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WATCH

CEDR

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Call 2015**

WATCH

**WATER management for road authorities in
the face of climate CHANGE**

D6

CASE STUDY

July 2018

CEDR Call2015: From desk to road

WATCH

WATER management for road authorities in the face of climate
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CASE STUDY

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EXECUTIVE SUMMARY

The objective of the WATCH project is to produce step-by-step methodologies for NRAs to apply as action points to enable more implementation of available research in the field of water management and thereby enhance resilience and robustness for NRAs towards a changing climate.

The WATCH case study is conducted as a desk study testing the deliverables on how an NRA can and will make use of the developed WATCH step-by-step protocols. The case study is conducted by the Danish Road Directorate and specifically on the M10 road, leading into the greater area of Copenhagen.

Following the step-by-step approach of the WATCH manual, the case study showed great usability on applying the WATCH deliverables into an NRA-context of road water management and how to take climate change into account. The applied manual fundamentally consists of two parts; a high level analysis for initial screening of risks and a detailed risk assessment, including elaborate socio economic analyses. The following lists the main conclusions and lessons learned as the result of the case study.

The manual proved very valuable in the case study by introducing a step-by-step approach for NRAs where it acted to integrate all considered parameters for inclusive risk analyses. In particular by introducing more elaborate approaches for socio economic analyses, which were considered to ultimately lead to enhanced basis for better decision making.

The steps in the manual and socioeconomic analyses illustrated how data gathering for sufficient and satisfactory analyses input were appointed a particular focus area for NRAs to allocate resource to in order to enable optimum input for the analyses. As a recommendation, it is highly valued to identify and include all relevant departments, staff members and other stakeholders to comprise all aspects and appoint key parameters for the analyses.

The socioeconomic analyses of, *multi criteria analyses (MCA) and cost benefit analysis (CBA)* showed beneficial to apply in the case study to gain more elaborate socio economic insight. As a result of the economic analyses, more tangible results are seen as output since these can feed directly into decision making contexts. Therefore, it is argued that conducting the WATCH approach on socio economic analyses is a proactive mean for climate change adaptation by itself.

Results from the socioeconomic analyses is considered to enable opening a window of opportunity to revise how and when grants are given, e.g. from the respective state, and at what degree, since the results may conclude that additional resource given for adaptation in early stages is considered to save resource through the entire life span, e.g. for the entire road construction or single assets, seen from a socioeconomic viewpoint.

Disclosure

As a reference of context and framework, the case study has been conducted as a desk study lead by the Danish Road Directorate, where data have been acquired in the Danish Road Directorate, from relevant sources and/or from both WATCH partners.

1. Introduction of the case study

1.1. *The WATCH project*

European NRA's 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 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 NRA's, 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 NRA's, including:

- A country comparison report showing the state of practice of existing water management and drainage approaches at different NRA's.
- 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 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.

1.2. *The WATCH case study objective*

Copious results on research and development are now available for NRAs to apply to adapt for climate change in various scales and with different methodologies and techniques. Yet, acting timely to climate change has proved overwhelming for many NRAs. In part due to high costs and in part due to a lack of a clear strategy on the subject (*Axelsen et al.*, 2016).

As a part of the WATCH project, a case study is conducted with the objective to analyse, test and demonstrate the WATCH deliverables on how an NRA can and will make use of the step-by-step protocols.

The case study has been conducted by the Danish Road Directorate where the M10 road leading

into the greater area of Copenhagen was chosen. The M10 was chosen as the case study road for the WATCH WP6, to test the manual in WATCH since it is an already existing major road that holds many characteristics, targeted by the WATCH objectives.

The following will initially describe the context of the case study; how the Danish Road Directorate conducts water management and how climate change is taken into account. Subsequently, the WATCH manual and socioeconomic analyses are tested as a desk study to highlight how these can be applied for an NRA and how the lessons learned provide recommendations for other NRAs to use the WATCH deliverables.

2. The Danish Road Directorate and water management

2.1. The Danish Road Directorate

In short, the Danish Road Directorate manages all state-owned roads in Denmark. The Danish Road Directorate plans, operates, maintains and tenders constructions of the state road network which constitutes roughly 4,000 km, which represents about five percent of the entire road network in Denmark. Though the state roads only represent around five percent of the entire road network, the importance in terms of mobility for the society is underlined as approximately 45 % of the entire road traffic in Denmark is conducted on the Danish state-roads. Furthermore, approximately 2,300 structures are managed; among these are minor bridges, water infrastructures, among others.

The Danish Road Directorate constructs via tendering processes where winning contractors construct roads, road furniture, water management systems, etc. either as a turnkey contract or shared with other entrepreneurs, depending on given tendering procedure and winning result.

In relation to climate change and road administration, the Danish Road Directorate has acknowledged that the primary challenge of climate change is water related, both in terms of cost and disruption of traffic. More specifically, it is expected that the ever increasing CO₂-emission and higher temperatures will cause an increase in precipitation quantities seen both in annual increase and, more importantly, also as more extreme occurrences. Additionally, storms and storm surges are anticipated to become more common and more forceful (*Vejdirektoratet*, 2014).

The Danish Road Directorate implemented a strategy on climate change in 2013 to streamline and incorporate climate change in planning, operations and construction in regards to the major state roads. The strategy contains three main topics with overall bullets summarizing action points, leading into more elaborate action plans. The three topics are

1. Managing flooding when it occurs
 - a. *having call-out services ready*
 - b. *informing road users about the flood*
 - c. *clearing up quickly*
 - d. *being part of the strategic road network*
2. Improving and adapting roads where possible
 - a. *analyzing the event*
 - b. *creating a database of events*
 - c. *implementing improvements*
 - d. *cooperating with the relevant authorities*
3. Preventing where possible
 - a. *screening for particularly vulnerable sections*
 - b. *participation in legislative work relevant to the management of rainfall on roads*
 - c. *exercising prudence in the planning and construction phase*
 - d. *considering climatic adaption in connection with carriageway widening*
 - e. *focusing on research, and developing methods and knowledge about climatic adaption*
 - f. *international cooperation and information-sharing in the field*

Specifically on water management, the Danish Road Directorate has clear-cut directives on water management, all to maximize flow, minimize traffic disruption and to fulfill the governing service criteria, depending on the specific road or road stretch.

2.2. Current state of practice regarding water management

2.2.1. General

To improve transferability of the case study results to other NRAs, insight is given in the basis for the case study, the following summarizes how the Danish Road Directorate plans and operates Major Danish roads in relation to water management, divided into various topics of water management. To place the case study into further context, roads managed by the Danish Road Directorate are situated in non-mountainous areas. As a consequence, water management in relation to tunnels, steep-gradient roads and designated melt-water resilience systems is not a part of the case study.

As a general standard, water management systems, e.g. drainage systems, are dimensioned to be able to cope with a 1 in 25 year precipitation event. More specifically, water systems on motorways are designed to manage and drain surface water up to 260L/sec/hectare, corresponding to a 1 in 25 year precipitation event over 10min in Denmark. Designing water management with a capacity of 260L/sec/hectare is considered and has proven to be amply able to meet the service criteria of the 1 in 25 year planning.

Other types of roads, typically smaller roads managed by the Danish Road Directorate, are designed to manage a 1 in 10 year precipitation event. Extraordinary design requirements must be met when specific local circumstances entail additional considerations. Such requirements often come into play when constructing new infrastructure.

2.2.2. Precipitation on the road

Water management in regards to precipitation is dealt with in different aspects. Alongside the above-mentioned standard, water management is planned and operated on account of prevailing geography, i.e. topography and soil characteristics, and adjacent possibilities in terms of retention systems.

Precipitation from elevated roads is commonly collected in sewer systems through drainage systems, ditches and culverts. All collected water is led into closed systems, e.g. controlled retention systems such as SUDS features.

Precipitation from roads situated in cuts is largely collected in troughs through road-edge drainage, ultimately collected in closed systems, e.g. controlled retention systems such as SUDS features.

2.2.3. Water management on minor bridges

Water is managed by edge-collecting to ensure a non-spill directly from the bridge to adjoined water infrastructure, and led to a nearby retention system where water is environmentally managed. These retention systems are in the form of basins, where water is environmentally managed by simple sedimentation driven by gravity.

The size of the particular retention system is determined by the respective catchment area and geographical characteristics. Very strict environmental rules are in effect in Denmark that, for instance, dictates a maximum discharge out of the controlled system of 1L/sec/hectare (4). In the controlled systems, water is treated predominately by microorganisms through passive treatment driven by gravity.

2.2.4. Water besides the road (pluvial flooding)

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

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

2.2.5. Water crossing the road (run-off flooding)

Culverts are used to enable water to cross beneath roads. The dimensioning of respective culverts is determined in size by the catchments area in order to be able to cope with a 25 year precipitation occurrence on most roads managed by the 4 Danish Road Directorate. Some roads vary in dimensioning from a minimum of a 10 year return pattern, depended on geography and strategic importance of the specific road.

2.2.6. Retention facilities

Retention systems are primarily in form of basins and reservoirs adjacent to the road of drainage. The design and dimensioning of these build in accordance with the existing road standards

Retention systems are generally designed in capacity and discharge to manage a 1 in 25 year precipitation event. Specifically, water systems on motorways are designed to manage and drain surface water up to 260L/sec/hectare, corresponding to a 1 in 25 year precipitation event over 10min. Other types of roads, typically minor roads managed by the Danish Road Directorate, are designed to manage a 1 in 10 year precipitation event

Extraordinary design requirements must be met when specific local circumstances entail additional considerations. In the case of retention systems such considerations are of environmental matters.

2.2.7. SuDS features

SuDS features are not explicitly mentioned as a requirement in Danish Road Standards. Yet, existing basins and reservoirs meet many of the criteria found in the definition of SuDS features.

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

2.2.8. Maintenance of water-related features

Danish roads and adjoining water management systems are designed to have as little maintenance needs as possible. Extra resources are spent during planning and construction of retention systems to minimize maintenance needs during operation.

Ditches, culverts, and similar are maintained by contractors for the drainage system(s) to maintain full capacity and potential. The frequency of maintenance is determined from each respective road or road section.

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

2.2.9. How is climate change taken into account?

Roads are designed and built in accordance with the existing road standards. In these standards, climate change adaptation, e.g. in the form of installing drainage systems capable of managing more water than necessary in present time, is built in based on recommendations of the Danish *Spildevandskomiteen*.

The Danish government has chosen to follow the A1B IPCC-scenario, illustrated in figure 1, coupled to a Danish context by the Danish Meteorological institute as basis for climate change adaptation planning, maintenance, and operations (*IPCC, 2007*). The Danish Road Directorate refers to this climate change scenario to be used for managing major Danish roads. Furthermore, a climate change adaptation strategy and action plan is implemented and is currently set into effect.

Implementing this strategy, the A1B climate change scenario is applied to determine the future requirement for water management for the Danish Road Directorate to maintain the same service level, e.g. for the year 2030. Applying the A1B climate change scenario, e.g. to the specific percentage of a needed increase in retention system and culvert capacity, is a decidedly challenging task. To enhance resiliency, the Danish Road Directorate will continuously will refer updated road standards on the requirement and cooperate with the *Spildevandskomiteen*.

Expert knowledge and experience has been applied to determine the future implications, challenges and requirement for water management in the context of the case study. The outcome is seen in risk assessments, e.g. in figure 10, table 3, among more.

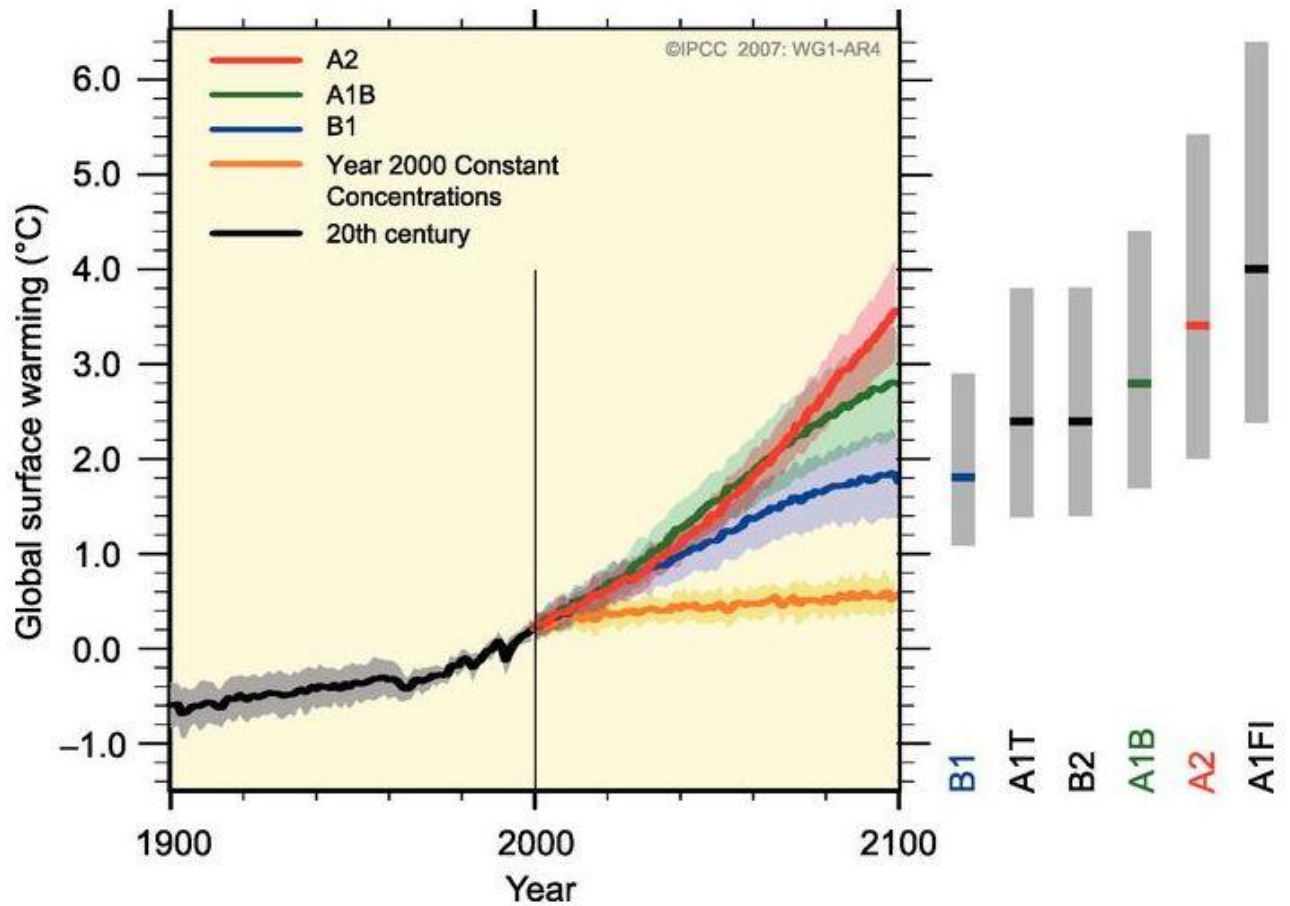


Figure 1 - Illustration of the climate scenarios from the IPCC 2007 report. The A1B scenario, used by the Danish Road Directorate, is marked green (IPCC, 2007)

Climate information is obtained from the Danish Meteorological Institute (www.dmi.dk) and the 'Spildevandskomiteen', a Danish engineering committee that has been in effect and acted as experts on water management since the 1940s (IDA, 2007).

2.3. Process models

In the Danish Road Directorate, four process models are in effect which respectively dictate steps to go through to ensure that all necessary phases of construction, operation and maintenance are conducted and undergone uniformly in all projects and in accordance with current regulations and road standards.

In the case study, the models are used as phase-divided specifications to gain knowledge about how to organize and implement planning and construction projects as well as tasks relating to road maintenance and capital maintenance.

These process models are illustrated below with overall headlines in part 2.3.1, 2.3.2, 2.3.3, and 2.3.4.

Conducting the case study will largely take departure in these process models since these form the daily and required steps for road management in the Danish Road Directorate. Therefore, consulting these with the manual and inherent socioeconomic analysis will test the WATCH outcome to existing and accepted process models for an NRA.

2.3.1. Major construction projects

The planning of major projects will be placed into the context of the illustrated process model which dictates the required work steps to undergo. Such projects involve planning and construction of major roads and road constructions, e.g. planning expansions of existing roads.



Figure 2 – Process model of major construction projects

2.3.2. Minor construction projects

This essentially differentiates from the process model in 1.3.1 in the size of the specific project, and thereby resource, both in terms of price and labour. As a key component in this regard, the requirements for elaborate environmental analyses are not mandatory which can be seen in the steps. The process model of minor constructions varies in usage from minor expansions to general improvements of existing roads.

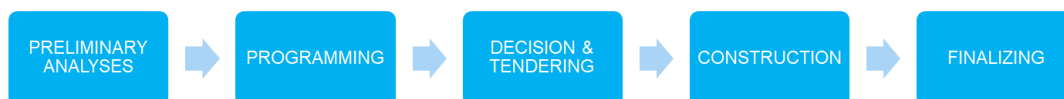


Figure 3 – Process model of minor construction projects

2.3.3. Preservation of capital of operation & maintenance

This process model is used to continuously assess and evaluate the fitting planning, action and methodology to maintain and operate major roads. This involves a broad spectrum of initiatives, all with the objective to maintain safety and mobility on major roads, e.g. maintaining water management systems to ensure full capacity and durability of the road construction itself. This is ensured via tendering processes where winning entrepreneurs are contractually responsible for agreed specifications of maintenance for operation of the roads.

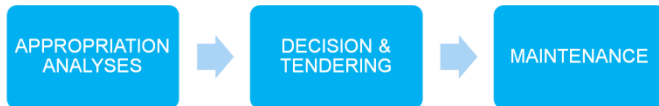


Figure 4 – Process model of preservation of capital of operation and maintenance

2.3.4. Road operation

The process model illustrated below resembles the model in 2.3.3, however, is solely in function on operations and on minor roads. Again with the objective to maintain safety and mobility on major roads, e.g. maintaining water management systems.



Figure 5 – Process model of preservation of capital of operation and maintenance

3. The Case Study Road

3.1. The case study area

The primary objective of the case is to demonstrate how the WATCH model can be applied and implemented in an NRA, in this case the Danish Road Directorate. The WATCH project concentrates the case study on a single, major road to test foregoing WATCH work package results and recommendations, ultimately leading to improved basis for decision making and to develop an adaptation strategy.

In order to increase the possibilities for other NRAs to make most use of the case study results and findings, the selection of the particular road was carried out to pinpoint a road which was a widely representative of a typical road construction type for NRAs across CEDR member countries and thereby enable optimum transferability.

The M10, a major road leading into the greater area of Copenhagen, is chosen as the case study road for the WATCH WP6, to test the manual and underlying protocol for socio economic analysis, the SuDS protocol and Climate Change protocol (*Foucher et al.*, 2018) in WATCH since it is an already existing major road that holds many characteristics, targeted by the WATCH objectives.

The M10 is the most used road in Denmark with an AADT of approximately 120.000 (2016 figures). M10 is the largest highway in effect in Denmark and figure 6 shows the entire road stretch and the geographical location.

Over a period from 2012-2017, the M10 has been subject to comprehensive lane-widening construction to enhance traffic capacity. This construction has required installation of new water management systems or updating the existing.



Figure 6 - Location of M10, marked blue

Described on an overall basis, M10 is situated close to the sea, low in terrain, through crossing streams leading into the sea and with some local depressions. Therefore, there is an apparent risk on many spots of the entire M10 of water-related complications, e.g. flooding directly caused by heavy precipitation and indirectly caused by sea level rise which will negatively affect the properties of stream discharge capabilities, leading to more stress on the road water management systems.

First and foremost, focusing on an already existing road, as opposed to a road in planning, represents the primary area of water management challenges of CEDR NRAs since not many new road lines are planned across CEDR member countries. The focus of improving future water management, e.g. due to climate change and environmental considerations, is therefore chiefly conducted on already existing roads.

Secondly, M10 heavily relies on water basins and retention systems as the first recipient for road water, where it is treated mostly through sedimentation led by gravity and then discharged to various second recipients.

Thirdly, oftentimes basic and non-uniform approaches from project to project on economic analyses are used to determine and dimension water management on Danish road. Therefore, the output on socio economic analyses in WATCH is considered decidedly valuable for the Danish Road Directorate and other similar European roads alike, for future road management to enhance capacity and mobility for already existing roads and, likewise, beneficial for future roads considering Climate change. This is widely regarded as one of the key outputs for the WATCH project; to enable improved basis for optimum decision-making processes through improved and more inclusive economic analyses.

The M10 is considered as a relatively young road after the recent lane-widening, both considering the road construction itself and because of the recent revision and update of the entire stretch in terms of water management assets. A young road is relatively expensive to repair, e.g. due to an incident caused by asset failure, since the road has yet to undergo much depreciation and deterioration.

As mentioned in Chapter 3, the M10 is the most used road in Denmark and has an AADT of 120.000. Furthermore, as seen in figure 7 below, the M10 is categorised in the highest level of strategic road importance, in-part due to the high number in AADT and also due to the geographical position where mainly commuters and road-cargo hauliers use the M10 as the primary source of infrastructure to reach the greater Copenhagen area or Sweden, coming from both the south and west. Alternative routes are not considered capable of to ensure continuous mobility, should the M10 be affected to a significant reduction in mobility or stand-still.

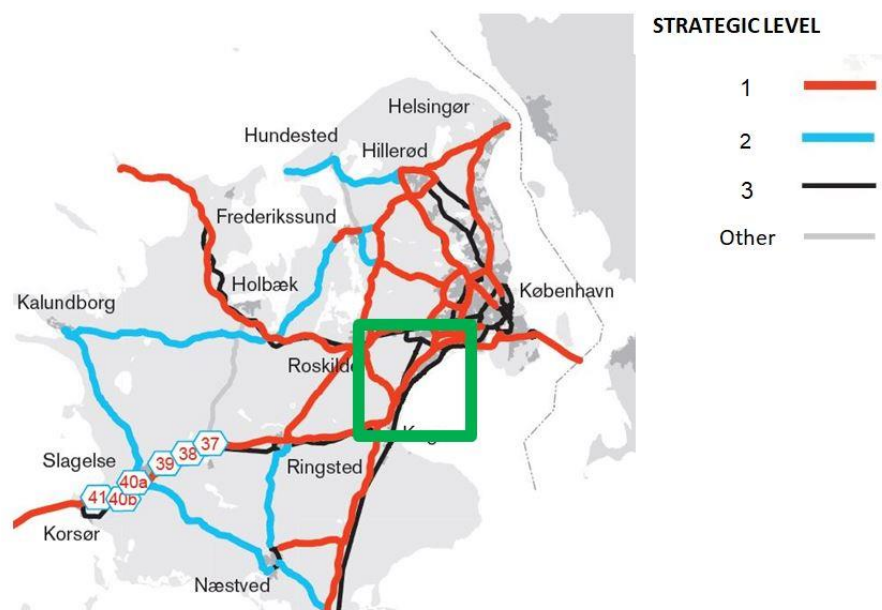


Figure 7 – illustration of the strategic road importance, 1 being the most strategic important, around the greater area of Copenhagen. M10 is marked in the green square

3.2. Approach

The WATCH case study is a desk study of how the WATCH outcomes can and will catalyse revisions, additions and further inspiration to existing process models of an NRA, in this case The Danish Road Directorate. The case study will deliver an insight into how the WATCH manual is received, analysed and can be applied and employed at NRA-level.

NRAs are often divided into divisions, respectively dealing with construction or maintenance and operations with their individual set of process models which set the standard for mandatory steps. Therefore, conducting the WATCH case study will be carried for both to test the WATCH manual to a wide extent. In this instance, the case study will be based on the process models as illustrated in section 2.3.

The case study has been conducted on the basis of dialogues with relevant staff, insights in process models, and current strategies on climate change.

A key objective of the case study is to apply the WATCH manual widely to test how the manual benefits in various steps in order to make the outcome as inclusive as possible and thereby also enhance the applicability for other NRAs to use the case study results.

The WATCH manual is part-based on the previous CEDR projects RIMAROCC and ROADAPT and consists of the decision tree with an inherent economic analysis. The respective NRA can go through this decision tree on a step-by-step basis to ultimately provide guidelines and thereby basis and inspiration for a new or improved design and maintenance plan, e.g. a climate change adaptation strategy for specific assets or the whole network.

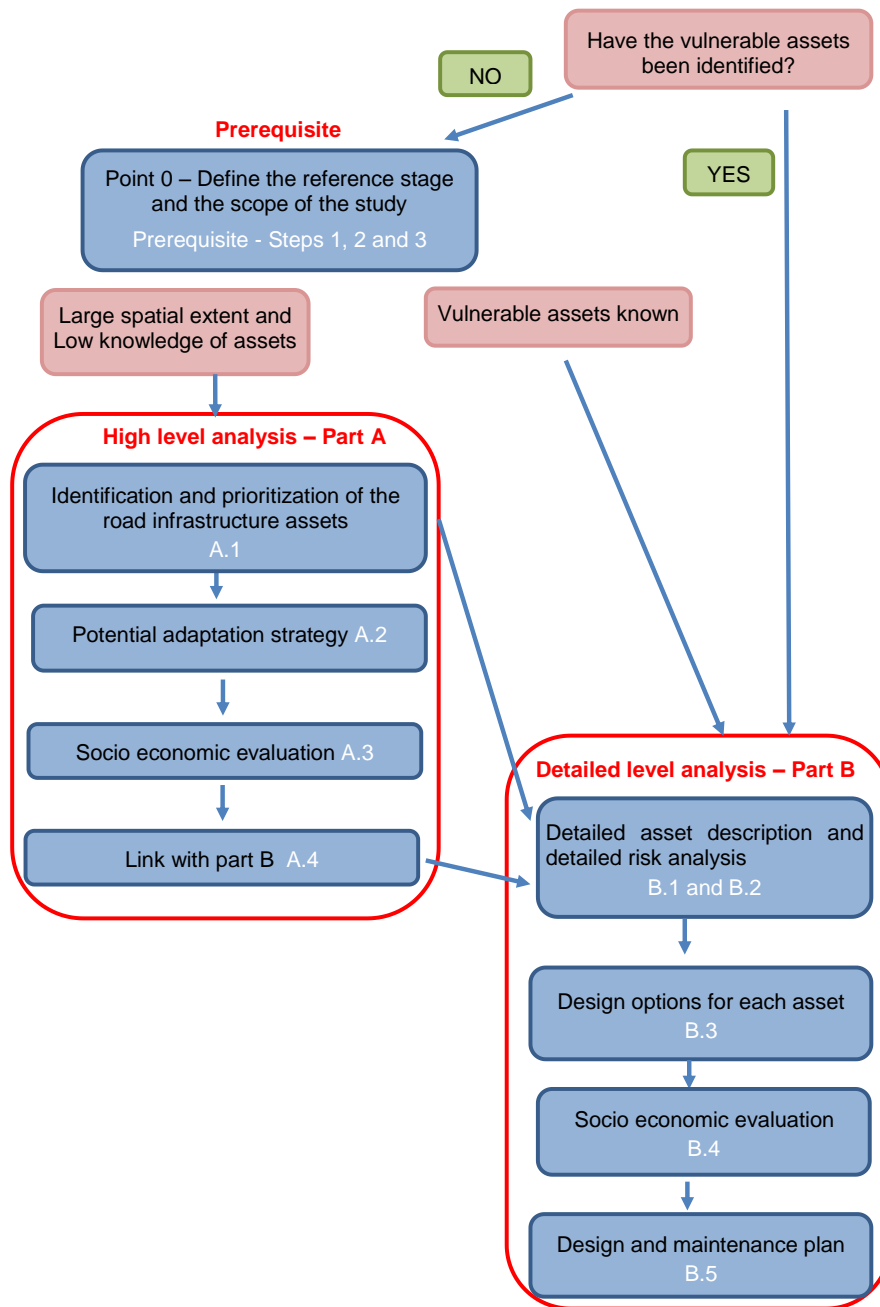


Figure 8 – Illustration of the decision tree of the WATCH manual. Part A refers to the high level analysis and part B refers to the detailed analysis (Foucher et al. 2018)

After initial steps in the manual, as illustrated in figure 8, the decision tree divides into part A and part B, also entitled the *High level* and the *detailed level*, depending on the need to further analyse. Part A and part B are listed in an overall manner as follows

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

- *appropriate for section or network scales*
- *enable a comparative analyse of the structures*
- *no need for detailed data (especially topographical data)*

Part B - Detailed risk evaluation / adaptation measures and strategies

- *appropriate for a single structure / a particular storm drain system*
- *appropriate for a structure defined as high priority from the global risk analysis method or already known as highly vulnerable,*
- *enable a detailed socio-economic analysis*

Through part A and B, the manual not only assesses the current resilience of the existing water management and risk evaluation but, furthermore, the future resilience of the water management assets is included to enhance basis for optimum maintenance and operation and construction over time.

The following sections are a walkthrough of the step-by-step approach of the WATCH manual and inherent socioeconomic analyses.

4. Prerequisite analysis and results (point 0)

4.1. Study area and scope

As a first step in the case study, point 0 in the manual, the reference stage needs to be established in order to find the starting point. The study area is, as previously mentioned, the M10 road, leading into the greater area of Copenhagen. As mentioned in section 1.4, 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.

The study area, in this report, is seen as the part of M10 which has undergone the mentioned construction, which entails the bulk of the entire stretch. Prior to every construction, contracts have been specified in preparation to the subsequent tendering on the basis various analyses which, in relation to the WATCH project, are

- data collection on existing assets
- data collection on added road surface area from lane widening
- data collection on catchment area
- data collection on impervious area
- hydraulic analyses for each water management system to ensure correct and necessary dimensioning as per section 1.2
- traffic flow analyses during construction

All types of construction on M10 were tendered and carried out in accordance with the process models as illustrated in 1.3, wherein current standards are specified.

The listed analysis points above constitute the risk analysis approach which entails gathering necessary data to plan and dimension in accordance with road standards. All of which will act to improve the main objective of the case study; to maintain continuous safety and mobility on M10.

4.2. Existing knowledge on assets and climate change impact

As described in 4.2.1, 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, as described in 2.2.

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. This is specified further in 2.2.

As an example of integrated risk analysis, the CEDR SWAMP project resulted in a Blue Spot model, which was subsequently custom tailored to analyse 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 shown in 2.3.1 during environmental analyses. 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. 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 (Bles *et al.* (1), 2015).

The QuickScan methodology is valued high since it combines real-world experience from experts with desk-based analyses and computations.

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.



Figure 9 - The M10 motorway in Denmark; the blue marking represents a vulnerable road stretch to flooding due to low capacity of storm water runoff. (Bles, T. (2) *et al.*, 2015)

The road stretch which was identified as vulnerable was appointed on more factors than 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, available on www.CEDR.eu.

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.

4.3. Conclusion

As stated before, 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 decision tree in figure 7, 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 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.

5. High Level (part A)

5.1. Introduction

Prioritizing the road assets on the M10 for risk level on a global level involves identifying the assets which are considered most vital and at the same time vulnerable to extraordinary high levels of stress, e.g. due to a changing climate causing more frequent water-related complications.

The output of the high-level risk analysis is to screen for these assets and to evaluate accompanying risks for a gained overview on the combined risk and an initial overview on where to allocate further resources in terms of more elaborate risk analyses and socioeconomic analysis.

5.2. Step 1 - High level risk analysis

As written in the WATCH manual by Foucher et al. 2018 and highlighted in Acting on Climate Change by Axelsen et al. 2016, working with climate change for NRAs is a complex task that involves multiple disciplines across NRA divisions, and the effects of climate change can cause different consequences to various types of assets and in a different way all dependent on geography. Working with climate change for European NRAs is mostly focussed on addressing the increased requirement for water management to be able to cope with a more extreme future climate in terms of a higher frequency of extreme precipitation. This is furthermore the central focus point for the WATCH project.

Dealing with water-related road management is predominately carried out by referring to road standards wherein specific return periods are stated as a go-to design and dimensioning foundation. However, these road standards can, at some road stretches now or in the foreseeable future, due to climate change, be labelled as obsolete since the assets in use are not able to comply with the level of service as written in the standards.

Hence, this common challenge for NRAs illustrates to necessity to undergo risk analyses to illuminate where consequences are most likely seen and to what affect for the network and society. Through such climate change driven risk analyses, the objective of the WATCH project is to prioritize the road assets according to the risk level through a global strategy and, from there, launch a detailed risk analysis where a socioeconomic analysis will highlight which strategy of climate change adaptation is most cost-effective, seen from a socioeconomic viewpoint, to improve decision making for NRAs to gain most adaption for the available resource.

Two methods of risk assessments are used here

- A screening inspired by the ROADAPT QuickScan methodology
- A screening based on the methodology described in the WATCH high level risk analysis

The ROADAPT QuickScan is employed as a screening methodology to conduct risk analysis since it is regarded as an established result and valuable approach of a previous CEDR project ROADAPT that has previously been in use in the Danish Road Directorate as a case study of the flooding risks in the Øresund region.

5.2.1. Risk screening, the ROADAPT QuickScan method

The screening has been conducted as listed in the manual by gathering experience and expertise from relevant staff, in this case engineers working with water management and planning staff, to qualitatively generate a global level analysis and identify vulnerable assets of the various types of water management systems.

Assets at stake

The screening has been conducted by evaluating the identified assets in terms of likelihood and consequence of failure. Three asset types were identified on M10 that are particularly important to address in the risk assessment in the context of water management to maintain continuous safety and mobility on M10. These asset types are

- Culverts
 - In the case of M10, culverts are used as a water management system to enable water crossing the road either for streams or from retention systems (SuDS features) onto another or into nature. The dimensioning of culverts is as described in 2.2.
- Retention systems
 - In the context of WATCH, retention systems used along M10, 54 in total, fit the description of a SuDS feature as described in 2.2.5 and 2.2.6. The dimensioning of retention systems is as described in 2.2. Since SuDS are in effect in Denmark, the WATCH deliverable on implementing SuDS from *Rooney (2018)* as an environmentally beneficial approach for climate change adaptation is not part of the case study.
- Pump stations
 - Pumps are used as the driving force of directing water away from road surfaces and constructions, primarily into retention systems. Pumps are installed in number and/or size to enable sufficient capacity and flow as described in 2.2.

Risk assessment, as a concept, is wide and can be done for many factors and at numerous scales. In this case study, the risk assessment is conducted by evaluating the likelihood of failure and the level of consequence of a failure. In the case study, failure is used as the bar of assessment since a failure means an inadequacy of capacity or capability of the given asset of evaluation. Common for all identified assets is that failure, by this definition, will cause flooding on the road surface or damage to the road construction, both measures for consequence in the risk assessment. Failure of the identified assets is defined below

Failure of Culverts

In the case of culverts, failure is defined as the point where these due to stress are unable to sufficiently enable water crossing the road, resulting in water to rise to a point of overflow causing flooding, either on the road or besides the road.

Failure of retention systems

Failure of retention systems is defined as the point where discharge of water in flow (L/sec) is less than that by supplied water from the adjoined water management system from the road itself and, possibly, from the adjacent catchment area to a degree of overflow. Such occurrence will cause cascading effects where overflow initially will cause flooding next to the road, potentially damaging the road construction, and

subsequently result in flooding on the road. Untreated road water is thereby led into the surrounding environment.

Failure of pumps

Failure of pumps is defined as the point where the total capacity of working pumps is inadequate to successfully lead water away from the road into the adjoined retention system or from one retention system to another, ultimately causing flooding on the road.

Assessment of likelihood and consequences

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.

Performing the risk assessment

Risk assessing the M10 on the global level is conducted by scoring the likelihood and consequence from 1-4, inspired by the ROADAPT case study. 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 as described in section 1.2 and all scores are set by evaluating and taking into account the current state of resiliency.

Likelihood of failure

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

Table 1 – illustration of likelihood scores

Consequence of failure

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 2 – illustration of consequence scores

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

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

Table 3 – 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

As seen in table 3 above, the scores vary between likelihood and consequence. Placing the scores in a matrix, as shown in figure 10 below, inspired by the ROADAPT case study, 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.

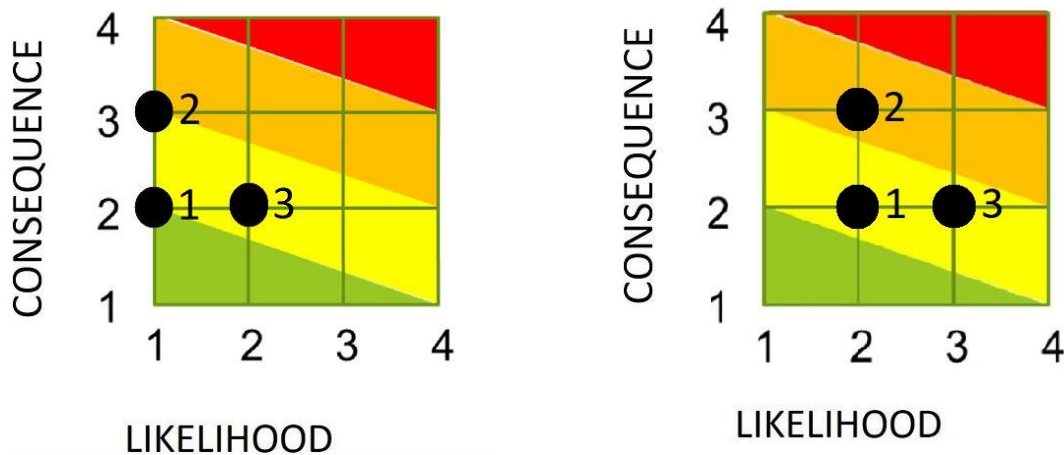


Figure 10 – illustration of risk scores placed in a matrix. 1 = Retention systems, 2 = Culverts, 3 = Pumps. Left: the risk assessment of the present day climate scenario. Right: illustration on how the climate change, as assessed, in 2030 will affect the risk assessments of the water management assets of an as is-strategy is chosen where no actions are taken to adapt the culverts to a changing climate.

Risk evaluation

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.

5.2.2. Further risk assessment using the manual steps

As a representable illustration on the manual part A step 1, the example below centres on one asset type, in this case culverts, since this is identified in the risk screening being the type of assets that shows the highest risk and needs further attention. Culverts are regarded as crossing structures (water crossing the road)

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

The proposed criteria for culverts 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

Sub-step 1.2 – Evaluation / scoring of the criteria

Define thresholds to score the criteria (following table)

- Each criterion is scored according to 4 classes:

Low	(1)
Medium	(2)
High	(3)
Very High	(4)

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	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 remarkable consequence assessed fill height > 2 m	Noteworthy As dimensionned 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

Figure 11 - Figure of scoring criteria

Score the criteria

- For each culvert, here examples are given for four different culverts
- For several cases:
 - Current stage
 - Future stage: horizon 2030 and 1 scenario (scenario A1B-IPCC) Note that ideally more scenarios are taken into account.

In figure 12 below the scoring is provided. 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				Future climate				Comments
			Culvert 1	Culvert 2	Culvert 3	Culvert 4	Culvert 1	Culvert 2	Culvert 3	Culvert 4	
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	

Figure 12 – Figure of an example on threat, vulnerability and consequence-scoring, in this case for culvert, for an optimum risk overview. Blue markings show the differences between current and future stage.

Comments on results:

- 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.

Sub-step 1.3 – Weighting of the criteria

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 scoring of criteria is exemplified in figure 13 and will be different for individual asset types.

	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%

Figure 13 – Figure of criteria scoring. The listed global weighting is qualitatively derived from the results of the scoring on the three factors. To translate this into a weighting, a 30% extra weight will arbitrarily be added to vulnerability which has a high global weighting and 30% lower weight to consequences which has a low global weighting.'

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

For culverts, which are defined as a crossing structure (water crossing the road) in the case study, the retained acceptability scale is illustrated in figure 14 below and further applied in the charts below.

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

Figure 14 – figure 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.

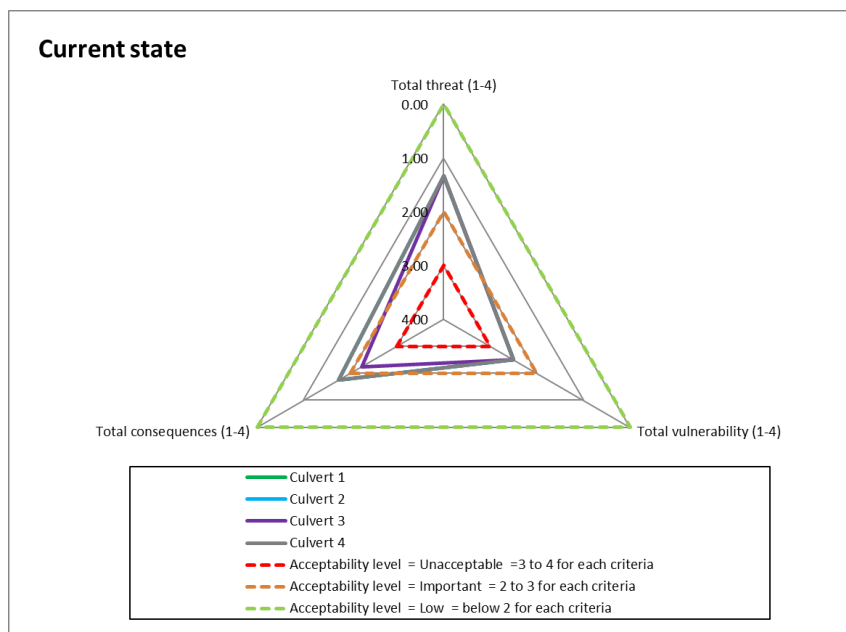


Figure 15 - Example of risk matrix for current stage

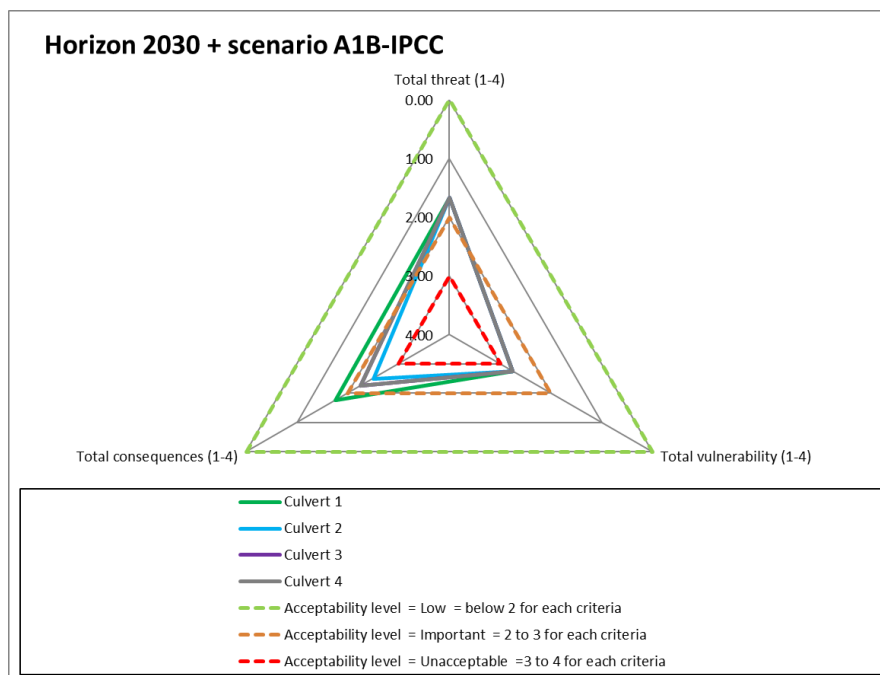


Figure 16 - Example of risk matrix for future stage = horizon 2030 + scenario A1B-IPCC

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 weighing	1.86	1.86	2.03	1.86	2.06	2.31	2.22	2.22
Average with weighing	1.94	1.94	2.05	1.94	2.16	2.33	2.27	2.27

Figure 17 – Illustration of categorization of risk criteria for various cases

Results / prioritization of the assets:

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 does not allow to clearly screen the culverts. When the socioeconomic analysis shows that measures are preferable, a clearer view of the risks of the culverts should be obtained using a more detailed analysis (part B of the manual).

During discussions internally at the Danish Road Directorate it appeared that the global level was deemed valuable for larger areas including several roads with various features.

5.3. Step 2 - Defining adaptation strategies

The risk analysis conducted in the case study generates arguments and learnings to revise or to add to the current strategy and process models currently in effect. Of the listed WATCH available strategies, an application of mitigating measures is valued most useful.

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.

To directly compare and to further holistically conclude on the optimum strategy to follow and implement these will be subject to further elaboration in the socioeconomic analysis, where the strategies are compared in terms of economic impact.

5.4. Step 3 - Global level socio economic analysis

The socioeconomic analysis will be conducted by applying the WATCH model for socio economy. For more elaborate description on this, the WATCH socio-economic analysis guidelines explain the academics and steps in this approach in detail. On an overall level, the analysis is illustrated in figure 18, seen below.

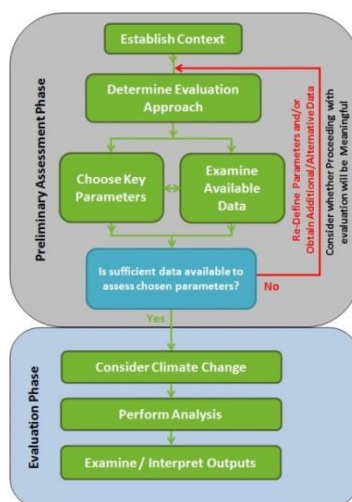


Figure 18 – Overall illustration of the WATCH model for socio economic analyses (Tucker et al., 2018)

These steps are further elaborated in the following sections.

5.4.1. Establish context

Conducting socio economic analysis for road construction, maintenance and operation is not widely used for current elaborate decision making, nor is it applied and implemented in the process models, seen in 2.3, as a set and unified step to undergo at the Danish Road Directorate. This is furthermore shown as a typical case of NRAs in the WATCH country comparison report.

In the context of WATCH and step 3 in part A in the manual, applying socio economic analyses for water management has as objective to study whether the socioeconomic impact of failure of the respective water management in function can affect the assessment of the current assets and further decision making.

For further context the reader is referred to the preceding sections. It is concluded that the purpose of the evaluation is to assess the risk to culverts on the M10. Furthermore, from the output of the risk assessment process, it is considered that for the High level analysis, a number of adaptation strategies are to be assessed, with the aim of undertaking a more detailed analysis of the optimum solution using a Part B analysis.

The three adaptation strategies identified are as follows (more information to be found in section 5.3.);

1. As is (current state):
2. Allocate Additional Resources for updating:
3. Updating or bypassing the strategy for service level:

5.4.2. Determine evaluation approach

As a primary economic and cost analysis, life cycle cost (LCC) is the conventionally and referred-to analysis when the Danish Road Directorates, and many other NRAs as seen in the country comparison report, conduct economic analyses in regard to road management. This analysis primarily takes into account construction and acquisition cost, durability/life span and maintenance cost during operation.

As a preliminary socioeconomic analysis, relating the LCC approach to the risk analyses, it is greatly considered that the failure of a given asset, resulting in flooding of a road, can affect the durability of the road construction itself and the further asset performance which may lead to more repairs and asset replacements that was otherwise originally considered in the LCC. Such change in the LCC-aspect is considered as a very significant additional cost for an NRA.

However, given the nature of the assessment (e.g. High Level) and the decision to screen the most vulnerable assets in the first instance, an MCA approach has been chosen as the evaluation method. The multi criteria analysis (MCA) is valued very useful at an early screening stage, e.g. where quantitative data is not yet sufficiently available. Through the MCA which takes its' departure in the section of defining strategies, the choice to update culverts on M10 is evaluated through an assessment of the potential loss of functionality of the road, should the asset fail due to inadequacy of resiliency.

5.4.3. Choose key parameters

As mentioned, socio economic analyses are not widely used as a parameter in decision making, e.g. through the process models. The following will describe the needed data input for concrete socioeconomic analyses for the listed points. The guidelines propose a set of criteria for the analysis. The user may add or delete criteria according to the demands and the context of the project. For the case study, the following criteria are chosen:

- Maintenance & Serviceability Issues
- Environmental costs
- Societal Impacts & Requirements
- Safety Constraints & Impacts

5.4.4. Examine available data

In the sections below a description a description is provided on the availability of the data regarding the chosen criteria.

Maintenance & Serviceability Issues (i.e. repair costs)

Conducting socio economic analyses in relation to maintenance and serviceability issues involves assessing the following points

- Price for replacement parts should be available from supplier/fitter
- Price for each worker should be considered – possibility of night work
- Price for traffic management measures should be considered

The case study revealed that the price for replacing or repairing assets and the specific labour input is down the very specific and individual asset failure and the degree of failure. Since most assets are individual in dimensioning and are situated in local specific

characterizations, e.g. due to catchment area specifics, gaining sufficient access to the particular asset to repair or replace varies greatly with a related varying cost.

The price for replacing or repairing given assets will be dictated from various parts. Chief among these are

- Price of repair or replacement of the specific asset
- Allowed time for closure or part-closure of the road, which is dictated on an hour-by-hour resolution from the road sector, specified for the individual road section on the major Danish roads.
- Should the allowed time for closure dictate a need for night work, which can easily be the case of the M10 due to the high strategic categorization and AADT, then the hourly price for labour input is more expensive, however, the work can in some cases be conducted in a faster manner due to fewer factors of interruptions, including a lesser degree of traffic disruption. For the WATCH project, the negative personal impact, e.g. social and health-related, of working at night is not taken into account since no representable data for similar projects nor directly applicable research on the matter could be included for the M10-based case study.

Environmental costs

Conducting socio economic analyses in relation to environmental costs involves assessing the following points

- Air Pollution Levels
- Carbon Dioxide Emissions
- Noise Pollution Levels
- Impact on Natural Landscape

Assessing the M10 for environmental costs in regards to asset inadequacies is considered to hold two main points;

Firstly, asset inadequacy or failure can in many cases lead to significant environmental impacts. As an example, should a pump or a pumping station prove inadequate or fail during an extreme precipitation event, a retention system can overflow and spill non-treated road water into the adjacent environment, effectively disabling the environmental properties of the retention system as a SuDS feature. At the time of spill, many stakeholders are affected. The main identified stakeholders are listed below

- Maritime environment
Due to the close proximity to the sea, road water from M10 may be led untreated into the maritime environment where organic pollutants, e.g. PAHs, can cause negative effects
- Agriculture
The adjacent agriculture can, as the maritime environment, be negatively affected by a discharge of untreated road water
- Land-based environment
Streams connected to the specific catchment area where the failing asset is situated can likewise be negatively affected by a discharge of untreated road water, causing potential damage to both flora and fauna

Coupling a price to such consequence of an asset failure involves obtaining data on the specific scale of the spill including measurements of the range of consequence.

Secondly, regarding noise, M10 is led through many areas characterised as urban areas. Therefore, noise levels and annoyance are key environmental aspects and factors to monitor

and consider. Should repair or replacement of assets prove necessary, e.g. due to failure or inadequacy to maintain the level of service, the changing noise emission from the road can have significant impact on the neighbouring residents.

The concrete socioeconomic price for a changing noise emission due to road work is dictated by the following factors

- Density of people living within the 58dB range of road noise
- Duration of road work
- The degree of night time vs. day time road work

Analysing added CO₂-emissions and air quality is not taken into account in the WATCH project. The strategies, as described in 5.3, will both respectively entail implications on the total CO₂ emission linked to the road and/or road section.

Through an as-is scenario, the traffic is at risk of more frequent lowered mobility and stand-still occurrences in the future due to a higher rate of flooding. This strategy will cause a more inefficient flow and a higher CO₂ emission.

Following a strategy of updating water management assets will be accompanied with CO₂ emissions through construction, although short in duration compared to the lifespan of the road. In turn, this strategy will eliminate the traffic flow inefficiency linked to the 'as is' strategy and thereby reduce CO₂ emission during the operation period of the road. Comparing these strategies and their respective impacts on CO₂ emissions is considered beyond the scope of the WATCH project and will require elaborate and extensive LCA analyses to determine precise reductions.

Societal Impacts & Requirements (effect, costs)

Conducting socio economic analyses in relation to societal impacts and requirements involves assessing the following points

- Impacts on road users as a result of increased journey times
- Cascading effects on other roads in the vicinity
- Effect on public transport network in the vicinity, especially in the event of failure of the system
- Level of confidence of the public and logistic transport companies in the ability of the road owner to deal with climate change impacts
- Impact on road network availability due to maintenance / replacement

The impact of a given traffic disruption, e.g. due to road work for asset repair or replacement, to the road users, is considered very consequential in nature on M10 due to the high AADT and strategic road categorisation as described in 1.3 and 2.3.2, respectively, and in the consequence analysis.

When the traffic on M10 is disrupted or even brought to a stand-still, the socio-economic consequences are considered substantial. Traffic will not sufficiently be able to use alternative routes to maintain mobility since the M10 is the main road infrastructure leading into Copenhagen from the south. The adjoining roads will therefore experience negative cascading effects since these roads are not dimensioned or capable to cope with the increase in traffic volume.

Parallel, and not far from the M10, public transportation is available in the form of trains stopping frequently on the way into Copenhagen. Although present, the public transportation in the vicinity is not considered sufficient in capacity to significantly assist to maintain mobility, e.g. for commuters, in the case of a substantial disruption in flow or a stand-still of

the traffic on M10. This is despite the fact that the tracks for the train infrastructure leading into Copenhagen is not regarded as vulnerable to climate change and flooding risks as the road and is thereby considered to be able to maintain its' respective mobility to a larger degree.

Safety Constraints & Impacts

Conducting socio economic analyses in relation to safety constraints and impacts is identified to involve assessing the following points in the case study

- Reduction in safety of network, potentially due to queues on the network and diversions to less safe networks
- Reduction in individual driver safety, potentially as a result of hydroplaning and/or reduced visibility due to excess surface water on the pavement

Asset failure during stress, e.g. through an extreme precipitation occurrence, will cause numerous factors to negatively contribute to a reduction in traffic safety on the road. The main factors are assessed to be

- Higher risk of flooding on the road causes an increase in risk of hydroplaning which increases accident probability.
- Higher degree of uneven and irregular driving behaviour, e.g. due to puddle-forming on the road, increasing the risk of accidents.
- Higher degree of splash and spray from the moving traffic causing a decrease in visibility, increasing the risk of accidents. The M10 is paved with a noise-reducing, SMA8-based pavement which on the positive side lowers noise, however, on the negative side can lead to a larger degree of splash and spray compared to the more conventionally used SMA11-based pavement.

Cost

Putting an exact price on a specific asset failure and the following consequences is not attainable for the M10 since no such occurrences have yet happened since the lane-widening ended in 2017.

An academic study was conducted in ROADAPT through the case studies where direct costs were related to specific threats, as illustrated in table 4. These direct costs can be applied to gain a more qualitative awareness on the cost of consequence. Here, direct technical costs of repair for assets are ranked in severity with the following categorisation

Category	Cost
1.	Less than k€ 25
2.	Between k€ 25 and k€ 100
3.	Between k€ 100 and k€ 500
4.	More than k€ 500

Table 4 – Illustration of how repair of assets are categorized and ranked (Bles et al (1)., 2015)

Making use of the criteria

For the four key parameters identified, an impact table is defined whereby each parameter is ranked based on an impact level of -2 to +2, depending on the impact of a failure of a culvert, shown in table 5. A positive score indicates the impact has benefits/reduced negative impact for the DRD (e.g. less cost or increased safety). A negative score means the measure has disadvantages/increased negative impact for the NRA (e.g. higher cost or decreased safety).

Impact Level	Maintenance & Serviceability Issues	Environmental issues	Societal Impacts & Requirements	Safety Constraints & Impacts
-2	Significant repairs	Significant impact on environment, untreated water flowing into sea, crossing streams	Re-routing of traffic/use of alternative transport mean due to road closures	Multiple Casualties/severe injuries
-1	Repairs above routine maintenance	Significant clear up on road, Environmental impact assessment possibly required	Significant delays due to lane closures (e.g. 6hr standstill)	Casualties/severe injuries
0	Neutral/N/A	Neutral/N/A	Neutral/N/A	Neutral/N/A
+1	Minor repairs in line with routine maintenance	Normal Clear up over greater area of road required	Minimal delays/congestion, no rerouting required, road operational	Minor injuries
+2	Minimal/no repairs	Minimal impact on the environment, normal clear up in localised area, untreated water on the road only	No delays/congestion, no rerouting required, road operational	Material Damage

Table 5: Impact Class Table

Equally, the costs of a particular strategy are ranked on a scale of -2 to +2, Table 6.

Category	Cost, C, in €
-2	$C \geq 500,000$
-1	$100,000 \leq C < 500,000$
0	Neutral/N/A
+1	$25,000 \leq C < 100,000$
+2	$C < 25,000$

Table 6: Direct Cost Category

5.4.5. Is sufficient data available to perform the analysis

In conducting the MCA to compare the proposed adaptation strategies, it is considered that a ranking system as described in the previous section is sufficient.

5.4.6. Consider climate change

For the purpose of this level of assessment, the impacts of climate change are incorporated by ranking the climate scenario on a scale of -2 to +2 as shown in table 7.

Impact Level	Climate Change Impact
-2	Increase in Frequency and severity of Flooding events such that threat of culvert failure is inevitable
-1	Increase in Frequency and severity of Flooding events such that threat of culvert failure is likely
0	Neutral/N/A
+1	Increase in Frequency and severity of Flooding events such that culverts are operating at full capacity
+2	Increase in Frequency and severity of Flooding events such that culverts are operating with a reasonable margin of safety against failure

Table 7: Impact Class Table

5.4.7. Perform the analysis

Based on the qualitative ranking system described in the previous section for the costs and impacts, the scores are tabulated in table 6 and table 7, respectively. In Table 8, the average impact is determined considering the key parameters alone. In the absence of assigning specific weights to each impact, this allows for some level of weighting for combined impacts for a given strategy. Subsequently in Table 9, the qualitative output for each strategy is summed to give the final score. The highest score represents the most optimum adaptation strategy which will be examined further in the more detailed level of analysis stage.

As is (current state)

Accepting a current state and capacity of an identified inadequate culvert will essentially entail approval of a too high frequency in flooding, rendering a potential loss of functionality of the M10, both in terms of immediate traffic disruption and potential short- and long-term damage of the road construction. The justifying point is a high resource demand associated with replacement or repair of the asset which has a direct cost and a socio economic cost, e.g. from traffic disruption.

Since there is a particular interest in maintaining mobility and safety on M10 due to the high number in AADT and strategic level, updating the identified culvert is valued particularly high. Albeit for a relatively limited time, updating the culvert will involve road work which will disrupt the traffic flow, causing a significant socio economic cost. However, this is not considered to exceed the risk of more frequent flooding, both in regards to likelihood and consequence.

Therefore, status quo is scored with a negative two on maintenance and service since it will have a negative impact for the Danish Road Directorate and the society with a risk of too frequent flooding, potentially causing damage which will require more maintenance and hindering performance of the road on mobility.

Environmental costs are scored with a negative 1 since multiple stakeholders, as listed in 2.3.2.3 *Environmental costs*, can be potentially affected negatively, e.g. by a too frequent flooding.

Societal impacts is scored with a negative two since the socio economic cost of too frequent flooding caused by an insufficient culvert have significant negative costs for the M10 performance on mobility.

Safety constrains and impacts is scored with a negative one since the higher risk of flooding causes a compromise on the general safety on M10, e.g. potentially increasing hydroplaning and/or splash and spray visibility issues.

All in all, the status quo receives a total of -1.5.

Allocating additional resources for updating

Increasing the capacity of the identified culvert, and thereby increasing the road resiliency, requires input of more resource than originally allocated; both in terms of new asset features and installation of these along with preceding engineering and hydraulic analyses to determine new specifications.

Although the needed resource of a updating the identified culvert and, in particular, installation of the specified update is considered to constitute a significant cost, the additional allocation of resource for updating the culvert is considered as an optimum solution seen from a socio economic viewpoint for M10 to maintain mobility and safety. Furthermore, this is particularly valued as an optimum solution since it will entail best basis for a high durability of the road construction through as with flooding occurrences as possible, which, in turn, will lead to less road maintenance and construction through the life span of M10.

In table 5, allocating additional resources for updating is scored with a positive one since this initiative will potentially lead to less damage to the culvert and the road itself and thereby a reduction in requirement needs.

Environmental costs is scores with a positive one since the adjacent environment with multiple stakeholders involved, as listed in 2.3.2.3 Environmental costs, will gain from a fully adequate and culvert which will lower the risk of flooding.

Societal impacts is scored with a positive one, predominately since the traffic will experience less disruption caused by flooding for the benefit of the M10 mobility.

Safety constrains and impacts is scored with a positive two since the M10 overall safety will increase as a result of less flooding risk. This is considered particularly important on M10 due to the high number in AADT and strategic importance.

All in all, the allocating additional resources for updating receive an average of a positive 1.25.

Updating or bypassing the strategy for service level

As a final solution to improve further decision making, is to initiate a revision of the governing road standards or to apply for a local exemption. The identified inadequate culvert was identified on the basis of the specifications seen in the road standards and the climate change adaptation strategy of the Danish Road Directorate. These are in effect to ensure a unified service level for all major Danish roads and what the road users expects from the Danish Road Directorate.

Still, a local exemption is seen as a solution which could turn out to be cost-effective all depended on the future precipitation pattern. On an overall level, this form of solution is not regarded desirable since the consequences of traffic disruption on M10 are very significant. Furthermore, a local exemption is not considered beneficial for the general trust towards any given national road authority. As an ending remark, such form of local solution is not considered very feasible nor has it previously been conducted as a mean to base economic solutions and decisions for in regards to water management.

The parameter of updating or bypassing the strategy for service level is scored with a negative one in table 5. The score is set since, alike the status quo, it can lead to a negative impact for the Danish Road Directorate with a risk of too frequent flooding occurrences, potentially causing damage which will require more maintenance and hindering performance of the road on mobility.

Environmental costs is scores with a negative one since multiple stakeholders, as listed in 2.3.2.3 Environmental costs, can be potentially be affected negatively, e.g. by a too frequent flooding

Societal impacts is scored with a negative two since the socio economic costs of too frequent flooding will result in significant societal costs on the M10 due to a potential loss on performance through mobility.

Safety constrains and impacts is scored with a negative one two since the overall safety on M10 can be compromised due to a higher risk of flooding.

All in all, the updating or bypassing the strategy for service level receives an average of a negative 1.

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 8: MCA Analysis – Averaging of Key Parameters

Strategy	Direct Cost	Averaged impact 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 9: MCA Analysis – Final Scores

5.4.8. Examine / interpret outputs

Through the MCA screening analyses, the allocation of additional resource to update an inadequate culvert is valued as the most optimum approach to base further decision making and socio economic analyses on.

5.5. Conclusion and link with part B

From the high level assessment 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.

6. Detailed risk evaluation for culverts (Part B)

6.1. Introduction

On a more detailed level, the part B of the manual has as objective to assess assets of identified high risk more elaborately to define adaptation measures.

The detailed risk assessment in the case study will be carried out for culverts as this water management asset is considered as having the highest consequence to road-flooding if the asset should fail on M10.

As a key part of the detailed level analysis, a more in depth socio economic analysis will be conducted to illuminate more and improved approaches to economic analysis and subsequent decision making for more resilient water management.

The following points from the WATCH manual (Foucher et al, 2018) will form the step-by-step approach to conduct the detailed risk analysis.

- Gaining useful climate data
- Determining current and future resilience of assets
- Define possible measures strategies
- Socio economic analysis
- Finalisation of strategy
- Action planning and monitoring

As described in the preceding paragraphs, the Danish road directorate has a high knowledge on assets and the individual state of these due to a recent lane-widening construction which has resulted in new or, if needed, updated assets in order for these be capable to have the M10 to live up to the current service level for optimum conditions on safety and mobility.

6.2. Useful climate data (Step 1, part B)

As seen in section 2.2.9, the Danish Road Directorate has incorporated the IPCC A1B, coupled to Danish conditions from the Danish Meteorological Institute, as a reference of climate change to road management, and therein water management.

Through the implemented and anchored climate change adaptation strategy in the Danish Road Directorate, the IPCC A1B scenario is used for climate change incorporation into dimensioning of water assets.

Current climate data is available from the reference period 1961-1990 and 2001-2010 from the Danish Meteorological Institute. The climate data, both from the present day climate and for the future is predominately applied as an input for IDF curve calculation to dimension water management systems through hydraulic analyses. These form the basis of specifics on required water management dimensioning in for tendering processes.

Through the WATCH climate change protocol, an enhanced use of climate data is seen available in the most recent document on climate change in Denmark through

where the estimated increase in temperature is 1-2 °C for around 2045-2065 compared to 1986-2005 and 1-3.7 °C for 2081-2100. The available rainfall statistics for the current climate are based on the period 1979-2012, which does not differ greatly from the reference period of the climate scenarios.

The climate of Denmark resembles a lot the climate in the Netherlands. If the observed changes in the Netherlands is observed and transferred to make a first check on the factors in Denmark (assuming no clear change in humidity), an expected 10-28 % change for the period 2045-2065 for extreme hourly rainfall, or factors ranging from 1.1 to about 1.28. The highest factors used in Denmark are higher (1.23-1.5), and for the period 2081-2100 the factors recommended for Denmark (1.2-2.0) are also higher than based on the estimate with the observed changes in the Netherlands (10 – 52 %) (Bessembinder, J. et al., 2018).

Through the WATCH protocol and IDA (IDA, 2017), table 10 is given with factors for generating future rainfall extremes are presented, compared to the rainfall statistics for the current climate (1979-2012).

	50 year horizon		100 year horizon	
	Standard	High	Standard	High
2 year return period	1.1	1.23	1.2	1.45
10 year return period	1.15	1.35	1.3	1.7
100 year return period	1.2	1.50	1.4	2

Table 10 - Recommended climate factors for Denmark based on three scaling methods, 17 climate models runs and five emission scenarios, time horizon 100 years ahead (Bessembinder, j. et al. 2018)

As an example us specific usage, should an NRA want to analyse based on what is considered the worst case situation for a road for a strategically important road, such as the M10, the NRA would most likely opt like to minimize the risk of problems due to local flooding. In such case it would be logical to select the factors under *high* in table 10 above for road planning and construction. If the expected life span of the drainage system, e.g. culverts, for the road is about 50 years, then the NRA should opt for the factors under the time horizon of 50 years.

In practice in Denmark, various climate factors take part in different tendering processes, dependent on the specific road stretch. In the case of M10, a climate factor of 1.4 was applied to ensure what is considered required for resilience for a changing future climate.

As described in 1.2, climate change is an acknowledged condition In the Danish Road Directorate to road management in the future, in particular within road water management. As a mean to address climate change, both now and in the future, the Danish Road Directorate has implemented a climate change adaptation strategy. This strategy enforces including climate change to be considered in planning, operation, maintenance, construction and monitoring major Danish Roads.

As a development to work in line with this strategy and as a way to further address climate change adaptation in an interdisciplinary approach, the WATCH report on climate change, *Climate and climate change: protocol for use and generation of statistics on rainfall extremes (7)*, is regarded as inspirational to gain more interdisciplinary synergy and results, leading to improved basis for resilient roads.

Working with climate change is a wide-ranging topic in an NRA, even purely within focusing on water management, which is considered to require an interdisciplinary approach for most success. The WATCH approach to working with climate change, as seen in figure 19 below, couples the analyses conducted on the engineering part, e.g. on asset dimensioning, to the inclusion of data collection methodologies and high level decision maker input to the selected climate change scenario to dimension, and thereby determine needed resource.

The WATCH step-by-step approach, as illustrated in figure 19 from *Bessembinder, J et al (2018)*, it is illustrated how to take climate change into account. The step-by-step approach was not applied in the case study since climate data and climate scenario is established at the Danish Road Directorate. For NRAs that have insufficient climate data at hand, this approach is considered of high value since it implements knowledge and viewpoints on an interdisciplinary basis, leading to a higher degree of organisational anchoring of working with climate change and thereby improved foundation for success.

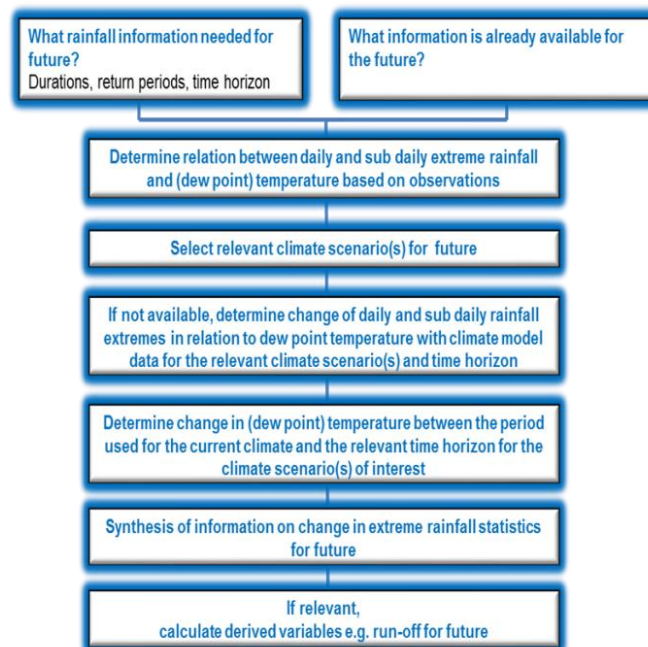


Figure 19 – the WATCH step-by-step approach on working with climate change (*Bessembinder, J et al., 2018*)

From the Danish Meteorological Institute climate data from the period 1961-1990 show that the region in which the M10 is situated has an annual precipitation of 695 mm. In figure 20 below, an IDF curve is shown and considered representable for the entire stretch of M10.

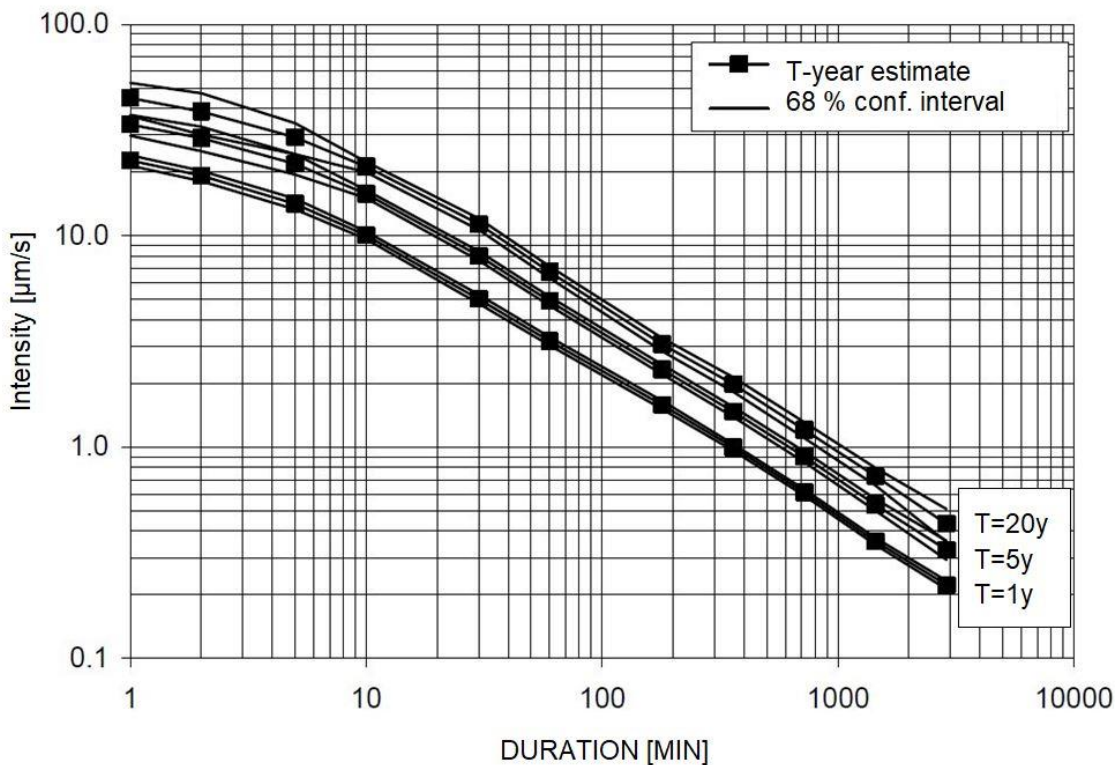


Figure 20 - A representative IDF curve for the entire M10 stretch (IDA, 2017)

6.3. Determining current and future resilience of assets (step 2, part B)

Culverts are in place and function in accordance road standards, largely dictated and inspired by the *Spildevandskomitéen*, and have recently been analysed and/or updated to enable required resilience. Thus, on the theoretical plan, the M10 culverts are regarded in updated, sufficient status. Over time, road standards are subject to updates, e.g. based on a changing climate and new solutions on water management. When updated and available through the *Spildevandskomitéen*, the Danish Road Directorate will incorporate the updates to ensure the same continuous service level.

Culvert data are available in a database, also geo-referenced with attributing data as listed below

- age of culvert
- capacity of culvert
- gradient of culvert
- dimensioning of culvert
 - diameter and length
- linkage to other assets of water management
- adjoining catchment area characteristics
 - size
 - streams
 - gradients

- perviousness, runoff coefficient
- degree of urban area
- proprietorship specifics
- maintenance requirements
- road AADT
- road level in relation to culvert
- road surface area

In relation to intrinsic analysis, in order to further assess the current and future resiliency of the M10 culverts, hydraulic calculations on multiple topics of water flow are conducted, such as

- downstream flow specification
- surface runoff specification
- upstream water level specification
- catchment area retention characteristics

These analyses have been conducted in order to ensure culverts to be capable to handle expected maximum peak flow, including the integration of the climate factor of 1.4 and to IDF curve calculation.

For the purpose of this case study no new analyses have been made, since this doesn't fit in the scope of the project. Furthermore, such analyses are very site specific and country dependent and therefore conducting such analysis in the case study would not directly help in demonstrating the manual regarding this step. For further methodology reference is made to the manual.

6.4. Selection of measures and strategies (step 3, part B)

As a supplement to 2.3.2.2 and the evaluation on resiliency, the Danish Road Directorate strategyon climate change adaptation specifies both reactive and proactive overall means. The detailed risk analysis will act to highlight where to allocate more focus on the organisational level to spend resources in the optimum manner. This is particularly valued beneficial in the following overall points from the strategy, as shown in in 2.2.

- Improve and adapt roads where possible
- Preventing where possible

Choosing a strategy largely relies on conducting a preceding economic screening and evaluation of the possible measures to implement to fulfil a strategy. These are shown in figure 21.

Furthermore, an additional point to enhance resilience other than asset dimensioning and state for optimum operation properties is the maintenance of the asset type to enable optimum conditions for the single asset type to function in operation as originally designed for. The Danish Road directorate tenders maintenance and specifies in accordance with road standards, down to the single water management asset. By tendering in such approach, the winning contractor is responsible for sufficiently frequency in maintenance actions to enable the asset to function properly.

On account on the detailed risk analysis, maintenance is therefore regarded as a critical parameter and strategy focus point for assets to function with full capacity and to ensure longevity for the

asset. Thus, results on resilience risk analyses are valued expressively beneficial to revise and potentially update the process models on maintenance and operations, 1.3.3 and 1.3.4, to enable best basis for tendering sufficient requirements to ensure adequate resiliency.

In *Foucher et al.* (2018), the illustrated Excel sheet below is available for specific diagnosis of measures. Here, exemplified in figure 21 on culverts. In this specific case, the measure of enhancing construction resiliency as a proactive measure to mitigate consequences is followed in the figure on the structure itself through retrofitting. The downstream area(s) is/are regarded as sufficiently capable to be able to handle additional water as a function of a more capable water asset (culvert). Mainly, since the areas are in close proximity to the end-recipient; the ocean east of M10 after water has passed through assets ensuring environmentally friendly water, e.g. retention systems such as SuDS features.

For the purpose of this case study the number of measures for further analysis is decided to be very limited to only two, This will facilitate the reader to understand how the manual functions. However, in a real life project, more strategies will need to be compared. These strategies for further analysis are:

- Do nothing
- Enlarge the culvert

Type of assets	Category of measure Ref [2]	Stage Ref [2]	Location of measures	Measures	Advantages	Disadvantages	Effectiveness of the measure (assumption : implementation done) - Ref [1] and Ref [2]						
							Increase of resistance	Decrease consequences	Recovery capacity	Adaptive capacity	Safety	Societal costs (Availability)	Repair costs
Crossing structures (water crossing the road)	Resilient Construction	Pre-action	On the structure itself	Retrofitting of the structure (the downstream site need to be taken into account - the measure cannot increase the downstream risk if there is a vulnerable area)			++	+3	+3	-2	+	+	0
	Resilient Construction	Pre-action		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)	Not to many works on the structure itself but reconstruction of the fill (less expensive)	traffic/road cut	+	-2	-3	-2	0	+	+
	Resilient Construction	Pre-action		Pipe jacking at high level for increasing conveyance but only for extreme events	No modification of classical floods functioning	warning on downstream side	++	+3	+3	-2	+	+	0
	Resilient Construction	Pre-action		Increase road network redundancy			0	+1	+3	-1	-	+	+
	Resilient Construction	Pre-action	Outside the structure	Add / Improve upstream retention / wetlands / infiltration			++	+1	+1	-2	+	+	+
	Resilient Construction	Prevention		Divert part of the flow toward another structure (downstream impact to be taken into account)			+	+2	+2	-2	-	+	0
	Resilient Construction	Prevention		Rebuild stretch of the road on safe ground			++	+1	+1	-2	-	+	-
	Monitoring and inspection	Pre-action		Monitoring / asset management (Keeping records of events and locations of over/loaded hydraulic systems + Keeping records of flooding events and locations)			0	+1	+2	-1	+	0	0
	Legislation, Regulation	Preparation		Revise/update relevant standards/legislation for design of structures			+	+2	+1	-2	+	+	+
	Legislation, Regulation	Pre-action		Traffic management / prepare contingency / emergency plans			+	+3	0	0	0	+	+
	Traffic Management	Prevention		Extreme weather alert			0	+2	+2	-1	0	+	+
	Traffic Management	Response		Be ready to act/built when ruin of the culvert : design study done	no urgent works minimise the costs avoid doing again later	warning on downstream side	0	-3	-3	+1	0	+	+
	Planning	Pre-action		Keep materials/structures in the vicinity			0	+2	0	-1	0	+	+
	Capacity Building	Pre-action	General	Prepare and educate road users about the effects of flooding events			0	+1	0	-1	0	+	+
	Capacity Building	Pre-action		Prepare and educate staff members about the effects of flooding events			0	+1	0	-1	0	+	+
Capacity Building	Pre-action		Prepare and educate people living in the vicinity of the structure about the effects of flooding events			0	+2	0	-1	0	+	+	
Capacity Building	Pre-action		Increase of awareness among road owners and road users regarding necessary climate change adaptation measures			0	+2	0	-1	0	+	+	
Traffic Management	Response		Above a certain rainfall event: closure of one lane			0	+3	-2	-2	+	+	+	
Traffic Management	Response		Above a certain rainfall event: stop the traffic by variable message sign			0	+3	-3	-2	++	+	+	
Traffic Management	Response		Above a certain rainfall event: reduction of speed limit			0	+3	-2	-2	+	+	+	
Resilient Construction	Pre-action		Avoid depression in the catchment area			0	+1	-3	-1	++	0	+	
Resilient Construction	Pre-action		Avoid urbanisation (or with mitigation measures), in the catchment area			0	+1	-3	-1	++	0	+	

Figure 21 – Example on the WATCH measures excel sheet. Example given for culverts. (Foucher et al. 2018)

Socio economic analysis (step 4, part B)

The WATCH approach to detailed socio economic analyses is described in full in the WATCH deliverable *Socio Economic Analysis Guidelines*. Also reference is made to Chapter 5.4.

6.4.1. Establishing the context

The main purpose of conducting socio economic analysis in regards to water management systems and climate change is to investigate whether results can facilitate better basis for decision making, both in terms of maintenance and operation and construction.

As described in 1.2, the Danish Road Directorate dimensions road water assets to be able to cope with a 25 year return period of precipitation pattern on major Danish roads.

Furthermore, the Danish Road Directorate acknowledges the changing climate will affect road management in Denmark with a general increase in stress and has therefore implemented and anchored a climate change strategy to ensure continuous awareness and monitoring for the major Danish roads to be able to meet the service criteria, both in the present day and with the future changing climate.

With this acknowledgement, it is accepted that future water management for roads will be affected the most. Therefore, the outcome of the WATCH project is considered decidedly fruitful and, in particular, to illuminate that more use and awareness of socio economic analysis approaches can facilitate better ways to allocate resource in a smarter way to ensure the highest degree of adaptation and thereby resilient roads.

The further case study on the socioeconomic analysis is conducted for culverts on an existing road, the M10. The case study on socio economic analysis analyses the use of the guidelines and is conducted by going through the guidelines step-by-step with relevant staff to illustrate how the guidelines can be applied to increase the awareness on resource needed for current and future resilient roads.

6.4.2. Determine evaluation approach

Four economic analyses are listed in the WATCH guidelines to socio economic analyses; Multi criteria analysis (MCA), Cost benefit analysis (CBA), Cost effectiveness analysis (CEA) and Life cycle cost (LCC).

As previously described in the global analysis, LCC is the conventional approach when the Danish Road Directorates conducts economic analyses in regards to road management. This analysis mainly takes into account construction cost, durability/life span and maintenance cost during operation.

However, when analysing whether socio economic analyses can facilitate better basis for decision making, a cost benefit analyses is employed to elaborate to a detailed degree. The same criteria are employed in the detailed socioeconomic analysis as in the high level analysis. These are elaborated here below.

6.4.3. Choose Key Parameters

Selecting the relevant parameters to evaluate the socio economic analyses is essential for benchmarking and to reference the evaluation and results. Going through the economic analyses, as described above, the following essential, key parameters are listed, including points for relevance in the context of the CBA.

- Maintenance and operation requirements
 - Evaluation of the sufficiency of maintenance during operation, e.g. on frequency and approach, to ensure full capacity of the culverts as designed for.
 - Is the culvert sufficiently adequate to ensure the service criteria, both in the present day climate and in the future?
 - Failure of a culvert can lead to overflow, possibly rendering the road construction compromised in integrity. Potential consequences are pavement failure, higher degree of rutting, cracking, among more. All can lead to more needed maintenance, e.g. premature road work requirements compared to original planning and construction specifics for the road.
- Environment effects
 - As a cascading effect into the adjacent environment, failure of a culvert can lead to significant costs through spill effects from other water management assets into adjacent environments, possibly leading to costly repairs and/or clean-ups. Recipients and stakeholders in this regards is chiefly regarded as agricultural land and owners, streams connected to the respective failing culvert, both upstream and downstream and the maritime environment
- Societal impact
 - The AADT is a key driver for the evaluation of the consequence of culvert failure. AADT is greatly related to the socio economic impact since it reflects a large number of commuters and commercial freight transportations which will be affected of traffic flow disruption. AADT is furthermore assessed to increase significantly

- during the lifespan of culverts, e.g. causing more significant consequences of flooding as illustrated in figure 9
- Safety and culverts
 - A decrease in safety entails higher risks of accidents which are substantially costly for the society, both in medical costs and loss of work/earnings
 - To what degree an identified inadequate culvert will lead more flooding and thereby a decrease in safety, is very difficult to assess over the life span of a culvert. For the case study, it is assessed that an insufficient culvert will lead to five

6.4.4. Examine Available Data

Data is considered widely available to place the key parameters into the socio economic analyses as proposed in WATCH. The following lists the key parameters and their respective data availability.

- Data on construction
 - Available in-house from previous and ongoing projects in various forms and sizes
 - Available for all considered relevant input types of construction, and considered up-to-date
- Data on Maintenance and operations requirements
 - Available in-house and considered up-to-date and sufficiently detailed
 - Failure of a culvert leading to flooding in various forms can lead to undesired water contents in the road construction itself. The consequence can be long term and/or immediate impacts, e.g.
 - erosion of embankments or similar supporting constructions
 - cracking of the surface layer due to sinking
 - rapidly rutting forming due to a decrease in bearing capacity
 - among more

Long term, oftentimes imperceptible, impacts are regarded an accelerated deterioration of the construction, leading to additional required repair through the life time of the construction which, again, will lead into more traffic disruption on the road, causing significant socio economic consequences.

Data needed as input is highly specific for the given consequence of culvert failure. Relevant data is considered to be in-house and needed as an input to analyse the comprehensiveness, all depended of severity.

- Environment effects
 - Failing culverts can lead to overflow and spill into the adjacent environment of various types. The consequence can be a loss in agricultural revenue through pollution from untreated road water and contamination of streams, among others. The direct cost of a given culvert failure and needed data to analyse is related the specific culvert failure consequence and the properties of the specific adjacent environment.
- Societal impact
 - Determined by the cost of standstill from the respective number in AADT. AADT is ready in-house and considered up-to-date. The cost of standstill, in this case

caused by culvert failure, is specific for the given day and time of day. The exact price must be achieved through specific analyses, and is considered obtainable from either in-house staff or external partners.

- Safety and culverts
 - A decrease in safety entails higher risks of accidents which is substantially costly for the society, both in medical and loss of work costs.
 - Data on a higher risk of reduced safety are not considered directly available and must be obtained from external partners.

6.4.5. Is sufficient data available to assess the chosen parameters

As seen above, whether data can be considered sufficient or insufficient largely depend on the parameter, usage and given scenario to analyse. The list of key parameters is regarded as essential to sufficiently conduct the WATCH socio economic analyses. More parameters can be added to a potentially more holistic analysis; however, the list shown above is regarded as the essential list where additional parameter may act to contribute to undesirable complexity which may exceed potential benefits of inclusion.

Therefore, the data not directly available to perform the socioeconomic analyses as proposed in the WATCH guidelines, MCA, CBA, CEA and LCC, are considered vital to obtain elsewhere, e.g. through internal R&D projects or by acquiring consultancy assistance, instead of revising the list of key parameters, in order to reach sufficiently applicable results. Thus, a revision of the established context and evaluation approach is not considered as the favoured approach to conduct the WATCH socio economic analysis on account on directly available data.

6.4.6. Consider Climate Change

The same approach to considering climate change is employed as written in the high level Part A analyses as described in 5.4.6.

6.4.7. Perform Evaluation

The cost benefit analysis (CBA) is employed as a socioeconomic analysis to compare strategies on a detailed degree, as prescribed in the WATCH socioeconomic guidelines in *Tucker et al.* (2018). From, the MCA in the global part of the case study, it was determined that allocating additional resource to update inadequate culverts was assessed as the most beneficial strategy to pursue as and to go further into detail with.

The CBA will act to quantify in monetary terms, the specific costs and benefits of identified relevant economic parameters that affect the socioeconomic assessment.

The parameters chosen to conduct the CBA on allocating additional resource to update culverts, compared to an as is-strategy, are listed here below. These were identified as the key parameters to quantify in monetary terms and provide a comprehensive input for the CBA specific for allocating additional resource for updating inadequate culverts on M10

- Maintenance & Serviceability Issues
- Environmental effects
- Societal Impacts & Requirements
- Safety Constraints & Impacts

Construction cost

As a benchmark for the two selected strategies, *as is* and *enlarging capacity of culverts*, the construction cost associated with enlarging a culvert is set to €2,500,000 per culvert.

The price of enlarging a culvert is based on a price per area to construct and implement. On M10, updating a single culvert it is evaluated to hold a construction area of 400 square meters (80 meters across and five meters wide) to update at a set price of €5,400 per square meter, including all: materials, labour input, road and traffic regulation and cordon, giving a price of €2,160,000.

This, however, will be in accordance current road standards which will in this manner enable climate resilience for the present day climate and 25 years ahead, e.g. through the integration of a climate factor of 1.4. Since the expected and designed life span of a culvert is 50 years, this climate resilience is not considered adequate throughout the culvert life span. Therefore, taking climate change further into account for the entire culvert life span, adding an additional 15 % to the construction budget to a total of €2,500,000 (round off) is considered to enable full climate resilience for the full life span. Thus, the €2,500,000 is used as a benchmark construction cost for the CBA to compare socioeconomic benefits of strategy choice.

Yearly maintenance cost per culvert

The average culvert size dictates the price of maintenance. As data input, the average cost of culvert maintenance on M10 is employed as representable data and is set to €4,500 annually per culvert.

The strategy of enlarging culvert size to enable more climate resilience will therefore, enlarging the culvert size will require more resource to maintain the culvert, e.g. due to more hours needed and material use. The maintenance is hereby upped by €500 annually.

Maintenance & Serviceability Issues

Maintenance and serviceability issues involve monetizing all related costs associated in a given flooding scenario. The monetized parameters which sum up the figures in the CBA tables are as follows and specified in accordance with representable data from the DRD.

- Resource input for clearing up after the flooding
 - o Removing debris, e.g. clogging the culvert
 - o Removing mud, gravel, etc. from the road
 - o Road cordon during clear-up
- Resource for repair and inspection
 - o Road damage repair
 - o Road inspection for latent damage
 - o Culvert inspection repair

The reduction in costs associated with the strategy of enlarging the capacity of the culvert is specified as the implementation of this strategy will cause less consequences of flooding.

Environmental effects

Environmental effects involve monetizing all related costs associated in a given flooding scenario. The monetized parameters are as follows and specified in accordance with representable data from the DRD. The sum of these is illustrated in the CBA tables

- Resource needed for clearing up
 - o To avoid further contamination of polluted road water into the adjacent environment
 - o Labour and hours needed as input for subsequent monitoring of the adjacent flora and fauna and determine damage and clean up
- Costs for compensation
 - o Farmland compensation, e.g. loss of crops and/or livestock due to flooding
 - o Compensation for private residents affected by the flooding
- Cost of noise pollution
 - o Added noise pollution during clean up associated with hospitalization costs

Societal Impacts & Requirements

Societal impacts and requirements involve monetizing all related costs related in a given flooding scenario. The following states the monetized parameters in the CBA based on representable data from the DRD and the combined figures are seen in the CBA tables.

- Journey delay time
 - o Socioeconomic costs due to traffic stand still or diminished flow, both for commuting and commercial freight transport
- Cascading effects of undesired traffic loads onto adjoining roads
 - o Damage to roads not designed to handle M10 traffic loads
 - o Overuse of adjoining roads due to an incapability to handle the M10 traffic load

Safety Constraints & Impacts

Safety constraints and impacts involve monetizing all identified relevant costs associated to a given flooding scenario. The monetized parameters listed below and are specified in through representable data from the DRD. The sum of these is illustrated in the CBA tables.

- Increase in accidents
 - o Increase in accident rate caused by flooding/water on the road
 - o Cost of accident clear-up
 - o Cost for the society per accident, including hospitalization, rehabilitation, physiotherapy, crisis counseling, etc.

Based on the results as seen in the CBA tables 11 through 16 below, allocating additional resource to update culverts identified as inadequate is illustrated as a sound decision based on an economic perspective in the current situation.

As seen in table 16, the analysis shows a B/C ratio between 1.4 and 3.1 depending on climate scenario for a discount rate of 3 %. A further elaboration of the economic analysis should, however, analyse further into a changing traffic density over time, and to the timing of the service disruption on the day, as traffic flow would change depending on the time of day, thus influencing the actual amount of the benefits.

Best results would be obtained through an analysis of the net present value (NPV) of the replacement in which also additional hazard levels would be incorporated in a much more elaborate and specific analysis. Furthermore, this analysis should include sensitivity analyses for socio-economic developments and resulting traffic density and climate change scenarios.

All in all, the CBA has illuminated how the inclusion of socioeconomic analyses provide results directly applicable into decision making processes, ultimately for the benefit of more resilient roads.

As an example on a positive cascading effect as a result, this can lead to improved basis for identifying the optimum level of maintenance to ensure ideal resiliency, leading to less risk of additional construction needed to ensure safety and mobility on the roads. This will furthermore lead to less construction required during the road or asset life span due to a minimum degree of damage and thereby less traffic disruption, which is considered significantly costly for the society.

The cost benefit analysis (CBA) is conducted by comparing the identified most beneficial strategy as found in the global level socioeconomic analysis, the MCA, namely allocating additional resource for updating, to a benchmark strategy of an as scenario. Though such comparison, the CBA will illuminate in monetary terms how the two strategies compare and/or benefit through implementation.

Using the available data as described in the section above on available data, these data are translated into representable monetary figures as an input feature to the CBA.

The cost of the associated construction of updating the culvert is monetized by assessing the typical extent (area) of a culvert on M10 to a representable construction cost per square meter of such. As seen in table 11, this amounts to €2,500,000 with a designed life span of 50 years.

The cost of the associated maintenance and serviceability is monetized by employing representable maintenance and serviceability costs for the single culvert after a flooding occurrence, as typically found on M10 or similar roads. Factors included are clearing up, clearing excess water and repair on and besides the road of various sorts. This amounts to a total of €190,000 per flooding caused by culvert failure.

Environmental effects costs are monetized by employing representable data on flooding associated costs to the adjacent environment. Factors included are agricultural revenue losses and direct costs of damage and monitoring and clearing up streams and catchment area for untreated road water. This amounts to a total of €65,000 per flooding caused by culvert failure. In this context, it must be noted that, although considered representable, the monetized amount for the associated environmental effects is decidedly problematic to establish since many factors must be addressed and included for a specific occurrence. For the sake of the case study, and in particular the CBA, the number of included factors is kept low and simple to be able to reach a monetized amount within too much related imprecision.

Costs associated with societal impacts and requirements in relation to flooding on M10 are monetized by including factors of AADT and a representable socioeconomic cost of a traffic standstill per vehicle, including commuters and commercial freight. In the case study, a traffic standstill of 6 hours is used to illustrate a representable consequence of a flooding occurrence due to a failing culvert. As a result, the associated cost related to a single flooding occurrence resulting in a 6hour traffic standstill amounts to €1.500.000.

The parameter of safety constraints and impacts is included in the CBA by monetizing a representable factor of how a flooding occurrence will increase the rate of accidents and coupling a representable associated cost per accidents. This amounts to a total of €10,000 annually.

As seen in table 15, climate change is taken into account by conducting the CBA for the year 2030, by factoring in how the A1B climate change scenario will affect the return period of flooding occurrence.

To perform the CBA over time in accordance with the expected life time of the asset, a discount rate of 3 percent is included in the calculations as the interest rate.

The following five tables as shown below provide the results of the CBA in which comparing the socioeconomic aspects of the as is-strategy to allocating additional resource to update, in this case

enlarging a culvert, illuminate the benefits of strategy choice and act as an input for decision making. After the tables, concise result examinations are provided on how the specific output figures are interpreted.

1. Table of direct construction costs

Strategy	Construction cost			Yearly maintenance cost per culvert	Total average yearly cost
	Construction cost	Expected lifetime of asset	Average yearly construction cost		
As is / No action	€0	On avg. 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 11 – Table of direct construction costs

* A 3% discount rate is employed for calculating the average yearly construction cost

2. Table of quantitative impact

Measure	Maintenance & Serviceability Issues	Environmental effects	Societal Impacts & Requirements	Safety Constraints & Impacts	Total impact	Return period of threat	Annual average expected impact
As is / No action	€190,000 per flooding caused by culvert failure	€65,000 per flooding caused by culvert failure	€1.500.000 For a 6h standstill on M10 due to flooding caused by culvert failure	€10,000	1,765,000	0.1/year	€176,500
Enlarging capacity of culverts	€190,000 per flooding caused by culvert failure	€65,000 per flooding caused by culvert failure	€1,500,000 For a 6h standstill on M10 due to flooding caused by culvert failure	€10,000	1,765,000	0.02/year	€35,300

Table 12 – Table of quantitative impact

3. Table of quantitative impact for a climate in 2030

Measure	Maintenance & Serviceability Issues	Environmental effects	Societal Impacts & Requirements	Safety Constraints & Impacts	Total impact	Return period of threat	Annual average expected impact
As is / No action	€190,000 per flooding caused by culvert failure	€65,000 per flooding caused by culvert failure	€1.500.000 For a 6h standstill on M10 due to flooding caused by culvert failure	€10,000	1,765,000	0.2/year	€353,000
Enlarging capacity of culverts	€190,000 per flooding caused by culvert failure	€65,000 per flooding caused by culvert failure	€1,500,000 For a 6h standstill on M10 due to flooding caused by culvert failure	€10,000	1,765,000	0.03/year	€52,950

Table 13 - Table of quantitative impact for a climate in 2030

4. Table of quantitative cost benefit assessment for present day climate

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

Table 40 - Table of quantitative cost benefit assessment for present day climate

5. Table of quantitative cost benefit assessment for the 2030 climate

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

Table 15 - Table of quantitative cost benefit assessment for the 2030 climate

6. Table of net benefit and B/C ratio of investment

Measure	Net Annual benefit	B/C ratio	Annual net benefit	B/C- ratio
When	present day climate	present day climate	2030	2030
Enlarging capacity of culverts (Construction cost €2,500,000)	€ 43,536	141,200/97,664 = 1.45	€202,386	3.09

Table 16 - Table of net benefit and B/C ratio of investment

6.4.8. Examine and interpret outputs

As a measure and input for optimum decision making, the WATCH socio economic analyses are considered beneficial to integrate in order to gain more insight into the holistic and societal impact, alongside a greater overview on the actual cost of water management and climate change for an NRA.

NRA's are typically funded by state grants through appropriation where specific resources are earmarked for construction and maintenance and operation. Unexpected expenses, e.g. due to a lack of resiliency of culverts causing too frequent flooding, are considered as a dominant factor for an NRA to re-evaluate budgets and thereby potentially cutting resource elsewhere.

The WATCH approach on socio economic analyses is found to facilitate better decision making to act proactively, e.g. to mitigate such unexpected expenses, and thereby enable a more effective allocation of resources, ultimately rendering roads more resilient and thereby increasing the general safety and mobility. Therefore, including socio economic analyses as suggested in *Tucker et al.* (2018) can illuminate that more initial funding, e.g. from the state, to enhance road resiliency can lead to less required resource input throughout the road lifespan and thereby act as a measure to revise how an NRA will and should be funded.

6.5. Finalisation of applicable strategy (step 5, part B)

The WATCH approach to finalisation of an applicable strategy is described in full in the WATCH manual by Foucher et al. 2018.

As a strategic supplement to the existing climate change strategy, the outcome of the WATCH global and detailed risk analyses, including the socio economic analyses and climate change protocol, is considered to possess high value in multiple areas in the Danish Road Directorate. As written in the socio economic analysis on interpreting the results, the process models are considered as key work approaches to implement the WATCH outcome and various stages of construction or maintenance and operation in order to facilitate optimum basis for decision making.

6.5.1. Identifying the best strategy

Identifying the best strategy to enhance asset resiliency and basis for optimum decision making will chiefly take departure in the detailed risk analysis and socioeconomic analysis. In this case study, culverts were illustrated to be the water asset type of highest risk and it was concluded that allocating additional resource to update culverts was the most beneficial strategy. This was shown in particular illustrated through the socioeconomic analysis.

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*

More detailed description of the stakeholder impact and affect can be found in the socio economic analyses.

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.

6.5.2. Action planning

Through the CEDR 14 report, *Acting on Climate Change*, the Danish Road Directorate has adopted the following template as seen in table 17 for action planning in regards to road management and climate change adaptation.

Action plan

Bullets in the strategy	Description and goals	Who is responsible?	Priority	End user	Time perspective	Overlap and cooperation	Costs	Deliverables

Table 17 - Template for action planning (Axelsen et al. 2016)

The action plan is seen as a vital instrument when revising and adding new items and approaches to an already existing strategy. In terms of the case study the action plan template can be applied to the process models and existing strategy on climate change adaptation.

The template seen in table 17 is considered to illustrate where and when specific actions are needed to assess the associated implications, such as needed resource. The following points are derived from the *Acting on Climate Change* and are identified as the main steps to undergo when constructing an action plan.

- *Clarify and detail the goals in the strategy.*
- *Pinpoint who is responsible for the individual projects and make sure that they are a part of the overall planning process for the road authority. If possible, describe small individual projects in detail.*
- *Prioritise the most urgent goals in the strategy.*
- *Set the most realistic timeline possible.*
- *Coordination between projects in different areas of the organisation is a key aspect when producing an action plan. Make sure that valuable cooperation and networking is identified.*
- *Project costs can be very difficult to foresee; a lot of initial adaptation projects do not need special funding.*
- *Defining deliverables helps to balance expectations.*

6.5.3. Implement action plan

For success of constructing and implementing an accepted action plan, it is regarded as beneficial to assess the points listed above in an approach similar to the QuickScan methodology, meaning gathering relevant departments and staff across various disciplines for a comprehensive and holistic result.

Furthermore, on account of the experience attained in the WATCH case study, it is considered vital to undergo and arrange continuous, frequent workshops with a QuickScan approach to update and potentially add to the action plan in order to incorporate new information and results during operation of a given road or asset.

As an example on how the action plan can be implemented in an NRA, table 18 from the *Acting on Climate Change* is provided as an illustration.

Action plan



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 18 - Action plan including examples of usage (Axelsen et al. 2016)

6.5.4. Monitoring, review and capitalisation

As proposed in RIMAROCC (Bles et al. (3), 2010), after the optimum strategy is identified on top of the foregoing WATCH analyses and an action plan is applied in the NRA to implement the strategy there will be a continuous practice of conducting frequent monitoring of the risk management and of the chosen adaptation measures. This is carried out to ensure the strategy of risk management and action planning is continually reviewed, and thereby updated, to prevailing conditions in order to enable the projected outcome is kept at optimum level throughout the strategy life span.

As means of capitalisation, the results from monitoring and reviewing will be employed to continually update actions of the applied strategy. As suggested in RIMAROCC, initiating, building and implementing a database to log the results of the applied action plan to enhance the basis for an improved overview of the effect and experience.

7. Conclusions, lessons learned and recommendations

In the 2015 CEDR call, *From Desk to road*, more elaborate implementation of already existing research results on climate change adaptation was requested through projects facilitating and enabling such process.

The WATCH project has as main objective to produce a manual to act as a step-by-step protocol, including guidelines, to ultimately enable better basis for decision making for smarter allocation of resources. In the case study, the WATCH deliverables have been successfully implemented in an NRA context and tested on the M10 in Denmark.

The following listed points are concluding remarks and lessons learned as obtained through the case study.

- The resulting manual proved very valuable in the case study by introducing a step-by-step manual for NRAs where it acted to integrate all currently considered parameters for inclusive risk analyses and, furthermore, included new perspectives and factors for a more comprehensive approach; in particular by introducing more elaborate socio economic analyses, which were considered to ultimately lead to enhanced basis for better decision making.
- In the case study, the steps in the manual and socio economic analyses illuminated how data gathering for sufficient and satisfactory analyses input were not found to be equally straightforward to combine or locate. As a recommendation on top of the case study experience, it is suggested for NRAs to focus on establishing more streamlined and unified data logging and database storing for transparent easy access, which in turn will create a better overview and will facilitate additional and better use of available data. Specifically, this is found in the WATCH manual – part B sub-step 2.5.

As an example, the global risk analysis proved straightforward to conduct as fewer data inputs were considered as key parameters to conduct the screening. The detailed level risk analysis proved as considerably more data and labour intensive to reach a point where the basis for comprehensive analyses was sufficiently reached, still the outcome of the detailed analyses was considered correspondingly more prolific for further input on decision making.

- The Danish Road Directorate has recently conducted risk analyses on the case study road, the M10, since a major construction of lane-widening has taken place over the past years. As a result, much data were considered as updated for the use on a manual and protocol alike the WATCH deliverable. Still, the case study in ROADAPT illustrated on actual risk spot on M10 where a culvert, among other assets, were identified as a cause for recurring complications on water management, leaving a stretch of road in risk of flooding. These ROADAPT findings were not applied in the recent risk analyses, which may lead to an argumentation of whether sufficient data input was employed. As an example, this shows a need for NRAs to make more use of available research results, which the WATCH is specifically aimed for and will facilitate through the manual.

Furthermore, the processes inspired by the QuickScan approach from the ROADAPT project, on screening risks on M10, illuminated that data availability for optimum risk and socio economic analyses, including geographic positioning were highly dependent on

the invited departments and the single staff member, which shows a particular point of attention for the respective NRA to be aware of when conducting such analyses. As a recommendation, it is particularly valued to identify and include all relevant departments, staff members and other stakeholders in order to take in all aspects and appoint key parameters for the analyses. This will in turn result in the most comprehensive results which lead to optimum basis for an increase in resilient roads.

- The Danish Road Directorate is in an advantageous position to make use of the WATCH deliverables since a climate change adaptation strategy is in effect. The strategy consists of various specifications addressing different project stages or organisational levels to incorporate climate change to ensure safety and mobility on major Danish Roads. The WATCH deliverables are therefore considered relatively direct to implement in the Danish Road Directorate.

On account of the case study experience, it is recommended that NRAs that have yet to develop and implement a strategy on climate change with a supporting action plan to initiate the establishing of such strategy. Inspiration can be found in the WATCH deliverables where a step-by-step protocol can act to identify needed factors for comprehensive adaptation for climate change, e.g. data availability and sufficiency and the need for external input as a supplement for adequate analyses input.

Further inspiration can be found in the CEDR report, *Acting on Climate Change*, where a specific section is designated for initiating strategies on climate change adaptation for NRAs.

- Through the case study, the four different socio economic analyses of the WATCH deliverable, in particular the MCA and CBA, proved to be very useful to provide a greater economic overview on the consequences of inadequate water management in relation to both general, day-to-day road water management for an NRA and furthermore in relation to the consequences associated with climate change and future water management.

The conducted socio economic analyses, MCA and CBA, showed beneficial to apply in the case study to gain further and more elaborate economic insight. The analyses were found to be applicable in various stages of road management, e.g. in construction and maintenance, and in various departments of an NRA.

As a result of the economic analyses, more tangible results are seen as output since these can feed directly into decision making contexts. Therefore, it is argued in the case study that conducting the WATCH approach on socio economic analyses is a proactive mean for climate change adaptation by itself since it will enable optimum basis for decision making and thereby identifying the smartest allocation of the available resource, ultimately leading to more resilient roads.

As an example, most NRAs obtain funds as grants from the respective state. Results from socio economic analyses are considered to enable opening a window of opportunity to revise how and when grants are given and at what degree, since the results may conclude that additional resources given for adaptation in early stages are considered to save resource through the entire life span, e.g. for the entire road construction or single assets, seen from a socio economic viewpoint.

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- As a supplement to the WATCH approach of conducting socio economic analyses, the DeTECToR project, also a part of the 2015 call, *From Desk to Road*, a methodology for more elaborate economic is considered to further give insight to how NRAs are able to implement economic analyses result to enhance basis for optimum decision making for more resilient roads.

In short, the DeTECToR project will produce a cost benefit tool which is composed of two modules; the first module will be used to assess the climate risk and the second analysis the costs associated with different adaptation actions and will be available as a web-based tool for NRAs.

It is recommended for NRAs to find inspiration for more elaborate economic analyses in regards to road water management and climate change by consulting the outcomes of both WATCH and the DeTECToR project.

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