth(m)	Flow Type	Normal Depth (m)	Critical Depth (m)	Outlet Depth (m)	Tailwater Depth (m)	Outlet Velocity (m/s)	Tailwater Velocity (m/s)
0.00	0.00	100.20	0.00	0.0	0-NF	0.00	0.00	0.00	0.00	0.00	0.00
1.60	1.60	100.94	**0.74**	0.37	1-JS1t	0.45	0.49	0.55	0.55	1.95	1.13
3.20	3.20	101.39	**1.19**	0.68	1-S2n	0.76	0.77	0.76	0.77	2.82	1.36
4.80	4.80	101.92	1.56	**1.72**	2-M2c	1.03	1.01	1.01	0.94	3.16	1.51
6.40	6.40	102.27	1.90	**2.07**	7-M2c	1.30	1.23	1.23	1.08	3.47	1.63
8.00	8.00	102.60	2.26	**2.40**	7-M2c	1.56	1.43	1.43	1.19	3.74	1.73
9.60	9.60	102.90	2.65	**2.70**	7-M2c	1.81	1.61	1.61	1.30	3.98	1.81
11.20	11.20	103.29	**3.09~**	2.99	7-M2c	2.00	1.78	1.78	1.39	4.18	1.88
12.80	12.80	103.81	**3.61~**	3.48	7-M2c	2.00	1.95	1.95	1.48	4.38	1.95
14.40	13.60	104.10	**3.90**	3.70	6-FFc	2.00	2.00	2.00	1.56	4.53	2.00
16.00	13.85	104.19	**3.99**	3.77	6-FFc	2.00	2.00	2.00	1.63	4.62	2.06

Figure 24: HY-8 Culvert summary table

B.2.4 Sub-step 2.4 – Asset risk evaluation in the context of the infrastructure

a) Objectives

The goal of this sub-step is to analyse the functioning of the asset, for current and future(s) stage(s), in regards of the criticality levels of the road and the surrounding areas.

The criticality levels are to be defined not only for the structure itself but also according to the infrastructure and the environment.

b) Output

The output is an asset risk evaluation for current and future(s) stage(s).

c) Method

Firstly, key issues regarding asset functioning and durability of the asset need to be defined. The key issues are linked to the road itself (e.g. level of submersion, critical points such as road in cuts, alternative options for rerouting) and the surroundings areas (e.g. persons, environment, other infrastructure, expected developments)

In regards to these key issues, criticality levels are determined (normal operation, degraded operation, breach operation).

The risk evaluation is done by comparing the hydraulic/structural analysis (previous sub-step B.2.3) with the different criticality levels.

d) Data collection

Use these gathered in previous sub-steps completed with additional data if needed.

e) Example

The following example concerns with assets dealing with water crossing the road (run-off flooding).

More example for the other asset types can be found in appendix 2.

<u>Define key issues regarding hydraulic functioning and durability of the asset</u>

- On the road itself: level of submersion of lanes, scour, critical points (road in cut, sag points), duration of submersion, duration of disruption of traffic, etcetera
- And within surroundings areas: upstream and downstream (persons, environment, other infrastructure, expected developments)

<u>Define criticality levels</u>

Asset diagnosis for current and future situation among the following criticality levels:

- Normal operation: design operation - no hazard for drivers or surroundings assets (other infrastructure, urban areas…) or the infrastructure itself
- Degraded operation of infrastructure itself : reaches the traffic lanes but still one lane available for traffic
- Degraded operation for the environment : reaches a surrounding vulnerable area
- Breach operation : submerged road, no traffic allowed and/or impact on road integrity and/or reaches leisure/activities areas, reaches a residential area

Criticality levels	Headwater elevation
Normal operating	up to 101.00 m
Breach level for surrounding area	103.00 m (urban area at stake)
Degraded operating of infrastructure	between 103.80 m (shoulder submersion) to 103.89 m (external lane submersion)
Breach level for the infrastructure	104.00m (total submersion of the road)

Table 21: Example of criticality levels for upstream water levels

Risk evaluation

Compare the different levels with the hydraulic/structural analysis (previous sub-step B.2.3)

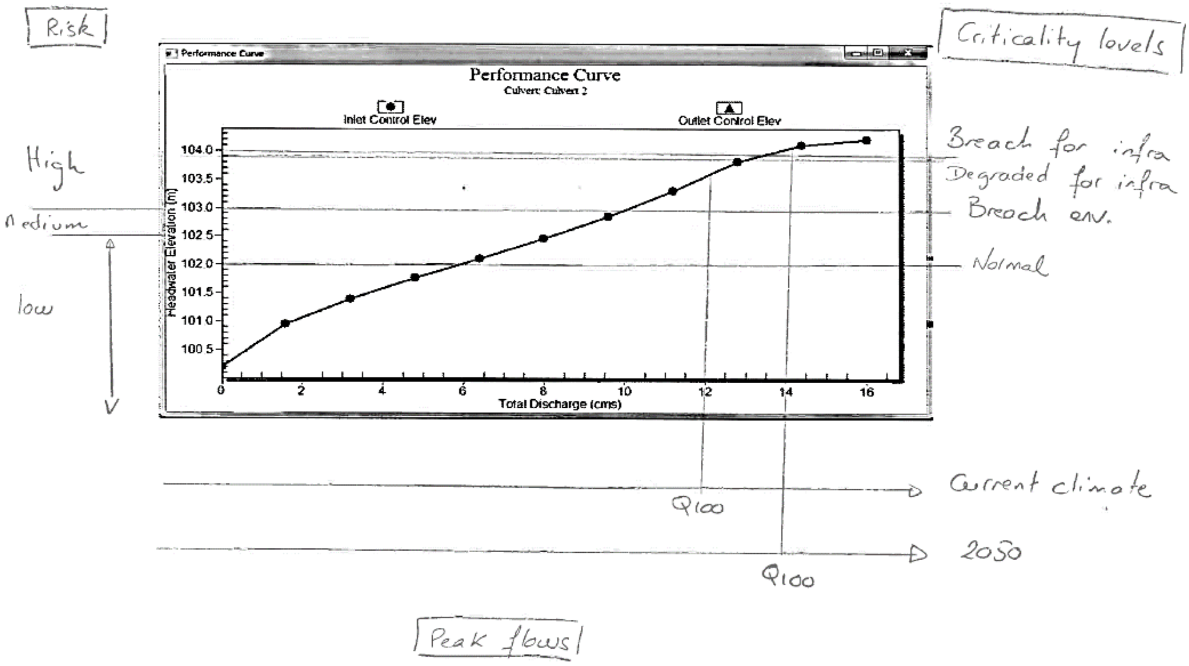

Figure 25: Example of risk evaluation for upstream water levels

This culvert which is already above breach environmental level will exceed breach level in 2050.

B.2.5 Sub-step 2.5 – Integration in a Road Asset management System (RAMS)

a) Objectives

The main goal of this step is to capitalise and keep tracks of the study. The RAMS can also be used to build vulnerability zoning.

b) Output

The outputs are the updating of the NRA' RAMS and the mapping of studied assets showing criticality levels.

c) Method

Data and calculations are gathered in a RAMS that could be access files, SIG or other tools.

d) Data collection

The data are gathered from all the previous steps and sub-steps.

B.3 Step 3 – Defining possible measures/strategies

a) Objectives

According to the diagnosis and risk evaluation of the asset, the goal of this step is to select and design the possible measure(s) to implement.

This step enables to select the possible measures to consider, design the possible/retained measure(s) and define the accompanying/organisational measures.

b) Output

The outputs are possible measures/strategies (such as the SuDS approach described in the SuDS Protocol – Rooney et al., 2018 [18] to be compared thanks to a socio-economic analysis in following step B.4.

c) Method

Selection of the measure(s)

Firstly, potential measures are selected on a case-by-case analysis according to the risk evaluation of the asset.

The excel sheet file CEDR-WATCH_Manual-measures and especially the effectiveness columns may help the user to select the possible measures.

The following selection process is a possible way to select measures. Obviously, it should be completed by a case-by-case analysis, as there is no recommendation that will apply to each case.

Moreover, some measures may have equal effectiveness, nevertheless, **the choice of the measure depends on how it is possible to implement according to the site and the context**.

The selection could be done as follow:

- For an asset in normal operation for both current and future stages:
  The most relevant categories of measures are Maintenance, Monitoring and inspection, Capacity building, Legislation and Planning. Moreover, extreme weather alert and traffic management should be prepared in case of exceptional events above the design criteria.

- For an asset in degraded operation :
  - If degraded operation is not acceptable (e.g. flooding of urban area upstream, flooding of lanes, flooding of vulnerable area, and pollution of receiving waters) then retrofitting is compulsory.
    "Increase resistance" of the measure should be equal to + or ++
    Nevertheless, in some cases, even if "increase resistance" is 0, it is also interesting to select a measure that decrease consequences
  - If degraded operation is acceptable (e.g. redundancy, no vulnerable areas in terms of quantity or quality) then decrease consequence should be a priority (especially safety and societal costs)
  - If degraded operation appears only in future(s) stage(s), the measures to implement could be postponed (adaptive planning)
  - The most relevant categories of measures are robust and resilient construction.

- For an asset in breach operation already in current stage, the best strategy is a no regret strategy (measure that is already beneficial, without any climate change occurring)
  - If breach operation is not acceptable (e.g. no redundancy, upstream/downstream vulnerable area, flooding of the road, pollution of receiving waters) then retrofitting is compulsory.
    "Increase resistance" of the measure should be equal to ++
  - If breach operation is acceptable (e.g. redundancy, no vulnerable areas in terms of quantity or quality) then decrease consequence should be a priority (especially safety and societal costs)

« On the structure » measures are particularly interesting in order to increase resistance of the asset itself.

Measures with impacts on recovery capacity and adaptive capacity are particularly interesting in regards to the uncertainties of climate change.

Nota: Importance of flexible measures:
"It can be advantageous to try to identify measures that are flexible and which can be characterised as "no-regret" options. Flexibility refers to the possibility of a measure to be changed in time. Since climate change is accompanied by a large degree of uncertainty, a flexible approach is favourable over a non-flexible approach. A no-regret measure is a measure that is already beneficial, without any climate change occurring." [1]

The climate analogue tool (reference is made to Bessembinder et al., 2018 [17]) can also be used to evaluate the relevance of the proposed measure or study new possible measures. The tool enables you to know if your concerned infrastructure will encounter in the future a climate that may be equal to an existing climate elsewhere within Europe. Then, you can acquaint how water management is done there and if some pertinent measures could be implemented to increase resilience of your area.

Obviously, the final choice of potential adaptation measures is done according to common sense, context, required longevity, future projects….

Reference is also made to RIMAROCC [1] sub-step 5.1 Identify options.

<u>Design of the measure(s)</u>

Once the measure(s) is(are) chosen, it must be sized to assess the precise required effectiveness.

<u>Define the accompanying/organisational measures</u>

The accompanying/organisational measures are needed in order to increase awareness, efficiency of the measure…

They are mainly select for the location "general" and "outside the structure".

Measures should also be defined for the other assets that were not studied in part B. Indeed, it is recommended to define actions even in the long-term for studying the other assets, increase maintenance…

The potential strategies are all the measures gathered for the network at stake.

d) Data collection

The **available measures** regarding the different types of assets (one tab for each type of assets) are found in the excel sheet file CEDR-WATCH_Manual-measures.

The table, which is partly based on the ROADAPT Part E database [2] will help the user to select the relevant measure.

The measures are provided with the following description

- Type of assets
- Category of measure [2]
- Stage [2],
- Location of measure:
    - On the structure itself
    - Outside the structure
    - General measure
- Description of the measures
- Advantages, disadvantages
- Effectiveness/impact ([1] step 5.1) defined on a qualitative range
    - Increase resistance: increase the threshold before damage will occur
    - Decrease consequences: if an unwanted event occurs, measures can be taken in order to minimise the consequences (safety, societal costs, repair costs, environmental effects)
    - Recovery capacity: enhancing a quick return to the pre-disturbed situation
    - Adaptive capacity: be prepared to take measures for the future

The last part of the tables (effectiveness) is a way to select the possible measure to implement.

The rating are explained in appendix 3. Reference is also made to the socio economic analysis guidelines (Tucker et al., 2018) [19] for further and more detailed explanation on how to select the best measures using different kinds of evaluation techniques.

For measures related to inspections and maintenance, the WATCH manual provides two more tabs in CEDR-WATCH_Manual-measures suggesting frequency and type of works. Two levels are considered for inspections: regular and heavy inspections. Regular inspections are key to an early detection of defects. Maintenance frequency depends on results of inspections as it is done when damages are discovered.

For measures related to maintenance of SuDS components, reference is also made to Rooney et al., 2018 [18] table 2-1 Maintenance measures for SuDS components (CIRIA, 2015)

For inspections and maintenance, reference is also made to SWAMP - Inspection and Maintenance - guide for reducing vulnerability due to flooding of roads [3]

e) Example

The following example concerns assets dealing with water crossing the road.

For a culvert classified as high risk, retro-fitting is compulsory. “Increase resistance” of the measure should be equal to ++

Possible measures are:

- Retrofitting/resizing of the structure. The downstream site need to be taken into account as the measure cannot increase the downstream risk if there is a vulnerable area
- Pipe jacking at high level for increasing conveyance but only for extreme events
- Add / Improve upstream retention / wetlands / infiltration
- Rebuild stretch of the road on safe ground

For a culvert classified as medium risk, rehabilitation may be needed but without requiring a reconstruction. Decrease consequence should be a priority and “increase resistance” of the measure should be equal to + (or ++).

Possible measures are:

- Add/improve upstream and downstream embankments protections
- Convert the road into a ford accompanied by traffic management
- Increase road network redundancy
- Traffic management / prepare contingency / emergency plans
- Extreme weather alert
- Above a certain rainfall event, stop the traffic by variable message sign
- Retrofitting of the structure with fusible fill (during an exceptional event, the structure itself has no or not lot of damages but the embankment is ruined)
- Divert part of the flow toward another structure (downstream impact to be taken into account)

For a culvert classified as low level risk, no specific intervention is required. Only maintenance, inspection and monitoring strategy is required as well as extreme weather alert and traffic management in case of exceptional events above the design criteria.

B.4 Step 4 – Performing a socio-economic analysis

The information provided in this chapter is described more elaborately in the document "Socio-Economic Analysis Guidelines" (Tucker et al., 2018) [17]

a) Objective

The objective of the Socio-Economic Analysis is to identify the best adaptation strategy, from step B.3, for an individual road drainage asset or sub-groups of drainage assets based on a wider range of project specific parameters, such as system performance, societal impacts, environmental impacts, resilience and robustness of the system etc.

b) Method

At this level of analysis, the framework shown in Figure 15 is also utilised however it is recommended that a more involved evaluation methodology is used.

In this case, a Cost Benefit Analysis (CBA) is typically the most appropriate approach to use as it is the most detailed approach that can be adopted however the availability of sufficient quantifiable data is considered a prerequisite as the purpose of a CBA is to quantify in monetary terms, the costs and benefits of all considered solutions. A CBA involves converting all benefits and costs into monetary terms, including environmental, social and other impacts and subsequently comparing them discounted over time.

At this level of analysis, it is recommended that a more complete or detailed list of parameters should be considered as follows;

- Technical Effectiveness (i.e. Performance) of the system;
- Maintenance & Serviceability Issues;
- Environmental Issues;
- Societal Impacts & Requirements;
- Safety Constraints & Impacts;
- Potential Impacts on Operation of the Wider Network;
- Resilience & Robustness of the System;
- Costs/Benefits associated with the system itself; and any knock on effects incurred as a consequence of this system. To be considered:
  - Costs/Benefits incurred by the NRA;
  - Costs/Benefits incurred elsewhere/by others;
- Availability and Adaptability of System;
- Land Availability and Acquisition Issues;
- Procurement.

However, it should be noted that in some cases, following the completion of a high level analysis, it may not be considered beneficial to include additional parameters. Rather, it may be preferential to carry out a more detailed assessment, considering the same parameters which were included in the high level analysis. The most appropriate approach to take will depend on a number of factors, including the overall context/objectives of the analysis, the level of data available and the findings of the Part A Analysis. Equally a CBA could be carried out at the High level of analysis and visa versa if desired.

c) Data Collection

The source of data will depend on the parameter being assessed, but typically data can be should be collected in the following means or from the following sources;

- From previous similar projects;
- Desk study;
- Existing studies;
- Climatologists, meteorologists
- Environmentalists

d) Examples

Reference is made to WATCH-case study, chapter 2.4.4 for more details [20].

Strategy	Construction cost in €			Yearly maintenance cost per culvert in €	Total average yearly cost in €
	Construction cost	Service Culvert	Average yearly construction cost		
As is /No action	0	On average. 30 years old as is and designed for 50 years	0	4,500	4,500
Enlarging capacity of culverts	2,500,000	50 years	97,164	5,000	102,164

Table 22: Total Average Yearly Costs (present climate)

Strategy	Maintenance & Serviceability Issues in €	Environmental effects in €	Societal Impacts & Requirements in €	Safety Constraints & Impacts in €	Total impact in €	Return period of threat	Annual average expected impact in €
As is / No action	190,000	65,000	1,500,000	10,000	1,765,000	0.1/year	176,500
	per flooding caused by culvert failure	per flooding caused by culvert failure	For a 6h standstill on M10 due to flooding caused by culvert failure				
Enlarging capacity of culverts	190,000	65,000	1,500,000	10,000	1,765,000	0.02/year	35,300
	per flooding caused by culvert failure	per flooding caused by culvert failure	For a 6h standstill on M10 due to flooding caused by culvert failure				

Table 23: Annual Average Expected Impact Costs (present climate)

Strategy	Yearly construction and maintenance cost in €	Annual average expected impact in €	Annual expected cost in €
As is / No action	4,500	176,500	181,000
Enlarging capacity of culverts	102,164	35,300	137,464

Table 24: Total Annual Expected Impact Costs (present climate)

Strategy	Maintenance & Serviceability Issues in €	Environmental effects in €	Societal Impacts & Requirements in €	Safety Constraints & Impacts in €	Total impact in €	Return period of threat	Annual average expected impact in €
As is / No action	190,000	65,000	1,500,000	10,000	1,765,000	0.2/year	353,000
	per flooding caused by culvert failure	per flooding caused by culvert failure	For a 6h standstill on M10 due to flooding caused by culvert failure				
Enlarging capacity of culverts	190,000	65,000	1,500,000	10,000	1,765,000	0.03/year	52,950
	per flooding caused by culvert failure	per flooding caused by culvert failure	For a 6h standstill on M10 due to flooding caused by culvert failure				

Table 25: Annual Average Expected Impact Costs (2030 climate)

Strategy	Yearly construction and maintenance cost in €	Annual average expected impact in €	Annual expected cost in €
As is / No action	4,500	353,000	357,500
Enlarging capacity of culverts	102,164	52,950	155,114

Table 26: Total Annual Expected Impact Costs (2030 climate)

Strategy	Net Annual Benefit in €	B/C ratio	Net Annual Benefit in €	B/C ratio
Time Period	*Present Climate*	*Present Climate*	*2030*	*2030*
Enlarging capacity of culverts	43,536	1.45	202,386	3.09

Table 27: Net Benefit and B/C ratio

In conclusion, it can be seen from the outputs that enlarging the culverts is a good solution compared to the do nothing approach, particularly for the 2030 climate.

It is noted that the example shown here is basic in nature and demonstrates the ability of a SEA evaluation in assisting in the decision making process. A more detailed evaluation considering more parameters, strategies, hazard return periods and climate change scenarios, for example, would be undertaken in a similar manner.

B.5 Step 5 – Finalisation of applicable/appropriate strategy

B.5.1 Sub-step 1 – Identifying the best strategy

For this sub-step, the user is referred to RIMAROCC [1] and the following sub-steps of the RIMAROCC framework:

- Sub-step 5.3 Negotiation with funding agencies
- Sub-Step 5.4 Present action plans

a) Objectives

Based on the ranking of the possible adaption measures defined in the previous step B.4, the goal of this step is to define the final design and maintenance strategy for all water management assets.

b) Output

The output is the final strategy.

c) Method

The action plan is done by prioritising the individual adaptation measures based on the results of the previous sub-step B.4.

Stakeholders should be invited to take part of the action plan (refer also to "Socio-Economic Analysis Guidelines" Tucker et al., 2018) [19].

Main stakeholders are:

- **NRA and the road users** because flooding of road surface and erosion of embankments are at first linked with the drivers' safety and thus the reputation of the NRA

- **The people living around the road** are also involved because in vulnerable areas, water depth increase may cause high damages to human beings and buildings

- Regarding environmental stakes: **water management authorities, Environmental agencies, agricultural administrations, fishing association** and people living around the road should be involved. Actually, an increase of flooded area upstream has a direct impact on the people living in the vicinity of the road (decrease of agricultural activities, leisure activities…). A change in peak flow downstream of the infrastructure or flooded area upstream has a direct impact on the people living in the vicinity of the road. Moreover, a change in water quality has a direct impact on the nearby environment: watercourses, potable water areas, leisure activities…

All actors within the watershed are concerned.

d) Data collection

The main input is the outcome of the previous step B.4.

e) Example

The example originates from the WATCH - case study [20]. Conducting the socio economic analysis on the M10, it is clear that a wide range of stakeholders must be involved to assess the complexity of all relevant factors. In regards to culvert stakeholders, the following list of stakeholders are identified as key contributors of relevant factors

- The Danish Road Directorate
- The road users
  - Commercial use of the M10
  - Commuters using the M10
- Neighbours to the M10, including density
- Adjoining agriculture to the M10 and both upstream and downstream catchment area
- Environment in and adjoining the M10 catchment area
- Commercial use of the M10
- Commuters using the M10

In the case of the M10, the relatively young age of the road construction and assets caused the strategic allocation of resource and focus towards maintenance since repairing or replacing the construction or assets to enhance resiliency was considered particularly costly since little depreciation and deterioration has yet materialized.

Had the M10 been close to reconstruction due to a relatively high age and thereby within few years subject for reconstruction or a general update, then the focus would have shifted towards allocating resources to construction rather than maintenance and operation.

Therefore, for now and the coming 5-8 years, maintenance will be the highest strategic focus point of consolidating or increasing resilience on the M10. As described, maintenance is regarded as a key focus area to ensure maximum durability of the road construction and assets on M10 and on any other road managed by the Danish Road Directorate. Examples of such maintenance topics are increasing the frequency of inspections, requirements for inspections, increase in maintenance frequency, e.g. clearing the area around a given water management asset for debris, increase in monitoring, more comprehensive data collection during operation, widening the geographic scope of maintenance actions to incorporate all relevant stakeholders, among more.

As an end-point specifically on M10 and other major Danish roads of similar size and age;

An increase in precipitation is considered to significantly and negatively contribute to an increase in debris and sediment-based clogging of water management assets, e.g. culverts, due to a higher degree of surface runoff. This places an extra emphasis on how revised strategies on maintenance during operation, e.g. based on socio economic analyses, can act as proactive climate change adaptation as an individual initiative.

The final implementation of the WATCH outcome in the Danish Road Directorate would be to incorporate the approaches as described in the global and detailed step-by-step methodologies as added points in the listed process models for a subsequent specification on requirements in the tendering process, leading to more resilient roads and road assets.

B.5.2 Sub-step 2 – Action planning

For this sub-step, the user is referred to RIMAROCC [1] sub-step 6.1 - Develop an action plan on each level of responsibility.

The user can also referred to CEDR report 'Acting on Climate Change [4] section 2, chapter 3 – Action planning.

a) Objectives

The strategy defined in the previous sub-step B.5.1 has to be detailed focusing on how to implement the action plan.

b) Output

The outcome is the detailed schedule and features of the action plan.

c) Method

As detailed in RIMAROCC [1] sub-step 6.1 - Develop an action plan on each level of responsibility:

- *Identify an appropriate level of detail; large-scale analysis requires more in depth description. Adopting a time schedule according to a specific study.*
- *Divide responsibility for approving and implementing the adaption action plan: responsibility for each activity is divided, including control activities.*
- *Action plans should be integrated into the management processes of the NRA and discussed with appropriate stakeholders. Decision-makers and other stakeholders should be aware of the nature and extent of the residual risk following risk mitigation.*
- *It is important to incorporate the time schedule and budget into the NRAs investment programme to ensure resources are available.*
- *Clarify the responsibilities and links between the various organisations participating in the road management.*
- *Detail resource demands in terms of staff, funds etc.*
    - *Per activity: how many working hours per staff grade, costs apart from staff etc.*
    - *Other demands, such as expertise from an external organisation, special equipment etc.*

d) Data collection

The main input is the outcome of the previous sub-step B.5.1.

e) Example

As an example on how the action plan can be used, table from the Acting on Climate Change [4] is provided as an illustration in the table below.

Bullets in the strategy	Description and goals	Who is responsible?	Priority	End user	Time perspective	Overlap and cooperation	Costs	Deliverables
Legislative work and standardisation	Identify all laws/directives/ norms/standards guidelines that are relevant to climate change adaptation.	Environmental/Technical department	1	Can affect all parts of the organisation	2016	EU-laws	€5,000	List of relevant documents
Assessment of natural hazards and collection of the information in a standardised way	The goal is to draw up guidelines for the systematic collection of incidents in order to be able to analyse events across the national state road network.	Maintenance division	2	Can affect all parts of the organisation	The guidelines should be ready by the end of September 2016	Traffic accident investigators	€10,000	Guidelines for the construction and maintenance of a system
Increase in the number of possibilities to reroute traffic	To have a well-functioning rerouting system for a large part of the state network. When a climate-related event closes the highway, alternative routes that are not affected by this event must be available.	Traffic division	1	Traffic division	2016-2019	Municipalities and other road owners, police	€2,000	Major highways have an updated plan for rerouting incl. signs.

Table 28: Action plan including examples [4]

B.5.3 Sub-step 3 – Implement action plan

For this sub-step, the user is referred to RIMAROCC [1] sub-step 6.2 - Implement adaptation action plan.

a) Objectives

This sub-step is the implementation of the action plan defined in previous sub-step B.5.2.

b) Method

As detailed in RIMAROCC [1] Sub-step 6.2 - Implement adaptation action plan:

Implementation of an action plan for climate change adaptation is similar to other development project implementation. It is beneficial for the NRA to use the same routines as in other development projects.

Implementation of an action plan is an operational step: the approved action plan is implemented by roads managers on each appropriate level.

A checklist could be used to follow the process, including questions such as: Is the funding in place? Are all stakeholders participating?

c) Data collection

The action plan is the main data accompanied by economic reports, progress reports, etcetera.

B.5.4 Sub-step 4 – Monitoring, review and capitalisation

For this sub-step, the user is referred to RIMAROCC [1] and the following sub-steps

- Sub-step 7.1 - Regular monitoring and review
- Sub-step 7.2 - Re-plan in case of new data or delay in implementation
- Sub-step 7.3 - Capitalisation on return of experience on both climatic events and progress of implementation

Proposition of additional criteria to be incorporated in standards

The following propositions originate from the reflexions that took place during the WATCH project, themselves based on RIMAROCC and ROADAPT but also from the analysis of international reports on climate change.

Indeed, most of the existing international reports dealing with climate change focus on the same elements: new climatic references, risk assessments, socio-economic evaluations and studies of exceptional event above the design criteria.

The following are propositions that have to be adapted to the context and the country.

Most of time, guidelines that impose performance requirements instead of means are more interesting but NRA can choose to enforce specific methods.

Recommendations will be split into short-term changes that are easily and rapidly applicable and medium term that are more accurate but involve longer implementation.

1. Generality

Additional criteria that could be added should explicitly mention climate change and how to take it into account.

Short term changes (easily and rapidly applicable) may be the following:

- Empirical recommendations to assess extreme peak flows according to climate change: for examples, in UK and Ireland increase of rainfall/flows by 20 %
- Impose analysis of the functioning for exceptional events above the design criteria
- Reinforce maintenance by incorporating minimum requirements especially in critical points (e.g. urban areas, sag points, roads in cut, slope reversal)
- Reinforce inspections as regular inspections are key to an early detection of defects
- Encourage Road Asset Management System in order to capitalize, monitor, keep tracks, knowledge of asset (make the vulnerability assessment easier).

Medium term changes (more accurate but longer implementation) may be the following:

- New assessment of extreme peak flows/extreme rainfall events by updating climatic references (or correcting for already observed trends) or advise how to use climate model data (to be done by meteorologists),
- Increase return period in critical points according to vulnerability study (e.g. RIMAROCC [1], QuickScan method [2], ROADAPT vulnerability assessment [2], blue spot method [3])
- Define new return periods to be taken into account or provide method to assess the appropriate value (socio-economic evaluation)
- Socio-economic evaluations of measures/strategies

2. For existing infrastructures

In order to accurately assess the current and future resilience of the infrastructure, it could be interesting to propose mapping of the vulnerable areas (e.g. blue spot method [3], QuickScan method [2], ROADAPT vulnerability assessment [2]) in order to carry on detailed assessment in these particularly vulnerable areas.

Specific maintenance needs should be monitored and maintenance plans adjusted to suit local requirements.

3. For new infrastructures

Short term changes (easily and rapidly applicable) may be the following:

- Increase safety margins in design (minimum freeboard and minimum dimensions).
- Impose to check the functioning for exceptional events above the design peak flow and analyse the impacts on protection measures
- Increase design return period in critical points (e.g. sag points, urban areas, roads in cut)
- Impose maintenance plans and schedules to be defined during the design phase
- Increase transversal slopes in order to evacuate extreme rainfall amounts as fast as possible (but taking into account driver safety).

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References

1. Bles, T., Y. Ennesser, J.J. Fadeuilhe, S. Falemo, B. Lind, M. Mens, M. Ray & F. Sandersen, Risk management for roads in a changing climate. A Guidebook to the RIMAROCC Method. ERA NET ROAD project. 2010
2. ROADAPT 'Roads for today, adapted for tomorrow-Guidelines' ROADAPT deliverables, 2015, available via www.cedr.fr

   A. Guideline on the use of climate change projections
   B. Guideline on the application of a QuickScan on climate change risks for roads
   C. Guideline on how to perform a detailed vulnerability assessment
   D. Guideline on how to perform a socio economic impact assessment
   E. Guideline on how to come to an adaptation strategy

3. SWAMP (2010)

   The Blue Spot Concept - methods to predict and handle flooding on highway systems in lowland areas

   Background Report - literature, questionnaire and data collection for blue spot identification

   The Blue Spot Model - development of a screening method to assess flood risk on national roads and highway systems

   Inspection and Maintenance - guide for reducing vulnerability due to flooding of roads
4. Grauert, M., task group 14, CEDR report 'Acting on Climate Change', 2016
5. Guérard H, Ray M, Le projet Gerici - gestion des risques liés au changement climatique pour les infrastructures - Premières leçons de trois années d'expérience d'étude des vulnérabilités - RGRA | N° 854 • décembre 2006 - janvier 2007
6. Ennesser Y., Quickscan report : A24 motorway in Portugal, 2014, CEDR project
7. Ennesser Y, Fadeuilhe JJ, New options for mobility and transport infrastructure in the post-carbon society, Roads, (2012)
8. Hallegatte S., Strategies to adapt to an uncertain climate change – CIRED -
9. Lenderink, G. & J. Attema, 2015. A simple scaling approach to produce climate scenarios of local precipitation extremes for the Netherlands. Environ. Res. Lett. 10 (2015) 085001. http://dx.doi.org/10.1088/1748-9326/10/8/085001
10. Kilgore R., Herrmann G., Thomas W., Thompson D., FHWA HEC17 "Highways in the River Environment-Floodplains, Extreme Events, Risk, and Resilience", 2016
11. EngineersCanada, PIEVC (Public Infrastructure Engineering Vulnerability Committee) Engineering Protocol For Infrastructure Vulnerability Assessment and Adaptation to a Changing Climate - PRINCIPLES and GUIDELINES - 2016
12. Plan National d'Adaptation au Changement Climatique, volet infrastructures et systèmes de transport, action 3 - Analyse des risques liés aux événements climatiques extrêmes sur les infrastructures, systèmes et services de transport - Recueil de concepts – CEREMA –France - (2015)
13. Ennesser Y, et al.., "Technical Assistance to Increase Climate - Resilience of Georgia's Road Network – Egis – World Bank group – 2017

14. The EU Strategy on adaptation to climate change - Strengthening Europe’s resilience to the impacts of climate change - European commission – 2013

    Commission staff working document - Guidelines on developing adaptation strategies (2013)

    Commission staff working document - Adapting infrastructure to climate change (2013)

15. European climate adaptation platform : http://climate-adapt.eea.europa.eu/
16. Bles T., De Lange D., Foucher L., Axelsen C., Leahy C., Rooney JP., WATCH - Country Comparison Report, 2017
17. Bessembinder J., Bouwer L., Scheeleet R., WATCH - Climate and climate change: protocol for use and generation of statistics on rainfall extremes and analogue tool, 2018
18. Rooney JP., Bles T., WATCH - Protocol for Adapting SuDS systems for Climate Change, 2018
19. Tucker M., Corbally R., O’ Connor A., Bles T., De Bel M., WATCH - Socio-Economic Analysis Guidelines, 2018
20. Axelsen C., Foucher L., Bles T., Tucker M., Corbally R., WATCH - Case study, 2018

Appendix 1 – Climate data

This appendix contains tables with links and information to available climatologies, rainfall statistics, climate scenarios, rainfall data sets, etc. These tables are also included in the document "Climate and climate change: protocol for use and generation of statistics on rainfall extremes" (Bessembinder et al., 2018) [17].

Table A1.1 Some examples of descriptions of the current climate from European countries. Also indicated is which periods are used to describe the current climate ('normals'; last update June 15, 2017).

Country	Web site	Current climate described with [A]
Austria	www.zamg.ac.at/cms/de/klima/klimauebersichten/klimamittel-1971-2000	1981-2010
Belgium	www.meteo.be/meteo/view/fr/16788784-Atlas+Climatique.html#navigate=1	1981-2010
Denmark	www.dmi.dk/vejr/arkiver/normaler-og-ekstremer/klimanormaler-dk/ www.dmi.dk/en/klima/climate-changes-over-time/denmark/	1961-1990
France	www.meteofrance.fr/climat-passe-et-futur/climat-en-france/le-climat-en-metropole#	1981-2010
Finland	en.ilmatieteenlaitos.fi/normal-period-1981-2010 ilmasto-opas.fi/en/ilmastonmuutos/suomen-muuttuva-ilmasto/-/artikkeli/1c8d317b-5e65-4146-acda-f7171a0304e1/nykyinen-ilmasto-30-vuoden-keskiarvot.html	1981-2010
Germany	www.dwd.de/DE/leistungen/klimadatendeutschland/langj_mittelwerte.html	1981-2010
Ireland	www.met.ie/climate-ireland/30year-averages.asp	1981-2010
Italy	www.isprambiente.gov.it/en/publications/state-of-the-environment/temperature-and-precipitation-climatic-normals-over-italy	1981-2010
Netherlands	www.klimaatatlas.nl/	1981-2010
Norway	www.senorge.no/index.html?p=klima	1971-2000
Portugal	www.ipma.pt/resources.www/docs_pontuais/ocorrencias/2011/atlas_clima_iberico.pdf https://www.ipma.pt/pt/oclima/normais.clima/	1971-2000 1981-2010 (provisional)
Spain	www.ipma.pt/resources.www/docs_pontuais/ocorrencias/2011/atlas_clima_iberico.pdf	1971-2000
Sweden	www.smhi.se/klimatdata www.smhi.se/klimatdata/meteorologi/nederbord/1.1628	1961-1990
Switzerland	www.meteoswiss.admin.ch/home/climate/past/climate-normals.html	1981-2010
United Kingdom	www.metoffice.gov.uk/public/weather/climate/gcpvn15h9	1981-2010

[A] Many countries also present the 'normals' for 1961-1990 and/or 1971-2000.

Table A1.2 Regional climate scenarios/projections in various European countries: links to the websites (source: among others Dalelane, 2014; links updated June 15, 2017).

Country	Website with regional climate scenarios[A]
Austria	https://www.bmlfuw.gv.at/umwelt/klimaschutz/klimapolitik_national/anpassungsstrategie/klimaszenarien.html (2015)
Belgium	www.kuleuven.be/hydr/cci/CCI-HYDR_rp.htm (2015)
Denmark	http://www.dmi.dk/fileadmin/user_upload/Rapporter/DKC/2014/Klimaforandringer_dmi.pdf (2014) http://www.dmi.dk/klima/fremtidens-klima/danmark/ekstrem-vejr/ (2014) www.dmi.dk/klima/fremtidens-klima/klimascenarier/nye-scenarier-fra-ipcc/
France	www.drias-climat.fr/decouverte www.meteofrance.fr/climat-passe-et-futur/le-climat-futur-en-france (2014)
Finland	ilmasto-opas.fi/en/ilmastonmuutos/suomen-muuttuva-ilmasto/-/artikkeli/74b167fc-384b-44ae-84aa-c585ec218b41/ennustettu-ilmastonmuutos-suomessa.html (2016) www.geophysica.fi/pdf/geophysica_2016_51_1-2_017_ruosteenoja.pdf
Germany[B]	DWD Klimaatlas: www.dwd.de/DE/klimaumwelt/klimaatlas/klimaatlas_node.html (2011) KLIWAS: www.kliwas.de/ (2015) GERICS: www.climate-service-center.de/products_and_publications/maps_visualisation/csm_regional/index.php.en (2015)
Ireland	idev.climateireland.ie/climatetool/viewer_main.html (2015) www.epa.ie/pubs/reports/research/climate/research159ensembleofregionalclimatemodelprojectionsforireland.html#.VlwLUt_hCEJ
Netherlands	www.climatescenarios.nl/ (2014)
Norway	https://klimaservicesenter.no/faces/desktop/scenarios.xhtml https://www.klimaservicesenteret.no/faces/desktop/article.xhtml?uri=klimaservicesenteret/klima-i-norge-2100 (2017)
Portugal	http://portaldoclima.pt/pt/ (2015?) www.ipma.pt/pt/oclima/servicos.clima/index.jsp?page=cenarios21.clima.xml siam.fc.ul.pt/
Spain	www.aemet.es/es/serviciosclimaticos/cambio_climat (2014?)
Sweden	https://www.smhi.se/en/climate/climate-scenarios (2014)
Switzerland	www.ch2011.ch/ (2011) (new scenarios to be released in 2018: CH2018)
United Kingdom	UKCP09: ukclimateprojections.defra.gov.uk/ (2011) (new scenarios to be released in 2018: UKCP18)

[A] Links to most recent scenarios for the various countries are shown (year indicated). Each country and organization uses its own methods to construct regional climate scenarios. Therefore, they cannot be easily combined or compared.
[B] More than one provider of climate scenarios or projections of climate change for this country.

Table A1.3 Overview of available **information on extreme rainfall statistics in the "current" climate**, for the countries in the WATCH country comparison report (Bles et al.., 2017): for general use (also for road design). (latest check: March 2018).

Country	Reference period/ year*	Point/ area statistics	Rainfall durations	Return periods	Comments
Austria	? Before 2005, varying length: 1->50 years	Point Method described how area statistics can be obtained	For points: 5 min. to 6 days	1/1 year to 1/100 years	• Link: ehyd.gv.at/ • Method: ehyd.gv.at/assets/ehyd/pdf/bemessungsniederschlag.pdf Based on modelled data and measured data; app.hydrographie.steiermark.at/berichte/seminargutachtennlv.pdf • Freely available, daily time series and statistics (look for "Bemessungsniederschlag" on the map with gridded data)
	?	?	?	?	• Link: www.zamg.ac.at/cms/de/klima/produkte-und-services/daten-und-statistiken/extremwertstatistik-1 • No detailed information on internet, not freely available
Denmark	1979-2012	Point	1 hour up to 24 hours Also > 24 hours?	½ years, 1/10 years, 1/100 years	• Link: https://universe.ida.dk/netvaerk/energi-miljoe-og-global-development/spildevandskomiteen/spildevandskomiteens-skrifter/ • Method: https://ida.dk/sites/default/files/svk_skrift30_0.pdf?_ga=2.138825715.1982837567.1497872368-1856766300.1497872368 • Excel file for calculating amounts and return times freely available
France	Varies per station	Point	6 min up to 48 (192) hours	1/1week to 1/2years and 1/5years to 1/100 years	• Link: http://services.meteofrance.com/e-boutique/climatologie/coefficient-montana-detail.html • Not freely available • More than 1000 rain gauges managed by Météo-France
Germany	1951-2010	Point	5 min up to 72 hours	1/1 year to 1/100 years	• Link: http://www.dwd.de/DE/leistungen/starkniederschlagsgutachten/starkniederschlagsgutachten.html • Method: http://www.dwd.de/DE/leistungen/starkniederschlagsgutachten/download/kostra_dwd_2010_pdf.pdf?__blob=publicationFile&v=8 • Not freely available
Ireland	1941-2004	point	5 min to 25 days	2/year to 1/500 years	• Link: www.met.ie/climate/products03.asp • Methods: www.met.ie/climate/dataproducts/Estimation-of-Point-Rainfall-Frequencies_TN61.pdf • Freely available, but should be requested
Nether-lands	2014 (1906-2014 detrended to 2014)	Point/area	2 hours to 10 days	2/year to 1/1000 years	• Link: www.meteobase.nl/ • Method: 62.148.170.210/meteobase/downloads/fixed/literatuur/Beersma2015_STOWArapport_actualisatie_meteogegevens.pdf

					• Hourly data used as basis, freely available • For transfer to area statistics: bibliotheek.knmi.nl/knmipubTR/TR332.pdf. Updated extreme areal rainfall statistics available in the course of 2018 for durations 15 min-9 days and area sizes 6- 1700 km2. Will be updated in 2018 • Also similar statistics for future (KNMI'14 scenarios for 2050 and 2085)
	2003-2016	point	10 min – 12 hours		• Yearly maxima for 10 min -12 hours used, freely available • Method: Neerslagstatistieken voor korte duren, actualisatie 2018 (Beersma et al.., 2018). http://www.stowa.nl/Upload/Publicaties%202018/STOWA%202018-12%20HR.pdf
Norway	Varying between stations, but at least 10 years between 1967-2014	Point and area?	1 min to 24 hours	1/2 years to 1/200 years	• Method: https://cms.met.no/site/2/klimaservicesenteret/rapporter-og-publikasjoner/_attachment/8171?_ts=1527e50a347 • Data: https://klimaservicesenter.no/faces/desktop/article.xhtml?uri=klimaservicesenteret/dimensjonerende-nedbor/ivf-verdier-fra-et-utvalg-malestasjoner • Tentative regional statistics for 7 regions • Trend detected in extremes on many stations • Freely available, also information on climate change
Sweden	1961-2011	point	1 to 30 days	1/year to 1/100 years	• Data and method: http://www.smhi.se/publikationer/extrem-nederbord-i-sverige-under-1-till-30-dygn-1900-2011-1.24660 • Based on daily data • Freely available
	1995-2008	point	15 min to 96 hours	1/year to 1/100 years	• Data and method: http://www.smhi.se/polopoly_fs/1.7847!/Meteorologi%20139.pdf • Based on 15 min data, freely available • Not clear whether also area statistics, but there is information about extreme rainfall over large areas: https://www.smhi.se/kunskapsbanken/klimat/extrem-arealnederbord-1.6153
United Kingdom	up to max of 2006	Point and catchment data?	1 to 192 hours	2 to 10,000 years.	• https://fehweb.ceh.ac.uk/ (FEH 2013 rainfall model) • Data: https://www.ceh.ac.uk/services/rainfall-frequency-grids • Method: https://www.ceh.ac.uk/services/flood-estimation-handbook (annual maximum (AM) and peaks-over-threshold (POT), and fixed and sliding event durations.) In volume 2 of this handbook also info on the application of ARF's is given • Hourly data as basis

Table A1.4. Links to some **rainfall datasets per country** with observations (station data or gridded data) or simulated data. (latest check december 2017).

Country	Name/Link(s)	Comments	Freely available?
Austria	http://www.zamg.ac.at/cms/de/produkte/klima/daten-und-statistiken/messdaten	Observations per station,	no
	http://www.zamg.ac.at/cms/de/produkte/klima/daten-und-statistiken/gitterdatensaetze	Gridded datasets, 15 min, 1 day or 1 month temporal resolution, spatial resolution often 1 km or 100 m, high resolution data starting in 1961 or later	no
Denmark	SVK http://svk28.env.dtu.dk/regnserier-kmd-7997.htm?	Point observations, at present 145 stations in Denmark, from 1979 on, 1 min resolution	?
	CGD: http://beta.dmi.dk/fileadmin/Rapporter/TR/tr12-10.pdf	Gridded data, 10 km resolution, 648 grid cells covering Denmark, 1980-2010, daily resolution	?
France	https://donneespubliques.meteofrance.fr/ https://publitheque.meteo.fr/okapi/accueil/okapiWebPubli/index.jsp	Daily and hourly station data, radar (high resolution) and satellite data, model data	no
	http://www.drias-climat.fr/commande	Bias-corrected daily gridded climate data for some models	yes?
Germany	http://www.dwd.de/DE/leistungen/klimadatendeutschland/klarchivtagmonat.html?nn=16102 http://www.dwd.de/DE/klimaumwelt/cdc/cdc_node.html	Hourly and daily station data Gridded datasets (current ant future climate, KLIWAS)	yes
	http://www.dwd.de/DE/leistungen/fuenfminutenwerterr/fuenfminutenwerterr.html	5 min data	no?
	http://www.dwd.de/DE/leistungen/starkniederschlagsauswertung/starkniederschlagsauswertung.html	5 min radar data, Method: http://www.dwd.de/DE/leistungen/radolan/radolan_info/abschlussbericht_pdf.pdf?__blob=publicationFile&v=2	no
	HYRAS	high resolution gridded daily dataset, description: http://www.schweizerbart.de/papers/metz/detail/23/82855/Central_European_high_resolution_gridded_daily_dat?af=crossref	?
Ireland	http://www.met.ie/climate/climate-data-information.asp http://www.met.ie/climate-request/	Daily data and hourly data	yes
Nether-lands	http://www.knmi.nl/nederland-nu/klimatologie-metingen-en-waarnemingen	Daily and hourly station data	yes
	http://www.klimaatscenarios.nl/toekomstig_weer/transformatie/index.html	Daily station data for future (KNMI'14 scenarios)	yes
	https://data.knmi.nl/datasets	Gridded data (1 km) for current and future climate (KNMI'14 scenarios)	yes
	https://data.knmi.nl/datasets	Radar data	yes
Norway	http://om.yr.no/verd/klimadata/	Station data and other data?	yes

	https://www.met.no/nyhetsarkiv/var-tjeneste-eklima-har-begrenset-tilgang https://www.met.no/frie-meteorologiske-data/frie-meteorologiske-data https://data.met.no/index.html	New website under construction, now any places that mention this	
	https://www.klimaservicesenter.no/faces/desktop/article.xhtml?uri=klimaservicesenteret/klima-og-hydrologiske-data/datagrunnlag-klimafremskrivninger	Climate model data for 1971-2100, daily data, 1*1 km or 12*12 km	yes
Portugal	https://www.ipma.pt/pt/produtoseservicos/index.jsp?page=dataset.pt02.xml	Gridded data, daily resolution, 0.2 ˚resolution (about 20 km), 1950 a 2003	yes
	https://www.ipma.pt/pt/produtoseservicos/index.jsp?page=dados.xml	Station data, 10 min, hourly and daily	?
Sweden	http://opendata-download-metobs.smhi.se/explore/#	Station data, 15 min, hourly and daily data	yes
	https://esg-dn1.nsc.liu.se/projects/esgf-liu/	Climate model data	Yes?
United Kingdom	http://catalogue.ceda.ac.uk/uuid/220a65615218d5c9cc9e4785a3234bd0	Among others daily, hourly and sub-hourly rain data from Met Office station network	?
	https://www.europeandataportal.eu/data/en/dataset/gridded-estimates-of-daily-and-monthly-areal-rainfall-for-the-united-kingdom-1890-2012-ceh-gear	Gridded daily rainfall data to 1 km for period 1890-2012, based on station data from UK Metoffice	?
	http://www.metoffice.gov.uk/climatechange/science/monitoring/ukcp09/download/daily/gridded_quantities.html	Gridded data for period 1960-2011, large number of climate indices, also on daily and multi-day extremes	yes
General for Europe	www.ecad.eu/	Daily observed data per station and many derived climate indices.	Downloadable if freely available. If not, derived data and climatology of stations can be obtained
	https://climexp.knmi.nl/selectdailyseries.cgi?id=someone@somewhere	Daily observed data per station. Use station names or coordinates to find stations in the GCHN-D database	yes

Table A1.5 Overview of available information on **future changes in rainfall in the climate scenarios** in Table 2.2 for the countries included in the WATCH country comparison report (Bles et al.., 2017). (latest check december 2017).

Country	Reference period	Time horizons	Scenarios[11]	Averages		Extremes			Comments
				Per yr	Per season	Multiple days	Daily	Sub-daily	
Austria	1971-2000	2021-2050 2071-2100	RCP4.5, RCP8.5	Yes	Yes	Per month	Wet days (rr1), Highest 1 day and 5 days rainfall per year (rx1day, rx5day), Rainfall amount wet days 30%-98% percentiles (rr1_30pct, rr1_60pct, rr1_90pct, rr1_95pct, rr1_98pct), Consecutive wet days per year (cwd_sum_days)	No	Info on temperature change, not on humidity
Denmark	1986-2005	2081-2100	RCP2.6, rcp4.5, rcp6.0, RCP8.5	Yes	Yes	-	-	-	http://www.dmi.dk/klima/fremtidens-klima/danmark/ekstrem-vejr/
	1961-1990	2021-2050, 2071-2100	A1B (ensemble average)	-	-	-	Highest 1 day and 5 days rainfall per year, Avg. rainfall amount on wet days, Nr days with >10 mm and > 20 mm	-	http://www.dmi.dk/klima/fremtidens-klima/danmark/ekstrem-vejr/
	1979-2012	50 and 100 years ahead	RCP4.5, RCP8.5	Yes ?	?	?	24 hours	1 hour and maybe shorter too	Method climate factors: https://ida.dk/sites/default/files/svk_skrift30_0.pdf?_ga=2.138825715.1982837567.1497872368-1856766300.1497872368
France	1976-2005	2021-2050 (Near) 2041-2070 (Mid-term) 2071-2100 (long-term	RCP 2.6 RCP4.5 RCP8.5 (A1B, A2, B1: model data available, but	Yes	Yes	Per month	Daily precipitation, Mean precipitation for wet days, Precipitation sum, Nr. wet days, Nr heavy precipitation days (>20 mm), Max. number consecutive wet days (>=1 mm), % of intense	No	http://www.drias-climat.fr/

[11] Information on the scenarios mentioned here is given among other in the ROADAPT guide line on the use of climate data (2015): http://www.cedr.fr/home/fileadmin/user_upload/en/Thematic_Domains/Strat_plan_3_2013-2017/TD1_Innovation/I1_Research/TGR_TPM/Transnational_calls/CEDR_Call_2012/CEDR%20Call%202012%20Climate%20Change/ROADAPT/ROADAPT_Part_A1_-_Guideline_on_the_use_of_data_for_the_current_and_future_climate.pdf

			not presented)				precipitation, drought period (consecutive days with <1 mm)		
Germany	1971-2000	2031–2060 2041-2070 2051-2080 2061-2090	RCP2.6, RCP8.5 (A1b)	No	Yes winter summer	No	number of days exceeding the 95th percentile threshold of daily precipitation	No	Climate Signal maps: http://www.mdpi.com/2073-4433/6/5/677
	1951-2006	2021-2050 2071-2100	A1B (range based on ensemble)	Yes	Yes	No	No, but can be obtained from the datasets	No	KLIWAS: http://www.kliwas.de/KLIWAS/DE/Home/homepage_node.html
Ireland	1961-1980 and 1981-2000	2021-2040 2041-2060 2021-2060	Low-medium (RCP45, B2) and high (RCP85, A1B and A2)	Yes	Yes	No	Wet Days (> 20mm/day), Very Wet Days (> 30mm/day) Number of wet days	No	Method and more detailed info: http://www.epa.ie/pubs/reports/research/climate/research159ensembleofregionalclimatemodelprojectionsforireland.html#.VlwLUt_hCEJ
Nether-lands	1981-2010	Around 2030, 2050, 2085	4 scenarios based on change of 2 levels of global temperature + 2 levels of circulation	Yes	Yes	Monthly changes in transformation tool	Wet days Daily sum with return time 1/10 y, 10 day sum with return time 1/10 y 50%, 90% and 99% percentiles for wet days	Hourly sum that occurs 1/1 year.	Info on temperature change and on humidity change Transformation tool: http://www.klimaatscenarios.nl/toekomstig_weer/transformatie/Toelichting_TP.pdf
Norway	1971-2000	2031-2060 2071-2100	RCP4.5 RCP8.5 (and 10% and 90% percentiles)	Yes	Yes	No	Nr of days with heavy rainfall (exceeded twice per year), intensity on days with heavy rainfall	Some info/prelimi-nary info: estimated 30% for 3-hour precipitation with 5 year reurn time for RCP8.5 (higher than increase daily extremes)	Report: https://cms.met.no/site/2/klimaservicesenteret/klima-i-norge-2100/_attachment/10990?_ts=159d5ffcffd
Sweden	1971-2000 (and 1961-1990?)	2011-2040 2041-2070 2071-2100	RCP2.6, RCP4.5, RCP8.5 (and 2C and A1b)	Yes	Yes	Max 7-day precipitation	Max. daily precipitation, nr. Of days with heavy precipitation	No	Background: https://www.smhi.se/klimat/framtidens-klimat/klimatscenarier/haag_en.html
United Kingdom	1961–1990	2010 to 2099 as overlap-ping 30-year time periods	Low, medium and high	Yes	Yes	Per month	Wettest day in summer/winter In weather generator: mean rainfall amount, the proportion of dry days, the variance and skewness of daily rainfall amounts and the lag-1	Hourly time series produced (besides daily), but change in hourly the same as for daily change (change inhourly rainfall not	Reports and guidance: http://ukclimateprojections.metoffice.gov.uk/22530

							autocorrelation used for fitting	seperately determined)	

Table A1.6 Methods for extreme runoff estimation, and commonly applied design standards (source: Bles et al.., 2017).

Country	Asset	Design standard	Runoff calculation methods
Austria	Culverts	100 year return period (duration depends on catchment area).	Prandtl-Colebrook
United Kingdom	Ditches	75 year return period	IH 124 Method for catchments > 0.4 km^2 ADAS Method for catchments < 0.4 km^2
	Culverts	For catchment areas >50ha and 100 year return period in England and Wales, and 200 year return period in Scotland.	Rainfall transformation methods based on runoff coefficients Method from the Flood estimation handbook (Institute of Hydrology, 1999) for drained areas > 50 ha.
France	Ditches	Ditches are sized for those implemented at crest of cut embankments (return period 100 yr.	Rational method based on IDF curves. Hydraulic calculation: Manning-Strickler equation.
	Culverts	Return period 100 years (plus check 1.5*Q100). There is no prevailing duration of precipitation in design as the time of concentration is calculated for each watershed.	Hydrology: rational method and Crupedix method and IDF curves for non-gauged catchments; Hydraulics: Manning-Strickler equation (preliminary design); Bernoulli and energy equations (detailed design).
Ireland	Ditches	Mean annual runoff for 75 year return period.	IH 124 Method for catchments > 0.4km2 ADAS Method for catchments < 0.4km2
	Culverts	Annual peak runoff for 100 year return period, plus (typically 300mm) freeboard (UK CIRIA C689 culvert design guide).	Rainfall transformation methods based on runoff coefficients
Nether-lands	Ditches	Roads in fill and bridges 10 years; roads in cut 50 years; tunnels 250 years	No information
	Culverts	Requirements for culverts are given by the water boards	Requirements for culverts are given by the water boards.
Norway	Ditches	For existing structures - often no information available about the design method or design capacity. 200 year return period (highways). 50-100 year return period (other roads).	Rational method and IDF curves. Revised guidelines (coming up soon) include several other methods, distinguish between catchment characteristics.
	Culverts	Annual peak runoff for 100 yr return period, plus (typically 300mm) freeboard (UK CIRIA C689 culvert design guide).	IDF curves No further information
Sweden	Culverts	50 year return period, in some cases 200 year return period.	No information
Denmark	Culverts	25 year return period (highways); 10 to 25 years return period for other roads.	No information

Appendix 2 – Additional examples

Sub-step B.2.3 Determining asset functioning

Assets dealing with precipitation on the road (conveyance field)

Method – lengths of saturation

Built abacus for different longitudinal slopes / road features / rainfall events (to be defined according to the existing network)

For one rainfall event, one longitudinal slope, one road feature, for a chosen calculation step, at each step, calculation of:

- Efficient area
- Time of concentration (use iterations related to flow velocity)
- Peak flow.

These calculations enable to define at which length the chosen asset is saturated

The following table provides an example based on rational method and Manning calculations

Length (m)	Width of platform (m)	Width of shoulder (m)	Width of fill-slope (m)	Efficient area (m2)	**Longitudinal slope (%)**	Time of concentration (min)	Rainfall intensity (mm/h)	Peak flow (l/s)	Average velocity (m/s)	Chosen Trapezoidal ditch
50	1.5	3	5	355	**1**	4.4	277.2	27	0.6	Earth 0,5*0.5m
100	1.5	3	5	710	**1**	5.6	258.0	51	0.7	Earth 0,5*0.5m
150	1.5	3	5	1065	**1**	6.6	245.1	72	0.8	Earth 0,5*0.5m
200	1.5	3	5	1420	**1**	7.5	235.6	93	0.9	Earth 0,5*0.5m
250	1.5	3	5	1775	**1**	8.5	227.6	112	0.9	Earth 0,5*0.5m
300	1.5	3	5	2130	**1**	9.4	220.6	131	0.9	Earth 0,5*0.5m
350	1.5	3	5	2485	**1**	10.2	215.1	148	1.0	Earth 0,5*0.5m
400	1.5	3	5	2840	**1**	10.8	211.4	167	1.4	Concrete 0,5*0.5m
450	1.5	3	5	3195	**1**	11.4	208.1	185	1.4	Concrete 0,5*0.5m
500	1.5	3	5	3550	**1**	12.0	205.1	202	1.5	Concrete 0,5*0.5m
600	1.5	3	5	4260	**1**	13.1	199.7	236	1.5	Concrete 0,5*0.5m
700	1.5	3	5	4970	**1**	14.1	195.2	269	1.6	Concrete 0,5*0.5m
800	1.5	3	5	5680	**1**	15.2	191.1	301	1.6	Concrete 0,5*0.5m
900	1.5	3	5	6390	**1**	16.2	187.5	333	1.7	Concrete 0,5*0.5m
1000	1.5	3	5	7100	**1**	17.1	184.2	363	1.7	Concrete 0,5*0.5m

Method – Capacity calculations

For one rainfall event, for a chosen calculation step, at each step:

- Calculate the peak flows with the dedicated formula (according to the standard) taking into account current and future climate data
- Calculate water depth /velocity / within the structure

Particularities to be taken into account on a case by case analysis:

- Over the edge run-off in storm drain system in fill but without safety barriers
- In cut with safety barriers, also consider water depth on shoulders and lanes
- If crossing pipes, reference is made to culvert possible methodology

Example of calculations

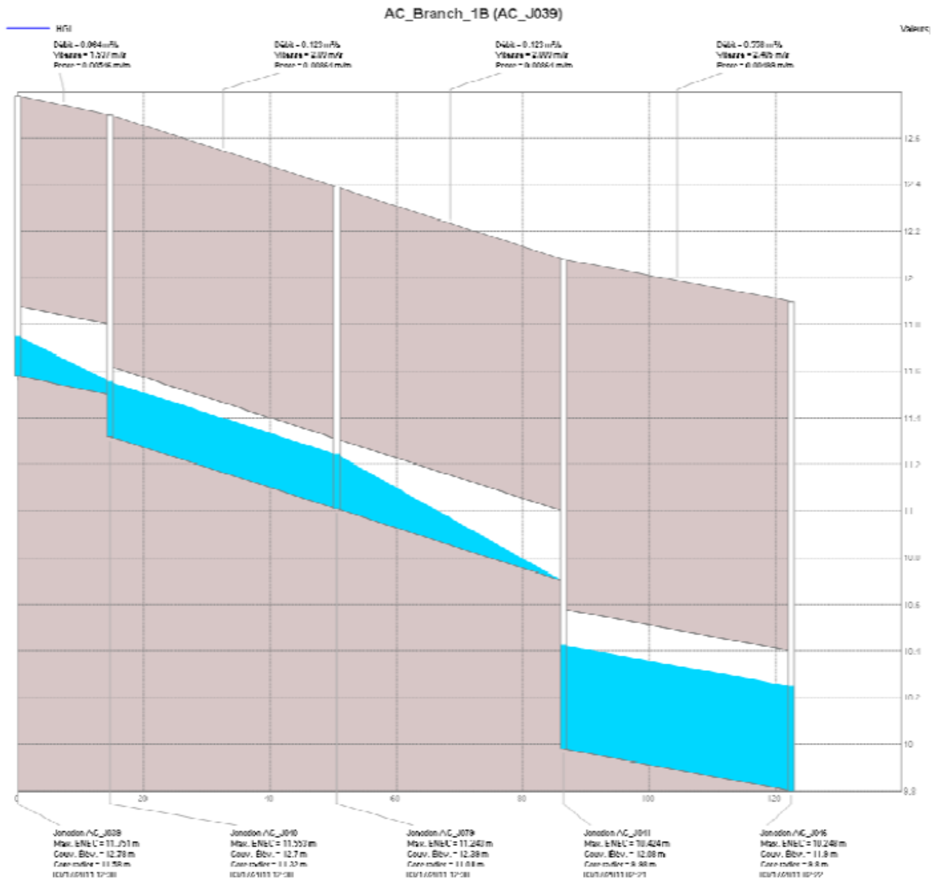
RESULTS OF CALCULATIONS									
Chainage (m)	Slope (%)	Intensity (mm/h)	Efficient area (m²)	Peak flow (l/s)	Water depth (m)	filling ratio (%)	velocity (m/s)	Tc (mn)	Structure reference
0	1.00%	0.00	0	0	0.00	0%	0.00	3.00	CAF400
25	1.00%	329.72	288	26	0.10	25%	1.06	3.39	CAF400
50	1.00%	306.16	575	49	0.14	35%	1.26	3.72	CAF400
75	1.00%	287.74	863	69	0.17	42%	1.39	4.02	CAF400
100	1.00%	272.54	1150	87	0.19	48%	1.48	4.31	CAF400
125	1.00%	259.58	1438	104	0.21	53%	1.54	4.58	CAF400
150	1.00%	248.29	1725	119	0.23	57%	1.59	4.84	CAF400
175	1.00%	238.28	2013	133	0.25	62%	1.63	5.09	CAF400
200	1.00%	229.31	2300	147	0.26	66%	1.66	5.34	CAF400
225	1.00%	221.17	2588	159	0.28	70%	1.69	5.59	CAF400
250	1.00%	213.73	2875	171	0.30	74%	1.71	5.83	CAF400
275	1.00%	206.88	3163	182	0.31	78%	1.72	6.08	CAF400
300	1.00%	200.78	3450	192	0.27	53%	1.80	6.31	CAF500
325	1.00%	195.13	3738	203	0.28	55%	1.82	6.54	CAF500
350	1.00%	189.89	4025	212	0.28	57%	1.84	6.76	CAF500
375	1.00%	185.01	4313	222	0.29	58%	1.86	6.99	CAF500
400	1.00%	180.43	4600	231	0.30	60%	1.88	7.21	CAF500
End of branch									

Method – Mathematical modelling

With the help of mathematical models (Infoworks, PCSWMM, Mike Urban, etcetera) define the hydraulic functioning of the network for different rainfall events:

- Creation of the network within the software (nodes with ground levels and depths, links with network dimensions, subcatchments with their features)
- Definition of design storms: according to the studied return periods, the rainfall duration, and the chosen method (double triangular rainfall, SCS method; Kieffer method, etcetera),
- Run-off method : according to the design storm and the run-off method, the program calculates the flow hydrograph at the outlet of each subcatchment,
- Routing in the network: The chosen routing method routes flows through the conveyance system.

Example with PCSWMM software



Sub-step B.2.4 Asset risk evaluation

Assets dealing with precipitation on the road (conveyance field)

Example of criticality levels:

- Normal operation level: corresponds to design functioning of the network,
- Critical operation level: beginning of shoulder / emergency lane submersion / beginning of urban area flooding
- Breach level: interruption of traffic because the water reaches the pavements and floods the infrastructure.

Of course for extreme flood, we may assume that the traffic is not possible. In this case, the risk remains only structural.

Assets dealing with precipitation on the road (quantity and quality aspects)

Key issues

Define Key issues regarding water depth / quality thresholds within road and surroundings areas: (persons, environment, other infrastructure, expected developments)

If a spillway is provided, the facility itself is protected for ruin but the consequences may be severe downstream by increase of peak flows especially in vulnerable areas (for example urban area).

Quantity

Example of criticality levels according to the surroundings area:

- Normal operation: design operation, no overflow - no hazard for surroundings assets (other infrastructure, urban areas) or the infrastructure itself
- Degraded operation: overflow but do not reach a surrounding vulnerable area
- Breach operation : overflow reaching a vulnerable area

Quality

Define criticality levels according to the surroundings area / receiving watercourses / ground water table, etcetera

Assets preventing pluvial flooding (water besides the road)

Key issues regarding hydraulic functioning and durability:

- Within surroundings areas: upstream and downstream (persons, environment, other infrastructure, expected developments)
- On the road itself: level of submersion of lanes, scour, critical points (road in cut, sag points), duration of submersion, etcetera

Criticality levels, for the environment and the infrastructure.

Area diagnosis for current and future situations among the following criticality levels:

- Normal operation: design operation - no hazard for drivers or surroundings assets (other infrastructure, urban areas) or the infrastructure itself
- Degraded operation for the environment : reaches a surrounding vulnerable area
- Degraded operation of infrastructure itself : reaches the traffic lanes but still one lane available for traffic
- Breach operation : submerged road, no traffic allowed and/or impact on road integrity and/or reaches leisure/activities areas, reaches a residential area

Appendix 3 – Criteria and rating of effectiveness of the adaptation measures

The reference for assessment of the adaptation measures is the present climate and the present practice of road construction and operation, but assuming that the road is vulnerable in the present climate as well. The assessment of the measure is found by answering the question 'What will be the impact if the NRA will implement this measure today?'

The scores for the effectiveness of the measure are given on a qualitative scale as it is relative to the project cost and the type of asset.

A '+' sign indicates a positive impact to the NRA (e.g. Less cost, more benefit) while a '-' sign indicates a negative impact to the NRA (e.g. more cost, less benefit). A similar ranking scale has been adopted in the qualitative MCA approach as adopted in the Socio-Economic Analysis (Tucker et al., 2018) [19].

An explanation of the scores is given below.

<u>Increase resistance</u>

Definition: Increasing the threshold before damage will occur (decrease of flooding, decrease of pollution…)

Score for assessing the measures in the database:

0 A negligible impact of the measure

\+ An average impact of the measure

++ A high impact of the measure

<u>Decrease consequences</u>

Safety

Definition: impact of the measure on the motorway user safety

Scores for assessing the measures in the database:

\- A negative impact on the user safety

0 A negligible impact on the user safety

\+ A positive impact on the user safety

Societal effects

Example: effect on other roads, level of confidence of the public…

Scores for assessing the measures in the database:

\- A negative impact on the societal effects

0 A negligible impact on the societal effects

\+ A positive impact on the societal effects

Repair costs

Direct technical costs

Definition: direct technical costs for implementing the measure, incurred by the motorway operator. These are total costs of ownership i.e. costs for construction and replacement, maintenance, traffic and incident management and repair of damage. Cost for the road user or society are not included.

An increase in cost for implementing the measure may be compensated by a decrease in cost for maintenance, repair or incident management. Thus, the net total cost for implementing the measure may be negligible or even positive (cost saving).

Scores for assessing the measures in the database:

- \- A negative impact on the repair costs
- 0 A negligible impact on the repair costs
- \+ A positive impact on the repair costs (savings)

Environmental effects

Environmental effects deals with two main fields: quantity (peak flow increase, flood increase…) and quality (water pollution).

Environmental quantitative effects

Score for assessing the measures in the database

- \- A negative impact of the measure on environment (flooding involving loss of crops, livestock …)
- 0 A negligible impact of the measure on environment
- \+ A positive impact of the measure on environment (decrease impact on crops and livestock…)

Environmental qualitative effects

Score for assessing the measures in the database:

- \- A negative impact of the measure on environment (decrease of fauna and flora, decrease of water quality…)
- 0 A negligible impact of the measure on environment
- \+ A positive impact of the measure on environment (increase water quality and bio-diversity….)

Recovery capacity

Definition: enhancing a quick return to the pre-disturbed situation, e.g. having pumps available to pump out water after flooding, insurance, well-trained people to help clean up and repair

Score for assessing the measures in the database:

- 0 A negligible impact of the measure on recovery capacity
- \+ A positive Impact of the measure on recovery capacity

Adaptive capacity

Definition: be prepared to take measures for the future. This means that there is some form of flexibility to change functions or assets over time, e.g. plan for the possibility to be able to change the drainage capacity in coming maintenance cycles.

Score for assessing the measures in the database:

- 0 A negligible impact of the measure on adaptive capacity
- \+ A positive impact of the measure on adaptive capacity