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Water management for road authorities in the face of climate change

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Abstract

European National Road Authorities (NRAs) have recognized for a long time that climate change will have a significant effect on their assets and operations. Especially, water management assets will be affected. The damage caused by floods and rain to infrastructure assets amounts to €600 million annually, making it by far the dominant weather impact already in the current climate, let alone in the future when it is expected that likelihood and intensity of intense rainfall will increase. Many challenges exist in addressing intense rainfall events into proper design and maintenance of water management systems. These challenges exist both in the field of climate science itself as well as in the translation of climate projections into proper design and maintenance of water management systems. This paper presents results of the WATCH project (WATer management in the face of climate CHange) that was commissioned under the CEDR 2015 call - Climate Change: From Desk to Road. It addresses climate change, socio economic evaluation and sustainable drainage systems.

Keywords: climate change, roads, drainage, water management, socio economic evaluation, SuDS.

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1. Introduction

European National Road Authorities (NRAs) have acknowledged for a long time that climate change will have a significant impact on their assets and operations. The damage caused by floods and rain to infrastructure assets amounts to €600 million annually, making it by far the dominant weather impact in relation to climate change. 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.

Under the CEDR 2015 call - Climate Change: From Desk to Road - these challenges come together. Within this call the WATCH project is working on the topic of water management for NRAs in the face of climate change. The project addresses the most important high frequency causes of road flooding that NRAs have identified in the CEDR report 'Adaptation to Climate Change': pluvial and run-off flooding in the area around the road, and heavy rain on the road itself (rain intensity). Furthermore, the project considers the drainage facilities that are designed and maintained by/for the NRA's with the purpose to enable a good water management of the road and as such a smooth and safe use of the road infrastructure.

This paper provides a summary of results of the project, which is producing a number of results of immediate benefits to NRA's, ready for direct implementation:

- Comprehensive manual 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. In this manual all below mentioned other outputs culminate.
- Guidelines to correctly interpret and apply relevant information extracted from climate projections, to be used in road drainage maintenance and design.
- Simple tool that shows climate analogues for rainfall extremes in Europe.
- Protocol for adapting Sustainable Drainage System (SuDS) systems for climate change, with applications for roads across Europe.
- Guidelines for a socio economic evaluation of adaptation and maintenance approaches for water management for optimized decision making properties of NRAs. Socio economic evaluations are seen as an essential, and often lacking, tool for implementation of climate change adaptation measures.

2. State of practice of water management by road authorities

The WATCH deliverables need to be implementable by NRA's. As such, the manual builds on the current state of practice and approaches of NRA's and how they take climate change into account. To achieve this, an overview has been compiled of existing water management and drainage approaches in the form of a study of the guidelines that are used in the NRA's, as well as interviews with NRA staff. Both design and maintenance approaches have been investigated. However, it appeared that climate change is only marginally considered in relation to maintenance and as such more information has been gathered on current design approaches.

The water management assets are structured, according to the hazard that is posed on them. A distinction is made in 3 types of hazards: (1) Precipitation on the road (Roads in fill (on embankment), Roads in cut (excavated), Tunnels, Bridges, Retention facilities and Treatment facilities), (2) Pluvial flooding (Assets to prevent flooding due to rainfall besides the road (embankment height, water management system, dikes, etc.) and (3) Surface run-off flooding (water crossing the road in Culverts).

The following countries have been investigated: Norway, Sweden, Denmark, the Netherlands, Germany, Ireland, United Kingdom, Austria and France. These countries provide a good overview over different cultures and geographical characteristics. Results of the country comparison are visualized in table 1 and most remarkable findings are summarized below:

- Type of assets: A big variety of assets for water management by NRA's exists. In the same time many similarities occur between countries.
- Guidelines / criteria:
  - Detailed design guidelines exist in all countries 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.

Table 1 Summary of findings of the country comparison

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.							

  - The required return periods hugely vary between countries for the same situations. The requirements are not underlined with cost benefit assessments.
  - The prevailing duration of precipitation for design of drainage and storm water management systems is not very clear, since dynamic calculations are made for several durations. It is estimated that the prevailing durations vary between 5 to 10 minutes for drainage of pavements and in the order of minutes to 6 hours for the design of storm water management systems.
- Rainfall data and climate change:
  - Intensity Duration Functions (IDF) curves for precipitation are used for the design, making use of mainly point data although this is not completely correct for modeling pluvial flooding and run-off.
  - National Meteorological institutes play a big role in providing data for the current and future climate.
  - Only Ireland, UK and the Netherlands consider climate change explicitly in the standards and use (with different backgrounds) a certain increase of precipitation intensity to accommodate climate change. In Germany an ensemble approach is used.
- Cost benefit analysis:
  - Cost benefit assessments are mainly used for identifying the best solutions on a project level. They do however most of the times not specifically address water management issues.
  - Cost benefit assessments for providing decision support on whether climate change adaptation measures need to be taken are not developed and implemented (yet, Netherlands in the near future).
- SuDS 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. SuDS are standard practice for storm water runoff in the Netherlands.
- Maintenance and climate change:
  - Maintenance standards do not include information on 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.

Using the results from the country comparison it becomes very clear that guidance is needed on how to address current and future resilience of the NRAs approach to water management, ensuring optimal maintenance planning and asset management and taking the potential of SuDS into account. For enabling decision making and implementation of the research, the guidance needs to include directions on socio economic analyses. These aspects are addressed in the subsequent sections of the paper.

3. The WATCH Manual

The manual aims at assessing current and future resilience of NRAs water management facilities, ensuring optimal design, maintenance planning and asset management. The approach considers two levels of analysis (high and detailed level) including risk assessment, socio-economic evaluation protocol and definition of measures and strategies. According to the road owner’s demands, the scale of the study, the complexity of the area and the knowledge of their assets, the NRA has the choice to start at any place in the method. Also an iterative approach can be adopted. Figure 2 shows the main steps and how the high and detailed levels interact.

On the high level, the analysis is performed for sub-groups of assets in order to identify the best adaptation strategy for those sub-groups (classification based on extrinsic site factors, infrastructure intrinsic factors, consequences and hazard level). The goal of this “screening” level is to prioritize the assets that should be further studied in the detailed level. Specific recommendations are provided for performing a global risk assessment for drainage facilities, based on, and on top of existing guidelines (e.g. RIMAROCC (Bles et al., 2010), ROADAPT, 2015) and assessments that already have been undertaken in various countries. The selection for a specific strategy for the subgroups is based on a global socio economic evaluation (Section 5).

On the detailed level, an analysis is carried out for each type of assets following 4 main steps: asset inventory, hydrological calculations, hydraulic analysis of the asset and asset risk evaluation. The adaptation strategy from the high level is translated into design options, up to the individual asset. Design and maintenance choices are compared using a socio-economic evaluation for specific assets (section 5). The final socio-economic evaluation, aggregated at the project level, should then be compared to the initial economic evaluation to confirm the validity of the strategy selected at the high level.

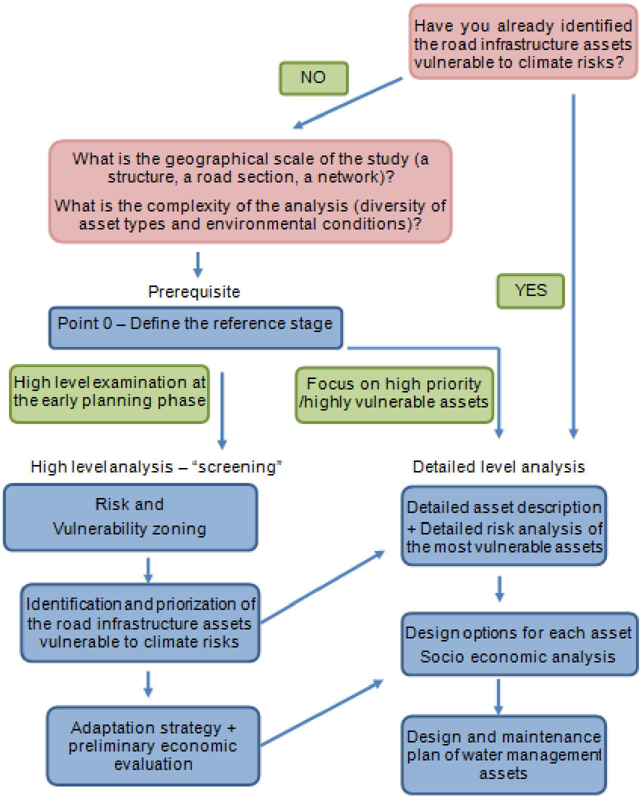

Figure 2: Main steps in the WATCH manual

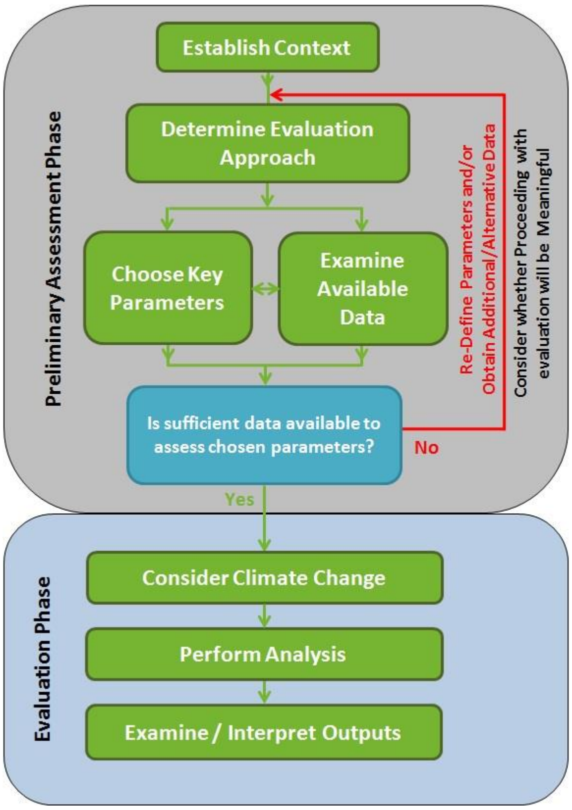

Figure 3: The Socio Economic Analysis Framework

4. Guidelines on how to take climate change into account

Weather extremes affect the road infrastructure and its functioning. To deal with these extremes knowledge about the occurrence of extremes in the current and future climate is needed. The information can be used for design, but also for checking whether existing assets still comply with the norms.

Extreme rainfall statistics or IDF-curves for the "current" climate are generally available in a country; however, it is useful to check which period this "current" climate describes. Due to trends in extreme rainfall statistics based on data from e.g. 1960-2000, IDF curves may not be representative for the climate around e.g. 2015. In these cases the available data may have to be adjusted. E.g. in the Netherlands the long term trend in extremes over the period 1906-2014 was removed such that the statistics where representative for the climate around 2014, resulting in about halving the return times. The protocol for extreme rainfall information for the current climate can be seen in figure 4. The first steps may look redundant, but it is often not clear what climate the available data is representative for and for which "current" climate data is needed.

It is often difficult to find all the necessary information if one is not an expert. In the WATCH project this information about available rainfall statistics including regional differences is collected for 8-9 countries. On the basis of the rainfall statistics, it is possible to estimate extreme runoff with the purpose of determining the required design.

Due to climate change the probability of many extreme weather events is expected to change (or has changed already). The theory behind the intensification of rainfall is that as the climate warms, more moisture will be available to a rainstorm, and this may cause more extreme precipitation. Projections for the future are made in most cases with the help of climate models. Lenderink & van Meijgaard (2008) showed that, above a certain temperature, the extreme hourly rainfall (often convective rainfall) can increase much faster with temperature than the extreme daily rainfall. However, most available climate models are still unable to represent convective processes that cause the local extreme precipitation.

The protocol for extreme rainfall information for the future climate consists of the steps that can be seen in figure 5. This approach is based partly on the approach described by Lenderink & Attema (2015). They set the changes in precipitation extremes proportional to the change in water vapor amount near the surface as measured by the 2m dew point temperature (based on temperature and relative humidity). This simple scaling framework allows the integration of information derived from observations and climate models and thus combines the advantages of both observations and climate models, but avoiding the disadvantages.

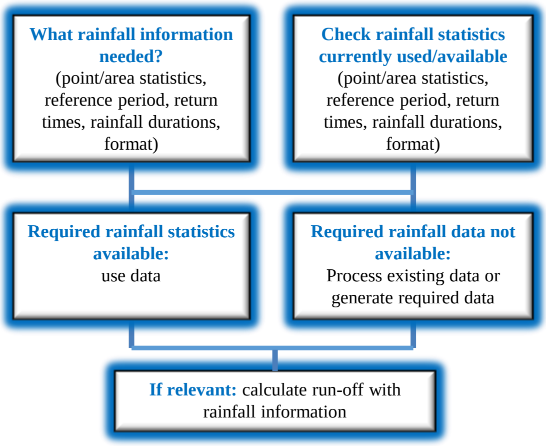

Figure 4: protocol for extreme rainfall information for the current climate

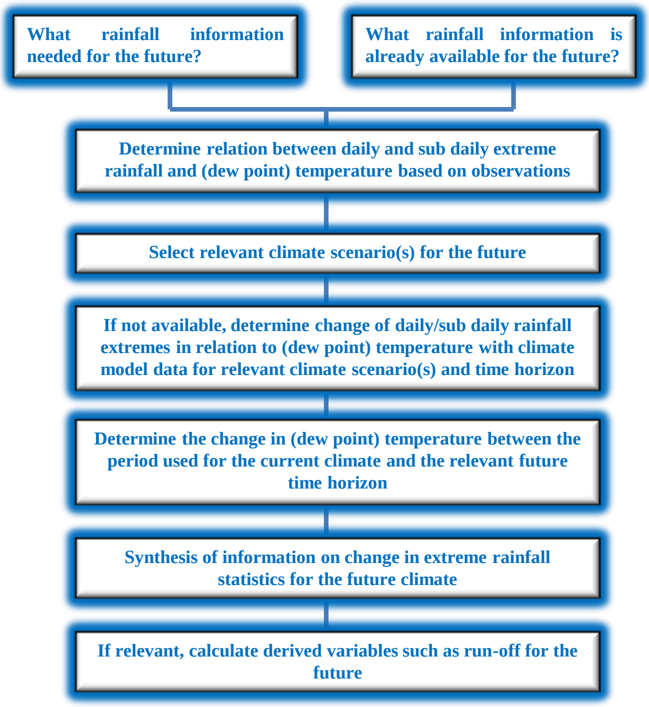

Figure 5: The protocol for extreme rainfall information for the future climate

Although most countries are using the same climate model information from large European projects, they all have their own methods to construct climate scenarios from them and to determine regional differences in projections. Hardly any of the climate change scenarios contains information on changes in short duration (less than one day) rainfall extremes. Climate scenarios are generally updated every 5-7 years, and future ones may contain more information on rainfall extremes.

The strong increase in rainfall extremes described by Lenderink & Attema (2015) will only occur if temperature is high enough (> 10-14 °C) and if sufficient moisture is available in the air. Observed relations between (short duration) rainfall extremes and (dew point) temperature can be used together with climate model derived data to estimate the range of possible changes in the future. If information on relative humidity is not available, the analysis can also be performed with air temperature, assuming that the relative humidity has hardly changed, although the relation between temperature and extreme rainfall is not as clear. Due to limited availability of sub-hourly data it is assumed that the changes for hourly rainfall extremes also apply to sub-hourly extremes.

The potential changes in extreme rainfall do not have to be determined for all available climate scenarios, but only for the relevant one or ones. When one wants to take into account the worst case, the climate scenario in which the highest change in extreme rainfall on daily or sub-daily level can be expected should be selected. Climate scenarios often give the changes between specific reference periods and for specific time horizons in the future. When one is interested in a time horizon in between these given time horizons in the climate scenarios, linear interpolation often gives a reasonable estimate of the temperature change until the time horizon of interest.

5. Socio-economic Analysis Framework

Various drainage systems (section 2) are available to road owners. However, notwithstanding the drainage system utilised, the asset under consideration and the hydrological event, an equally important consideration is the assessment of the relative strengths and weaknesses of the available drainage systems and the measures that can be taken to design, maintain or adapt these systems as part of effective water management procedures in the face of climate change. To this end, a Socio-Economic Analysis is of paramount importance to enable the optimum solution to be chosen for a given adaption measure/scenario.

In the context of WATCH, a socio-economic evaluation of climate change integration in decision making for managing water on roads is essential due to the large investments, required to implement adaptation measures. The approach adopted considers a variety of stakeholder interests, such as technical, environmental, social, and financial in order to determine the most appropriate drainage system to employ. Any evaluation must have a starting point and purpose and to this end, the WATCH socio-economic analysis framework, Figure 3, is proposed to illustrate the process in a step by step manner. Each step in the process provides guidance on the key questions that stakeholders should address before embarking on an analysis in order to identify the potential costs and benefits, economic and otherwise, incurred for a proposed solution. It is intended that the framework can be applied by any primary stakeholder for different scenarios when considering the design, maintenance and upgrading/adaptation of drainage systems with due consideration of climate change.

Establishing the Context: This step will provide important insight into the most suitable evaluation approach to be adopted and sets the scope for the remainder of the evaluation analysis. The context developed should align with the stakeholders overall mission statement, considering the external context (e.g. external stakeholders, its local, national, and international environment) and internal context of the organisation (e.g. internal stakeholders, approach to governance, contractual relationships etc.), and the context of the risk management principles and process. The output should provide answers to the following (typical) questions; what is the purpose of the evaluation? What is the context and priorities of the individual/organisation conducting the analysis? What is the planning stage of the project? The preferred level of analysis i.e. a high level or detailed analysis? Is the assessment for a new scheme or an existing road? What are the key parameters? What return period is being considered? What are the outputs of the socio-economic evaluation to be used for and how will they be interpreted?

Determine Evaluation Approach: The evaluation approach refers to the method adopted to measure the costs/benefits associated with each solution. There are a number of methodologies which can be adopted, and this step aims to allow the user to identify which methodology is most suitable for their specific application. The methodology could be fully quantitative, fully qualitative or a mix of quantitative and qualitative evaluation depending on a number of factors including the output requirements of the analysis, the parameters considered in the analysis and the data available. Typical methodologies include; Multi-Criteria Analysis (MCA), Cost Benefit Analysis (CBA), Cost Effectiveness Analysis (CEA) and Life Cycle Costing (LCC). It is important to note however, that the level/quality of data available will often determine whether it is feasible to adopt a quantitative/qualitative approach for any given parameter to be assessed, but it is also important to consider the approach in terms of the context/objectives of the evaluation. For example, MCA is typically used for creating consensus building among stakeholders to create a common understanding between various disciplines if little or no quantitative information is available. On the other hand a CBA requires that sufficient quantifiable data is available as all benefits and costs are converted into monetary terms.

In line with the General Methodology for the risk assessment process in WATCH, and the implementation of the framework in the Case Study (Section 7) two levels of analysis are proposed when making a design or maintenance plan. At the high level, it is proposed that a Multi-Criteria Analysis is considered to evaluate the best adaption strategy for a sub group of assets. This assessment will be based on a set of key or hyper parameters, largely considered relevant to all schemes. 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 global. At the detailed level, a cost-benefit analysis is considered to assess individual or specific 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.

Choose Key Parameters: This step involves selecting the parameters which should be considered as part of the evaluation. The parameters chosen should be relevant to the context, and should be chosen based on the objectives of the socio-economic evaluation as described when establishing the context. The number and type of parameters chosen will likely have an influence on the complexity of the evaluation and the preferred methodology. If, for example an MCA approach is adopted, then qualitative parameters would suffice. Typical parameters (non exhaustive) to be considered could include; 1. Technical Effectiveness (i.e. Performance) of the system; 2. Maintenance & Serviceability Issues (i.e. repair costs); 3. Environmental effects; 4. Societal Impacts & Requirements (effect, costs); 5. Safety Constraints & Impacts; 6. Potential Impacts on Operation of the Wider Network and 7. Resilience & Robustness of the System. In the context of the WATCH approach, for a Global analysis, it is recommended that items 2, 3, 4 and 5 should be considered as a minimum.

Examine Available Data: In this step all relevant/available data should be collated and the quality and suitability of the data should be assessed, considering a number of factors (e.g. the origin of the data, the quality and accuracy of the data etc.).

Is sufficient data available to assess the chosen parameters? This intermediate step involves considering if the available data allows a meaningful socio-economic evaluation to be carried out. Output of this step will consist of an itemised list of all the available data and an assessment of whether it is suitable or not for the evaluation.

Consider Climate Change: In this step, the effects of climate change (Section 4) are introduced in advance of performing the analysis and evaluating the output. Given the large number of uncertainties associated with climate change, in addition to the ‘as-is’ scenario, consideration should be given to multiple future scenarios which will need to be incorporated into the evaluation The output of this step is a description of the hazard intensity, such as flood level, for the multiple climate change scenarios that are deemed important to include in the evaluation. These can then be used to assess implications for different options, including the ‘as is’ scenario.

Perform Evaluation: The objective of this step is to perform the evaluation analysis, using an appropriate methodology, in order to determine the advantages and disadvantages (e.g. cost, benefits) associated with each parameter within a particular solution. The outputs of the evaluation are the costs and benefits associated with each design, maintenance or adaptation option under consideration. All costs/benefits should be evaluated for each drainage solution being considered, but also in the case of an existing road for the “As-Is” reference scenario, whereby no modification or upgrade is made to the drainage system currently in place. The format of the outputs should be presented in an appropriate manner to allow a comparison to be made, in the next step, between each option considered.

Examine and Interpret Outputs: The objective of this stage is to interpret the outputs of the socio-economic evaluation and ultimately choose the most suitable option. The outputs should be examined in relation to the overall identified objectives. This step is particularly important in the case of a semi-quantitative evaluation, whereby a decision is required on the best solution given differing outputs for the parameters assessed. For example an outcome could result in costs of €1 million to provide a ‘Medium’ risk of flooding, and a ‘Low’ risk of driver fatality, while an alternative outcome could result in costs of €10 million to provide a ‘Low’ risk of flooding, and a ‘Low’ risk of driver fatality. In this case, it would be necessary to review the objectives to assess whether cost or flood levels should be the key parameter in the decision making process. For CBA, LCC, CEA this step is more straightforward, requiring each option to be ranked based on a numerical evaluation.

6. SuDS

Specific attention is paid to SuDS systems as an answer to the challenges of climate change. SuDS philosophy is to mimic the natural hydrological cycle. Urbanisation causes land to be covered with large areas of impermeable surfaces that alter the natural drainage regime. SuDS offer an integration with nature, by promoting: the temporary storage of surface water (ponding), infiltration, the harvesting of rainwater at source, evapotranspiration, groundwater recharge and the re-use of stormwater (Roy et al. 2008). SuDS can increase morphology, provide amenity and biodiversity value, minimise the rate and quantity of discharge and protect or enhance the quality of receiving watercourses.

Nowadays, flooding and water pollution, arising from Climate Change, are key drivers of SuDS policy. Their mitigation is underpinned by legislation (both national and international), principally the Water Framework Directive (WFD). This directive indirectly encourages the retrofitting of SuDS to improve water quality. SuDS, after all, have been touted as a significant part of the solution to all drainage problems.

Design of SuDS

The SuDS philosophy, and effective stormwater management in general, requires a series of measures incorporating source, site and regional controls to be applied to form a stormwater management train, that will ensure that specific runoff quality and quantity aspects are addressed. O’Sullivan et al (2011) found that understanding of this concept was not widespread amongst drainage practitioners, suggesting that experience is generally limited to SuDS installations for single infrastructure developments. Often only specific SuDS features are in place, not covering all aspects of the stormwater management train.

There is no unique solution and each situation has to be evaluated on its own merits and suitable SuDS solutions applied. The means to achieve these objectives are many and varied. Factors such as site suitability, available space, cost, maintenance regimes and community acceptance must be considered to ensure successful implementation (Dublin Drainage Consultancy, 2005).

The various SuDS features can generally be categorised as 'hard' SuDS and 'soft' SuDS. Soft SuDS resemble natural features and include techniques such as swales, ponds and wetlands. Hard SuDS are more similar to traditional methods, but incorporate SuDS principles. Examples of these are attenuation crates/tanks, permeable pavements and proprietary SuDS features such as filtration systems and vortex separators (Kirby 2005).

Figurre 6: typical SuDS features (from left to right: filter drain, swale, wetland)

Treatment processes and effects of climate change

The principal treatment processes in a SuDS system are described below. In the description the effects of climate change on these treatment processes is described.

- Sedimentation is one of the primary removal mechanisms in SuDS. Most pollution in stormwater runoff is attached to sediment particles and therefore the removal of sediment will achieve a significant reduction in pollution loading to receiving water bodies. Sedimentation is achieved through reduction in flow velocities to a level at which the sediment particles fall out of suspension. However, care must be taken through design and appropriate maintenance regimes to ensure the risk of re-suspension is minimised during extreme rainfall events that may occur more frequently and/or more intensely in the future due to climate change.
- Biodegradation is a natural biological treatment process that is a feature of several SuDS systems - systems that are subject to both wet and dry conditions. Biodegradation is understood to be temperature dependent and probably will be affected when temperatures change in the future. In addition to the physical and chemical processes of SuDS systems, biological treatment may also occur. Microbial communities may be established in the ground using the oxygen within the free-draining materials and the nutrients supplied with the inflows, to degrade pollutants such as hydrocarbons and grease. The level of bioremediation activity is affected by environmental conditions such as temperature. The temperature dependence of these aerobic microbes (responsible for this additional layer of treatment) needs to be further investigated, but it is generally accepted that the chemical and biological treatment mechanisms found in SuDS systems are enhanced with increasing temperature. If a change in climatic conditions brings about significantly wetter weather, the oxygen dependent microbes could be reduced. This in turn could diminish the removal of hydrocarbons before the runoff is released into the groundwater or a watercourse.
- The presence of vegetation adds a physical filtration aspect to SuDS systems. In the case of filter strips leading to swale/basins, the majority of hydrocarbons are removed by the first stage. If vegetation has been affected by drought, this element of the treatment train will be absent (in a worst-case scenario or significantly diminished at best).

7. Case demonstration

The M10 in Denmark has been chosen as a case study road for the WATCH project with the objective to test and streamline the WATCH deliverables, since it's an already existing major road that holds many characteristics, targeted by the WATCH objectives.

The distinction, as recommended in the manual to adopt a two-step approach, starting with a high level and ending with a detailed analysis that is back-upped with a socio economic analysis, proved to be very successful. It provided more efficiency in terms of the effort that is needed for data gathering and also helped to communicate with the decision makers about the necessity to go in more detail at high risk locations. As an example of such success, going through the manual from high level into the detailed level in the case study, it was clearly illustrated how gathering, mapping, and joining relevant, detailed data for the specific water management system on the M10 was not as fluent as initially thought, when inquiring and communicating across relevant departments. Therefore, it was highlighting that a revised strategy on more transparency and a more unified database were key points to address for future optimized flow.

Especially in the detailed level, cost benefit analyses proved to act as an essential instrument for decision making and implementation of the WATCH outcomes. The socio economic framework was tested and it appeared that the outcomes indeed helped to convince NRA staff that climate change should be taken into account in design and maintenance. More specifically, implementing socio economic analyses on a higher degree proved to act as a valuable KPI-input to, more focussed and effective, allocate resources for adaptation. Moreover, the WATCH outputs on cost benefit analyses were considered very valuable to revise strategies on climate change adaptation and to compare water management options with a new viewpoint by including socio economy more elaborately.

The M10 heavily relies on water basins and retention systems as the first recipient for road water, where it's treated mostly through sedimentation led by gravity and then discharged to various second recipients. The case study evaluated how SuDS can be applied for the future, taking climate change into account. The WATCH SuDS protocol has been applied and proved to provide valuable recommendations.

Figure 7: The M10 motorway in Denmark; the blue sections are vulnerable to flooding. (ROADAPT, 2015)

8. Conclusion

To cope with the expected increase of intensity of rainfall due to climate change, a manual and underlying protocols and guidelines to enable decision making in this field of high uncertainties have been developed. Although the high uncertainties and sometimes limited availability of specific data, it proves to be possible to gain useful climate data for design and maintenance of road water management assets. The project deliverables have been successfully implemented and tested in a case study on the M10 in Denmark, showing that the manual and SuDS protocol are of help to develop an adaptation strategy. The socio economic analysis framework proved to be useful for both decision making and implementation of the results in the NRAs organisation.

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9. References

Bles, T., Y. Ennesser, J.J. Fadeuilhe, S. Falemo, B. Lind, M. Mens, M. Ray & F. Sandersen, 2010. Risk management for roads in a changing climate. A Guidebook to the RIMAROCC Method. ERA NET ROAD project

Dublin Drainage Consultancy. (2005) Greater Dublin Strategic Drainage Study (GDSDS). New Development Policy – Technical Guidance Document, Vols 1–5.

Grendstad, G., task group 16 and 17, CEDR report 'Adaptation to Climate Change', 2011

Kirby, A. (2005) SuDS – Innovation or a Tried and Tested Practice? Proc. Inst. Civil Eng. Munic. Eng., 158 (2), 115–122.

Lenderink, G. & E. van Meijgaard, 2008. Increase in hourly precipitation extremes beyond expectations from temperature changes. Nature Geoscience 1, 8, pp. 511-514, doi:10.1038/ngeo262.

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

O'Sullivan, J. J., Bruen, M., Purcell, P. J., & Gebre, F. (2012) Urban drainage in Ireland–embracing sustainable systems. Water and Environment Journal,26(2), 241-251.Roy et al. 2008

ROADAPT deliverables, 2015, available via www.cedr.fr