Conférence Européenne des Directeurs des Routes
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WATCH

CEDR TRANSNATIONAL ROAD RESEARCH PROGRAMME

Call 2015

WATer management for road authorities in the face of climate CHange

D5.1

Socio-Economic Analysis Guidelines v3:

July 2018

CEDR Call2015: From desk to road

WATCH

WATer management for road authorities in the face of climate CHange

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Socio-Economic Analysis Guidelines v3

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EXECUTIVE SUMMARY

This report provides a detailed description of the Socio-Economic Analysis Framework developed in the WATCH project. It is intended that the framework can be used by Primary Stakeholders to assist in the decision making process in respect of the design, maintenance and upgrade/adaptation measures of drainage systems as part of effective water management procedures in the face of climate change.

The framework is presented in two phases in a step by step manner and consists of eight steps in total. Each step is described with respect to the Objective of the step, the Methodology proposed to undertake the step and the expected Output from the step. A typical user of the Framework is described along with brief example scenarios of how the framework is applied. Equally two levels of analysis are described, in line with the overall risk assessment approach adopted in the WATCH project, namely a High Level (Part A) Analysis or Detailed (Part B) analysis.

In the initial Preliminary Assessment phase, five steps are described, namely, establishing the Context, Determining the Evaluation Approach, Choosing the Key Parameters, Examining the available data and Assessing whether the available data is sufficient to assess the key parameters. It is noted that these five steps are intrinsically linked and an iterative process may be required as the inputs to a particular step are dependent on the output of the preceding step.

In establishing the context, the objectives of the analysis are decided which should align with the external, internal and risk management contexts of the organisation undertaking the analysis. Having completed this step, the evaluation approach must be decided. Four possible methods are described, in order of increasing data needs; Multi Criteria Analysis (MCA), Life Cycle Costing (LCC), Cost Effective Analysis (CEA) and Cost Benefit Analysis (CBA). The choice of method is largely dependent on the objectives of the analysis, the level of detail required (i.e. High Level or detailed analysis) and the type and suitability of the data available i.e. quantitative (CBA), qualitative (MCA), semi-quantitative (LCC, CEA) to carry out the Socio-Economic Analysis.

The remaining three steps in this phase are concerned with selecting the key parameters, determining the availability of the required data to define the key parameters adequately and an assessment of whether or not this data is suitable for undertaking the analysis. Having established that all the appropriate information is available to carry out a meaningful Socio-Economic Analysis, the Evaluation Phase of the framework considers the effects of Climate Change, Performing the Evaluation and Examining and interpreting the outputs. Ultimately, the outputs from the final step should form the basis of the decision making process.

Lastly, best practice recommendations on how to conduct the analysis and implement the framework are provided through reference to the case study presented in WATCH Deliverable D6.1 (Axelsen, D. 2018).

1 INTRODUCTION

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 Scope of Deliverable D5.1

As described in WATCH *Deliverable D1.1, Country Comparison Report* (Bles *et. al*, 2017) various drainage systems are available to road owners depending on the asset under consideration and the source of flooding, such as, for example, storm water run-off systems, attenuation ponds, wetlands and SuDS. Equally, the report describes the current protocols implemented in the referenced countries for taking into account the effect of Climate Change on the design and maintenance of drainage systems.

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

In order to be of benefit to an NRA's decision making process, the Socio-Economic Analysis approach adopted must consider a variety of stakeholder interests (i.e. technical, environmental, social, and financial) in order to determine the most appropriate sustainable drainage system to employ.

This report provides a detailed description of the framework for the Socio-Economic Analysis approach being developed within the WATCH project. Each step in the process provides guidance on the key questions that stakeholders should address before embarking on an analysis in order to identify the potential costs and benefits, economic and otherwise, incurred for a proposed solution.

Application of the framework is presented with reference to the Case Study report of WP6 (Axelsen, D. 2018). The recommendations demonstrate the rationale for providing more resilient and durable road infrastructure for different groups within the NRAs (asset owners, asset managers and service providers).

Furthermore, the Socio-Economic Analysis presented is considered a prerequisite for implementation of the WATCH projects results. As such, the approach adopted is closely linked to WATCH Deliverable D4.1, Manual (Foucher *et.al.* 2018) as described in Section 3.

2 SOCIO-ECONOMIC ANALYSIS

2.1 Introduction

It is generally accepted that significant capital investment is often required by Stakeholders to implement climate change adaptation measures on their road infrastructure assets. Consequently, effective decision making is of paramount importance in the management of the European road networks. There are numerous tools available to assist in the decision making process, one of which is a Socio-Economic Analysis.

A Socio-Economic Analysis is a study that analyses the advantages and disadvantages of the relationships between various strategies and the stakeholders, including society, who would be impacted by those strategies. In the context of WATCH, these strategies consider the most appropriate design, maintenance and upgrading/adaptation options for water management on roads with due consideration of climate change.

2.2 Background

In order to develop a scope for the Socio-Economic Analysis guidelines, a review of relevant literature and international best practice was carried out at the beginning of the process, considering their relevance to climate change adaptation for water management in the road sector. Furthermore, the criteria which were highlighted by analysis methods in the literature were considered with the aim of developing recommendations from a user's perspective, considering the pros and cons of existing guidelines and addressing the shortcomings with these current guidelines. It is intended that the methods identified can be used to frame the approach and criteria that will be used in the Socio-Economic Analysis methodology being developed in WATCH. =

Following a review of the relevant literature, Table 1 below summarises the literature that the authors considered most relevant to the WATCH project.

Source	Document (s)	Organisation
ROADAPT (Roads for today, adapted for tomorrow)	(a) Guideline – Part B, Performing a Quick Scan on risk due to climate change (2015) (b) Guideline - Part D, Socio-economic impacts analysis (2015) (c) Guideline - Part E, Selection of adaptation measures and strategies for mitigation (2015)	CEDR Call 2012: Road owners adapting to climate change
RIMAROCC (Risk Management for Roads in a Changing Climate)	A Guidebook to the RIMAROCC Method (2010)	ERA-NET Road 2008, Road Owners Getting to Grips with Climate Change
Integrated Urban Drainage Pilot Studies	Surface Water Management Plan Technical Guidance (2010)	Department for Environment, Food and Rural Affairs (DEFRA)
Transport Analysis Guidance (TAG)	(a) Unit A1.1 – Cost-Benefit Analysis (November 2014) (b) Unit A3 – Environmental Impact Appraisal (December 2015)	UK Department of Transport
HARMONY (Procedures for the Design of Roads in Harmony with wildlife)	Deliverable D - Recommendations on Appraisal Process and Report on Consultations (2015)	CEDR Call 2013: Roads and Wildlife – Cost efficient Road Management
HEATCO (Developing Harmonised European Approaches for Transport Costing and Project Assessment)	Deliverable 5 – Proposal for Harmonised Guidelines (2006)	FP6 Scientific Support to Policies' (SSP) 2002: The development of tools, indicators and operational parameters for assessing sustainable transport and energy systems performance (economic, environmental and social)
Project Appraisal Guidelines (PAGs) for National Roads	(a) Unit 1.0 – Introduction (2016) (b) Unit 6.0 – Cost Benefit Analysis Overview (2016) (c) Unit 6.1 – Guidance on conducting CBA (2016) (d) Unit 7.0 – Multi Criteria Analysis (2016) (d) Unit 7.1 – Project Appraisal Balance Sheet (2016)	Transport Infrastructure Ireland (TII)
DeTECToR	Cost-Benefit Analysis Tool Functional specification (2017, Work in Progress)	CEDR Call 2015: Climate Change – From Desk to Road

Table 1: Relevant Literature

2.3 The WATCH Socio-Economic Analysis Framework

2.3.1 Introduction

Any analysis must have a starting point and an overall objective. In this regard, an analysis framework is required to illustrate the process in a step by step manner. The Socio-Economic Analysis framework developed in WATCH, which is split into two phases, a Preliminary Assessment phase and Evaluation phase respectively, is shown in Figure 1.

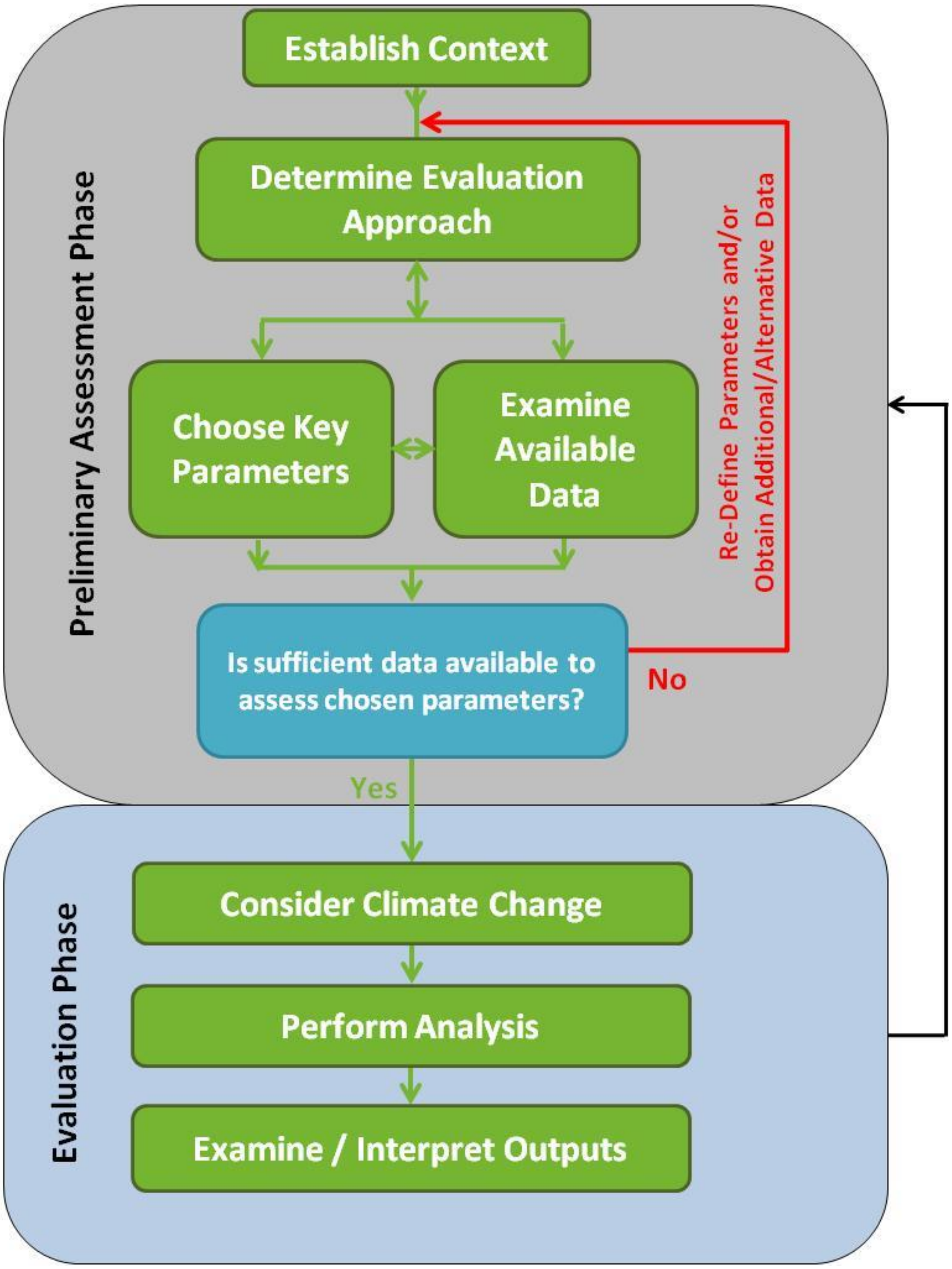

Figure 1: WATCH Socio-Economic Analysis Framework

2.3.2 Stakeholders

Typically, stakeholders can be divided into two groups, namely, primary and secondary stakeholders. Primary stakeholders are those persons/organisations who are directly involved in the decision making process, in this case, with respect to the design, maintenance and upgrading/adaptation of drainage systems for roads in the face of climate change. Secondary stakeholders, on the other hand, are those persons/organisations who, while not involved in the decision making process, can influence or be influenced by the process. Typical stakeholders, characterised by their type, are shown in Table 2. It should be noted that some persons/organisations can be classified as primary or secondary depending on their role in the project (i.e. depending on contractual arrangements, procurement routes etc.).

Stakeholder	Type
Levels within an NRA including; • Network Manager; • Regional Major • Major Projects Department • Asset Manager	Primary
Local Authority / Municipality	Primary/Secondary
Maintenance Contractor	Primary/Secondary
PPP Concessionaire	Primary/Secondary
Consultancy working on behalf of the aforementioned parties	Primary/Secondary
Society	Secondary

Table 2: Stakeholders

2.3.3 Application

It is intended that the framework can be applied by any primary stakeholder for different scenarios when considering the design, maintenance and upgrading/adaptation of drainage systems with due consideration of climate change. Some examples of typical scenarios in which it is envisaged that the proposed framework can be applied are shown in Table 3;

Scheme	Scenario
New Design	**1**. To identify the most appropriate solution of a drainage design, from a cost benefit view point, on a major road, in order to maximise the capacity of the system which is at greater risk from the threat of flooding events with a higher return period. For example, consider the options of a grass channel/swale versus a piped drainage system. In terms of cost, the grass channel/swale will be cheaper to construct, however this approach may require additional land-take, and the road authority may not be familiar with the maintenance requirements, both of which could be important when considering expenditure over the life cycle of the system. However, it offers greater flexibility to respond to future climatic conditions and provides benefits for water quality and attenuation during extreme rainfall events.
	2. To asses various drainage designs, from a cost and benefit point of view, within an environmentally sensitive section of a new motorway where the accepted level of risk of the failure of the drainage system is low. For example consider the options of a SuDS approach versus a 'Sealed Drainage system'. The SuDS approach, though less expensive, may require additional land-take, but provides benefits in terms of water quality, biodiversity and attenuation. However, the particular SuDS system will have to be carefully considered to respond to local climatic conditions and local water quality pressures to ensure the appropriate level of treatment is provided prior to discharge to ground and/or receiving water bodies. On the other hand, the 'sealed drainage system', (which could for example comprise sealed drainage pipes and 'lined' channels and ponds) will protect the groundwater from contamination. However, this approach does not offer treatment of surface water discharges through a staged 'management train' of SuDS components, rather, "end-of-pipe" solutions at outfalls to receiving watercourses (e.g. petrol interceptors & ponds) which require regular maintenance and the use heavy plant/machinery. In this case, though more expensive, the latter solution could better as the threat of contamination of the groundwater is potentially lower.
Maintenance	**1**. To facilitate the decision making process for spending maintenance budget based on a low level of risk acceptance and benefits of alternative systems. In this case much will depend on the capacity of the road operator to respond to the particular requirements of the drainage system adopted. So for example, the SuDS approach may require specialist routine and seasonal maintenance practices – grass cutting & pruning, as well as the removal of contaminated soil/subsoil in basins and ponds (possibly annually depending on AADT and local environmental pressures). On the other hand, 'Traditional' drainage systems will require the removal of silt from gullies/catchpits, which require heavy plant and machinery but nonetheless represent the 'status-quo.' Traditional drainage systems are less sensitive to future climatic changes (e.g. plant-die off during periods of drought or changes in temperature).

Scheme	Scenario
Upgrade/Adaptation	**1**. To quickly identify the optimal cost solution (e.g. cheapest or quickest) solution to alleviate a flood that has occurred on a road section. In this scenario, additional land–take may not be feasible as the consultation/compulsory acquisition process may be lengthy and prohibitive. Interventions would therefore be largely restricted to the existing road reservation. The options could therefore be - upsizing existing pipes versus constructing grass channels over existing filter drains in the verge in order to provide additional conveyance & flood attenuation. However, this would mean a “doubling-up” of maintenance philosophies - grass cutting/pruning & removal of silt from catchpits and hence increased costs over the life cycle of the system
	2. To select the optimal solution to alleviate flooding on an existing road section identified as problematic with respect to flooding, whereby, notwithstanding the costs, minimising the risk of flooding is of critical importance. This will require short-term and longer term considerations such as; ecological enhancements, improvement in the quality of receiving water bodies, biodiversity, adaptability to future changes in climate and local amenity value.
	3. Upgrading an existing drainage scheme on a road widening project. As 2. above, but land-take requirements and local environmental pressures will be the key considerations
	4. Upgrade of drainage / implementation of SuDS to improve quality of surface run-off into nearby watercourses. As 3 above.
	5. Upgrade of drainage within environmentally sensitive section of motorway. As 2 in ‘New Design’ with land-take being a key consideration.
	6. Upgrade of drainage to reduce ongoing maintenance costs where regular flood response is required**.** As 3 above

Table 3: Typical Scenarios

2.3.4 Step by Step Overview of Framework

The following sections describe the process of carrying out each step within the two phases of the framework. Each step is described using a similar format to the ROADAPT quickscan approach (ROADAPT Consortium 2015) which describes each step using the following sub-headings; Objective, Methodology to be used and Output. Evaluation methods have been selected on the basis of work done in the ROADAPT Guideline Part D (ROADAPT Consortium 2015) and practical guides for economic evaluations (Pearce *et. al* 2006, Atkinson, G. & Mourato, S. 2015).

2.3.4.1 Preliminary Assessment Phase

This phase of the analysis is concerned with setting the objectives, deciding on the most suitable evaluation approach and collating and assessing the information required to carry out the analysis. The steps in this phase are intrinsically linked and a number of iterations through the process may be required to reach a consensus on whether it is worthwhile proceeding to the Evaluation Phase.

(a) Establishing the Context

Objective:
The objective of establishing the context of the required Socio-Economic Analysis is to identify and consider the aspects that are relevant to the stakeholder implementing the analysis. Equally, consideration should be given to the scope of the project (e.g. a new design, operation and maintenance or a major rehabilitation) and the budget available. This will provide important insight into the most suitable evaluation approach (and with this, the data requirements) to be adopted and set the scope for the remainder of the evaluation analysis.

Methodology:
The context developed should align with the stakeholders overall mission statement, considering the external and internal context of the organisation, and the context of the risk management process. The context of the evaluation is likely to influence a number of the subsequent steps. For example, the key parameters to be considered are likely to be different depending on the organisation carrying out the evaluation, or the context/objectives of the organisation. In addition, the output requirements of the evaluation, along with the overall objective will likely be different depending on whether it is being applied as part of the design of a new road or to assess upgrade options on an existing road.

This step requires a stakeholder analysis involving the key decision makers within the relevant organisation, answering some of the pertinent questions relating to the scheme (design, maintenance or upgrade/adaptation) under consideration. The methodology proposed in establishing the external and internal context and the context of the risk management process risk is as per ISO 31000, Risk management – Principles and guidelines (2009).

The external context considers all of the external environmental parameters and factors that influence how an organisation manages risk and tries to achieve its objectives. The internal context considers all of the internal environmental parameters and factors that influence how it manages risk and tries to achieve its objectives while the risk management refers to a coordinated set of activities and methods that is used to direct an organization and to control the many risks that can affect its ability to achieve objectives.

Output:
The output should consist of a description of the external and the internal context and the context of the risk management process for the proposed solutions.

In relation to the external context the output should include external stakeholders, its local, national, and international environment, as well as key drivers and trends that influence its objectives. It includes stakeholder values, perceptions, and relationships, as well as its social, cultural, political, legal, regulatory, financial, technological, economic, natural, and competitive environment.

In relation to the internal context the output should include its internal stakeholders, its approach to governance, its contractual relationships, and its capabilities, culture, and standards. Governance includes the organization’s structure, policies, objectives, roles, accountabilities, and decision making process, and capabilities include its knowledge and human, technological, capital, and systemic resources.

The risk management process should not only identify key risks but also define the procedures and protocols to be adopted to manage risk, including risk management principles, a risk management framework, and a risk management process.

At the end of this step, a non-exhaustive list of issues which should have been considered includes:

- What is the purpose of the evaluation?
- What are the external and internal contexts and priorities of the organisation and how do these influence the decision making process?
- The preferred level of analysis i.e. a High Level or detailed analysis?
- What is the project planning stage (e.g. initial scheme, planning, draft design, detailed design)?
- Whether the evaluation is to be used to assess options for a new scheme or an existing road?
- What are the key parameters (section 2.3.4.1 (c)) that need to be considered depending on the level of analysis envisaged?
- What return period is being considered for the design life of drainage options considered or for the assessment of an existing drainage system?
- What are the outputs of the Socio-Economic Analysis to be used for and how will they be interpreted?
- What are the primary risks (i.e exposure) envisaged and the risk management protocols of the organisation undertaking the evaluation?
- What are the impacts (environmental, financial etc.) of the project?

(b) Determine Evaluation Approach

Objective:
The objective of this step is to decide on an appropriate evaluation approach to measure the impact or effect, including economic consequences, associated with each solution. There are a number of evaluation approaches which can be adopted depending on requirements derived from the previous step and the available data, and this step aims to allow the user to identify which approach is most suitable for their specific application. The evaluation approach adopted could be fully quantitative, fully qualitative or a mix of quantitative and qualitative evaluation depending on a number of factors including the output requirements of the analysis and the parameters considered in the analysis. It is important to note however, once *the preferred approach, in terms of the context/objectives of the evaluation, has been considered, the level/quality of data available will often determine whether it is feasible to adopt such an approach for any given parameter to be assessed.*

Methodology:
The evaluation can be carried out on scale ranging from a quantitative analysis, using numeric values, to a dimensionless qualitative score (a ranking procedure or dimensionless scale at the most simplistic level of analysis). Certain parameters are more amenable to quantitative assessment than others, for example the cost of the design and construction of a typical drainage solution can generally be estimated based on preliminary dimensions/quantities and an estimate of the associated financial costs. Other aspects may be less well defined and it may be more appropriate to use a form of qualitative scale to assess the impacts. Nonetheless, the input (and consequently the output) will depend on the evaluation approach adopted and the availability of relevant data.

There are a range of methods that can be used in undertaking a Socio-Economic Analysis as described below, in order of increasing data needs.

1. Multi Criteria Analysis (MCA)

MCA can be used to broaden the scope of an analysis, and is typically used for creating consensus building among stakeholders to create a common understanding between various disciplines and can be used when little or no quantitative information is available (though an MCA can include calculated or quantitative data) As such, scores achieved for performance and costs of (all) measures or strategies do not necessarily need to be conveyed in quantitative monetary terms, but can simply be expressed in physical units or in qualitative terms.

MCA enables solutions to be assessed against more than one objective and is particularly useful in offering stakeholders a quick and cost effective way of short listing solutions and comparing them against strategic objectives in a structured way. As such, it can provide a useful framework to evaluate different solutions with several criteria, including situations in which stakeholders have different interests. Typical information required to carry out an MCA includes;

- The options, alternatives, scenarios, policy measures or strategies that have to be compared to each other;
- The evaluation criteria (e.g. safety, operation, policy, environment, social factors etc.) that will be used to assess these options (i.e. the parameters chosen as part of the 'Choose Key Parameters' step);
- The importance of these criteria (i.e. the weights);
- The scoring of the options on the different criteria. These evaluations can be given a numerical or ordinal (comparative) scale.

A drawback of the method is that the weighting and scoring of the criteria is a subjective process and requires a multidisciplinary team to reach a general consensus. This can be difficult to achieve, particularly if a large number of parameters or criteria are being assessed and/or stakeholder interests are diverse.

An MCA can be used as an alternative or complementarily to appraisal techniques which primarily use monetary valuations (e.g. items 3 and 4 below) when there are different impacts to be considered where certain important parameters are not monetiseable, such as certain social or environmental preferences impacts.

Example Scenario:

Consider the case of the upgrade of the existing drainage on a road widening scheme with the overall aim of reducing the frequency of flood events. It is assumed that a high-level assessment (i.e. Part A, High Level Analysis) of the drainage infrastructure along the route is initially required in order to identify the most suitable adaptation approaches. The assessment is to be carried out based on four key parameters (See Section 3.2); installation/maintenance costs, environmental impacts, societal impacts and safety. Furthermore it has been decided that one of the key objectives of the analysis is to assess the economic costs associated with loss of functionality of the road. This is typically undertaken using a traffic model, the outputs of which can be used to calculate the economic costs associated with delays and road closure. While estimates of maintenance/installation costs (i.e. direct costs) may be available, it is assumed that, at this stage, the costs associated with the other three parameters are not available (i.e. qualitative data available only). In this case a Semi-quantitative MCA approach would be suitable, allowing all key parameters to be incorporated at a high level to allow the most appropriate adaptation strategies to be identified. The MCA also allows stakeholders to apply different weights on particular aspects which they deem most important, outlining differences in appreciation of varying alternative strategies between distinct stakeholder groups.

2. Life Cycle Costing (LCC)

LCC considers the total cost of ownership of an asset(s) that will be incurred during its lifetime and includes acquisition costs, operation costs, maintenance costs and disposal costs. As such, an LCC enables stakeholders to identify least cost alternative solutions discounted over time. It is important to note that it is an evaluation on costs only with performance of different measures or strategies considered more or less equal (as these are not taken into consideration). Quantitative Data is required on costs and if the goal is only an evaluation of the costs, an LLC would be sufficient. Performance is typically presented qualitatively. If the performance of the various options being compared is not more or less equal then a LCC is not suitable.

Example Scenario:

In this case consider the example of the quickest way to identify the least expensive solution to alleviate a flood that has occurred on a road section. The objective of the analysis is to select a drainage system, at the lowest cost, assuming that the benefits associated with all other parameters are considered equal (or not of primary concern). The underlying assumption here is that each drainage option is equal in terms of performance i.e. each design will sufficiently remove the water from the road, so the cheapest/quickest solution to install will be the most suitable. In this case an LCC is the most appropriate approach as it allows the key parameters (installation costs & time) to be considered, without requiring detailed assessments to be made of the benefits and performance of each solution.

3. Cost Effectiveness Analysis (CEA)

A CEA is an analysis that compares the relative costs and effects of different solutions and is used to identify the most cost effective option for achieving a set of predefined objectives. It presents alternatives in order to identify the option to achieve the most effective result at least cost. It considers the cost and (combined) performance of measures towards a specific policy objective (goal). The aim of the analysis is to select the solution that for a given output level, minimises the present value of the costs or alternatively for a given cost, maximises the output level. This type of analysis is particularly useful when considering solutions whose benefits are presently unknown and are very difficult to monetise and can be used if the project target is a set standard and it is desirable to keep the normal costs as low as possible. Data on costs of measures is required quantitatively in monetary terms and at least semi-quantitative effects of measures on policy objective are required. It is suitable for selection of measures (or strategies) for which data on costs and performance are available, but no (monetised) benefits. Typically, the CEA is expressed in terms of a ratio where the denominator is a gain in some measure and the numerator is the cost associated with this measure and will output a cost per measure. So, for example if there are a number of drainage solutions available with the objective of ensuring a road remains operational to normal levels during a flood, then the analysis would return the cost per hours of normal operation.

It is particularly useful in two cases as follows;

- In determining the maximum effectiveness of a solution, given a fixed budget and a number of alternative solutions;
- In determining the minimum cost given a target level of effectiveness.

Typical information required to carry out a CEA includes;

- Primary objective of the intervention (i.e. design, maintenance, upgrade/adaptation) under consideration;
- An indicator that measures this objective;
- Comparable estimates of costs of each intervention under consideration.

A limitation of this method is that it focuses on the primary objective and as such secondary or tertiary objectives may be ignored thus making the use of a cost-effectiveness analysis counterproductive in case the secondary/tertiary effects are significantly large.

Example Scenario:

In this case consider the example of identifying the optimal solution to minimise the risk of precipitation on the road in a new tunnel. It is assumed that the primary objective is to remove the water on the road and ensure the maximum level of tunnel availability, where tunnel availability is considered as the amount of time where surface water levels are below the required threshold. Costs are available for the various drainage options however the benefits associated with other parameters cannot be easily measured / monetised and are not considered to be of major importance for the scheme. In other words the costs represent a quantitative measure while the other parameters such as the environmental effects, societal effects etc. are, in many cases, only likely to be assessed in a qualitative manner. In this case a CEA is the most suitable method as it allows the cost of each proposed design option, and the associated time of tunnel availability per year to be compared on a relative scale as a ratio of cost per hour of availability provided by each solution.

<u>4. Cost Benefit Analysis (CBA)</u>

The purpose of a CBA is to quantify in monetary terms, the costs and benefits of all considered solutions. CBA involves converting all benefits and costs into monetary terms, including environmental, social and other impacts and subsequently comparing them discounted over time.

Typical information required to carry out a CBA includes;

- A monetary value of each benefit/cost (i.e. value of time, air quality, damage from collisions, etc.);
- The monetary value of all discounted costs and cost profile over the lifetime of the asset including; capital costs (i.e. construction costs, capital maintenance and renewals) and current costs (i.e. maintenance and operation) and include possible negative social and environmental effects;
- The monetary value of discounted benefits (including residual values) and the benefit profile over the lifetime of the programme, including positive social and environmental effects

A cost-benefit analysis method is the most detailed approach that can be adopted however the availability of sufficient quantifiable data is considered a prerequisite. While it is reasoned that a cost benefit analysis can only be used if all significant effects can be quantified / monetized, it can be argued that some of the smaller effects can be included in the cost benefit as a positive or negative cost effect.

Example Scenario:

Consider again the case of the upgrade of the existing drainage on a road widening scheme with the overall aim of reducing the frequency of flood events. As before, it has been decided that the objective of the analysis is to assess the economic costs associated with loss of functionality of the road. It is assumed that a high-level assessment (i.e. Part A High Level Analysis) of the drainage infrastructure along the route has already been undertaken and a number of design options are identified considering installation/maintenance costs, environmental impacts, societal impacts and safety. At this stage, it is decided to include a number of additional parameters and to attain detailed historical information which will allow all costs and benefits to be monetised for all of the parameters considered for each upgrade option available. In this case a CBA would be a suitable approach as it will provide a specific, monetary value for all design options, allowing the most appropriate solution to be identified, i.e. the alternative with the highest Net Present Value.

Output:
The output of this step consists of an agreed evaluation method. The methods described above can be used in different stages of planning and require different types and accuracy of input data, however the chosen method largely depends on the purpose of the evaluation and, in particular, the available data.

It is worth noting that many NRA's currently have protocols in place which require the need to use one of the methodologies described above when assessing the viability of a project. For example, in Ireland, any capital expenditure project > €20 million requires a CBA to be carried out, while any minor project between €5million and €20 million requires an MCA. However there does not appear to be a consistent approach across all European NRA's to define which methodology is most suitable for a particular project appraisal.

(c) Choose Key Parameters

Objective:
The purpose of this step is to select the relevant parameters which should be considered as part of the evaluation.

Methodology:
The basis of any Socio-Economic Analysis lies in the definition of the reference situation, which should be used to benchmark the findings of the evaluation through the establishment of measurable differences between parameters for different alternatives. It is likely that the parameters chosen to form the basis of the evaluation will be strongly influenced by the definition of the reference situation, which is typically represented by the 'as-is' existing scenario.

Through brainstorming sessions or a desk study, the parameters chosen should be relevant to the context, and should be chosen based on the objectives of the Socio-Economic Analysis as defined when establishing the context. Equally, the number and type of parameters chosen will likely have an influence on the complexity of the evaluation which in turn should be consistent with the evaluation approach selected. If, for example an MCA approach is adopted, then qualitative parameters would suffice.

Output:
The output of this step should be a list of all parameters which are to be considered within the Socio-Economic Analysis, with a description of how each parameter should be measured/evaluated and possibly monetised. The parameters chosen should be consistent with context established at the outset and the evaluation approach adopted and can be a numerous as required to address the scope of the evaluation. As part of the WATCH project a Stakeholder workshop took place in early 2017. Based on the findings of the workshop, the following parameters were found to be of most relevance to the NRA‘s in attendance.

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

11) Procurement.

It is important to note that this list is not exhaustive, and these parameters may not necessarily be relevant for every project or NRA. The selection of the parameters will largely depend on the objectives of the evaluation and the context of the organisation carrying out the assessment. As such careful selection of the most appropriate parameters is paramount for a meaningful output from the SEA evaluation. For example, if for a new design 'Land availability and acquisition issues' are neglected, the SEA evaluation might favour a solution which is not actually feasible, or which underestimate the costs if Compulsory Purchase Orders are ultimately required.

(d) Examine Available Data

Objective:
The purpose of this step is to collect the relevant data for the key parameters and assess its relevance (i.e. qualitative/quantitative) to the chosen evaluation approach.

Methodology:
Using a desk study, all relevant/available data should be collated and the quality and suitability of the data should be assessed, considering a number of factors, including, but not limited to:

- The origin of the data and its relevance/appropriateness for use;
- The level of detail, quality and accuracy of the data;
- The time-scale over which the data is available;

Output:
The output should consist of a description of the extent of data available for each parameter. This step is intrinsically linked with identifying the key parameters and the evaluation approach adopted as lack of suitable data could enforce the selection of parameters or the evaluation approach adopted. In essence sufficient/appropriate data should be available to assess each parameter as desired. Consequently, the output of this step might result in reconsideration of the evaluation approach and key parameters.

In Appendix A of this report, typical data sources are presented for the various measures that can be used to assess the Key Parameters. This list is non-exhaustive and merely provides an indication of the type of data that could/should be considered.

(e) Is sufficient data available to assess the chosen parameters

Objective:
Having examined the data available and determined the approach to be adopted to assess the costs/benefits associated with each parameter, the objective of this intermediate step involves considering if the available data allows a meaningful Socio-Economic Analysis to be carried out based on the parameters being evaluated.

Methodology:
Using a desk study approach, the data should be assessed for suitability for the chosen parameters.

Output:
The output of this step will consist of an itemised list of all the available data and an assessment of whether it is suitable or not for the evaluation. For example, the purpose of the evaluation may be solely to compare the costs of different drainage solutions with the goal of identifying the cheapest to install. If there is not enough information on construction costs then the previous step may have determined that only a qualitative approach could feasibly be used. Based on the objectives of the evaluation, it may be considered that a

qualitative output would not be useful, and hence progressing to the evaluation stage may not be considered worthwhile. In this case it would be useful to go back and decide whether the parameters being assessed should be amended, or whether additional/alternative data could be sourced which would facilitate a more appropriate quantitative approach. Such data may be available for another road with similar characteristics.

If, after reconsidering the chosen parameters and the available data, a meaningful output from the analysis is unlikely, it may not be considered worthwhile to proceed with the assessment. On the other hand, if the available data is deemed to facilitate a suitable Socio-Economic Analysis in relation to the overall context/objectives then the evaluation should be progressed to the Evaluation Phase.

2.3.4.2 Evaluation Phase

In this phase, the effects of Climate Change are introduced in advance of performing the analysis and evaluating the output. At any step in this phase it may be required to review the decisions/assumptions made in the Preliminary Assessment phase, particularly if the output is not consistent with the initial objectives of the analysis.

(f) Consider Climate Change

Objective:
The purpose of this step is to incorporate the relevant climate change scenarios, which are being developed in WP2 of the WATCH project and assess how they can influence the Socio-Economic Analysis.

Methodology:
In its most basic form, climate change is typically considered through the adoption of climate change factors from design standards relevant to the region. Such factors typically indicate that a percentage change (e.g. 10% or 25% increase) should be applied to the design values used to size various drainage elements to account for the effects of climate change. However, many of the suggested climate change factors presented in design standards could be considered to be somewhat arbitrary and may not necessarily be appropriate to represent the actual effects of climate change. At a more advanced level, the use of region-specific climate data should be considered, determined, for example, using the methods as described in Bessembinder *et. al.* (2018), to more accurately identify the values that should be adopted to account for climate change for the chosen return period(s).

However, given the large number of uncertainties associated with Climate change, consideration should be given to multiple future scenarios which will need to be incorporated into the evaluation. In addition to future scenarios, equally important is the ‘as-is’ scenario i.e. how the current effects of climate change are incorporated into the design, maintenance and adaptation of drainage systems.

Output:
The output of this step is a description of the hazard intensity, such as flood level, for the multiple climate change scenarios that are deemed important to include in the evaluation. These can then be used to assess the implications for different options, including the ‘as is’ scenario.

(g) Perform Evaluation

Objective:
This objective of this step is to perform the evaluation analysis in order to determine the advantages and disadvantages (e.g. cost, benefits) associated with for each parameter within a particular solution.

Methodology:
Using one of the approaches in Section 2.3.4.1 (b), the evaluation is performed for all criteria and proposed solutions. The relevant data for each adaptation strategy being considered within the evaluation should be utilised to evaluate the associated costs and benefits, either on a qualitative scale or a quantitative measure. The adaptation strategies under consideration will vary from scenario to scenario, and depend on a number of factors, including the availability in the given area, whether the evaluation is being carried out for a new or for a retrofit design, or perhaps if the evaluation is being used to inform planning, development of standards/guidelines, and/or education. Note, a general description of the methodology and outputs are provided in the sections below. In Section 4.3 and Section 4.4 of this report, worked examples of the MCA approach (Part A, High Level Analysis) and CBA approach (Part B, Detailed Analysis) respectively are presented with reference to the Case Study. These examples illustrate how an evaluation could be conducted using the available data for the chosen key parameters (i.e. typical templates, calculations etc.).

Output:
The outputs of the evaluation are the costs and benefits associated with each design, maintenance or adaptation strategy under consideration. Where it is deemed appropriate, related costs/benefits should be combined (i.e. economic costs could include: costs of materials, construction costs, maintenance costs etc.).

All costs/benefits should be evaluated for each drainage solution being considered, but also in the case of an existing road for the “As-Is” reference scenario, whereby no modification or upgrade is made to the drainage system currently in place. The format of the outputs should be presented in an appropriate manner to allow a comparison to be made, in the next step, between each option considered.

(h) Examine and Interpret Outputs

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

Methodology:
In many cases, the outputs from the previous stage will consider a mix of quantitative and qualitative measures. The outputs should be examined in relation to the overall context/objectives as identified at the outset. For example, the evaluation may provide the construction costs associated with a number of drainage solutions, along with the reduction in the expected flood damage for a given return period compared to the current flood risk situation. In addition, environmental impacts may be considered on a low, medium, high scale and it will be at the discretion of the NRA or organisation conducting the NRA to

identify the best solution considering all of the various costs and benefits associated with each.

Output:
The output from this stage should form the basis for the decision making process. The outputs should be compared against the initial context and if a detailed analysis has been conducted then it should be checked against the High Level analysis to assess whether all the objectives of the initial focus have been met. The overall output from this step should be a ranking of all options considered, including the 'As-Is' reference scenario, ultimately identifying the most suitable option in the context of the Socio-Economic Analysis.

3 SOCIO-ECONOMIC ANALYSIS PROTOCOL

3.1 Introduction

In the WATCH Manual, (Foucher *et.al.* 2018) two levels of risk analysis, Part A (high level) and Part B (Detailed level), are proposed when making a design or maintenance plan. Since the Socio-Economic Analysis is seen as a necessary step for implementation of results and a tool for decision support, the Socio-Economic Analysis protocol will address these two levels.

At the *High Level* (Part A) an analysis is performed for an individual asset or sub-groups of asset types in order to identify, at the global project level, the best adaptation strategy for those sub-groups Specific recommendations are provided for performing a high level risk assessment for drainage facilities. In effect the analysis at this level serves as a screening process aimed at highlighting vulnerable assets. Furthermore, all water management assets need to be classified in sub groups, based on extrinsic site factors, infrastructure intrinsic factors and hazard level. For each of these sub groups, an initial climate change adaptation strategy needs to be established for the project. The selection for a specific strategy for the sub groups will be based on a High Level Socio-Economic Analysis.

At the *Detailed level* (Part B) a detailed analysis is carried out following two main steps: gathering required climate data (step B.1) and determining the current and future resilience of the asset (step B.2). At this detailed level, the adaptation strategy from the higher level will be translated into design options (step B.3), up to the individual asset or sub-group of assets. In effect the analysis at this level is focused on risk at an asset level. Design choices will subsequently be prepared using a Socio-Economic Analysis for specific assets. The final Socio-Economic Analysis, aggregated at the project level, should then be compared to the initial economic evaluation to confirm the validity of the strategy selected at the High level.

3.2 High Level Analysis

At the High Level, an analysis is carried out to evaluate the best adaptation strategy for an individual asset or sub group of assets. Typically (but not always) an MCA approach is most suitable for this level of analysis. This assessment should be based on a set of key or hyper parameters. This will require using global cost estimates of measures (e.g. construction and maintenance cost per km of storm water system). The cost estimates may be compared to the benefits which will be aggregated at project level, because most benefits are related to the downtime of the infrastructure, i.e. the reliability of travel time

While is proposed that all the key parameters identified in Section 2.3.4.1 (c) be considered for a High Level Analysis, it is recommended that for a *Part A High Level Analysis* the following items should be considered as a minimum;

1) Maintenance & Serviceability Issues;
2) Environmental issues;
3) Societal Impacts & Requirements;
4) Safety Constraints & Impacts;

This list of eleven items identified in Section 2.3.4.1 (c) is not considered exhaustive and stakeholders may consider different/additional parameters. Equally, detailed data is not necessarily required for this level of analysis as it is anticipated that the outputs from this analysis will inform the stakeholder as to whether a more detailed analysis is required.

3.3 Detailed Level Analysis

At the detailed level, a more involved analysis is considered to assess individual or specific assets based on a wider range of project specific parameters, such as system performance, societal impacts, environmental impacts, resilience and robustness of the system etc. In this case, a CBA is typically the most appropriate approach to use.

At this level of analysis, it is recommended that a more complete or detailed list of parameters, as per Section 2.3.4.1 (c), should be considered. However, it should be noted that in some cases, following the completion of a High level analysis, it may not be considered beneficial to include additional parameters. Rather, it may be preferential to carry out a more detailed assessment, considering the same parameters which were included in the High Level analysis. The most appropriate approach to take will depend on a number of factors, including the overall context/objectives of the analysis, the level of data available and the findings of the Part A High Level Analysis.

It is important that the various impacts associated with each parameter are defined. Moreover, consideration needs to be given at this stage to the method that might be employed to assess each impact proposed, as this may determine whether it is viable to proceed with this method or not. For example, Table 4 shows some measures which could be used to evaluate various environmental impacts - similar examples for the other key parameters are provided in Appendix B.

Environmental Impacts & Requirements			
Parameter Details	**Method of Assessing Parameter**		
	Type	**Unit (if Applicable)**	**Description**
Air Pollution Levels	Quantitative	µg/m^3 per hour	Assessment carried out using a measurement device (for example, an Automatic Air Quality monitor). At the design phase information can be obtained from a desk top study of similar assessments.
Noise Pollution Levels	Quantitative	dB	Assessment carried out using a measurement device (for example, an Automatic Air Quality monitor). At the design phase information can be obtained from a desk top study of similar assessments.

Table 4: Example measures table for Parameter Impact and Assessment Method (note similar detail is provided in Appendix B for all parameters)

4 APPLICATION OF WATCH SOCIO-ECONOMIC ANALYSIS FRAMEWORK

4.1 Introduction

As described in the WATCH Manual (Foucher *et. al* 2018), a risk based decision support framework (or Decision Tree), Figure 2, has been developed which can be used by Asset Managers to determine the most suitable design, maintenance and adaptation strategies for road drainage systems given the growing threat to these systems as a result of climate change.

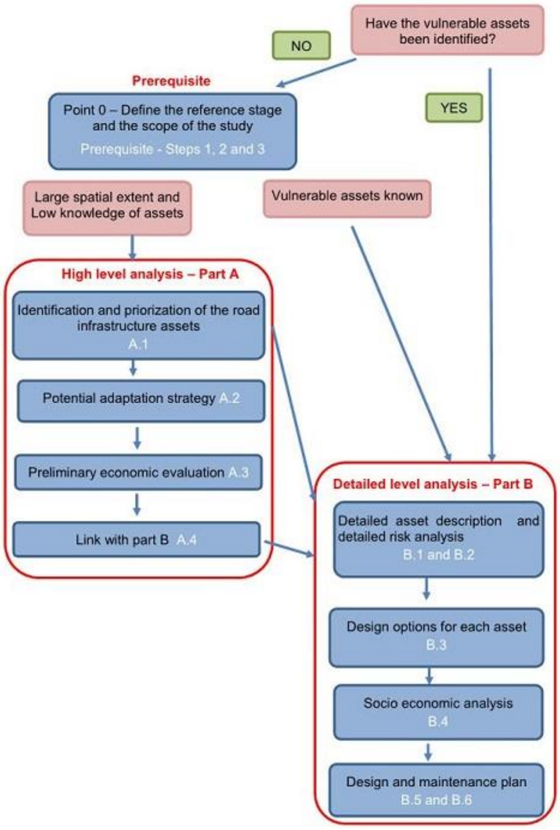

Figure 2: Risk Analysis Decision Tree

The application of this framework has subsequently been demonstrated in the Case Study report, at both the high level and detailed level of analysis for the M10 in Denmark, Figure 3 (Axelsen, C. 2018). The M10 is a major road leading into the greater area of Copenhagen and is the most highly trafficked road in Denmark with an AADT of approximately 120,000 (based on 2016 figures). The road is situated close to the sea, in predominantly low terrain with some local depressions with crossing streams leading into the sea. Consequently, various locations on the road are subject to water related threats such as, for example, pluvial flooding caused directly by heavy precipitation and indirectly by sea level rise, potentially resulting in more stress being put on the water management systems on the road.

Figure 3: M10 (Marked in Blue)

In accordance with the steps associated with the decision tree in Figure 2, a Socio-Economic Evaluation is to be carried out, as per Step A3 and Step B4, for the High Level and Detailed Level of Analysis respectively. In the previous sections of this report, an overview of the WATCH Socio-Economic Analysis Framework and a description of the associated steps involved in undertaking the analysis were described.

As such, in the following sections the implementation of the SEA framework, as described in Section 2 and Section 3, is demonstrated in the context of this case study road, at both the High Level and Detailed Level of analysis. Furthermore, guidance is provided on the processes involved at each step. In order to put the SEA into context at both the high level and detailed level of analysis, a brief description of the risk assessment process applied on the M10 is also provided. For more detailed information the reader should refer to Axelsen (2018).

4.2 Risk Assessment of the M10

4.2.1 Introduction

As described in the Case Study Report, three asset types are identified on the M10 that are of particular importance to maintain continuous safe operation of the M10, namely Culverts, Retention systems and Pump Stations. In determining the risks to these asset types, the failure of the system was used as the defining metric since an exceedance in capacity implies failure can lead to an exceedance of capacity and thereby potentially resulting in flooding on the road or damage to the surface or structural integrity of the road. For culverts, failure is defined as the point where the capacity is exceeded such that flooding can occur either on the road or besides the road. For retention systems, failure is defined as the point where the discharge from the system is less than the water supplied, whether from an adjoining water management system on the road itself and/or, possibly from the overflow from an adjacent catchment area. This can result in cascading effects where overflow initially will cause flooding next to the road, potentially damaging the road surface or structural integrity, and subsequently result in flooding on the road. For pump stations, failure is defined as the point where the total capacity of working pumps is inadequate to successfully pump the water away from the road into an adjacent retention system or from one retention system to another, ultimately causing flooding on the road.

Using an initial screening process based on ROADAPT, a risk assessment on the high level is conducted by scoring the likelihood and consequence from 1-4 for the three aforementioned asset types. Taking climate change into account, the scoring is conducted for the both the present day scenario and 2030 scenario.

Based on this high risk analysis, a risk matrix (Foucher *et. al.* 2018), Figure 4, was prepared where •1, •2, and •3 indicate Retention Systems, Culverts and Pumps respectively. As can be seen from the matrix, the risk level for all three asset types is relatively low, however culverts are the assets that will be most affected by climate change.

(a) Present Climate (b) 2030 Climate

Figure 4: Risk Matrix

4.2.2 High Level Analysis

Subsequently, in the case study, as a representative example on the application of the High Level Analysis of the Manual, Part A, Step 1 as per Figure 2, an example of the risk assessment process is carried out on four culverts with the aim of prioritising the road assets according to the risk level in order to:

- Define a global strategy,
- Undertake a detailed risk analysis (Part B) and Socio-Economic Analysis on high priority facilities to prioritise the assets and define adaptation strategies.

In accordance with the methodology the high priority assets are determined in four steps;

- Selection of the most relevant criteria for the risk analysis considering Threats, Vulnerabilities and Consequences;
- Evaluation of the criteria;
- Weighting of the criteria according to their relative importance;
- Aggregating the weighted criteria for prioritizing the road assets.

The various criteria were defined and for each of the threats, vulnerabilities and consequences and assigned scores according to four classes (low, medium, high and very high). The criteria were ultimately scored considering the current situation and for climate effects as predicted for 2030 + scenario A1B-IPCC. Weightings were applied to the risk components of the criteria and risk acceptability levels defined. Subsequently, a series of risk envelopes were produced for each of the four culverts, Figure 5 and Figure 6.

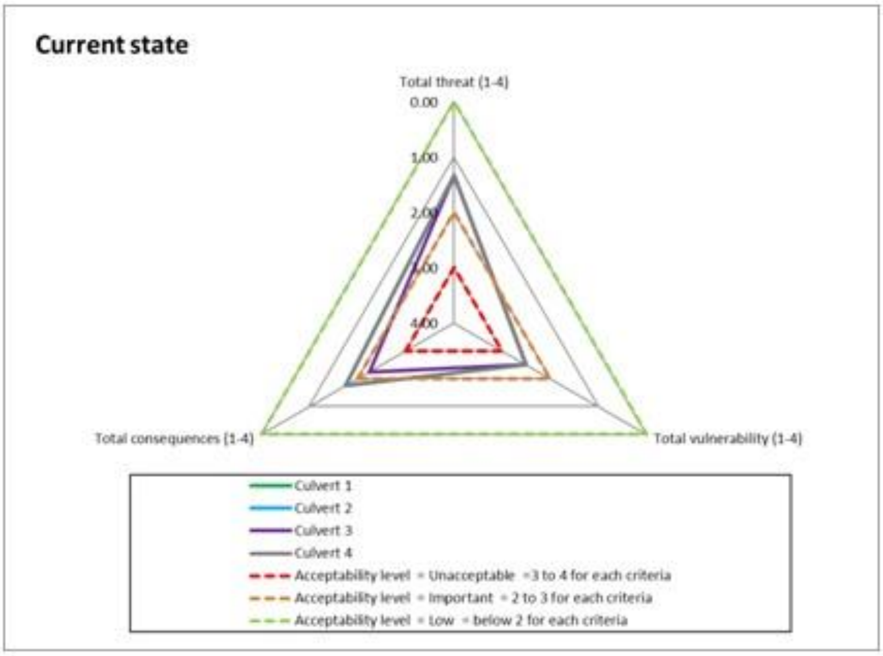

Figure 5: Risk Envelope for current situation

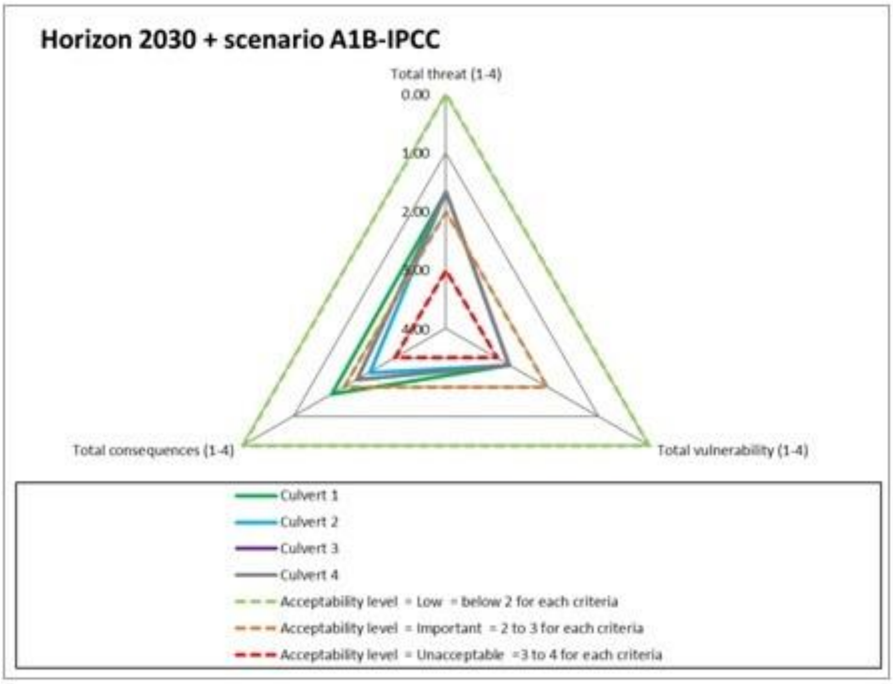

Figure 6: Risk Envelope for 2030 + scenario A1B-IPCC

From the results, it is noted that for the current state, the culverts are within the acceptable low level of risk. For the future climate, the scoring increases due to the increase of the threat, the increased age of the assets and further developments near the road. All the culverts exceed the limit between low and important acceptability levels.

As such, it is concluded that a further more detailed analysis should be carried out for the culverts (part B of the manual).

4.2.3 Detailed Level of Analysis

Having identified the high risk assets from the Part A analysis, these are then assessed using a detailed level analysis (Part B) in order to define adaptation measures. In accordance with the methodology Part B is divided into five steps;

- Step 1 - Gathering required climate data;
- Step 2 - Determining current and future resilience of assets;
- Step 3 - Defining possible measures/strategies;
- Step 4 - Performing a Socio-Economic Analysis;
- Step 5 - Finalising of applicable/appropriate strategy.

For further detail on these steps in relation to the case study, reference should be made to the aforementioned Case Study Report.

4.3 High Level Socio-Economic Analysis Evaluation

In the following sections each step in the High Level Socio-Economic Analysis is described in the context of the Case Study. To this end, the analysis is used to evaluate the most suitable adaptation strategy for culverts, identified as one of the high risk assets in the Part A risk assessment methodology as described in the previous section.

4.3.1 Establish the Context

Objective:
The objective of establishing the context of the required Socio-Economic Analysis is to identify and consider the aspects that are relevant to the stakeholder implementing the analysis. Equally, consideration should be given to the scope of the project and the budget available i.e selecting the most suitable adaptation strategy under which to carry out a detailed level of analysis. As the decision makers, Stakeholders are the focal point of this step in the SEA evaluation and typically involves numerous stakeholder brainstorming sessions (or stakeholder analysis) to consider in detail the list of (non exhaustive) issues as outlined in Section 2.3.4.1 (a) of this report.

Methodology:

In the context of the case study, the Danish Road Directorate (DRD) is the primary stakeholder as they manage all the state owned roads in Denmark. In addition to issuing the tenders for proposed works on the state owned roads, the DRD plans, operates, and maintains the network, which consists of approximately 4,000 Km of roads or 5% of the entire road network in Denmark, which includes approximately 2,300 structures (i.e. bridges, water infrastructure etc.). Although this seems like a low percentage of the road network under their jurisdiction, the importance in terms of mobility for society cannot be overstated as approximately 45 % of the entire road traffic in Denmark uses the Danish state-roads.

While no such detailed stakeholder sessions took place in the context of this case study, the author of the Case Study report is a DRD employee and conducted the case study on the basis of numerous discussions with relevant staff within the DRD. The purpose of these discussion were to gain an insight into the context of the organisation, the process models utilised for various types of projects, their approach to water management (including design protocols and systems utilised) and the strategies in place for addressing Climate Change. As such, the following paragraphs describe some of the key issues that the DRD would address when dealing with the management of their water systems, highlighting some of the key considerations when establishing the context.

Output:
The output of this step consists of a description of the external and internal context of the DRD and the context of the risk management processes for the proposed solutions. Given there were no stakeholder workshops as part of this project, specific details of these items are not available, however, based on the information arising from the internal meetings that took place between the author and relevant staff within the DRD, reasonable conclusions can be made about the DRD’s approach to water management in the face of climate change and answers can be provided to some of the issues that should be addressed as listed in Section 2.3.4.1 (a). It also provides some rationale to the thought process when establishing the context.

In addressing the issue of the ‘purpose of the evaluation’, there are a number of factors which leads the DRD to have an interest in assessing the water systems on their network in the face of climate change, and in particular, assets on the M10.

In the first instance, it is acknowledged that conducting a Socio-Economic Analysis can facilitate better basis for decision making, both in terms of maintenance and operation and construction. Also, adopting a risk based approach to flooding, satisfies the regulatory requirements under the EU flood Directives (Directive 2007/60/EC).

Secondly, the DRD has acknowledged that the primary challenge of climate change is water related, both in terms of cost and disruption of traffic. In fact, the DRD 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 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 in the future as follows;

1. Managing flooding when it occurs;
2. Improving and adapting roads where possible;
3. Preventing where possible.

Roads are designed and built in accordance with the existing road standards. In these standards, climate change adaptation is incorporated based on recommendations of the Danish *Spildevandskomiteen* a Danish engineering committee that has been in effect and acted as experts on water management since the 1940s (*IDA*, 2017). The Danish government has chosen to follow the A1B IPCC-scenario, illustrated in Figure 7, aligned for the Danish Context, by the Danish Meteorological institute as basis for climate change adaptation planning, maintenance, and operations (*IPCC*, 2007). Furthermore, a climate change adaptation strategy and action plan is being implemented as part of their asset management procedures.

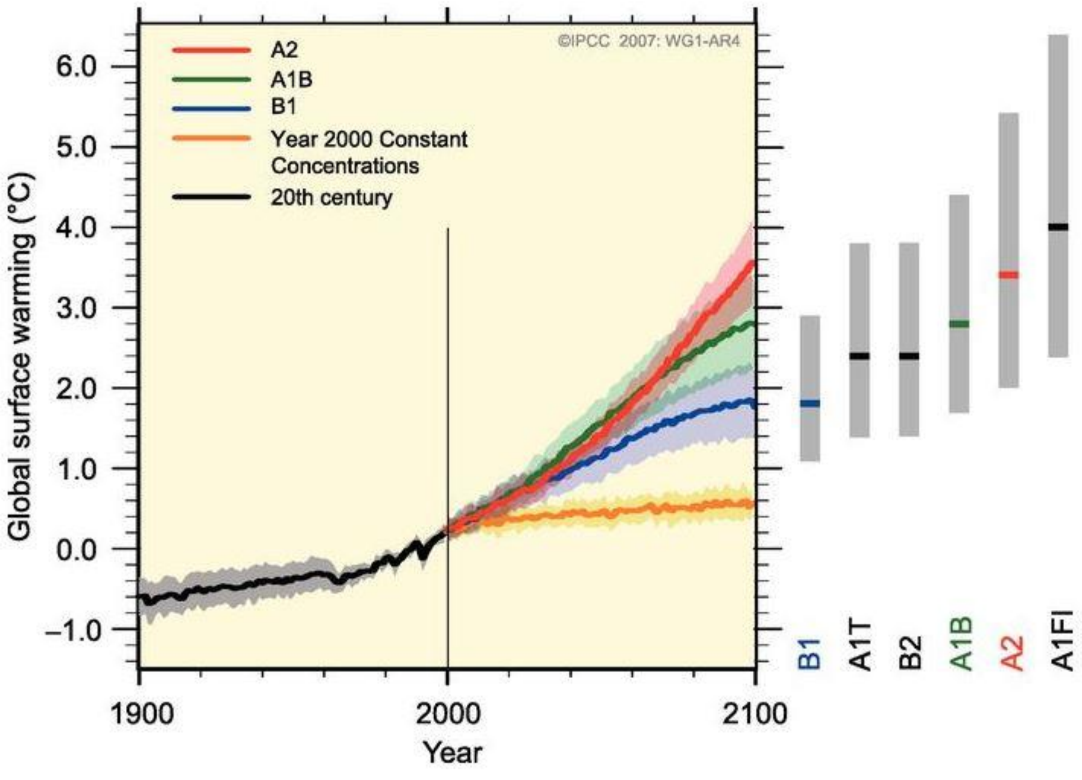

Figure 7: Illustration of the climate scenarios from the IPCC 2007 report. The A1B scenario, used by the Danish Road Directorate, is marked green (IPCC, 2007)

Thirdly, the M10 is considered a critical road in Denmark and it is clear that the consequence of a water asset failure leading to reduced safety and mobility can have a significant effect on society and as such keeping the road operational at all times is extremely important for the DRD. Equally, the DRD has clear-cut directives focused on ensuring maximum flow, minimum traffic disruption and fulfil the governing service criteria, depending on the specific road or stretch of road.

The M10 is the most heavily trafficked road in Denmark with AADT of approximately 120,000 (2016 figures) and is categorised at the highest level of strategic importance, Figure 8, not only due to the high AADT but also due to its geographical location where it is the primary route to the greater Copenhagen area or Sweden, coming from both the south and west. In addition to the high AADT there are also no alternative routes considered capable of ensuring continuous mobility of the road traffic in the event that the M10 is flooded.

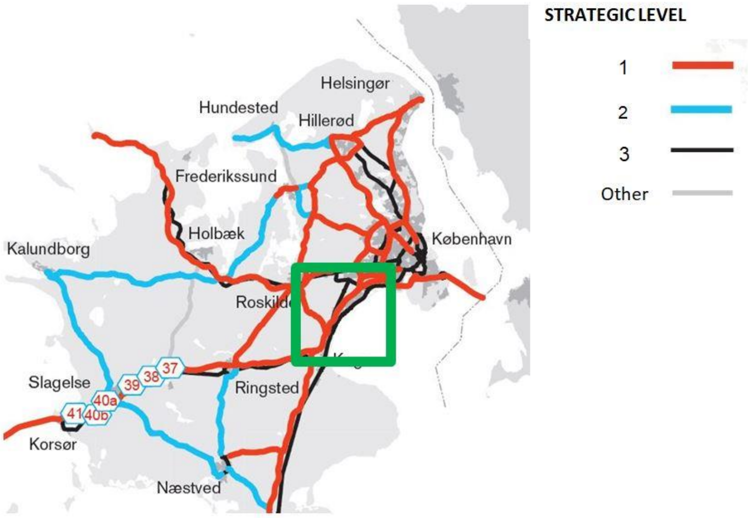

Figure 8: Strategic Importance of road network (M10 identified by the Green Square)

Equally, a previous study in the ROADAPT project (Bles *et al* 2015) identified some areas of the M10 are vulnerable to flooding, Figure 9, though the flooding was not pluvial related alone and was also susceptible to flooding as a result of as crossing streams, weakening of road embankments, inundation from coastal regions and increases in groundwater levels.

Figure 9: M10 Vulnerable Flood zone

The M10 is also a relatively new road and underwent significant lane widening between 2012 and 2017 to increase capacity. Consequently, large numbers of the water management systems on the M10 are newly installed, so the evaluation is focusing on an existing scheme and the possible adaptation strategies that may be required in the future as a result of increased flooding due to climate change.

As the evaluation is focused on an existing road, the important water systems in place are already known in advance of the analysis namely, culverts, retentions systems and pumps. It is worth noting that as the roads managed by the DRD are situated in non-mountainous areas systems such as tunnels, steep-gradient roads and designated melt-water resilience systems are not relevant to their network. Out of the aforementioned relevant assets it is also acknowledged that culverts typically result in the most rapid flooding of the road and hence the assessment of these assets is the focus of the study.

In terms of ‘return periods’ the DRD has a protocol. 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.

As such, it would seem a reasonable conclusion, when establishing the context of the evaluation that the purpose of the evaluation should be 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;

1. As is (current state):

Accepting the current capacity of a culvert which has been identified as potentially inadequate can lead to an increased risk of failure of the culvert. This can result in potential loss of functionality of the M10, both in terms of traffic interruption and the potential for short- and long-term damage of the road with corresponding impacts on society and the environment As such, while this ‘do nothing’ approach is likely not to be the preferred adaptation strategy for culverts in the face of climate change, including the approach in the evaluation allows a relative comparison against the other proposed strategies.

2. Allocate Additional Resources for updating:

Allocating additional resources for updating, in this instance, implies enlarging the capacity of the culverts. Increasing the capacity of the culvert inevitably requires investment; however this is a viable option in order to maintain mobility and safety on the M10 and limit the societal and environmental impacts in the long term.

3. Updating or bypassing the strategy for service level:

A further strategy considered is to revise the governing road standards or apply for an exemption to these standards at a local level. The high risk of culverts was identified on the basis of the specifications 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, such as downgrading the strategic importance of the road, is seen as a solution which could turn out to be cost-effective. On an overall level, this form of solution is not regarded desirable since the consequences of traffic disruption on M10 are very significant and the risk to the road from extensive flooding becomes unacceptable. Equally, a local exemption is not considered beneficial for the general trust towards any given national road authority as an increased risk of flooding on the road can have significant societal impacts. 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.

4.3.2 Determine Evaluation Approach

Objective:

The objective of this step is to decide on an appropriate evaluation approach to measure the impact or effect, including economic consequences, associated with each solution.

Methodology:

There are a range of methods that can be used in undertaking a Socio-Economic Analysis, in order of increasing data needs as follows; Multi Criteria Analysis (MCA), Life Cycle Costing (LCC), Cost Effectiveness Analysis (CEA) and Cost Benefit Analysis (CBA) as described previously in Section 2.3.4.1.

Output:

It is noted, that within the DRD, an LCC is the conventional approach used when considering the management of their road assets over the entire life cycle. This analysis mainly takes into account construction cost, durability/life span and maintenance cost during operation. However certain factors, such as for example accelerated road damage due to severe flooding, are not considered in an LCC and consequently such events can add costs which may not have been initially anticipated. Consequently, for the purpose of this example, an alternative evaluation approach is proposed.

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.

4.3.3 Choose Key Parameters

Objective:

The objective of this step is to select the relevant parameters which are to be considered as part of the evaluation.

Methodology:

Through brainstorming sessions or Stakeholder Analysis, the parameters chosen are relevant to the context, and are chosen based on the objectives of the Socio-Economic Analysis as defined when establishing the context.

Output:

As the purpose of the high level analysis is to screen the assets under consideration using an MCA approach, it is considered sufficient in this case to select only four parameters as per Section 2.3 and only a qualitative assessment of the parameters is undertaken.

The key parameters to be assessed in the Multi Criteria Analysis, based on the recommendations provided in Section 3.2. These parameters are to be assessed for each of the adaptation strategies as outlined when establishing the context.

1) Maintenance & Serviceability Issues;
2) Environmental issues;
3) Societal Impacts & Requirements;
4) Safety Constraints & Impacts.

4.3.4 Examine Available Data

Objective:
The objective of this step is to collect the relevant/available data and assess the suitability of this data in line with the objectives of the evaluation.

Methodology:
In the Case Study report, it is noted that the Author liaised with numerous staff members within the DRD to gain an insight into the data available for the four key parameters to be assessed as per the previous section.

Output:
For the purpose of demonstrating the MCA, it is assumed that quantitative data is not readily available and the impacts of a particular strategy are ranked on a numerical scale depending on the perceived importance of a particular strategy and impact to the DRD.

For the four key parameters identified, an impact table is defined whereby each parameter is ranked based on a impact level of -2 to +2, depending on the impact of a failure of a culvert, Table 5. A positive score indicates the impact has benefits or a lower impact for the DRD (e.g. less cost or increased safety). A negative score means the measure has disadvantages or a higher impact for the DRD (e.g. higher cost or decreased safety). Note, as indicated in Table 5, the ranking score for the Impact level should be related to the classification of the consequence criteria adopted in Table 6 of the Manual (e.g. -2 is equivalent to Very High Impact).

Impact Level	**Maintenance & Serviceability Issues**	**Environmental issues**	**Societal Impacts & Requirements**	**Safety Constraints & Impacts**
-2 (Very High Impact)	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 (High Impact)	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 (Medium Impact)	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 (Low Impact)	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 ≥ 500,000
-1	100,000 ≤ C < 500,000
0	Neutral/N/A
+1	25,000 ≤ C < 100,000
+2	C < 25,000

Table 6: Direct Cost Category

4.3.5 Is sufficient data available to assess the chosen parameters?

Objective:
The objective of this step is to assess whether the available data is sufficient to allow a meaningful SEA evaluation to be undertaken considering the objectives of the analysis and the key parameters identified.

Methodology:
Using a desk study approach, or similar (i.e. stakeholder discussions/agreement) the data available is assessed for suitability.

Output:
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.

4.3.6 Consider Climate Change

Objective:
The purpose of this step is to incorporate the relevant climate change scenarios and assess how they can influence the evaluation analysis.

Methodology:
Climate Change is typically considered through the adoption of climate change factors from design standards relevant to the region. Such factors typically indicate that a percentage change (e.g. 10% or 25% increase) should be applied to the design values used to size various drainage elements to account for the effects of climate change.

At a more advanced level, the use of region-specific climate data should be considered, determined, for example, using the methods as described in Bessembinder *et. al.* (2018), to more accurately identify the values that should be adopted to account for climate change for the chosen return period(s).

Output:
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 (Very High Impact)	Increase in Frequency and severity of Flooding events such that threat of culvert failure is inevitable
-1 (High Impact)	Increase in Frequency and severity of Flooding events such that threat of culvert failure is likely
0	Neutral/N/A
+1 (Medium Impact)	Increase in Frequency and severity of Flooding events such that culverts are operating at full capacity
+2 (Low Impact)	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

4.3.7 Perform Analysis

Objective:

The objective of this step is to perform the evaluation analysis in order to determine, in this case qualitatively, optimum adaptation strategy for culverts in the face of climate change in the context of the M10.

Methodology:

In this particular case study, an evaluation is undertaken using an MCA approach for each adaptation strategy considering a qualitative assessment of the costs and impacts for the key parameters with due consideration given to climate change. To this end the adaptation strategies and impacts are tabulated and based on a shared consensus within the DRD, scores are assigned to the impact of each key parameter relative to the strategy.

In considering the scores assigned to the key parameters the following were considered:

Maintenance & Serviceability Issues:

The cost for replacing or repairing road assets is dependent on various factors such as:

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

However, it is worth noting that while some measures may seem costly, there may be some associated benefits. For example, if night work is required, then while the hourly cost for labour input is more expensive, the works can be carried out in a relatively shorter timescale due to fewer interruptions, such as for example, reduced traffic on the road. Equally it is worth noting that as a result of night work, there might be a corresponding negative impact from a societal point of view i.e. the impact on the workers themselves or residents in the vicinity the M10.

Environmental issues:

Assessing environmental issues involves assessing the following points;

- Impact on Natural Landscape;
- Noise Pollution Levels.

In relation to the impact on the natural landscape, if for example, a culvert fails during an extreme precipitation event, it is possible that untreated road water can spill into the adjacent environment. Given the proximity of the M10 to the sea, this may result in organic pollutants entering the sea, effecting the marine environment. Equally, untreated road water can impact the flora, fauna and surrounding animal habitats.

In respect of noise, for example, the M10 runs through a number of urban areas. Therefore, noise levels, in the short term during repair can have significant impact on the neighbouring residents and are dependant, for example, the duration of the road works and the degree of night time vs. Day time works.

Societal Impacts & Requirements:

A number of societal impacts are considered such as;

- The Impacts on road users as a result of increased journey times;
- The Cascading effects on other roads in the vicinity;
- The Effect on public transport network in the vicinity, especially in the event of failure of the system;
- The 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.

Safety Constraints & Impacts:

A number of safety impacts are considered such as;

- Reduced safety due to increased traffic volumes if there is congestion;
- Reduction in individual driver safety due to an increased number of vehicles, hydroplaning and/or reduced visibility due to excess surface water on the road;
- Reduced safety on alternative roads if traffic is rerouted.

Output:

Based on the qualitative ranking system described in the previous section for the costs and impacts, the scores are tabulated in Table 8 and Table 9 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.

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 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

4.3.8 Examine/Interpret Outputs

Objective:
The objective of this step is to examine and interpret the outputs of the SEA evaluation in the overall context of the analysis.

Methodology:
At this point the results are assessed relative to the objective of the evaluation i.e using a high level approach to determine the optimum adaptation strategy for culverts in the face of climate change.

Output:
The output from this stage should form the basis for the decision making process. In assessing each strategy against the impacts, the results can be interpreted as follows;

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 potentially requiring significant repairs, leading to high costs. . If flooding is extensive and spills into the surrounding environment, the environmental impacts can also be high as a result due to pollution which would have associated costs. Equally, traffic disruptions can lead to reduced mobility and safety of road users can also be compromised due to, for example, excessive water on the road, reduced visibility and congested traffic. As such, the scores for the key parameters, Table 8, are low i.e. negative impact. Leaving the culvert 'as is', i.e. no upgrade, minimizes the initial directs cost (i.e. a positive score), however, given the negative impact scores, the overall output from the analysis, Table 9, produces a negative score of -0.5 (i.e. an overall negative impact for the DRD.

In terms of increasing the capacity of the culvert, while this may require more resources (e.g. direct costs, a negative score), in effect this solution will lead to an increase in the resilience of the system to cope with extreme flooding, thus reducing the negative impacts of the ‘as-is’ strategy. As such, this strategy results in a positive outcome considering the key parameters that have been assessed, Table 8. Combining these scores with the direct costs and climate change impact, Table 9, it can be seen that the impacts, in effect, outweighs the potential costs and as such an overall positive score is achieved, +0.25 i.e. less impact for the DRD.

In relation to updating or bypassing the strategy for service level, this solution is not preferable 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. It should be noted that this form of local solution is not considered very feasible nor has it previously been conducted as a means on which to base economic solutions and decisions in regards to water management. As such, the scores for the impact considering the key parameters are low, Table 8, i.e. a negative impact. While the initial costs for this option are low (i.e. a positive score), combined with the Impacts of the key parameters and Climate change, the result is an overall negative score, -1 i.e. a negative impact.

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

4.4 Detailed Level Socio-Economic Analysis Evaluation

In the following sections each step in the Detailed Level Socio-Economic Analysis is described in the context of the Case Study.

4.4.1 Establish the Context

Objective:
The objective of establishing the context of the required Socio-Economic Analysis is to identify and consider the aspects that are relevant to the stakeholder implementing the analysis. As previously discussed in Section 4.3.1, consideration should be given to the scope of the project (e.g. a new design, operation and maintenance or a major rehabilitation) and the budget available. Equally, stakeholder brainstorming sessions (or stakeholder analysis) are undertaken to consider in detail the list of (non exhaustive) issues as outlined in Section 2.3.4.1 (a) of this report.

For the purpose of this example, it is considered that the high level analysis has already been conducted and as such, the objective at this point is to addresses the outcome of the High Level Risk Assessment and subsequent high level MCA.

Methodology:
The methodology in establishing the context follows the same process as described in Section 4.3.1 for the high level analysis, except in this case the objectives are more clearly defined as a high level analysis has already been undertaken.

Output:
Having conducted the high level analysis the detailed analysis is undertaken to compare the optimum adaptation strategy, as determined based on the high level MCA analysis, namely allocating additional resource for updating (i.e enlarging the culverts), benchmarked against the current or ‘as is’ situation. Through such comparison, the detailed level analysis, using a CBA approach, highlights in monetary terms how the two strategies compare.

4.4.2 Determine Evaluation Approach

Objective:

The objective of this step is to decide on an appropriate evaluation approach to measure the impact or effect, including economic consequences, associated with each solution (current state versus allocating resources for updating).

Methodology:

As described previously there are a number of methodologies available to conduct the SEA evaluation, namely, MCA, LCC, CEA and CBA.

Output:

For the purpose of the detailed level of analysis, in order to facilitate more informed decision making and notwithstanding the other viable approaches described in Section 4.3.2, a Cost Benefit Analysis approach is adopted.

4.4.3 Choose Key Parameters

Objective:

The objective of this step is to select the relevant parameters which are to be considered as part of the evaluation.

Methodology:

Through brainstorming sessions or Stakeholder Analysis, the parameters chosen are relevant to the context, and are chosen based on the objectives of the Socio-Economic Analysis as defined when establishing the context. In preparing the case study deliverable discussions took place with the relevant staff within the DRD.

Output:

As the purpose of the detailed level analysis is to compare the current state with a reallocation of resources for enlarging the culverts, it is considered sufficient in this case to reassess the four parameters as per Section 2.3, as follows;

1) Maintenance & Serviceability Issues;
2) Environmental Issues;
3) Societal Impacts & Requirements;
4) Safety Constraints & Impacts.

These parameters are to be assessed for both the current state (i.e. ‘As is’) assuming no action will be taken and the option of enlarging the culverts (i.e. allocating resources to upgrade).

4.4.4 Examine Available Data

Objective:

The objective of this step is to collect the relevant/available data and assess the suitability of this data in line with the objectives of the evaluation. It should be noted that derivation of the numbers for each criteria provided in the following sections is outside the scope of this project and the values provided by the DRD are representative values only.

Methodology:

The Author of the Case Study liaised with numerous staff members within the DRD to gain an insight into the data available, from a cost and benefit point of view, for the four key parameters to be assessed as per the previous section.

Output:

As a more detailed analysis is being undertaken more detailed data is required in quantitative form. Based on the outcome of discussions within the DRD, cost data, as a direct cost and effect, for the two strategies and key parameters was determined. This data is presented below and accompanied with a brief description of how these quantities were derived. In all cases data has been obtained based on internal discussions with in the DRD and data based on previous and ongoing projects

Construction & Yearly Maintenance costs: (direct)

As a benchmark for the two selected strategies, the construction cost, yearly maintenance costs and expected service life, for a single culvert upgrade is provided in Table 10.

Strategy	**Construction Cost in €**	**Yearly Maintenance Cost in €**	**Expected Service Life**
As is i.e. no action	0	4,500	On average 30 years old and designed for 50 years
Enlarging Capacity of Culverts	2,500,000	5,000	50

Table 10: Direct Construction & Maintenance Costs

In relation to *construction costs*, a cost of €5,400/m^2, including all: materials, labor input and road and traffic management have been estimated to construct and implement a single culvert upgrade on the M10. As such, for a construction area of 400m^2 (80m x 5m), the cost per culvert is €2,160,000. However this is in accordance with the current road standards which consider climate change resilience for the present day + 25 years (i.e. a climate factor of 1.4). As the expected life span of a culvert is 50 years, resilience to future climate is not considered adequate therefore an additional 15% is added to the construction cost to ensure the culvert is adequately designed for its intended service life of 50 years. Consequently the total cost/culvert is 1.15 x €2,160,000 or €2,484,000, rounded to €2,500,000 (note, it is assumed this is a real price i.e. adjusted after inflation etc.). Thus, the €2,500,000 is used as a benchmark construction cost for the CBA to compare socioeconomic benefits of strategy choice.

The *yearly maintenance cost* for a culvert is dictated by the average size of the culvert. Based on representative data from the DRD this is estimated at €4,500/year per culvert. As for the direct construction cost, the additional maintenance requirements (i.e. increased labour costs and materials) enlarging the culvert for climate resilience, above the current design standards, is assumed to be in the region of 10%. Consequently the yearly maintenance cost /culvert is 1.10 x €4,500 or €4,950, rounded to €5,000. Thus, the €5,000 is used as a benchmark yearly maintenance cost for the CBA to compare socioeconomic benefits of strategy choice

Quantitative Impacts (effects):

For each of the key parameters, Table 11 provides a quantitative cost estimate of the impact on a particular parameter with the subsequent paragraphs providing a brief description of these impacts and the factors considered in estimating the costs. The cost for each impact involve monetizing all related costs associated with the impacts of a culvert failure after a flooding event and are based on representative data obtained within the DRD.

Strategy	Maintenance & Serviceability Issues	Environmental effects	Societal Impacts & Requirements	Safety Constraints & Impacts
As is i.e. 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
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

Table 11: Impact costs

For *Maintenance and serviceability issues* the amount of €190,000 provided in Table 11 considers the following;

- Resource requirement for post flood clear up including:
  - Removing debris from the culvert;
  - Removing mud, gravel, etc. from the road;
  - Traffic Management during clear-up.
- Resource requirement for inspection & repair works including:
  - Repair of road damage;
  - Road inspection for latent damage;
  - Culvert inspection & repair

For *Environmental effects* the amount of €65,000 provided in Table 11 considers the following;

- Resource requirements for post flood clear up:
  - Actions to avoid further contamination of polluted road water into the adjacent environment;
  - Labour costs for subsequent clear up, assessing damage and monitoring of the adjacent flora and fauna.
- Costs for compensation:
  - For farmers e.g. loss of crops and/or livestock due to flooding;
  - For private residents affected by the flooding.
- Cost of noise pollution:
  - Added noise pollution during clear up

For *Societal impacts and requirements* the amount of €1,500,000 provided in Table 11 considers the following;

- Journey delay time:
  - Socioeconomic costs due to traffic stand still or congestion, both for commuters and commercial freight.

- Cascading effects of re-routed traffic onto alternative routes:

- Damage to roads not designed to handle M10 traffic loads;
- Overuse of adjoining roads due to an incapability to handle the M10 traffic load;

For *Safety constraints and impacts* the amount of €10, 000 provided in Table 11 considers the following.

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

4.4.5 Is sufficient data available to assess the chosen parameters?

Objective:
The objective of this step is to assess whether the available data is sufficient to allow a meaningful SEA evaluation to be undertaken considering the objectives of the analysis and the key parameters identified.

Methodology:
Using a desk study approach, or similar (i.e. stakeholder discussions/agreement) the data available is assessed for suitability.

Output:
In conducting the Cost Benefit Analysis to compare the current (or ‚‘as is‘/no action) approach against the strategy of enlarging the culvert it is important to have the critical information, to allow a comparison of the strategies over the life cycle of the asset.

It is recommend that as an output of this step; the available information is tabulated and identified as being sufficient (or otherwise) to conduct the analysis. At this point it may be necessary to review the information available or possibly reassess the evaluation approach chosen considering the context of the evaluation.

For this particular case study, a sample table is illustrated in Table 12 and 13 respectively.

	Construction Costs					Mainatenance Costs				
	Data Avaiability		Sufficient Data?		Comments	Data Avaiability		Sufficient Data?		Comments
Strategy	**Yes**	**No**	**Yes**	**No**	**(IF applicable)**	**Yes**	**No**	**Yes**	**No**	**(IF applicable)**
As is i.e. no action	✓		✓		Based on Representative data from DRD	✓		✓		Based on Representative data from DRD
Enlarging Capacity of Culverts	✓		✓		Based on Representative data from DRD	✓		✓		Based on Representative data from DRD

Table 12: Data Suitability Check - Strategies

	Impact Costs				
	Data Avaiability		Sufficient Data?		Comments
Parameter	**Yes**	**No**	**Yes**	**No**	**(IF applicable)**
Maintenance & Serviceability Issues	✓		✓		Based on Representative data from DRD
Environmental Issues	✓		✓		Based on Representative data from DRD
Societal Impacts & Requirements	✓		✓		Based on Representative data from DRD
Safety Constraints & Impacts	✓		✓		Based on Representative data from DRD

Table 13: Data Suitability Check - Impacts

4.4.6 Consider Climate Change

Objective:
The purpose of this step is to incorporate the relevant climate change scenarios, which are being developed in WP2 of the WATCH project and assess how they can influence the Socio-Economic Analysis.

Methodology:
A step by step approach has been developed in the WATCH project (Bessembinder *et. al.* 2018), Figure 10, which can be used for estimating possible changes in sub-daily and daily rainfall extremes in the future, from which hydraulic designs of water assets can be undertaken for increased rainfall intensity.

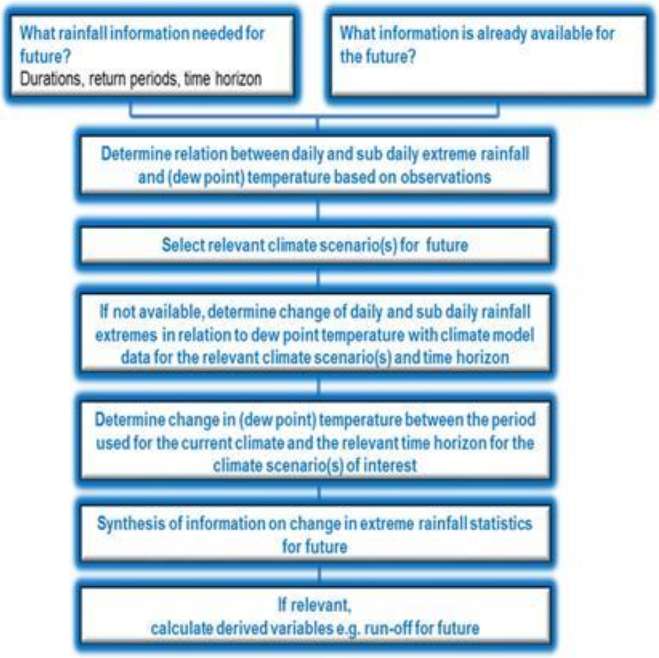

Figure 10: Step By Step approach for estimating future rainfall

It should be noted that in this case study the step-by-step approach was not applied since incorporating climate change is already established within the Danish Road Directorate. For NRAs that have insufficient climate data at hand, the approach of Figure 10 is considered of high value since it implements knowledge and viewpoints on an interdisciplinary basis.

Output:
The output of this step is a description of the hazard intensity, such as flood level, for the multiple climate change scenarios that are deemed important to include in the evaluation. These can then be used to assess the implications for different options, including the 'as is' scenario.

The Danish Road Directorate adopts climate change scenario A1B of the IPCC report of 2007 for managing the water assets on major Danish road. 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.

As described in Section 4.4.4., the DRD uses a factor of 1.4 to incorporate climate change effects when proportioning water management systems and, as will be shown in Section 4.4.7, this is adopted for the as is situation for the present climate, with an additional allowance for climate change up to the design life of 50 years.

Equally, in Section 4.4.7, an evaluation is carried out considering the climate in 2030. To this end, climate change is taken into account by conducting the CBA by factoring in how the A1B climate change scenario will affect the return period of flooding occurrence (i.e a higher return period is used).

4.4.7 Perform Analysis

Objective:
The objective of this step is to perform the evaluation analysis in order to determine the advantages and disadvantages (e.g. cost, benefits) associated with for each identified parameter for the particular strategy of no action or enlarge the culverts measured again the key parameters.

Ultimately in this study, the goal is to determine the annual expected cost (i.e total cost/year) for each strategy, for both the present climate and 2030 climate scenarios and determine the Benefit/Cost ratio (B/C ratio) which is provides an indication of the value of the investment in the long term (or over the service life of the culvert).

Methodology:
In this particular case study, a cost benefit analysis evaluation is performed for all criteria and proposed solutions over the service life of the culvert, namely benchmarking the ‘as is’ situation with the strategy of enlarging the culvert by considering both the present climate and climate for 2030. The relevant data for each adaptation strategy being considered within the evaluation is used to evaluate the associated costs and benefits on a quantitative basis.

The steps involved in carrying out the CBA are as follows with a summary description in subsequent paragraphs;

(a). Calculate the *total average yearly cost* of construction and maintenance for each strategy for the *present climate*.
(b). Calculate the *average annual expected impact* of each parameter for each strategy for the *present climate*.
(c). Determine the *annual expected costs* for each strategy based on the outcome of (a) and (b) above.
(d). Calculate the *average annual expected impact* of each parameter for each strategy for the *2030 climate*.
(e). Determine the *annual expected costs* for the 2030 day climate scenario for each strategy based on the outcome of (a) and (c) above.
(f). Determine the *Net Annual benefit and Benefit/cost ratio* of the investment for each strategy.
(g). Evaluate results (see Section 4.4.8)

Output:
The outputs for each step, (a) to (f) are provided in Table 14 to Table 19, with a brief description below of how these values are calculated.

<u>(a) Total Average Yearly Cost (present climate):</u>

The average yearly costs, Table 14 for each strategy are determined based on the combined direct construction and maintenance costs for each strategy over the service life of the culvert. In calculating this figure, it is assumed a 3% discount rate is applied to convert the future monetary value of the investment for a particular strategy to the present value. In effect the discount rate considers the time value of money.

In Table 14, the construction and maintenance costs have been taken from Section 4.4.4., Table 10.

The Average yearly construction cost for the ‘no action’ strategy is €0 as this is already invested and is considered a sunk cost.

Assuming, an amortizing loan scenario (where the interest rate = discount rate) the Average yearly construction cost for enlarging the culvert is determined as follows;

$$Construction\ Cost_{AY} = {}^{A}\!/_{D}$$

Where;

A = Initial construction cost

D = discount factor = ${\{[(1+i)^n]-1\}}\big/{[i(1+i)^n]}$

i = Periodic interest rate (or discount rate)

n = Period of 'loan' or service life

In this case, assuming yearly payments, A = €2,500,000; i = 3% and n = 50 years;

$$\text{Construction Cost}_{AY} = €97{,}164$$

<u>(b) Average annual expected impact (present climate):</u>

The annual average expected impact costs, Table 15 for each strategy are determined based on the impact costs as provided in Section 4.4.4, Table 11 and the return period for a flood event, which causes failure of the culvert. Note, it is assumed that the costs of each impact are equivalent for each strategy.

The Total Impact cost for each strategy is merely a summation of the impact costs for each parameter assessed for each strategy. The annual average expected costs are subsequently determined by considering the return period of the flood event that can cause failure of the culvert. For the 'as-is' strategy, a 10 year flood is considered (10% chance of being exceeded in one year) while the 'enlarging the capacity of the culvert' strategy considers a 50 year flood (2% chance of being exceeded in any one year).

Consequently, for the 'as-is' strategy, given a Total impact cost of €1,765,000 and a flood with a 10% chance of being exceeded in any one year, it is assumed that the annual average expected cost is 10% of €1,765,000 or €176,500. Equally, for strategy of enlarging the capacity of the culvert, and a flood with a 2% chance of being exceeded in any one year, the annual average expected cost is 2% of €1,765,000 or €35,000.

<u>(c) Annual expected costs (present climate):</u>

The Annual expected costs for the present climate, Table 16, involve summation of the Total Average Yearly Cost from (a) above and the Annual Average Expected Impact costs from (b) above for reach strategy. Note, these calculations assume the level of damage (i.e. failure) is the same for each event.

<u>(d) Average annual expected impact (2030 Climate):</u>

In a similar manner to (b) above, the annual average expected impact costs, Table 17 for each strategy are assumed to be the same as those for the present climate as per Section 4.4.4, Table 11. In the case of the 2030 climate however, the return period has been amended considering an increase in the rate of occurrence and severity of floods.

As such, the Total Impact cost for each strategy remains the same as the present climate. The annual average expected costs are subsequently determined by considering the return period of the flood event that can cause failure of the culvert. For the 'as-is' strategy, a 5 year flood is considered (20% chance of being exceeded in one year) while the 'enlarging the capacity of the culvert' strategy considers a 33 year flood (3% chance of being exceeded in any one year).

Consequently, for the ‘as-is’ strategy, given a Total impact cost of €1,765,000 and a flood with a 20% chance of being exceeded in any one year, it is assumed that the annual average expected cost is 20% of €1,765,000 or €353,000. Equally, for strategy of enlarging the capacity of the culvert, and a flood with a 3% chance of being exceeded in any one year, the annual average expected cost is 3% of €1,765,000 or €52,950.

(e) Annual expected costs (2030):

The Annual expected costs for the 2030 climate, Table 18, involves summation of the Total Average Yearly Cost from (a) above and the Annual Average Expected Impact costs from (d) above for reach strategy.

(f) Net Annual benefit and Benefit/cost ratio:

Having determined the Annual expected costs for each strategy, the net annual benefit and B/C ratio can be determined for the selected strategy (i.e. enlarging the culverts) against the as is strategy, Table 19. The Net Annual benefit is determined for each climate scenario (present day and 2030) is the difference between the Annual Expected Cost for enlarging the culverts and the Annual expected Cost for the as-is (no action) strategy. The B/C ratio is calculated by dividing the total discounted value of the benefits by the total discounted value of the costs (or the original investment). Consequently;

For the present Day Climate;

Net Annual Benefit = €181,000 - €137,464 = €43,536
B/C Ratio = (€176,500-€35,300)/€97,164 = 1.45

For the 2030 Climate;

Net Annual Benefit = €357,500 - €155,114 = €202,386
B/C Ratio = (€353,000-€52,950)/€97,164 = 3.09

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

Table 14: Total Average Yearly Costs (present climate)

Strategy	Maintenance & Serviceability Issues in €	Environmental effects in €	Societal Impacts & Requirements in €	Safety Constraints & Impacts in €	Total impact in €	Return period of threat	Annual average expected impact in €
As is / No action	190,000 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 15: Annual Average Expected Impact Costs (present climate)

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

Table 16: Total Annual Expected Impact Costs (present climate)

Strategy	Maintenance & Serviceability Issues in €	Environmental effects in €	Societal Impacts & Requirements in €	Safety Constraints & Impacts in €	Total impact in €	Return period of threat	Annual average expected impact in €
As is / No action	190,000 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 17: Annual Average Expected Impact Costs (2030 climate)

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

Table 18: Total Annual Expected Impact Costs (2030 climate)

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

Table 19: Net Benefit and B/C ratio

4.4.8 Examine and Interpret Outputs

Objective:
The objective of this step is to examine and interpret the outputs of the SEA evaluation in the overall context of the analysis.

Methodology:
The outputs of the evaluation are the costs and benefits associated with each of the two strategies under consideration and a comparison of the monetary benefits associated with enlarging the capacity of culverts against the ‘as is’ (do nothing) approach. At this point the results are assessed relative to the objective of the evaluation i.e is the strategy of enlarging culverts a suitable approach from an economic point of view relative to the do nothing strategy considering various socio-economic impacts?

Output:
The output from this stage should form the basis for the decision making process.

In assessing the B/C ratios it is worth noting that as a general rule of thumb, if the benefit is higher than the cost, undertaking that particular strategy represents a good investment. In both cases, of the present day climate and 2030 climate the Annual expected costs (i.e including benefit) are €137,464 and €155, 114 respectively, both higher than the annual average cost of €102, 164.

In the first instance it can be seen that the Annual expected costs, for both climate scenarios, for enlarging the culverts are less than the annual expected cost for the ‘do nothing’ approach.

Equally, a B/C ratio greater than 1 indicates a good investment and the higher the B/C ratio the better the investment. From Table 19, it can be seen that the B/C ratio for both climate scenarios for enlarging the culverts are both greater than 1. Also, for the 2030 climate the B/C ratio (3.09) is higher than the B/C ratio for the present day climate (1.45) –this implies that increasing the capacity of the culverts for the 2030 climate is the optimum investment choice. This is further highlighted in Table 16 and Table 18 where the Annual expected cost for enlarging the culverts is less than the cost for the do nothing approach. It is also worth noting that the conclusion from the Risk Assessment process, Section 4.2.2, indicated that culverts were most at risk for the future climate.

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

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

5 CONCLUSIONS

The purpose of adopting a Socio-Economic Analysis evaluation approach is to assist stakeholders in the decision making process in relation to the management of their drainage assets in the face of climate change.

This report, in the first instance, provides an overview of the Socio-Economic Evaluation Analysis approach developed as part of the CEDR funded WATCH project. The framework is structured in a step by step manner and the requirements for each step are described in terms of the Objective of the step, the Methodology required to carry out the step and the Output of the step.

Subsequently, implementation of the framework is demonstrated in detail through its application to the case study road, the M10 in Denmark.

The approach proposed is not prescriptive but rather recommendations are provided as how to approach each step, the evaluation method to be used and the selection of the key parameters.

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APPENDIX A – Links to Sample Data for Key Parameters

No.	Data Type	Parameters (Section 2.3.4.1 (c))	Country	Link	Description
1	Road Safety	Societal Impacts & Requirements; Safety Constraints & Impacts	Ireland	http://www.rsa.ie/en/RSA/Road-Safety/	Road Safety Authority Statistics (Collision Data etc.)
			Denmark	https://www.dst.dk/da/Statistik/emner/erhvervslivets-sektorer/transport/trafik	Statistics Denmark, a comprehensive public database for various statistics
			France	http://www.securite-routiere.gouv.fr/la-securite-routiere/l-observatoire-national-interministeriel-de-la-securite-routiere/series-statistiques/donnees-brutes	French Road Safety Observatory (ONISR) Database related to injury road traffic accidents (some data available in English)
			Netherlands	https://www.swov.nl/en/facts-figures/datasheet/road-map-road-safety-data	Database with road, traffic and accident characteristics in the Netherlands (available in English).
2	Traffic Data	Societal Impacts & Requirements; Potential Impacts on Operation of Wider Network; Environmental effects;	Ireland	https://www.nratrafficdata.ie/	Data collected from the TII traffic counters located on the National Road Network, including AADT, % HGV's & Coverage
				https://www.tiitraffic.ie/	Provides access to Live Traffic Information, live Travel times and live weather updates on the road network
				http://data.tii.ie/Datasets/	Data records of items such as, among others, Travel Times, Travel flow, Weather data, noise mapping, archaeology sites, road safety
			Denmark	https://trafikkort.vejdirektoratet.dk/	Maps of traffic flow
				https://www.dst.dk/da/Statistik/emner/erhvervslivets-sektorer/transport/trafik	Statistics Denmark, a comprehensive public database for various statistics
			France	http://trafic-routier.data.cerema.fr/vers-un-portail-de-connaissances-sur-les-donnees-a25.html	Database under construction Data on non-real-time traffic (only in French)
				https://ckan.cerema-dtm.fr/	Database providing links to real time traffic (only in French)
			Netherlands	https://www.anwb.nl/verkeer	Provides access to Live Traffic Information and live Travel times

No.	Data Type	Parameters (Section 2.3.4.1 (c))	Country	Link	Description
3	**Open Source Public Sector Data**	**Societal Impacts & Requirements; Potential Impacts on Operation of Wider Network; Environmental effects;**	Ireland	https://data.gov.ie/datasets	Contains data from various Public Sector services or 'themes' such as for example Transport, Environment, Finance and Agriculture, Fisheries. Datasets are available for items such as traffic information, a record of flooded roads, collisions, vehicle emissions, etc.
			France	https://doc.data.gouv.fr/	Open platform for French public data (some data available in English)
4	**Official Statistics Portal**	**Societal Impacts & Requirements; Potential Impacts on Operation of Wider Network; Environmental effects;**	Ireland	http://www.statcentral.ie/	Statistics produced by government departments and state organisations covering areas such as, among others, People and Society, Environment, Climate and Energy, Business sectors and the Economy
			France	https://www.insee.fr/fr/accueil	National Institute of Statistics and Economic Studies Statistics on the French economy and society (Available in English)
			Netherlands	https://opendata.cbs.nl/statline/#/CBS/en/	Statistics produced by the Central Bureau of Statistics covering areas such as, among others, Population, Nature and Environment, Traffic and Transport. The latter includes data on networks (km and other characteristics); traffic intensity, transport of goods & persons and vehicles. (partly available in English)
5	**Guideline & Reference document**	**Societal impacts & requirement; Safety constraints and Impacts; Environmental effects**	Netherlands	https://www.rwseconomie.nl/kengetallen	Database from Road Authority with recommended guidelines including standard (monetary) valuation numbers and relevant (Dutch) statistics on safety (number of accidents/ type of transport), accessibility, and environmental effects.

No.	Data Type	Parameters (Section 2.3.4.1 (c))	Country	Link	Description
6	**Guideline & Reference document**	**Costs/Benefits Associated with the System Itself and Cascading Effects Incurred as a Consequence of this System;**	Netherlands	https://www.rwseconomie.nl/documenten/rapporten/2016/augustus/augustus/externe-en-infrastructuurkosten-verkeer-in-nederland-2014	Guideline with standard numbers (i.e. based on value of time, value of a statistical life, ecosystem services) for estimating the costs and effects of infrastructure projects in the Netherlands, including standard numbers
				http://www.mkba-informatie.nl/mkba-voor-gevorderden/richtlijnen/aanvulling-op-de-leidraad-oei-directe-effecten/	Guideline and reference document on determining & monetising the direct effects of an infrastructure project.
				http://www.mkba-informatie.nl/mkba-voor-gevorderden/richtlijnen/aanvulling-op-de-leidraad-oei-indirecte-effecten-infrastruct/	Guideline and reference document on determining & monetising the indirect/ cascading effects of an infrastructure project on other markets.
7	**Guideline & Reference document**	**Availability & Adaptability**	Netherlands	https://www.cpb.nl/sites/default/files/omnidownload/CPB-Notitie-5dec2017-Hoe-omgaan-met-felxibiliteit-in-infrastructuurbeleid-en-mkbas-infrastructuur.pdf	Guideline on how to assess 'flexibility' (among others gradual investment over time& spatial reservation) of infrastructure in cost-benefit analysis of projects.
8	**Public Transport Data**	**Societal impacts & requirement; Safety constraints and Impacts; Environmental effects**	Ireland	https://data.smartdublin.ie/dataset/public-transport-nta	GIS mapping of the routes and route variants in the Dublin Bus route network, the Bus Eireann (i.e. Nationwide) route network and commercial bus operators route networks published by the National Transport Authority

No.	Data Type	Parameters (Section 2.3.4.1 (c))	Country	Link	Description
9	**Origin Destination Data**	**Societal Impacts & Requirements; Potential Impacts on Operation of Wider Network;**	Ireland	http://www.cso.ie/en/census/census2016reports/powscar/	Tabular Data on commuting practices
10	**Hazards (weather, floods etc.)**	**Technical Effectiveness (i.e. Performance) of the System**	Ireland	http://www.cfram.ie/pfra/interactive-mapping/	Flood maps for predefined catchment area for various return periods
				http://www.floodmaps.ie/	Information on reported/recorded flood events
				https://www2.metweb.ie/	Weather information for Ireland from Met Eireann, the The Irish Meteorological Service
			Denmark	http://www.dmi.dk/vejr/	Weather information and forecast from Denmark, The National Danish Meteorological Service
			France	http://www.georisques.gouv.fr/cartes-interactives#/	Interactive map on natural, mining and technological risks (only in French)
				https://www.vigicrues.gouv.fr/	Real time flood risk information service (only in French)
			Netherlands	http://www.klimaateffectatlas.nl	The atlas provides an initial impression of the (future) threats of flooding, water logging, drought, and heat
11	**Ordnance Survey Data, Land zoning**	**Land availability and Acquisition Issues;**	Ireland	https://www.osi.ie/	Geographic data with various mapping tools available (MapGenie, GeoHive etc.) from Ordnance Survey Ireland whose function is to create and maintain the definitive mapping records of the State
				http://www.myplan.ie/	Land zone maps of planning etc.
			Netherlands	http://www.nationaalgeoregister.nl/	Database with geographic data made available by cooperation between various public entities.
12	**Eurostat**	**Societal Impacts & Requirements**	Europe	http://ec.europa.eu/eurostat/data/browse-statistics-by-theme	Database of European Statistics in areas such as, among others, Population, Transport and Environment & Energy

No.	Data Type	Parameters (Section 2.3.4.1 (c))	Country	Link	Description
13	**Environmental Information**	**Environmental Effects**	Ireland/ Europe	http://www.epa.ie/irelandsenvironment/	Information and data from the Environmental Protection Agency (EPA) on Ireland and Europe's Environment covering topics such, among others, as air quality, land and soil and climate
			Ireland	https://gis.epa.ie/EPAMaps/	Interactive mapping of environmental data
				https://www.dccae.gov.ie/en-ie/environment	Information on the environment from the Department of Communications, Climate Action & the environment
			Denmark	http://www.miljoeportal.dk/myndighed/slutbrugerloesninger/Sider/default.aspx#slutbrugerGIS	GIS database, portal of environmental data
			France	http://www.eaufrance.fr/donnees/acceder-aux-donnees	List of databases related to water (underground water, wetlands, pollution data…)
				http://www.data.eaufrance.fr/	Public database on water
				http://www.statistiques.developpement-durable.gouv.fr/environnement/1097.html http://www.statistiques.developpement-durable.gouv.fr/donnees-ligne/t/eider-2.html	Department of Ecological and Economic Transition Data on habitat (water, air, nature, land use ...), resource management and waste, pressures and impacts of human activities on the environment. environment, natural and technological risks, the economy of the environment (accounts, jobs, training ...), opinions and practices, as well as international operations **EIDER** Database
				http://carmen.naturefrance.fr/	**CARMEN** database (CARtographie du Ministère de l'Environnement / Cartography of department of environment)
				http://geoidd.developpement-durable.gouv.fr/geoclip_stats_o3/index.php?profil=FR#l=fr;v=map1	Observation and Statistics Service / Service de l'Observation et des Statistiques (SDES) Interactive map **Géoïdd France** (geography and indicators on sustainable development) (only in French)
				http://geoidd.developpement-durable.gouv.fr/geoclip_stats_o3/index.php?profil=LITTORAL#v=map10;i=eau_qual_sta_lit.qualite_eau_baignade;l=fr	Observation and Statistics Service / Service de l'Observation et des Statistiques (SDES) Interactive map **GOID littoral** for coastlines (only in French)

No.	Data Type	Parameters (Section 2.3.4.1 (c))	Country	Link	Description
14	**Construction costs for Civil Engineering and Highway structures**	**Maintenance & serviceability Issues; Costs/Benefits associated with the System itself and cascading effects incurred as a consequence of this system; Procurement;**	UK	http://www.rics.org/ie/shop/Spons-Civil-Engineering-and-Highway-Works-Price-Book-2018-20686.aspx	Costs for both general and civil engineering works and highway work including labour, plant and material elements. Cost guidance is given at a number of levels, from the more general functional costs to detailed unit costs. *NOTE - this document is not freely available*

APPENDIX B – Assesment of Key Parameters

1. TECHNICAL EFFECTIVENESS OF SYSTEM (i.e. PERFORMANCE) OF THE SYSTEM			
Parameter Details	**Method of Assessment of Parameter**		
	Type	**Unit (if Applicable)**	**Description**
Rate of wear of system	Qualitative	N/A	Rank the speed at which the system is expected to wear
Ability of a network to continue to operate (even at partial capacity) in the event of an extreme climate event.	Qualitative	N/A	Rank operational levels of system
Maximum capacity of a system (useful in considering extreme climate events).	Quantitative	% / Volume (litres)	Max. water storage / attenuation of each system
Potential of system failure (and therefore flooding) of the network at a local and also wider level.	Qualitative	N/A	Rank likelihood of failure

2. MAINTENANCE & SERVICEABILITY ISSUES			
Parameter Details	**Method of Assessment of Parameter**		
	Type	**Unit (if Applicable)**	**Description**
Frequency, and scale, of predicted/required maintenance	Quantitative	€/year	Based on number of predicted/required services in a given year can determine total costs/year (from previous projects, suppliers etc.)
Costs of predicted/required maintenance: i. Replacement parts (as required) ii. Required manpower to carry out maintenance/upgrading of system iii. Potential Traffic Management measures that may be required iv. Impact of closing/restricting network in order to carry out maintenance.	Quantitative	€/Year	i. Costs for replacement parts should be available from supplier/fitter ii. €/hour (day/night) for each worker should be considered iii. €/hour for traffic management measures should be considered (e.g. road closures, rerouting) iv. €/hour for traffic management measures should be considered
Ease of Maintenance: i. Ease of Access to site that maintenance is required ii. Availability of replacement parts (as required)	Qualitative	N/A	Ranking system which ranks the levels of ease with which a potential drainage system could be assessed and maintenance carried out.

3. ENVIRONMENTAL EFFECTS			
Parameter Details	**Method of Assessment of Parameter**		
	Type	**Unit (if Applicable)**	**Description**
Air Pollution Levels	Quantitative	µg/m^3 per hour	Measurement device (e.g. Automatic Air Quality monitor). Using a desk top study information can be obtained from similar assessments, supplier etc..
Carbon Dioxide Emissions	Quantitative	Tonnes CO2	Measurement of extra CO2 emissions released. At the design phase information can be obtained from a desk top study of similar assessments.
Noise Pollution Levels	Quantitative	dB	Measurement device (e.g. decibel meter). At the design phase information can be obtained from a desk top study of similar assessments.
Impact on Natural Landscape	Qualitative	N/A	Ranking system which ranks the predicted impact on the surrounding natural landscape

4. SOCIETAL IMPACTS & REQUIREMENTS			
Parameter Details	**Method of Assessment of Parameter**		
	Type	**Unit (if Applicable)**	**Description**
Impacts on road users as a result of increased journey times in the case of queues and diversions on the route due to failure of system.	Quantitative	Hours	Increase in journey times; queuing times (Consider the 'Value of Time' concept)
Cascading effects on other roads in the vicinity (e.g. increased traffic on alternative roads)	Qualitative/Quantitative	N/A/Hours	Increase in journey times; queuing times (Consider the 'Value of Time' concept)
Effect on public transport network in the vicinity, especially in the event of failure of the system. i. Overuse of network ii. Public transport delays due to overcrowding on network iii. Public transport delays due to extra traffic on transport routes	Quantitative	% Increase / Number of Users	Assessed by comparing the user numbers of a transport system in a normal week compared with that generated in the week of a traffic event, with diversions in place; Or Compare the typical delays on the transport network in a normal week compared with the delays that arise in the week of a traffic event.
Level of confidence of the public and logistic transport companies in the ability of the road owner to deal with climate change impacts	Qualitative	N/A	Ranking system based on user Survey regarding the day to day operational issues relating to the road network
Impact on road network availability due to maintenance / replacement / rehabilitation works or traffic interruption.	Qualitative	N/A	Ranking system on operational levels

5. SAFETY CONSTRAINTS & IMPACTS			
Parameter Details	**Method of Assessment of Parameter**		
	Type	**Unit (if Applicable)**	**Description**
Impact on safety for road users (vehicles, cyclists, pedestrians) i. Reduction in safety of network, potentially due to queues on the network and diversions to less safe networks (Queues can result in small accidents, and therefore mainly material damage. Diversions to less safe routes may result in more severe accidents, with more severe consequences e.g. loss of life) ii. Reduction in individual driver safety, potentially as a result of aquaplaning and/or reduced visibility due to excess surface water on the pavement (and therefore a higher risk of accident).	Quantitative Quantitative / Qualitative?	% increase in accidents /€ % increase in accidents / N/A	i. Use collision data in the vicinity of a given site, or a similar site elsewhere for reference - for example, in Ireland, RSA (Road Safety Authority) Collision Data could be used. Could also assess this parameter by considering vehicle damage in monetary terms (average repair costs for previous collisions). ii. Use of data relating to collisions in the vicinity of a given site, or a similar site elsewhere for reference - for example, in Ireland, RSA (Road Safety Authority) Collision Data could be used.

6. POTENTIAL IMPACTS ON OPERATION OF WIDER NETWORK			
Parameter Details	**Method of Assessment of Parameter**		
	Type	**Unit (if Applicable)**	**Description**
Surrounding Routes: i. Potential knock-on effect on other roads in vicinity, especially the potential for increased traffic on these roads in the case that the original route becomes flooded.	Quantative	% Increase Number of Users/Delay times	Determine user numbers or delay times
Public Transport Network: i. Potential knock-on effect on public transport network in vicinity if road is closed (i.e need to use other modes of transport)	Quantitative	% Increase / Number of Users	Assessed by comparing the user numbers of a transport system in a normal week compared with that generated in the week of a traffic event, with diversions in place; Or Compare the typical delays on the transport network in a normal week compared with the delays that arise in the week of a traffic event.
Societal Consequences: i. Potential impacts on road users (commuters, hauliers etc.) as a result of increased journey times in the case of queues and diversions on the route due to failure of system. ii. Decrease in safety of network, potentially due to queues on the network and diversions to less safe networks. iii. Reduction in confidence of the public and logistic transport companies in the ability of the road owner to deal with climate change impacts.	Quantitative Quantitative Qualitative	Hours % increase in accidents / € N/A	i. Assessed by examining an increase in journey times; time in queue - considering the 'Value of Time' concept ii. Use data relating to collisions in the vicinity of a given site, or a similar site elsewhere for reference - for example, in Ireland, RSA (Road Safety Authority). Could also consider vehicle damage in monetary terms - perhaps by obtaining average repair costs for previous collisions. iii. Could possibly accumulate users opinions regarding the day to day operational issues relating to the road network, & apply a ranking system at this point.

7. RESILIENCE & ROBUSTNESS OF SYSTEM			
Parameter Details	**Method of Assessment of Parameter**		
	Type	**Unit (if Applicable)**	**Description**
Robustness of System: i. Actual capacity of system plays a part in determining its robustness in the case of an extreme weather event.	Quantitative	% / Volume (litres)	Max. water storage / attenuation of each system
ii. Level of ability of a system to withstand non- weather related extreme (once-off) events, e.g. natural disaster	Quantitative	Depends on event type	System capacity calculation for extreme event intensity
Resilience of System: Adaptation ability of a system to cater for a scenario that arises elsewhere in the network, and has a knock-on impact on the system in question, e.g. failure of an adjacent drainage system	Quantitative	Depends on system parameter being assessed	System capacity calculation (deterministic or probabilistic)

8. COSTS/BENEFITS ASSOCIATED WITH THE SYSTEM ITSELF AND CASCADING EFFFECTS INCURRED AS A CONSEQUENCE OF THIS SYSTEM			
Parameter Details	**Method of Assessment of Parameter**		
	Type	**Unit (if Applicable)**	**Description**
Costs/Benefits incurred by the NRA:			
i. Reduction/Increase in revenue amounts accrued by an NRA (through tolls, etc).	Quantitative	€	i. Assess by comparing the revenue generated in a normal week compared with that generated in the week of a traffic event
ii. Costs of implementing adaptation measure:			ii.
a. Design Costs	Quantitative	€	a. Fees for an engineer/contractor to design a given drainage system.
b. Construction Costs	Quantitative	€	b. Cost to construct a system.
c. Costs of employing required manpower for job	Quantitative	€	c. €/hour for each worker.
d. Traffic management costs	Quantitative	€	d. €hour cost for personnel, signage etc.
iii. System maintenance and service costs:		€	iii.
a. cost of replacement parts	Quantitative	€	a. Consider average cost per year to maintain and service each system.
b. cost (& frequency) of required inspections (routine and otherwise)	Quantitative		b. Could collect data from suppliers/fitters regarding part costs.
iv. Cost of repair/mitigation measures post-failure of system in place at the time.	Quantitative		iv. Cost of replacement parts, labour, comparing to previous projects etc.

8 (Cont.) COSTS/BENEFITS ASSOCIATED WITH THE SYSTEM ITSELF AND CASCADING EFFFECTS INCURRED AS A CONSEQUENCE OF THIS SYSTEM			
Parameter Details	**Method of Assessment of Parameter**		
	Type	**Unit (if Applicable)**	**Description**
Costs/Benefits incurred elsewhere/by people other than the NRA:			
i. Time Lost/Extra Time spent in queues/diversions by road user – 'Value of Time' concept.	Quantitative	Hours	i. Assess by examining increase in journey times; time in queue - considering the 'Value of Time' concept
ii. Extra running costs incurred by each road user as a result of delays, e.g. increased fuel usage, wear of parts and materials.	Quantitative	€	ii. Assess by comparing the typical fuel usage along the normal route, with the required extra fuel usage along the route that diverted traffic follows in the case of a traffic event.
iii. Loss of pass-by trip revenue for businesses along a now closed route that traffic has been diverted away from.	Quantitative	€	iii. Assess by comparing the revenue generated by the businesses in a normal week compared with that generated in the week of a traffic event
iv. On the other hand, potential increase in pass by trip revenue for businesses along a route that traffic has been diverted along and wouldn't otherwise traverse.	Quantitative	€	iv. Assess by comparing the revenue generated by the businesses in a normal week compared with that generated in the week of a traffic event
v. If an adaptation measure is implemented effectively, the likelihood of flooding is greatly reduced (and therefore consequences are also drastically reduced).	Quantitative	€	v. Assess by comparing the financial outlay in the case of a flooding event, along with that if an event does not occur (delays, repair to infrastructure, etc.)

9. AVAILABILITY & ADAPTABILITY OF SYSTEM			
Parameter Details	**Method of Assessment of Parameter**		
	Type	**Unit (if Applicable)**	**Description**
Availability of System:	Quantitative	€	Inability to procure a locally readily available system may result in increased costs, programme delays etc.
Adaptability of System	Qualitative	N/A	A ranking system could be used to identify whether the system is easily adaptable to a particular maintenance or upgrade of an existing system.

10. LAND AVAILABILITY & ACQISATION ISSUES			
Parameter Details	**Method of Assessment of Parameter**		
	Type	**Unit (if Applicable)**	**Description**
Financial cost of acquiring land (CPO, etc.)	Quantitative	€	Consider typical land values in the area
Potential time loss at land acquisition stage of negotiations.	Quantitative	€	Consider 'Value of Time' concept - perhaps look at land sales that have taken place recently in the vicinity (if possible) and get an idea of typical delays that may occur.
Areas of archaeological/architectural interest and/or ecological significance located in the vicinity of the site which might have an impact on any potential development.	Quantitative	€	Delays that might be incurred in the case of discovery of one of these areas (value of time concept). Financial implications of mitigation/avoidance as required

11. PROCUREMENT			
Parameter Details	**Method of Assessment**		
	Type	**Unit (if Applicable)**	**Description**
Administrative cost of procurement process	Quantative	€	Estimate of costs of undergoing a procurement process