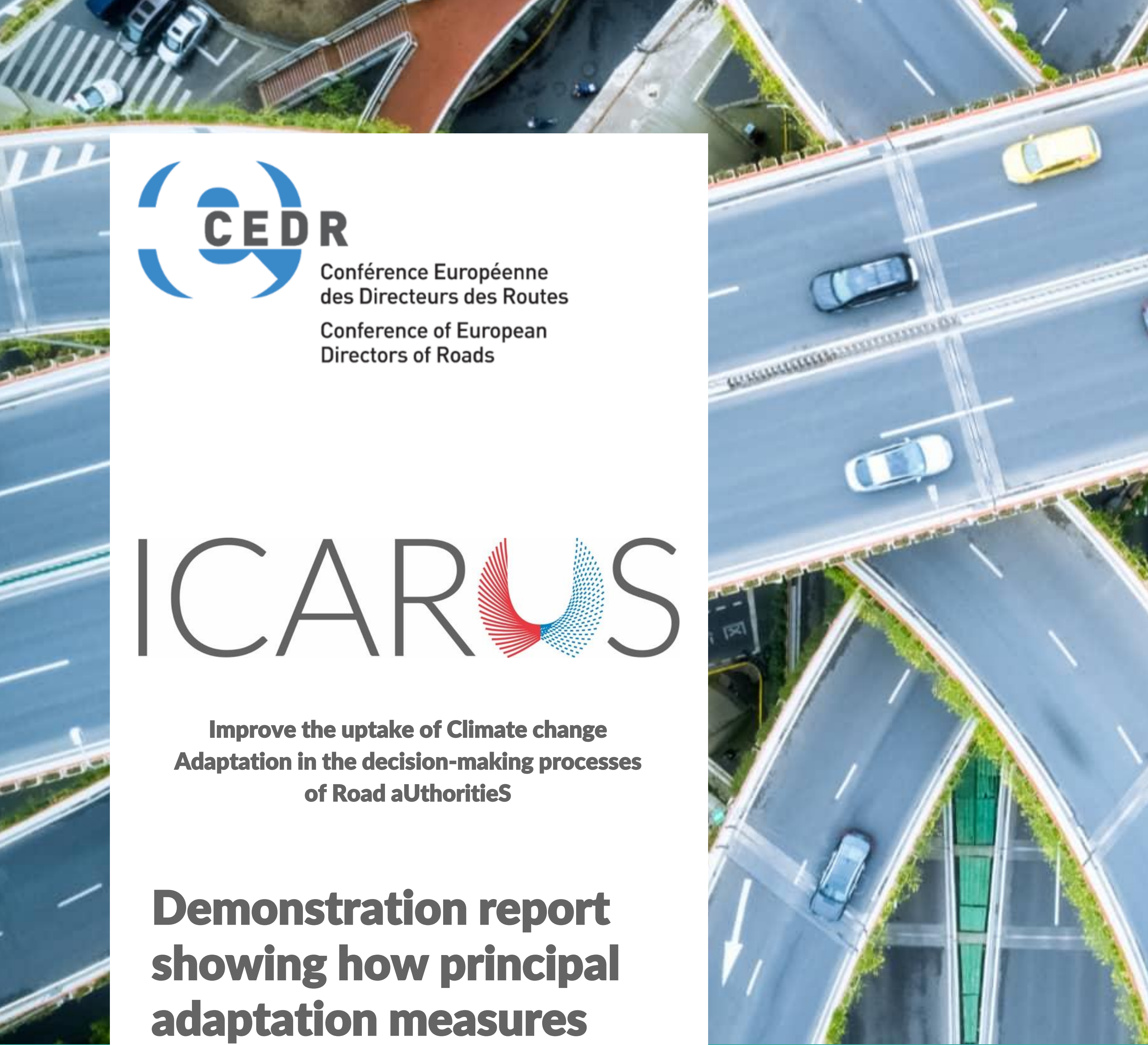

Conférence Européenne des Directeurs des Routes

Conference of European Directors of Roads

ICARUS

Improve the uptake of Climate change Adaptation in the decision-making processes of Road aUthoritieS

Demonstration report showing how principal adaptation measures can be evaluated

Deliverable D3.2 Version 1.0

June 2024

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CEDR call 2021: Climate Change Resilience

Deliverable D3.2 Version 1.1

Demonstration report showing how principal adaptation measures can be evaluated

June 2024

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Summary

While the significance of resilience and climate change adaptation is well understood, practical implementation remains a challenge. Integrating climate change adaptation into decision-making processes can be complex, often resulting in a gap between knowledge and action.

This report supports the implementation of climate change adaptation within NRAs processes by providing guidance on what implementation of adaptation means in practice. This is done by case studies and practical examples. In these examples we demonstrate how the approaches as described in earlier deliverables within the ICARUS project can be executed and used.
These practical examples describe how to define adaptation options and demonstrate how optimum service levels can be determined.

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This guideline demonstrates the application of 10 key adaptation measures with concrete descriptions regarding (i) guidance on their implementation, (ii) how costs, benefits and co-benefits can be evaluated and (iii) best practices.

Subsequently, this report is followed by an example which demonstrates how to determine which adaptation options can be considered based on a cost-effectiveness analyses. . The example makes use of minimum service levels for evaluating resilience and adaptation options based on quantification and valuation of associated costs and wider benefits. It also describes the difficulties for implementation which include how to deal with uncertainties (e.g. time horizons, different climate scenarios and uncertainties in economic valuation). It is recommended to account for these uncertainties by describing them or combining them with decision-making under (deep) uncertainty approaches.

Finally, this guidance provides practical guidance regarding the communication of the results. Within the NRA, three different audiences have been identified previously and are included in the implementation plan; these are strategic, tactical, and operational. The key objective is to ensure that there is awareness of the ICARUS project, the resources available, and links to other resources (e.g. previous CEDR projects, PIARC, national strategies). The different audiences should be involved at the different stages of implementation and by making use of different means. This includes narratives/storylines, good visualisation and access to the different data sources regarding the resilience assessment, as well as the effect of adaptation options.

Table of Contents

1 INTRODUCTION

This demonstration report is compiled to provide both a synthesis and a demonstration of the results of Work Package 2: Adaptation and Resilience Measures and Work Package 3: Appraisal Methodologies, Benefits and Costs developed in the ICARUS project. The purpose of the report is to provide practical guidance for the NRAs, on what implementation of adaptation means in practice. This is done by case studies and practical examples.

The report provides guidance on the following topics:

- Application of 10 key adaptation measures of guideline D2.2 with concretised descriptions regarding (i) guidance on their implementation, (ii) how costs, benefits and co-benefits can be valued and (iii) best practices. The key adaptation measures are chosen to show the variety of options over different stages of the project life cycle: Nature-based Solutions (NbS) as well as "grey" options, and opportunities for emerging technologies.
- The second topic discussed in this deliverable is how to define and use minimum service levels for evaluating resilience and adaptation options based on quantification and valuation of associated costs and wider benefits (input from T2.2 and T3.2 via D2.2)
- Finally, guidance is given regarding the communication of the results. Whilst the ICARUS project will have training as part of the deliverables, ultimately, many of the results of the projects and the learnings will need to be communicated internally within NRA organisations. Here we describe key considerations as to what should be communicated, to whom and by whom.

These practical applications fit the ICARUS framework at different stages, as described in Figure 1.1 where they are described as part of the ICARUS framework and in relation to the other ICARUS deliverables.

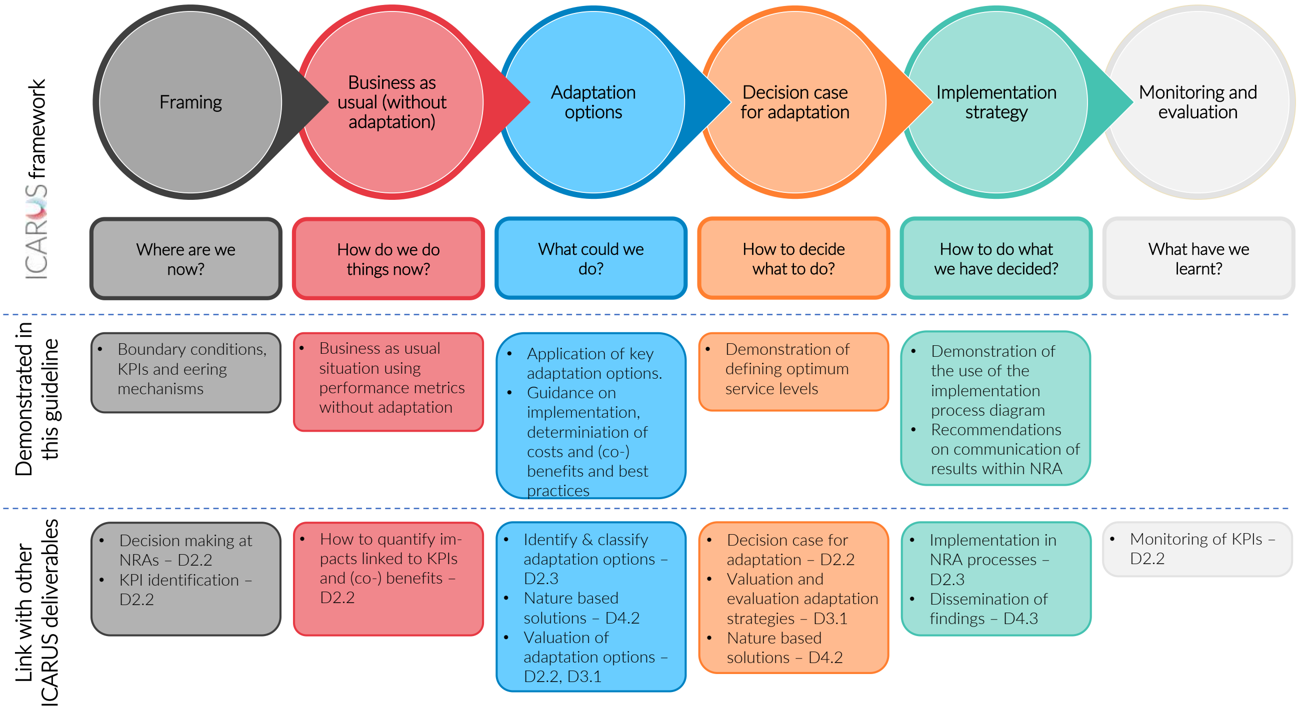

Figure 1.1Overview of the steps in the ICARUS framework regarding decision-making and implementation of climate adaptation at NRAs, as well as how these different steps are addressed in this deliverable and covered by the other ICARUS deliverables.

1.1 Key messages of previous ICARUS guidelines

This demonstration report builds upon previous deliverables within the ICARUS project. Following from Deliverable 2.2 (Guidelines on using performance metrics to make the case for adaptation) and Deliverable 2.3 (Guidelines providing an overview of and characterisation of adaptation options, with recommendations on implementation) several recommendations were given for implementation. These can be summarised into four main points:

1. Decision-Making at NRAs:

When implementing climate change adaptation at NRAs it is important to understand the steering mechanism and decision criteria used by the NRA (e.g. is the NRA decision-making based on service-driven, budget-driven, optimum-service-driven or policy-driven measures). Research may be necessary to understand how climate change impacts the KPIs, that are used for monitoring the performance of the road network. If climate events, let alone climate change, are not reflected in the KPIs, it generally won't be possible to make a case for adaptation, since climate events won't lead to a lower measured performance of the road. When it is not understood how climate change affects the performance of the KPIs, it won't be possible to underline in the resilience assessment how climate change will lead to a lower performance.

One other thing of high importance is to ensure that climate change adaptation finds its way into the daily processes of NRAs. Many different NRA staff members have an active role and different layers of the organization should be engaged. This ranges from continuous shifts between strategical decisions at the strategical level, practical assessments at the tactical level and key input from the operational level. Engagement at all levels is a prerequisite for successful implementation. It is recommended to have one person in charge of the entire process. This person should be able to interact clearly with the other two levels. This should then also be communicated effectively across the different levels of decision-making (strategic, tactical, operational).

2. Using Performance Metrics for Climate Adaptation:

In the resilience assessment and appraisal of adaptation options performance, metrics should be used and be connected to the KPIs (see category before). This means that KPIs should be translated into benefits and co-benefits such that these are tangible and can be quantified in feasible metrics. Also, thresholds should be identified to be able to include climate hazards effectively in KPIs, which is needed to justify the need for climate change adaptation.

3. Gaining Insight into Adaptation Options:

When identifying adaptation options, consider that valuation and appraisal of adaptation options inherently introduces uncertainty. The accuracy depends on the necessary level of detail for implementation, but also on available resources. To limit uncertainty, it is important to choose appropriate baseline scenarios to be able to contextualize the results.

4. Making the Case for Adaptation:

There are three methods to make the case for adaptation. Method 1 involved? linking the KPIs with climate hazards. This will enable NRAs to understand how climate hazards impact on road performance. Based on this the adaptation needs can be determined to anticipate future changes (this is related to recommendations 1 and 2). Method 2 focuses on changing the guidelines to incorporate climate change adaptation based on optimizing costs, benefits and co-benefits. Method 3 focuses on project-specific adaptation and is closely interlinked with Method 2, because it addresses adaptation needs based on project context, considering political factors, past climate events, and stakeholder involvement. The project-specific adaptation should provide the necessary evidence to be able to adapt the guidelines wisely.

This demonstration report builds upon these recommendations which aim to enhance decision-making and promote effective climate adaptation strategies. In this Demonstration Report, we will provide tangible and practical examples of how to build a case for adaptation with a focus on changing guidelines based on project-specific output.

1.2 Reading Guide

This demonstration report consists of three main parts. Chapter 2 describes a demonstration of how adaptation options can be detailed and assessed. This demonstration provides 10 key principle adaptation and resilience options (as described in D2.3). These will also include examples of Nature-based Solutions and are used for a wide domain of external threats as described by the climate impact drivers (Deliverable 1.1).

Chapter 3 demonstrates how to define which adaptation options are suitable and how to define an optimum service level based on a example situation. It is followed by a description of how the implementation process (D2.3) can be used effectively (Chapter 4).

This demonstration report ends with the communication of results internally at the NRA to ensure uptake by the NRA at all different levels (Chapter 5).

2 ASSESSMENT OPPORTUNITIES OF ADAPTATION OPTIONS

In this chapter, a demonstration of how a selection of adaptation options may be evaluated is provided, along with guidance on case studies and examples for each adaptation option. The adaptation options are selected from the database of adaptation options developed for ICARUS Deliverable 2.3 (de Paor et al, 2024). They are chosen to provide a broad overview of different types of adaptation options including Nature-based Solutions (NbS), grey measures and those where emerging technologies (EmT) can contribute. Each adaptation option is analysed with respect to how they may be evaluated. This evaluation can consider costs, benefits and co-benefits as described in ICARUS Deliverable 2.2 and can help inform the business case for adaptation (Bles et al., (2023)). The examples are chosen and written such that NRAs will be able to do similar analyses for other adaptation options when these are identified as appropriate for assessing to increased resilience of the road network.

Additionally, case studies and examples of implementation are also provided to demonstrate to NRAs how adaptation may be implemented.

2.1 Selection of Example Adaptation Options

10 adaptation options were selected from the database of adaptation options, and these will be described in further detail in Section 2.2 where more detailed guidance on their implementation is provided. A concerted effort was made to choose a variety of adaptation options to address a range of climate impact drivers. In addition, an assortment of Nature-based Solutions (NbS), “grey” options and those with potential emerging technologies (EmT) were selected which may be implemented at different stages of the project life cycle.

The selected adaptation options are shown in Table 2.1.

Table 2.1 Example Adaptation Options Selected with some key information from the database of adaptation options in ICARUS Deliverable 2.3 (de Paor et al, 2024)

Example No.	CID	Impact on Infrastructure	Adaptation Measure	Asset Type	Asset Scale	Road Project Life Cycle Stage	Impact Chain Stage	NbS	EmT
1.	Heat and Cold - Frost (Extreme Event)	04-4 Instability / subsidence of roads by thawing of permafrost	Monitoring to detect potential problem areas, establish cause-impact relationships; maintain specific construction and maintenance records	Pavements: bituminous, concrete, semi-rigid	Network	Operation and Maintenance	Exposure	N	Y
2.	Wet and Dry - River Flood (Extreme Event)	01-1 Flooding of road surface due to failure of flood defence of rivers and canals due to snowmelt or rainfall	Improve forest management in the catchment area	Geotechnics, including landslips and rock falls, cuts	Object - Connection - Network	Construction	Impact	Y	Y
3.	Wet and Dry - Heavy Precipitation and pluvial flood (Extreme Event)	01-2 Pluvial flooding (overland flow after precipitation, increase of groundwater levels, increase of aquifer hydraulic heads) due to extreme rainfall events	Resize drainage systems to meet threats	Drainage of earthworks and pavements, sewers	Object - Connection - Network	Construction	Vulnerability	N	N
4.	Wet and Dry - Heavy Precipitation and pluvial flood (Extreme Event)	02-1 Overloading of hydraulic systems crossing the road causing erosion of road embankments and foundations due to extreme rainfall	Inspect and clean watercourses regularly	Geotechnics, including landslips and rock falls, cuts	Object	Operation and Maintenance	Vulnerability	N	Y

Example No.	CID	Impact on Infrastructure	Adaptation Measure	Asset Type	Asset Scale	Road Project Life Cycle Stage	Impact Chain Stage	NbS	EmT
		events (heavy showers, long periods of rain)							
5.	Wet and Dry – Landslide (Extreme Event)	03-1 External slides affecting the road following extreme rainfall events and after drought	Cutting back the slope to a shallower angle	Geotechnics, including landslips and rock falls, cuts	Network	Construction	Vulnerability	Y	N
6	Wet and Dry - Wildfire Conditions (Extreme Event)	Lower visibility for users. Increased risk of respiratory illnesses for employees working near fires due to release of toxic gases.	Mowing of verges	All road infrastructur e	Network	Operation and Maintenance	Vulnerability	N	Y
7	Wet and Dry - Wildfire Conditions (Extreme Event)	Loss of mechanical properties of the pavement material.	Changing land use in the proximity of the road to other vegetation	All road infrastructur e	Network	Planning and Detailed Design	Exposure	N	N
8.	Wind - Tropical Cyclone (Extreme Event)	Road signs damaged or fallen trees and other obstacles blocking the road, power lines damaged, bridge cables damaged, Unexpected dynamic behaviour in bridges	Protection of wind exposed road sections and assets with planted forests and other vegetation.	All road infrastructur e	Connection - Network	Construction	Exposure	Y	N

Example No.	CID	Impact on Infrastructure	Adaptation Measure	Asset Type	Asset Scale	Road Project Life Cycle Stage	Impact Chain Stage	NbS	EmT
		(suspension cables, piers, ...) Uncomfortable road use and risk of accidents for tall vehicles and trucks.							
9.	Snow and Ice - Heavy Snowfall and Ice Storm (Extreme Event)	06-7 Loss of driving ability due to icing and snow	Supplying heat to the pavement, harvested in summer and stored underground	Pavements: bituminous, concrete, semi-rigid	Connection	Initial Proposal Stage	Vulnerability	N	Y
10.	Coastal and oceanic -Sea level rise (Slow-onset processes and trends)	02-3 Bridge scour due to sea level rise, extreme wind speed, wind direction, and extreme rainfall events	Install jetties to support the slope or protect bank from erosion	Geotechnics, including landslips and rock falls, cuts	Object - Connection	Construction	Vulnerability	potential	Y

2.2 Description of Selected Adaptation Options

A description of each of the chosen database options is provided in this section with additional detail on associated benefits and co-benefits and examples of how they may be implemented in practice in the future. As explained in ICARUS Deliverable 2.2 (Bles et al., (2023)) we make a distinction between benefits and co-benefits. Benefits are linked to the primary objectives of the NRA, often expressed in KPIs. The co-benefits are linked to other policies that may also influence the decision-making process. The adaptation options presented here may also be combined with other measures in the database to support adaptation to multiple climate impact drivers or of different infrastructure types.

2.2.1 Example 1a: Monitoring to detect potential problem areas

Adaptation option		Monitoring to detect potential problem areas with instability
Climate Impact Driver		Heat and Cold - Frost (Extreme Event)
Critical contextual information		Instability / subsidence of roads by thawing of permafrost affecting pavements (bituminous, concrete and semi-rigid) with an impact on the asset scale while measuring on a connection/network scale.
Effectiveness of adaptation option		Monitoring techniques like: Thermokarst observation, Surface characteristics monitoring, and remote sensing applications. This will provide crucial data for terrain susceptibility assessments and environmental considerations. • helps road authorities make informed decisions regarding route planning, construction techniques, and ongoing maintenance. • provides crucial indicators of permafrost degradation, enabling road authorities to assess potential risks and vulnerabilities in specific terrains. • presents precise data necessary for designing adaptable infrastructure or planning maintenance. • Assists in developing strategies for the long-term resilience of roads by simulating early consequences of climate change on asset/connection/network level.
Involved NRA process and typical NRA guidelines		NRA can use the monitoring information to make informed decisions about route planning, construction techniques, and ongoing maintenance to ensure the resilience and longevity of roads in permafrost-affected areas.
Best practices		Establishing a comprehensive monitoring network to track permafrost conditions, integrating data from diverse sources as discussed in the case studies [1-6] helps in utilizing this information for risk assessments, and vulnerability mapping. Also, all involved stakeholder engagements are crucial for better-informed decision-making and adaptive management strategies, ensuring resilient infrastructure development in permafrost-affected areas.
Lifetime of adaptation option		During operating and maintenance life. To maintain throughout the life of the infrastructure and as a basis for future decisions.
Dependencies with other developments		-
Valuation	Cost	Costs can vary widely based on the scale of the monitoring network, the complexity of data analysis, the frequency of surveys, and the use of advanced technologies. Yet, the use of remote sensing technologies, such as LIDAR and high-resolution satellite imagery, may contribute to higher upfront costs but could potentially reduce long-term expenses.
	Benefit	Benefit 1: Improved Durability and structural integrity. <u>Effect or expected outcome:</u>

		Reduction in frequency and level of replacement/ upgrading needed due to loss of the structural bearing capacity of the infrastructure and damage of the material properties due to thawing. Parameter for assessing magnitude of effect: hours worked, units of material, fuel machine hours. Possible means of Measurement: Wages, hours of service loss, machinery and materials needed. Possible means of valuation: infrastructure durability, number of distresses and/or failures per year (i.e).
		Benefit 2: Contribution to climate change positively through early permafrost thawing detection. Effect or expected outcome: LOC in the air quality. Parameter for assessing magnitude of effect: Variation in the volume of greenhouse gasses released to atmosphere/temperature change record. Possible means of Measurement: atmospheric observations Possible means of valuation: Identification of the total Global Warming Potential (GWP) change.
	Co-benefit	Photographs and visual aids serve as powerful tools for communicating the impacts of permafrost degradation to a broad audience, including policymakers, stakeholders, and the public raising awareness and gaining support on the need for acting.
Relevant data and data sources		(Zeng et al., (2022)), (Wieczorek et al., (2009)), (Boike et al., (2021)), (Osterkamp et al., (2000)), (US, (2003))

2.2.2 Example 1b: Maintain specific construction and maintenance records

Adaptation option	Maintain specific construction and maintenance records
Climate Impact Driver	Heat and Cold - Frost (Extreme Event)
Critical contextual information	Instability / subsidence of roads by thawing of permafrost or groundfrost affecting pavements: bituminous, concrete, semi-rigid and with impact on the network scale.
Effectiveness of adaptation option	Integrating accurate modelling, proactive intervention strategies, and consideration of diverse scenarios enables NRA to identify the pivotal processes leading to accelerated thaw rates and road failure and thus make better decisions to enhance infrastructure resilience Benefits: • active ground cooling can help prevent or significantly mitigate the impacts of permafrost or groundfrost on infrastructure, reducing the likelihood of road failures and associated maintenance costs. • Identifying lateral destabilization processes and employing simulation models enables the implementation of measures to take place before critical levels of permafrost degradation are reached, preventing irreversible damage. • the maintenance and construction records are pivotal for optimizing strategies and making better informed decisions in the face of changing climate conditions, saving time and cost.
Involved NRA process and typical NRA guidelines	NRA can use measures to reduce emergency repair costs, extend the lifespan of roads, and strategically allocate resources based on vulnerability assessments.
Best practices	• Maintaining a well-organized library of infrastructure records to aid decision-making. • Ensuring accurate modelling manners to consider highly reliable interpretations.

Lifetime of adaptation option		During operating and maintenance life. To maintain throughout the life of the infrastructure and as a basis for future decisions.
Dependencies with other developments		-
Valuation	Cost	• Keeping specific construction and maintenance records can be very difficult in remote Arctic regions (or in other regions exposed to very extreme conditions).
	Benefit	Benefit 1: Durability <u>Effect or expected outcome:</u> changes in the emergency maintenance costs, frequency of road failure, and effectiveness of resource allocation. <u>Parameter for assessing magnitude of effect:</u> Material savings, labour needed, machinery, time. <u>Possible means of Measurement:</u> costs of material, wages, degree of intervention <u>Possible means of valuation</u>: Condition of infrastructure, time of recovery, Period of loss of service
		Benefit 2: Availability and accessibility. <u>Effect or expected outcome:</u> Change in the time needed for decision-making and intervention. <u>Parameter for assessing magnitude of effect:</u> LOS, travel time, change of traffic flow. <u>Possible means of Measurement:</u> serviceability of network <u>Possible means of valuation:</u> Condition of infrastructure, time of recovery, time of loss of service Benefit 3: Safety <u>Effect or expected outcome:</u> Maintain an acceptable level of safety. <u>Parameter for assessing magnitude of effect:</u> identifying patterns, high-risk areas, and common causes of incidents. <u>Possible means of Measurement:</u> Conduct regular safety audits and assessments of the road infrastructure. <u>Possible means of valuation:</u> Incident data analysis
	Co-benefits	• By addressing vulnerabilities early on, the need for large-scale and reactive interventions is reduced. This ensures a better manner of resource allocation and noticeable savings. • Critical component of transportation infrastructure has their stability better ensured through less risk of accidents and hazards associated with sudden failures enhancing public safety
Relevant data and data sources		(Trofimenko, et al., (2017)), (Varlamov et al., (2022)), (Boike et al., (2021)), (Jiang et al., (2020)), (Scheer, et al., (2024)), (Allard et al., (2024)), (Doré et al., (2022)

2.2.3 Example 2: Forest Management in the Catchment Area

Adaptation option	Forest Management in the Catchment Area
Climate Impact Driver	Wet and Dry - River Flood (Extreme Event)
Critical contextual information	Flooding of road surface due to failure of flood defence of rivers and canals due to snowmelt or rainfall. An associated impact on roads with embankments will be the potential for landslips and rock falls where there are prolonged periods of heavy rain.

		This affects the road at a connection level if the road is blocked by small flooding or a landslip or at the network level if there is wider flooding. Forest management involves planting appropriate trees which will reduce the impact risks through the following process: • Tree roots physically anchor the soil, reducing the risk of landslips. • The presence of trees will also reduce the rate at which rainfall hits the ground as it hits leaves, branches and twigs. • Fallen leaves/needles on the forest floor can hold some water to reduce the rate of water infiltration. • In the growing season, trees will remove water from the soil through evapotranspiration. The presence of tree roots, fallen leaves and branches will physically slow the flow of water on hills into rivers and streams and spreads the time for rainfall entering the river.
Effectiveness of adaptation option		Likely to be effective where a specific risk has been identified. If used as a solution where few or no trees exist presently, recognise that it will take some years to become established. There are processes around AI and machine learning that can optimise the solution. Slowing of rainwater/snowmelt and reduced flow of water into streams/rivers improves availability by reducing the likelihood of flooding blocking roads, improves infrastructure safety and increases the resilience of the road network. Physical stabilisation of soil/ground from trees reduces the risk of landslides improving infrastructure safety and increasing the resilience of the road.
Involved NRA process and typical NRA guidelines		NRAs have guidelines for the management of trees and vegetation on their soft estate (verges and embankments) but this will go beyond the road envelope and require specialist forest and land management. The NRA is also unlikely to own the land in question.
Best practices		The use of 'off-road' measures to enhance resilience is relatively new and little in the way of good practice has been published. The concept of whole catchment area planning to reduce flood risk, rather than concentrating on individual schemes would be relevant in this area.
Lifetime of adaptation option		Unlike hard engineering solutions, with a specified design life (and associated maintenance schedule), forest management is an ongoing process and whilst individual trees will grow at different rates, and some will die or require felling, overall the forest can be maintained over time.
Dependencies with other developments		Whilst forest management should slow rainfall onto the road, it will not eliminate it, therefore, the requirement for adequate road pavement drainage and appropriate maintenance of the drainage remains.
Valuation	Cost	The cost of purchasing or leasing the land will vary considerably depending on the location. The cost of planting young trees is relatively low although it will take some time before the benefits are realised. The failure rate of young trees can be quite high, so there might be some requirement for replanting the early stages. Forest management costs

		will also be relatively low, especially as the forest matures and offers opportunities for timber products to be harvested.
	Benefits	Benefit 1: Ecosystem Services Effect or expected outcome: Biodiversity net gain. Parameter for assessing magnitude of effect: Level of Change in biodiversity. Possible means of Measurement: Record the change of diversity through its richness (numerical value of genetically or functionally related individuals' groups) and evenness (of the different species or functional groups' relative abundance present in an area).(Louis Specht & Specht, 2013) Possible means of valuation: Value of Biodiversity index Benefit 2: Accessibility Effect or expected outcome: better water management to reduce effects on traffic flow and (LOS) Level of service. Parameter for assessing magnitude of effect: Level of change: How much is the travel time expected to change, and what is the volume of vehicles affected? Possible means of Measurement: Traffic models estimating travel time under normal and disruptive conditions. Environmental assessments tracking changes in green cover. / Surveys or community feedback on perceived improvements Possible means of valuation: Estimates on the value of travel time. / Cost savings from unneeded maintenance. Benefit 3: Job Opportunities Effect or expected outcome: Creation of demand for specialists in forest and land management in addition to timber harvesting investments. Parameter for assessing magnitude of effect: Quantity of jobs created, availability of business lines, Potential for forest products from ongoing management. Possible means of Measurement: Statistical observation data from government labour statistics, industry reports, or job market platforms. Possible means of valuation: periodic updates on the employment status fulfilled. Benefit 4: Safety Effect or expected outcome: Reduction of flooding events on the nearby infrastructure. Parameter for assessing magnitude of effect: Risks associated with infrastructure use. Possible means of Measurement: Number of affected users, frequency of flood accidents Possible means of valuation: Value of statistical life Benefit 5: Climate Change Effect or expected outcome: Carbon Sequestration through the forest's natural behaviour and prevention of uncontrolled wildfires that release large amounts of carbon into the atmosphere. Parameter for assessing magnitude of effect: Measure changes in greenhouse gases (GHGs) periodically Possible means of Measurement: remote sensing measurements to monitor the effects of forest disturbances and changes in land cover.

		Possible means of valuation: Evaluate the quantity of carbon sequestered in both vegetation and soils, along with the associated emissions and removals of greenhouse gases (GHGs).
	Co-benefits	Potentially negative embodied carbon Biodiversity benefits Recreational benefits such as walking, biking or equestrian trails Potential for coppicing for biofuel or forest products from ongoing management. Potential uplift in land value following forestation Potential revenue opportunities for NRA by partnering with commercial operators to monetize forest environment, e.g. cycle hire, horse trekking, café/restaurant.
Relevant data and data sources		(Hall & Cratchley, 2005), (Connell, 2004), (Cooper et al., 2021)(Phillips et al., 2022) (Mitchell et al., 2017)

2.2.4 Example 3: Resize drainage systems to meet threats

Adaptation option	Resize drainage systems to meet threats
Climate Impact Driver	Wet and Dry - Heavy Precipitation and Pluvial Flood (Extreme Event)
Critical contextual information	Road drainage plays a crucial role in preventing flooding by managing the flow of water on and around roads. Proper road drainage systems are designed to collect, channel, and redirect rainwater, preventing it from pooling on the road surface or surrounding areas. Drainage systems are routinely designed for a particular design life to respond to a specific return period of flood events. Failure to maintain sufficient drainage systems can lead to localized flooding at the asset and connection level, which leads to further impacts at the network level. In recent years, the flood event considered in design has been enhanced to consider climate change related increases in rainfall and associated pluvial flooding. In some instances, even these predictions are inadequate and further increases in drainage sizing may be required. Some examples of specific elements which may be enhanced include: 1. Surface Water Drainage: Road drainage systems such as gutters, ditches, and curbs that collect rainwater running off the road surface. 2. Stormwater Drains: In urban areas, stormwater drains are installed to collect rainwater from roads and direct it into the municipal stormwater management system. 3. Culverts and Bridges: Roads often cross natural watercourses. Culverts and bridges are designed to allow the natural flow of water beneath the road, preventing blockages and facilitating the movement of water during heavy rain. 4. Retention Basins: Some road drainage systems include retention basins or detention ponds, which temporarily hold excess water during heavy rainfall. These may also be enlarged during design for additional capacity. 5. Permeable Pavements: In some cases, permeable or porous pavements are used to allow water to pass through the road surface and be absorbed into the ground below. This can help reduce surface runoff, assisting the drainage systems described above.

Effectiveness of adaptation option		This approach is considered a direct "grey" solution which may effectively remove the vulnerability of road connections to this hazard. When the return period and climate safety factor are appropriately considered, and the drainage channel is maintained sufficiently, this option effectively removes the risk of flooding. Significant reduction in flood risk versus other adaptation options. This assists in meeting KPIs required by NRAs (refer to ICARUS D2.2, Table 4-1) including condition (less road damage due to flooding), availability and pavement condition. Crucially, flooding can be a significant safety-critical risk which can be alleviated by appropriate drainage.
Involved NRA process and typical NRA guidelines		All NRAs will have their own design documents related to the proper design of drainage systems (see referenced examples above). Designers acting on behalf of NRAs are required to adopt these principles as required by the NRA. Further work may be required in the future to coordinate European legislation for drainage design across CEDR NRAs.
Best practices		Recent best practice in drainage system design is exemplified by the phenomenon of Sustainable Drainage Systems (SuDS). These are innovative approaches to managing surface water runoff in a more environmentally friendly and sustainable manner. Traditional drainage systems often focus on quickly removing rainwater from urban areas, leading to issues such as increased flood risk, pollution, and loss of natural water flow patterns. SuDS, on the other hand, aims to mimic natural drainage processes and provide multiple benefits to the environment.
Lifetime of adaptation option		Drainage systems are often designed for a standard structural design life of 50-120 years. Regular maintenance is required throughout the lifecycle including rodding of culverts, cleaning and patch repairs where necessary.
Dependencies with other developments		Critical dependency is the level of maintenance of the drainage system. Clogged / dirty drains will not be sufficient to address extreme rainfall and pluvial flooding. Consideration of climate change increases in the CID is essential for proper design.
Valuation	Cost	The cost of drainage systems varies significantly depending on various conditions. For example, the cost of a culvert can vary based on the size and type of culvert, materials used, site conditions, and local labour and material costs. Culverts come in different shapes and materials, including precast concrete, corrugated metal, plastic, and others. Additionally, the complexity of installation, including factors like excavation, backfill, and site preparation, can influence the overall cost. In general, the increase of culvert size is considered a comparatively high-cost adaptation measure for this CID.
	Benefits	Benefit 1: Safety <u>Effect or expected outcome</u>: Prevention of water pooling and slippage accidents on the infrastructure towards reduction of accidents and fatalities. <u>Parameter for assessing magnitude of effect</u>: Safety, quantification of risks, number of accidents. <u>Possible means of Measurement</u>: Mortality rate, road accident rate, number of Incident reports related to flooding events. <u>Possible means of valuation</u>: LOC of number of road users, frequency of loss of service LOC of number of road users, Economic valuation of

		safety improvements. Environmental valuation of reduced risk of injuries/fatalities. Benefit 2: Durability Effect or expected outcome: Prevention of water overflowing post hazards and damaging water infrastructure. Parameter for assessing magnitude of effect: Frequency of Replacement and upgrading of the pipe breaks and pump failures. Geotechnical assessments on the effectiveness of the resized drainage system. Possible means of Measurement: number of wearing parts replaced, amount of labour needed, period of intervention. Possible means of valuation: Incident count of leakage problems, and cost benefits from network flooding reduction Benefit 3: Accessibility Effect or expected outcome: Drainage-related clearance time: Parameter for assessing magnitude of effect: Level of change in the drainage system's performance, number of users affected. Possible means of Measurement: Engineering assessments of drainage system improvements, delay computation and travel speed. Possible means of valuation: time valuation of improved access and reduced disruptions.
	Co-benefits	Comparatively few co-benefits as this is considered a direct flooding management option. Some non-measurable co-benefits listed in ICARUS D2.2 may include: • Biodiversity and ecosystem benefits (wildlife corridors). This can lead to social benefits including walking corridors etc. • Improved road user experience. • Stabilized flow of water into streams/rivers and enhanced water quality.
Relevant data and data sources		(Highways England (2022)) (TII Publication (2015))

2.2.5 Example 4: Inspect and Clean Water Courses Regularly

Adaptation option	Inspect and Clean Water Courses Regularly
Climate Impact Driver	Wet and Dry - Heavy Precipitation and pluvial flood (Extreme Event)
Critical contextual information	Overloading of hydraulic systems crossing the road causes erosion of road embankments and foundations due to extreme rainfall events (heavy showers, long periods of rain) affecting drainage of earthworks and pavements with object/connection/network impact scale.
Effectiveness of adaptation option	Proactive monitoring, regular maintenance, and well-designed drainage systems are an effective and essential approach to directly address potential erosion issues, enhance the longevity of road embankments, and contribute to overall infrastructure stability. • Regular monitoring and maintenance of drainage systems help prevent erosion of road embankments, ensuring the stability and longevity of the infrastructure.

		• Proper slope design on road surfaces and ditches contributes to the self-cleaning functionality of drains, maintaining the stability of the overall road system. • Monitoring water levels in manholes serves as an early warning system for downstream blockages. • Proactive monitoring and maintenance can prevent more significant issues, potentially saving costs associated with emergency repairs or extensive reconstruction.
Involved NRA process and typical NRA guidelines		NRA can serve in initiating comprehensive long-term plans, enforcing design guidelines, implementing quality assurance measures, and investing in monitoring systems for early detection of potential issues.
Best practices		Establishing a systematic and scheduled maintenance program, incorporating effective debris removal, sediment control, and vegetation management serves in ensuring optimal drainage and prevent erosion of road embankments.
Lifetime of adaptation option		During the Operation and Maintenance life, regular maintenance is required throughout the lifecycle to avoid blocking the road drainage system
Dependencies with other developments		-
Valuation	Cost	Routine cleaning expenses might range from a few thousand to tens of thousands of Euros annually per kilometre of road but vary based on factors like the length and complexity of the watercourse, accessibility, and local labour and equipment costs.
	Benefit	Benefit 1: Job Opportunities <u>Effect or expected outcome:</u> Creation of jobs to ensure proactive monitoring and regular maintenance. <u>Parameter for assessing magnitude of effect:</u> training programs registration, number of jobs taken. <u>Possible means of Measurement:</u> Statistical observation data from government labour statistics, industry reports, or job market platforms <u>Possible means of valuation:</u> Surveys and statistical results
		Benefit 2: Durability <u>Effect or expected outcome:</u> Early detection savings and infrastructure longevity. <u>Parameter for assessing magnitude of effect:</u> change in the effort needed to resolve a potential blockage issue, level of maintenance needed. <u>Possible means of Measurement:</u> Amount of labour needed; money and time spent on maintenance service. <u>Possible means of valuation:</u> Routing cleaning expenses and savings, value of wages.
		Benefit 3: Accessibility (Zhang et al., 2017) <u>Effect or expected outcome:</u> Prevention of users experiencing longer travel times or inaccessibility to certain connections during a flooding event. <u>Parameter for assessing magnitude of effect:</u> Level of change in the travel time in rainy events /number of users affected. <u>Possible means of Measurement:</u> Reliability values, evaluation of improved access and reduced disruptions, Surveys on accessibility of network/connection. <u>Possible means of valuation:</u> Reliability of travel time during flooding events, percentage of LOS change

	Co-benefit	• Proper drainage management can prevent soil erosion, reducing sediment runoff into nearby water bodies and contributing to overall environmental conservation. • Contribute to safer road conditions, reducing the risk of accidents and enhancing overall community safety.
Relevant data and data sources		(Glendinning et al., (2015)), (Serda et al., (2013)), (Steenbergen et al., (2019))

2.2.6 Example 5: Cutting slopes to a shallower angle

Adaptation option	Cutting slopes to a shallower angle
Climate Impact Driver	Wet and Dry – Landslide (Extreme Event)
Critical contextual information	Steep roadside embankments have an increased risk of landslides and landslips following periods of heavy rainfall. Very steep slopes may also have limited options for trees and other flora to help stabilise the slope. Landslides and landslips are generally localized events impacting the asset and connection level, although, in some situations, there are wider network level implications due to often long diversions onto roads with lower capacities.
Effectiveness of adaptation option	Reducing the steepness of embankments is an effective measure to prevent the risk of landslides. Making the embankments shallower reduces the risk of landslides or landslips and increases the resilience of the network as shallow slopes are less susceptible to landslips than steep ones. It also increases the likelihood of high network availability and reduces the risk of delay. The solution is well understood and relatively easy to achieve meaning there is a high degree of certainty with the likely increase in resilience/decrease in risk that would be achieved from undertaking this adaptation measure. This can make assessment of the costs and benefits relatively easy to quantify based on the reduction in risk of a route being severed due to a landslide.
Involved NRA process and typical NRA guidelines	Information on slope stability and slope gradient for cuttings and embankments can be found in documents such as the UK's Design Manual for Roads and Bridges.
Best practices	There is abundant scientific data on slope steepness and landslide risk. The British Geological Survey[1] has information and case studies on the subject, as well as a national landslide database for Great Britain. Other countries will have similar resources.
Lifetime of adaptation option	Cutting of slopes to a shallower angle should be a long-term solution in reducing the risk of landslides. In terms of speed of implementation, this is an adaptation option that could be completed in a relatively short timescale, subject to detailed design and planning approval.
Dependencies with other developments	For new construction, incorporating shallow slopes into the design can be beneficial in areas where steeper gradients are likely to pose landslide/landslip risks.

[1] https://www.bgs.ac.uk/discovering-geology/earth-hazards/landslides/

		For existing roads, the surrounding land use is likely to be a constraint, as the NRA may have to acquire some of the adjacent land to cut the slope. This may be achievable if the surrounding land is low value, but unlikely to be feasible where there is housing or industry on the surrounding land. In either case, there will be context-specific considerations such as geology and climate; for example, a slope in the Scottish Highlands might be a higher risk than a similar gradient in the Mediterranean.
Valuation	Cost	The cost of construction of a shallow slope on a new road is likely to be insignificant, to the overall highway construction, even if some additional adjacent land must be acquired. Assuming there are no significant surrounding land constraints, cutting an existing slope is likely to be more expensive than for new construction due to the requirement for vegetation clearance, removal of excess material and new planting. However, these kinds of earthworks are a relatively low-cost activity compared to hard engineering solutions.
	Benefits	Benefit 1: Safety Effect or expected outcome: reducing the risks related to slope dynamics accidents or connection blockage on network users. Parameter for assessing magnitude of effect Detect LOC of probability of slope failures or landslides LOC of number of risks encountered on users. Possible means of Measurement: costs of maintenance or reconstruction. Possible means of valuation: potential savings or avoidance of costs associated with slope failures or maintenance. Benefit 2: Accessibility Effect or expected outcome: Improved accessibility of the road for pedestrians, cyclists, and other vulnerable road users. Parameter for assessing magnitude of effect: Number of users. Possible means of Measurement: Visual means and observations Possible means of valuation: user feedback and satisfaction. Benefit 3: Durability Effect or expected outcome: feasibility of solution for road maintenance. Parameter for assessing magnitude of effect: level of effort needed for maintenance. Possible means of Measurement: Cost of construction of a shallow slope compared to overall highway reconstruction costs ratio. Possible means of valuation: Cost savings.
	Co-benefits	There are relatively few if any, co-benefits. Depending on the location, a shallower slope might offer the potential for a wider range of planting, so increasing biodiversity. There may be the potential to add an off-highway cycling/walking/equestrian route at the same time as undertaking the works at a low additional cost. There may be better visibility to and from the road (e.g. for animals running to road) which may lead to lower likelihood of collisions with animals.
Relevant data and data sources		This is a well-understood area, with abundant guidelines available on slope dynamics and slope stability. (Hall & Cratchley, 2005), (Connell, 2004), (Cooper et al., 2021)

2.2.7 Example 6: Mowing of verges

Adaptation option		Mowing of Verges
Climate Impact Driver		Wet and Dry – Wildfire Conditions (Extreme Event)
Critical contextual information		Insufficiently maintained verges give rise to excessive growth of woody vegetation, which increases wildfire vulnerability leading to lower visibility for users and increased risk of respiratory illnesses for employees working near fires due to release of toxic gases. Wildfires can also cause damage to asphalt pavements (for example, surface cracking and pavement melting.). Wildfire in verges typically impacts at the connection level, but the hazard can spread to significant areas leading to network-level impacts. In general, there is little need for mowing other than to prevent the establishment of woody vegetation (or for non-biodiversity purposes). As road verges are generally routinely mowed for aesthetic reasons, a single mow per year is often sufficient to reduce the vulnerability to the required level. Further mowing may have co-benefits associated with biodiversity.
Effectiveness of adaptation option		Yearly mowing is sufficient to effectively remove the impact of the roadside verge on wildfire risk. The risk is increased when NRAs fail to maintain verges for various reasons. This will generally not address wildfire risk for surrounding land, which can still impact driver visibility and toxicity. Referring to specific benefits mentioned in ICARUS D2.2, this is a low-cost method of increasing availability (delays due to potential wildfire risk are minimised) and safety (injuries/deaths due to potential wildfire risk are minimised).
Involved NRA process and typical NRA guidelines		Most NRAs have their own protocols in place related to the required maintenance of verges. For example, see Transport Infrastructure Ireland (2012). This generally relates to mowing from an aesthetic, and crucially, a biodiversity standpoint. Generally, yearly mowing will be a good balance between cost, maintaining biodiversity potential, and reducing wildfire vulnerability.
Best practices		Mowing is generally considered a simple and low-cost aspect of road maintenance. Each NRA will have their own practices, for example, see Transport Infrastructure Ireland (2012). An emerging technology in this field is studying the use of Automowers in combination with sensors which can be used to monitor biodiversity-related issues (flowering plants of high value, insect-rich environments etc.). This can potentially be used to track high-risk plants for wildfire hazards.
Lifetime of adaptation option		Verges are regularly mowed as part of highway maintenance. Mowing is generally carried out 1-3 times per year, although a single mow per year is often sufficient (O'Brien and Connolly, 2022).
Dependencies with other developments		Mowing is generally a balance between, in order of priority, biodiversity potential, aesthetics, wildfire risk, and cost. Each of these is generally well balanced with a single yearly mow.
Valuation	Cost	Verge mowing is considered a low-cost part of routine road maintenance. This is generally carried out for reasons other than

		wildfire resilience. For this reason, the cost from a resilience perspective is close to nil.
	Benefits	Benefit 1: Safety Effect or expected outcome: Reduction of wildfire vulnerability that led to lower visibility for users and reduced risk of respiratory illnesses due to the release of toxic gases. Parameter for assessing magnitude of effect: Assess change in the threshold of tolerable wildfire risk. Analyse the level of change in historical wildfire data. Possible means of Measurement: Conducting air quality tests to measure the reduction in toxic gases released during wildfires-percentage of land damaged/fire. Possible means of valuation: Evaluation of the economic benefits of reduced wildfire risks, considering potential savings in firefighting efforts, medical expenses, and land damage. Benefit 2: Climate Change Effect or expected outcome: Reduction in GHGs released into the atmosphere due to wildfires. Parameter for assessing magnitude of effect: Reduction in the frequency and severity of large-scale wildfires. Possible means of Measurement: Evaluation of the carbon sequestration potential of maintained verges compared to overgrown areas subject to fires. Possible means of valuation: Quality of air Benefit 3: Ecosystem Effect or expected outcome: enhancement of local ecosystems through the maintenance of healthy vegetation in the verges. Parameter for assessing magnitude of effect: Ecological health of the ecosystem. Possible means of Measurement: Biodiversity surveys, soil health assessments, Ecological monitoring Possible means of valuation: Quality of the biodiversity and ecological health of the land
	Co-benefits	Some co-benefits related to ICARUS D2.2 (Table 5-1), in addition to those above, include: • Improved aesthetics • Enhancement to biodiversity. The frequency of mowing, time of year, and method of mowing (e.g. removal of cutting or not) will generally benefit different types of biodiversity. More info is available in OBrien and Connolly (2022)
Relevant data and data sources		(Obrien et al, (2016)) (Obrien and Connoly (2022)) (Brice et al. (2022)) (TII (2012)) (Casartelli and Mysiak (2023)) (SIREN Policy Brief (2023))

2.2.8 Example 7: Change of land use in proximity of road to other vegetation

Adaptation option		Change of land use in proximity of road to other vegetation
Climate Impact Driver		Wet and Dry – Wildfire Conditions (Extreme Event)
Critical contextual information		During prolonged periods of dry and warm weather, conditions develop that increase the risk of wildfires developing, i.e. leaves and pine needles on the forest floor drying and becoming highly flammable, crops becoming dry and woody and grassland also drying and becoming flammable. Should this spread to the roadside and adjacent lands, the high temperatures can damage the mechanical properties of the road, particularly asphalt roads. It can reduce safety through lower visibility and cause/exasperate respiratory illnesses. Wildfires typically impact the connection level, but the hazard can spread to significant areas leading to network-level impacts. There are various options for reducing fire risk including thinning vegetation to create fire breaks, reducing the presence of flammable plants and dead vegetation and planting wire fire-resistant plan
Effectiveness of adaptation option		There will be a balance to be made between minimising/eliminating fire risk through the complete absence of planting and promoting conditions that promote biodiversity for normal conditions. Adapting the vegetation on the soft estate could be a viable option to reduce the potential for fire to spread from adjacent land and damage the road surface. Given the potentially high costs of pavement resurfacing and the severance of a connection, protection in the form of vegetation management could be a cost-effective solution in certain locations. It could maintain safety by reducing the risk of reduced visibility. It would potentially maintain high availability and reduce the risk of delays through smoke (lower visibility) or impacts on the pavements from fire and extreme heat. It also lowers the risk of poor air quality.
Involved NRA process and typical NRA guidelines		Currently, NRAs have processes in place for the management of their soft estate, particularly for grass mowing and pruning and occasional felling of trees.
Best practices		Each NRA will have guidelines for soft estate management including planting and a maintenance regime. Adopting an alternative planting regime will need to take account of existing flora and fauna, particularly insects that might be native to the local area. Additionally, consideration will need to be given to both the climatic region (e.g. arctic vs Mediterranean) and local conditions such as soil type and any microclimates.
Lifetime of adaptation option		Vegetation management is an ongoing process, such as mowing, as described in Example 6.
Dependencies with other developments		Vegetation management needs to be considered as an overall process in terms of aims, planting schemes and plant selections and maintenance.
Valuation	Cost	The cost of undertaking this will be highly dependent on the choice of actions taken. A change to the maintenance regime to ensure dead material and leaf litter were routinely removed, where they might currently be left to biodegrade would represent a modest increase in maintenance costs. A complete replacement of existing vegetation with

		new (especially mature plants) would have a comparably higher capital and operational cost.
	Benefits	Benefit 1: Safety Effect or expected outcome: Improved Road safety. Parameter for assessing magnitude of effect: frequency and severity of road accidents. Possible means of Measurement: road safety audits, % change in accidents throughout the road history before and after Possible means of valuation: safety of infrastructure, quantification of accident reductions Benefit 2: Ecosystem Effect or expected outcome: enhancement of local ecosystems through the maintenance of healthy vegetation in the verges. Parameter for assessing magnitude of effect: Ecological health of the ecosystem. Possible means of Measurement: Biodiversity surveys, soil health assessments, Ecological monitoring Possible means of valuation: Quality of the biodiversity and ecological health of the land Benefit 3: Durability Effect or expected outcome: Improved longevity of infrastructure. Parameter for assessing magnitude of effect: Frequency of infrastructure to degradation, Unit of material, frequency of maintenance, percentage of material wear. Possible means of Measurement: Cost of materials, maintenance, and labour wages, Possible means of valuation: Lifecycle cost analysis, durability improvements
	Co-benefits	There may be the potential to increase biodiversity through amended planting schemes. Fire-resistant plants often are also more drought-resistant, which could help plant survival rate in times of extended drought.
Relevant data and data sources		(Trenčanová, B. et al. (2022)) (O'Sullivan et al. (2017)) (SIREN Policy Brief (2023))

2.2.9 Example 8: Protection of wind exposed road sections and assets with planted forests and other vegetation

Adaptation option	Protection of wind exposed road sections and assets with planted forests and other vegetation
Climate Impact Driver	Wind - Tropical Cyclone (Extreme Event)
Critical contextual information	Road signs damaged or fallen, fallen trees and other obstacles blocking the road, power lines damaged, bridge cables damaged, Unexpected dynamic behaviour in bridges (suspension cables, piers, …) and uncomfortable road use and risk of accident for tall vehicles and trucks. All road infrastructure affection at connection and network scale.
Effectiveness of adaptation option	Utilizing planted forests and vegetation in protecting wind-exposed road sections lies in their ability to act as natural windbreaks, reducing wind

		velocity, thus enhancing road safety, and mitigating environmental factors • Forests act as natural barriers, reducing wind velocity and minimizing the potential for damage on exposed road sections. • Reduced crosswind strength and alignment helps prevent accidents, especially for high-profile vehicles like trucks and buses. • Properly designed hedge barriers can effectively block the blowing of snow onto the road, contributing to safer winter driving conditions.
Involved NRA process and typical NRA guidelines		NRAs are involved through incorporating vegetation into road design standards, collaborating with environmental agencies to assess optimal species and locations, funding research on the effectiveness of green infrastructure, and actively engaging with local communities for input and support.
Best practices		NRA should conduct site-specific assessments, carefully select appropriate vegetation species, adhere to best practices in design and maintenance, and regularly monitor the performance of planted forests and vegetation along wind-exposed road sections to ensure an effective adaptation behaviour.
Lifetime of adaptation option		Construction. Regular maintenance is required throughout the lifecycle including pruning trees and clearing roads of fallen branches
Dependencies with other developments		Also, see example 7
Valuation	Cost	Cost indication and references
	Benefit	Benefit 1: Climate Change <u>Effect or expected outcome:</u> Improved air quality and reduced temperature. <u>Parameter for assessing magnitude of effect:</u> Temperature change, Carbon Sequestration <u>Possible means of Measurement:</u> delta temperature, metric tons of carbon stored per area. <u>Possible means of valuation:</u> value of improved climatic conditions
		Benefit 2: Safety <u>Effect or expected outcome:</u> Reduction in the frequency and severity of accidents and damages. <u>Parameter for assessing magnitude of effect:</u> reduction in the occurrence and severity of accidents on road sections. <u>Possible means of Measurement:</u> Quantifying changes in the number of accidents, types of accidents, and severity levels. <u>Possible means of valuation:</u> Quality of travel
		Benefit 3: Accessibility <u>Effect or expected outcome:</u> enhanced connectivity and ease of travel. <u>Parameter for assessing magnitude of effect:</u> travel time, road closures, ease of transportation. <u>Possible means of Measurement:</u> expenses associated to changes in the efficiency of travel and reduced delays. / Duration of road closures. <u>Possible means of valuation:</u> transportation costs, potential business losses
		Benefit 4: Ecosystem Services <u>Effect or expected outcome:</u> enhancement of local ecosystems through the maintenance of healthy vegetation in the verges. <u>Parameter for assessing magnitude of effect:</u> Ecological health of the ecosystem. <u>Possible means of Measurement:</u> Biodiversity surveys, soil health assessments, Ecological monitoring

		Possible means of valuation: Quality of the biodiversity and ecological health of the land
	Co-benefit	• helps in mitigating climate change by reducing the concentration of greenhouse gases through carbon sequestration.
		• the use of vegetation helps dissipate wave energy, reducing the strength of storm surges and protecting coastal infrastructure.
		• appropriate vegetation selection influences the distribution of temperature and moisture along road sections.
		• establishment of planted forests and vegetation can contribute to biodiversity conservation enhancing ecological balance.
Relevant data and data sources		(Kocur-Bera et al., (2024)), (Chu, et al., (2013)), (Tamang et al., (2009)) (O'sullivan et al., 2017)

2.2.10 Example 9: Interseasonal heat transfer

Adaptation option	Interseasonal heat transfer
Climate Impact Driver	Snow / Ice
Critical contextual information	Snow and ice can block the road and/or cause dangerous driving conditions. The use of rock salt can be an effective measure to prevent ice but requires the mechanical action of tyres to be effective. Salt can also damage flora near the roadside and interact with concrete bridges and structures. As snow or ice are linked to cold weather, this tends to be a network-level event, or at least affecting large parts of the network. Direct heating of the pavement has been explored as a way of improving safety and potentially extending pavement life.
Effectiveness of adaptation option	The effectiveness of the option would be high and would have environmental benefits over the use of salt or brine solutions. Some systems could potentially be reversed to cool the roads in summer to prevent rutting and deformation. The key benefit is the elimination of snow and ice with a high degree of operational effectiveness. This improves safety through a reduction in the risk of incidents or accidents. In terms of removing snow, increases the availability of the network and increases network resilience. There could potentially be some benefits around pavement quality should heating in winter help to reduce cracking and potholes and cooling in summer help to prevent rutting and deformation.
Involved NRA process and typical NRA guidelines	The decision to use such a solution would be part of the NRA's winter maintenance schedule and procedures. Whilst research on the systems has been undertaken for many years, and has a high TRL level, to date it has not been deployed on a wide scale.
Best practices	The technology is relatively simple and similar in operation to a refrigerator or heat pump. TRL undertook a trial on this on an access road in 2002, using equipment supplied by a commercial equipment supplier. More recently, Chalmers University in Sweden has undertaken trials on using low-temperature groundwater to raise the road surface temperature to just above freezing.

		French company, Eurovia, has a 'Power Road' concept where renewable heat captured from roads can be used to heat nearby residential buildings, pre-heat water for outdoor swimming pools or be stored to de-ice roads and footways in winter.
Lifetime of adaptation option		Initial Proposal Stage
Dependencies with other developments		For the system to be installed would require excavation of the road surface course and potentially some or all of the base course. As such it would likely be most effective practically if installed either as part of a new road construction or reconstruction of an existing road.
Valuation	Cost	The system would need to be deployed over a wide area to be effective, and this would represent a significant capital cost, even if the operational costs might be in the same area as applying salt. As such, its use may be restricted to specific use cases such as car parks, rest areas, airport runways or small private roads that are not routinely salted.
	Benefits	Benefit 1: Safety <u>Effect or expected outcome:</u> elimination of snow and ice danger effects on infrastructure. <u>Parameter for assessing magnitude of effect:</u> occurrence and severity of accidents. <u>Possible means of Measurement:</u> number and scale of accidents <u>Possible means of valuation:</u> quality of life and properties Benefit 2: Durability <u>Effect or expected outcome:</u> Improved Road quality and life. <u>Parameter for assessing magnitude of effect:</u> extension of life span variation before and after, unit of material and maintenance costs. <u>Possible means of Measurement:</u> costs and expenses for maintenance <u>Possible means of valuation:</u> resurfacing costs, repair expenses, and overall infrastructure investment
	Co-benefits	The main co-benefit would be the reduced impact on the road infrastructure and surrounding vegetation that can be caused by applying salt to the road. There would potentially be an improvement in road safety due to the immediate nature of road heating, to deal with unexpected sharp falls in temperatures at specific locations that might not be covered by gritting. The success of snow/ice removal with salting relies on pavement-tyre interaction meaning that gritted roads can still require snowploughing if there is little/no traffic. Heating of roads would negate this requirement improving road availability. There could potentially be a biodiversity and road safety risk if animals were attracted to a road with a warmer surface temperature than the surrounding area.
Relevant data and data sources		(Carder (2002)) (Johnsson (2019)) (Cortes et al. (2012)) (Cortés et al., 2012)

2.2.11 Example 10: Install jetties to support the slope or protect bank from erosion

Adaptation option		Install jetties to support the slope or protect bank from erosion
Climate Impact Driver		Coastal and oceanic-Sea level rise (Slow-onset processes and trends)
Critical contextual information		Scour due to sea level rise, extreme wind speed, wind direction, and extreme rainfall events. Impact on Geotechnics, including landslips and rock falls, cuts with object and connection impact scale.
Effectiveness of adaptation option		Jetties stabilize navigation channels and tidal inlets, preventing the substantial buildup of sand and contributing to preserving a sufficient opening for water exchange, benefiting both the environment, navigation and protecting infrastructure indirectly. Effectiveness can be achieved in different ways: • Mitigation of potential adverse ecological consequences on infrastructure by modulating sediment transport patterns. • improvement and impact on the efficiency of transportation infrastructure. • Effectiveness of water exchange in lagoon environments supports both navigation and environmental stability, directly benefiting NRAs by maintaining open channels.
Involved NRA process and typical NRA guidelines		NRA can utilize jetties to enhance coastal infrastructure, improve navigability, and support economic development, while also considering environmental sustainability thus mitigating potential adverse ecological consequences.
Best practices		Jetties serve in enhancing navigability and promoting land-based activities by preventing sediment accumulation on the updrift side yet necessitate careful consideration of potential downdrift erosion and overall coastal management strategies to ensure long-term effectiveness and mitigate adverse ecological impacts.
Lifetime of adaptation option		Construction. Unexpected variations of sea level rise can cause instabilities during the exploitation phase. To avoid consequences on the road, the installation of jetties can be foreseen.
Dependencies with other developments		-
Valuation	Cost	Costs mainly are due to construction and maintenance of jetties and can vary widely depending on their size, materials used, location, and engineering requirements (initial construction expenses, ongoing maintenance costs, and potential environmental monitoring expenditures)
	Benefits	Benefit 1: Safety <u>Effect or expected outcome:</u> Decreased risk of accidents or injuries related to slope instability or erosion. <u>Parameter for assessing magnitude of effect:</u> number of potential accidents or injuries. Percentage of reduction in the risk of injuries/fatalities/disaster incidents. <u>Possible means of Measurement:</u> Incident reports related to slope instability or erosion. <u>Possible means of valuation:</u> Value of risk related of injuries/fatalities. Benefit 2: Durability CIRIA C731 The International Levee Handbook RP957, 2013 <u>Effect or expected outcome:</u> Reduce impact of coastline erosion during severe storms <u>Parameter for assessing magnitude of effect:</u> Level of change in slope stability. Reduction in replacement costs.

		Possible means of Measurement: Cost assessments, Workforce, and material usage monitoring. Possible means of valuation: Economic valuation of reduced replacement costs Benefit 3: Ecosystem(Oras, n.d.) Effect or expected outcome: enhancement of the coastal ecosystem. Parameter for assessing magnitude of effect: Record the change of diversity through its richness (numerical value of genetically or functionally related individuals' groups) and evenness (of the different species or functional groups' relative abundance present in an area). Possible means of Measurement: LOC in the populations of species, habitat integrity, and species interactions. / Nature-based recreation savings Possible means of valuation: economic value of avoided costs related to ecological restoration and conservation efforts. Benefit 4: Accessibility Effect or expected outcome: Improved accessibility to coastal areas. Parameter for assessing magnitude of effect: time and efficiency of transportation to coastal areas. Possible means of Measurement: expenses due to changes in travel and delays. Possible means of valuation: savings associated with reduced travel time. Benefit 5: Job Opportunities Effect or expected outcome: Creation of jobs to ensure proactive monitoring and, regular maintenance. Parameter for assessing magnitude of effect: training programs registration, number of jobs taken. Possible means of Measurement: Statistical observation data from government labour statistics, industry reports, or job market platform/ enhanced economic activity. Possible means of valuation: Surveys and statistical results
	Co-benefits	• contribute to tourism and port development. • preserve biodiversity, ecosystem services, and recreational opportunities for the local community.
Relevant data and data sources		(The European Climate Adaptation Platform Climate-ADAPT (2023)), (Payo et al., (2015)), (Morales et al., (2018)), (Guo et al., (2021))

3 Demonstration of defining optimum service levels for suitable adaptation options

The previous chapter demonstrates how to assess different adaptation options using terms of costs, benefits and co-benefits. This chapter will demonstrate how to identify whether an adaptation option is suitable, but also how to define optimum service levels when suitable adaptation options have been identified.

This is being done based on a fictive example that regards the impact of extreme events. The example focuses on extreme rainfall, and thus how to make the case for a climate hazard which is characterised by low probability and high potential consequences. The chapter starts with describing the example followed by two sub-chapters on how to identify the most suitable adaptation options and how to implement this in guidelines. The chapter ends with a perspective on how optimum service levels can be determined for slow-onset processes.
Figure 3.1 explains the stepwise approach for adapting guidelines to optimise performance, with specific elements related to our example on extreme events included on the right-hand side.

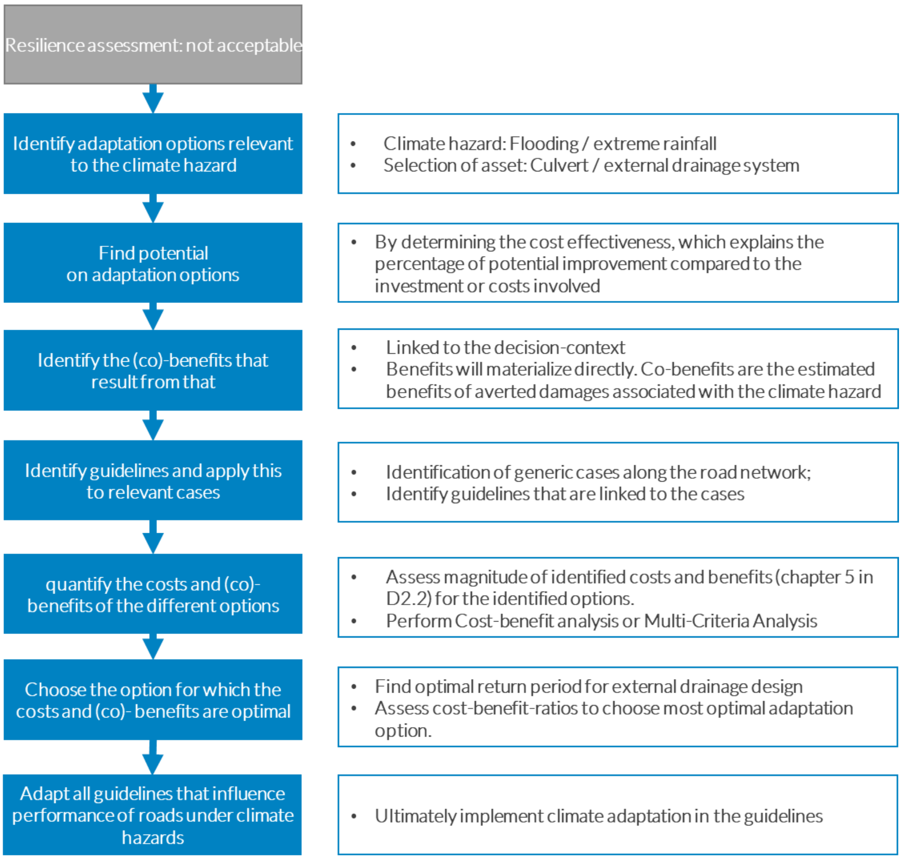

Figure 3.1 Process to make the case for climate adapting maintenance guidelines to optimize performance. In our example: extreme events.

3.1 Introduction to the Example

The example used in this chapter regards extreme rainfall concerning a road asset and the decision-making case between different options to alter the guidelines that cover the design for the specific asset.

Example context

The example regards a 5 km road stretch of a major highway with three lanes (Figure 3.2). The highway was built 15 years ago and is the main connection between two large industrial cities. The highway is designed to support both the transit between cities and the link to other major roads and highways across the country, thus contributing to the larger road network. Following feasibility studies, the design was decided to include 6 lanes, 3 in each direction, separated and margined by safety metal barrier. There is an approximate distance of 5 km between the cities therefore the highway crosses fields and forests, and neighbours' a few small villages.

There is a traditional closed culvert midway, between the 34 and 39 km mark, where a river crosses beneath the highway. The culvert is designed for a 2-year event with a climate factor of 1.0, hence, no consideration of climate change impacts. The culvert has a diameter of 2 m with a max flow of 7,500 L/s. The river catchment upstream of the culvert is 4,411 ha and primarily consists of green fields and forest.

Figure 3.2 Illustration of the example area where the road under consideration is depicted. The bold orange line indicates the road stretch and the two larger grey areas are the cities.

Overall, the highway is highly regarded and a key element in the local economy. The average number of daily users is 76,400 and the average travel time to complete the stretch between the two cities is three minutes.

The catchment area of the stream upstream is currently not considered to have any significant environmental or recreative value. Many years ago, the river was canalized, and adjacent areas used for agricultural purposes. Today, the land is no longer cultivated but is not accessible for recreational purposes or the like.

In 2021, an intense rainfall caused flooding, as the capacity of the culvert was exceeded. Although the water did not reach the lanes during the event, the accumulation of water at the brinks of the highway raised concerns about the structural integrity of the highway during and after the high-water situation.

Hydraulic assumptions and climate change

The catchment area of the stream is assumed to be 44 km2 and has a runoff coefficient of 0.1. The stream has a total length of 14 kilometres with a 0.2% slope. The time of concentration is 240 min.

The culvert has a diameter of 2,000 mm and is designed for a 2-year event using a climate factor of 1, thus, no climate change was considered for the design of the culvert. The culvert is designed for 17L/s/ha with a maximum flow is 7,500 L/s.

It is estimated that a 2-year event in 2123 will have a peak flow of 9,200 L/s (climate factor = 1.25[2]) and that a 50-year event in 2123 will have a peak flow of 22,600 L/s (climate factor = 1.45)

Key figures and decision context

After the event in 2021, concern is raised as to whether recent changes in weather patterns pose a challenge to the traditional design of the external highway drainage, as heavy rain affects optimal functionality. The intense rainfall event in 2021 that raised concerns about the timely structural integrity of the highway, motivated an assessment which showed that for many culverts rainfall intensities corresponding to that of a 5-year event will cause water accumulation on the road. With this finding, it was decided that the level of resilience was unacceptable.

Textbox 3.1 Key figures for the road and of relevance to the KPIs in the example.

Key figures for the road:

Annual average daily traffic: 76,400

Average speed: 105 km/h

Average travel time: 3 minutes

Average number of fatalities: 0.3/year

Average number of injuries

- Severely injured: 7 /year
- Minorly injured: 19/year

The road stretch is a main contributor to the larger national road network and an important connection between the two larger industrial cities. Thus, the road is central to general connectivity and plays a major role in economic activity and cohesion, especially for the larger two industrial cities.

The governing NRA of the road stretch has an overarching objective regarding connectivity and safety of the road. These objectives are reflected in the KPIs of the NRA being:

- Availability measured simply as the value of travel time.
- Safety measured simply as the value of yearly fatalities and injuries.
- Cost of repair and maintenance

The NRA decision criteria include policies concerning biodiversity and carbon reduction. Co-benefits of adaptation should be considered regarding the effect on environment and biodiversity and that carbon reduction targets should be achieved by 2045.

Section 3.2Error! Reference source not found. and 3.3 follows through the stepwise approach for the NRA to make the case for adaptation.

3.1.1 Assumptions and advice for use

The example and calculations presented here reflect a real-life situation for demonstration purposes. Still, the example is constructed with the main purpose of demonstrating how climate change adaptation options can be selected. The values of the costs and effectiveness of adaptation options, as well as the calculations done. are inherent simplifications of reality to be able to clearly demonstrate

[2] See e.g.: Larsen et al. 2009.

the point. Therefore, the example should only be used as a demonstration for NRAs to gain an understanding of how to choose and appraise adaptation options.

3.1.2 Prerequisites before finding suitable adaptation options

The following prerequisites are considered (including some barriers which need to be removed):

- From the decision context it should be clear which steering mechanisms are used for decision-making within the NRA. Furthermore, it should be clear which KPIs are used as decision criteria, how they are related to the climate indicators and which thresholds are used to decide when resilience is acceptable or not (both now and in the future).
- The resilience assessment has been performed and can be compared with the thresholds as identified from the decision context.
- The resilience assessment results in the baseline or *business-as-usual* scenario, without adaptation options. This baseline can incorporate future changes including adaptation options to the current situation and thus demonstrate the added benefits due to adaptation.
- There should be sufficient resources (both in expertise, time and budget) for the development of the adaptation plan.
- Sufficient data is needed and will be illustrated in the following steps.
- Several expertise is needed: Expert input from the operational level related to experience on failure mechanisms and experts from the tactical level related to how failure will impact the performance criteria.
- Expertise on adaptation options and how to appraise the different adaptation options. Preferably with experience in bow-tie methodology and/or decision-making under deep uncertainty.

Experts with an economic background for performing the appraisal of adaptation options.

3.2 Identification of suitable adaptation options

After the resilience assessment has been performed, the first step is to determine what are the suitable adaptation options for implementation. In our example we assume the resilience assessment has already been performed and concluded that resilience is not acceptable due to the exceedance of KPI thresholds aligned with the organisation's decision context.

3.2.1 Selecting potential adaptation options

The first step is to find potential appropriate measures. To do this there are several options:

1. Use the overview of adaptation options based on the adaptation options database (D2.3). Several key examples have been analysed in Chapter 2 of this deliverable.
2. Together with experts at the NRA decide what appropriate measures are.

This will result in a long list of potential measures against flooding due to extreme precipitation and that would result in achieving the mentioned optimization levels. For our example, this could look like the overview as demonstrated in Table 3.1.

Table 3.1 A long list of measures against flooding of the highway (measures to be further detailed when a cost-benefit assessment is being performed and when implemented in practice)

Maintenance More frequent scraping of verges (up to 3 m from road, 4-8 cm below road surface)
Maintenance Improved maintenance frequency of the pavement
Maintenance of road drainage system: inspection of potholes/ drains and cleaning as necessary in case of expected intense precipitation
Retention by using an upstream Nature-based Solution to increase the retention capacity of the stream.
Monitor verge height and maintain as necessary
Conveyance by increasing the size of the culvert to divert water away and from accumulating on the road
Construction Increase height of road embankment (to prevent flooding of the road)
Construction Increase discharge capacity of drainage system by adding culverts or increasing the size of the culverts

3.2.2 Perform a cost-effectiveness analysis of the adaptation options

When selecting which adaptation options should be considered it is essential to identify the cost-effectiveness of each of the potential adaptation option. The different adaptation options can be described in short factsheets that describe the characteristics, costs and effectiveness (for increasing resilience) of the option. For example, for the option to increase the capacity of drainage systems by adding extra culverts, this would look as follows:

	Adaptation option: Increase discharge capacity of drainage system
Description	With increasing rainfall intensity influenced by climate change, there may be a need for a precipitation drainage system with greater discharge capacity. Increasing the size of the culverts will increase the discharge capacity of the precipitation drainage system, provided the system has sufficient capacity/volume.
Costs	The cost estimate for an increase in precipitation drainage system with larger culverts is 38,750 kr. per kilometre (15 culverts per kilometre).
Effectiveness	The effectiveness of increasing runoff capacity through additional and/or larger culverts has been estimated by experts to be 60 percent.

When applying this to our example and long list of potential measures this may result in a cost-effectiveness table as shown in Table 3.2. This table describes the cost-effectiveness, which explains the percentage of potential improvement compared to the investment or costs involved. This is expressed as the costs per % improvement (in this case the reduction of exposure). Subsequently, the adaptation options can be compared. Sometimes an option with a low overall efficiency can still provide a relatively good cost efficiency, when investments are low. When ranking the adaptation options, it is possible to identify which adaptation options would be an option for evaluation (Chapter 3.3.3) or implementation (Chapter 3.3). Based on the example in Table 3.2 the values marked in green show the best cost-effectiveness (all cost-efficiency lower than 750 is considered as potentially suitable) and therefore are probably best to be considered in a potential appraisal.

Textbox 3.2 Determination of cost-efficiency.

Determination of Cost-Efficiency
The cost-efficiency is a unit that describes the costs related to a percentage improvement. This is calculated as the total costs of the measure divided by the overall efficiency. For the example in our case study on increasing discharge capacity of the drainage systems this would result in a cost-efficiency of 38,750/60=645,83 (kr. %$^{-1}$). Ranking this for all adaptation options to be considered helps in selecting the adaptation options to be considered.

Table 3.2 Cost Effectiveness of adaptation options against pluvial flooding.

Measure	Overall efficiency	Costs (Kr.)	Cost Efficiency (kr. %$^{-1}$)
Improved maintenance roadside	30%	26,100	870
Improved maintenance pavement	5%	3,800	760
Improved maintenance of road drainage system	40%	126,100	3152.5
Retention by using an upstream Nature-based Solution	90%	63,750	708.34
Monitor verge height and maintain as necessary	80%	112,000	1,400
Increase height of road embankment (prevent flooding)	100%	112,000,000	1,120,000
Increase discharge capacity of drainage system	60%	38,750	645.83

Based on the calculation and ranking of the cost-effectiveness of the several adaptation options it shows that two options have a cost efficiency of less than 750 kr. per % increase. Those include the increase of discharge capacity of drainage systems which costs 38,750 kr. for a 60% efficiency. The other option is a NbS which is more costly but also more efficient.

3.3 Example: determination of optimum service levels and update of guidelines

This section demonstrates how to determine optimum service levels and implement the results in guidelines[3].

To make the case for climate adaptation, the NRA needs to identify the benefits and co-benefits associated with altering the guidelines and applying this to relevant cases. This step follows the climate adaptation strategy stemming from Section 3.2.

[3] This section serves as a more detailed elaboration of approach 2b for making the case for climate adaptation, as presented in Chapter 6 in Deliverable D2.2.

The described example below focuses on making the case for optimising performance through an update of guidelines . By changing the guidelines, climate change adaptation finds its way into implementation through practice.

3.3.1 Identification of guidelines that influence performance of roads under climate hazards

The first step involves the identification of the governing guidelines for the specific road asset. In the example as used in this chapter (see Section 3.1), the governing NRA has a guideline[4] for the design of drainage structures which covers the dimensioning, design, construction, and maintenance of common drainage structures[5]. The guideline primarily deals with dimensioning of internal drainage (direct runoff from the road). However, the performance of roads will be influenced by the design of both internal and external drainage.

For this reason, the focus for the NRA will be on revising the external drainage as a way to introduce adaptation options to achieve optimised performance.

Textbox 3.3 Definition of external drainage system.

Existing guideline: External drainage
External drainage includes intercepting pipelines that collect road runoff and lead it to another drainage system or recipient, including open and closed water courses under the road. External drainage serves to collect and divert runoff from the surrounding terrain, and climate factors should not be applied for such topographic runoff.

In our example the guide, currently used by the NRA, mainly focuses on the dimensioning of internal drainage of the road asset. The culvert is designed up to a 2-year event. For rainfall intensities higher than that, the service level of the road will be impacted.

The different options, that are considered in the example, to alter the guidelines regard two dimensions:

1) the level to which the drainage capacity should be changed,
2) the specific adaptation option to support this level of change.

For the first dimension it is decided to consider two levels:

- Optimisation level 1 is defined as an increase in the drainage capacity so that water will not start to accumulate on the road until a 5-year event in the year 2045
- Optimisation level 2 is defined as an increase in the drainage capacity so that water will not start to accumulate on the road until a 10-year event in the year 2045.

3.3.2 Identification of (co-)benefits associated with optimisation levels

In this step, the task is to consider the identified (co-)benefits (see Section 3.1) of the example in relation to the two defined optimisation levels (see Section 3.3.1) that follows from the decision context and resilience assessment. This should result in a description of the criteria used to evaluate the (co-) benefits.

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[4] In Deliverable 2.2, the general term 'guideline' is used as a term that can also be read as standard, procedure or norm.
[5] Guideline, Danish Road Directorate

Optimisation Level 1 involves updating the guideline for the road stretch by increasing the dimensioning up to a 5-year event in a future climate. The result of this increase in drainage capacity is that the road will not be impacted until a 5-year event. In essence, this means that the KPIs of availability and safety (Section 3.1, Textbox 3.1) will start to be impacted by the rain intensity associated with a 5-year event. In the same way, optimisation level 2 increases the drainage capacity, so that the KPIs will not be impacted until a 10-year event in a future climate.

Moreover, the two climate adaptation strategies (see Section 3.2.1, Table 3.2) are both assumed to be able to realise the increased drainage capacities defined for optimisation levels 1 and 2. However, while the increase in the size of the culvert will not realize any co-benefits, the NbS is expected to do so, in the form of increased recreational value in the catchment area. These aspects are summarized in Table 3.3.

Table 3.3 Summary of identified (co-)benefits associated with optimization levels 1 and 2, respectively for the two adaptation options.

	Optimisation level 1		
		Increase size of culvert	Nature-based Solution
Benefits	Benefits associated with KPIs		
	- Availability	*Improved compared to reference scenario*	*Improved compared to reference scenario*
	- Safety	*Improved compared to reference scenario*	*Improved compared to reference scenario*
	- Decrease in costs associated with repair and maintenance after flooding of the road	*Improved compared to reference scenario*	*Improved compared to reference scenario*
Co-benefits	Increase in co-benefits associated with ecosystem services	*No benefits associated with increasing the culvert*	*Co-benefits associated with applying nature-based solutions.*
	Optimisation level 2		
		Increase size of culvert	Nature-based Solution
Benefits	Benefits associated with KPIs		
	- Availability	*Significantly improved compared to reference scenario*	*Significantly improved compared to reference scenario*
	- Safety	*Significantly improved compared to reference scenario*	*Significantly improved compared to reference scenario*
	- Decrease in costs associated with repair and maintenance after a flooding of the road	*Improved compared to reference scenario*	*Improved compared to reference scenario*
Co-benefits	Increase in co-benefits associated with ecosystem services	*No benefits associated with increasing the culvert*	*Co-benefits associated with applying Nature-based Solutions.*

3.3.3 Evaluation of selected adaptation options

The evaluation of the selected measures starts with an assessment of the impact on the NRA's KPIs. Furthermore, an assessment of the catchment area is conducted to identify the values to be used in the evaluation. In this process, the NRA distinguishes between the benefits directly associated with the KPIs and the co-benefits not linked to the KPIs. It is central to do an evaluation of the current state of the asset under consideration (in this example, the 5 km stretch of road), as it is today without any measures taken to enhance resilience, and the adjacent areas of the road network likely to be influenced by altering the guidelines. We refer to the current situation as the reference scenario.

In our example, values associated with the road network (KPIs) include availability (travel time, valued depending on motive[6,7]) and safety (value of a reduction in the number of injuries/fatalities on the road network). As explained in the introduction, availability and safety are the sole two measures, on which the NRA's performance is based on, and thus of importance in their decision-making.

In addition to the KPIs, the NRA looks for any wider benefits that might be realised from implementing either of the two climate adaptation options. The NRA sees that the nearby catchment area has the potential to provide additional ecosystem services in the form of increased recreational value for any visitors (Figure 3.3). Currently, the areas illustrated on the map below are not accessible due to dense vegetation and very wet and swampy soil.

The NRA realises that if the areas are made accessible, e.g., in connection to implementing a Nature-based Solution, they might provide value to the local citizens.

Figure 3.3Illustration of the identified green areas in the nearby catchment area, with potential to provide additional ecosystem services in the form of increased recreational value.

3.3.4 Quantify the costs and (co-)benefits of the different adaptation options

Based on the cost-effectiveness analysis, a detailed evaluation can be performed for the selected adaptation options. This should provide information on how to choose between the different adaptation options and will provide justification for the application of the options to specific situations. When the adaptation options to be considered (Section 3.2.1), along with the criteria for (co-)benefits and units in which they are expressed (Section 3.3.2Error! Reference source not found.) are known, the next step is to quantify the costs and (co-) benefits of the different options. There are several ways to do this, most commonly, a multi-criteria analysis (MCA) or a cost-benefit analysis (CBA) is applied. More details on these different approaches are described in D3.1.

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[6] The specific calculations are based on trips made for either business or leisure purposes.

[7] Section 3.1, Textbox 3.1

Based on the previous steps, for our example, the NRA has identified the (co-) benefits that need to be considered concerning the different adaptation options and for the two optimisation levels. Since the identified (co-)benefits and costs can be monetised the NRA decides to conduct a CBA, to make the case for adaptation.

Costs and benefits that need to be considered in the process are:

- Value of availability and safety decrease during extreme rain events. Thus, the benefits of implementing climate adaptation options can be estimated as the averted damages associated with Optimization Level 1 and Optimization Level 2, respectively.
- Value of averting repair and maintenance costs associated with extreme rainfall: The reference scenario is linked to maintenance and repair costs in the case of a 100-year event. For both Optimization Levels 1 and 2, these costs will be eliminated for a 100-year event.
- Value of the co-benefits of increased recreational value of the adjacent areas: The implementation of a Nature-based Solution will enhance the recreational value of the catchment area for the citizens in neighbouring cities and other visitors.
- Costs associated with implementing the two different adaptation options: Increasing the dimensioning of the external drainage will be associated with costs both for the Nature-based Solution as well as increasing the size of the culvert.

The next few sections will go through the estimation process for each of the four categories.

Benefits associated with the KPIs

Estimation of the benefits associated with increasing the drainage capacity are quantified regarding the reference scenario. To do this, the *damages* associated with extreme rain events are estimated for both the reference scenario, optimisation level 1 and optimisation level 2. The *benefit* of increasing the drainage capacity to optimisation levels 1 and 2, respectively, can then be estimated as the difference in associated damages compared to the reference scenario.

The NRA conducts hydraulic simulations for four different return periods to assess the damages associated with these in the reference scenario. Simulations are run for 5-year, 10-year, 25-year, and 100-year events. An assessment of the quantified effects on safety and travel time for the four extreme events is included in Textbox . The simulations represent the present-day climate, and the expected effect of climate change is included at a later stage.

Textbox 3.4 Assessment of damages associated with extreme rain events on safety and availability in the reference scenario, optimization levels 1 and 2.

Damages associated with KPIs in the reference scenario:
The current dimensioning of the culvert is designed for a 2-year event. Thus, availability will be affected already at events exceeding the intensity of a 2-year event. The hydraulic simulations show that at a 5-year event, water will start accumulating on the road, especially in the outer lane. In effect, speed will be slowed and increase the travel time for users on the road stretch, due to the reduced speed and (possible) traffic jams in places where water has accumulated in the outer lane. The average percentage increase in travel time in this example is estimated to be around 50 pct. The increase in travel time is estimated based on the national traffic model, which can calculate the change in travel time from the decrease in speed due to water accumulation of water.

At a 10-year event, the level of water accumulation will increase, and two out of three lanes will be affected in specific places on the road stretch. The chance of aquaplaning is high and travel time is increased by around 110 pct., compared to normal.

By a 25-year event all three lanes are heavily impacted by the accumulated water and travel time is increased by more than 200 pct. At a 100-year event, the road will practically be blocked due to very high levels of accumulated water, resulting in an estimated increase in travel time of around 400 pct.

As for availability, safety will be impacted by a five-year event in the reference scenario. The impacts on safety are simply measured as an increase in the probability of a fatality or injury as per 24 hours[8]. In the reference scenario, this decrease in safety is estimated to be 15 pct. at a 5-year event, 20 pct. at a 10-year event, and 25 pct. at a 25-year event. By a 100-year event, the safety level is assumed not to be impacted, since the road will not be used.

In addition to the damage costs associated with availability, the NRA estimates that a 100-year event to be associated with cleaning and repair costs of around 1,000,000 kr. This estimate is based on experience from previous events.

Optimisation level 1 increases the drainage capacity so that damages will not occur until a 10-year event. Therefore, the damages associated with a 5-year event in the reference scenario will not occur with optimization level 1 until a 10-year event. Similarly, the damages associated with a 10-year event in the reference scenario will not occur until a 25-year event at optimization level 1, and similarly for a 100-year event. The cleaning and repair costs associated with a 100-year event is estimated to be 750,000 kr.

Optimisation level 2 increases the drainage capacity even further. The result is still that both availability and safety will be affected at a 10-year event, however only by half of the impact of a 10-year event at optimization level 1. The hydraulic simulations show that this will also be the case for the 25-year event and 100-year event; damages will occur as for optimization level 1, however only by half of the estimated damages. The cleaning and repair costs associated with a 100-year event is estimated to be 500,000 kr.

[8] The quantification of safety in the example is based on an ideal example, where data availability enables quantification of all effects on KPIs. However, the Danish Road Authority does not collect data on the effects of extreme weather events on road safety. Thus, it has been necessary to base the example on fictive numbers with regard to the level of change in safety within 24 hours of an extreme rain event. If the NRAs are to implement climate adaptation in their decision-making making and this is to be based on quantifiable measures to make the case for adaptation, it is suggested that collecting data on extreme events impact on safety would be of value. This, since safety plays a central role as a KPI for most NRAs and data would enable the valuation of climate adaptation's impact on this.

Based on the quantification of the effects described in Textbox , the *monetized value* of the effects can be estimated. This is done by applying unit price values, for the cost of delay, fatalities and injuries (both severe and minor). Such values are, in Denmark, provided by the Danish Ministry of Transport and are updated yearly[9]. Table with unit prices can be found in the appendix 7.1. Textbox 3.5 provides examples of how the value of availability and safety is calculated, respectively. All damage costs can be found in appendix 7.1.

Textbox 2.5: Calculation example of estimated damage costs of delay and damage costs associated with severe injuries.

Estimation of damage costs of delay (availability) associated with a five-year event in the reference scenario:
It is assumed that an extreme rain event will impact the availability of the road for around 24 hours. The estimated delay for each traveller will be 100 seconds ≈ 0.0278 hours.

Value of delay per person: 0.0278 hours x 283.80 kr./person-hour = 7.88 kr./person
Value of delay for 76,400 users: 7.88 kr./person x 76,400 persons = 602,287 kr.

Thus, the damage cost of delay for a 5-year event is estimated to be 602,287 kr.

Estimation of damage costs of safety (severe injuries) associated with a 5-year event:
It is assumed that an extreme rain event will impact the safety of the road for around 24 hours. The estimated decrease in safety (increase in risk of injury) is estimated to be 15 pct. The average number of severe injuries per year on the road stretch is 7 ≈ 0.019 pr day.

Increase in risk of 15 pct.: 0.019 severe injuries/day x 0.15 = 0.0029 severe injuries/day
Value of increase in risk: 0.0029 severe injuries/day x 6,212,052 kr. = 17,870 kr.

Thus, the damage cost of an increase in the number of severe injuries for a 5-year event is estimated to be 17,870 kr. The same calculations are made for minor injuries and fatalities.

All estimated damage costs can be found in Appendix 7.1. Based on the total estimated damage costs for each return period (including both safety, availability and potential repair), damage cost curves are constructed by interpolating between the estimated costs associated with each of the four return periods. Damage curves are estimated for both the reference scenario, optimization levels 1 and 2 and are visualized in Figure 3.4.

The damage curves are a useful representation of the damages associated with different rain events and how the damages associated with each of the three scenarios (references scenario, optimisation level 1 and optimisation level 2) compare. However, the damage curves do not account for the difference in probabilities of the events. Therefore, it is necessary to represent the damages associated with each of the rain events in a way which reflects the probability of their occurrence. This is done by transforming them into a so-called *risk-density curve*. The derivation of these is explained in appendix 7.2.

[9] TERESA og Transportøkonomiske Enhedspriser

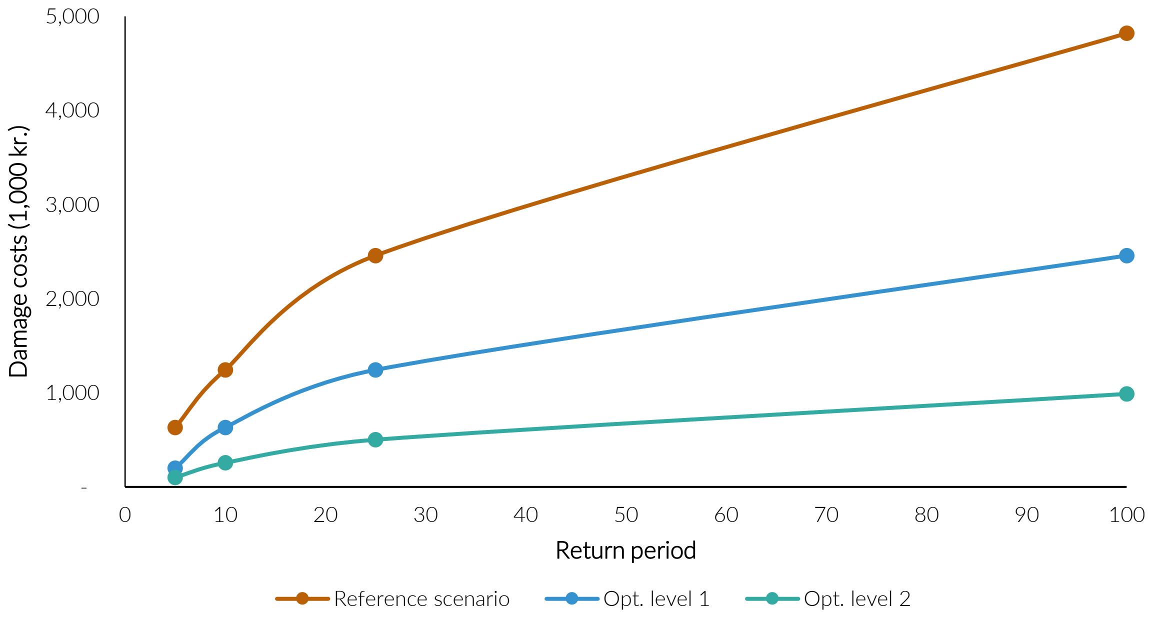


Figure 3.4 Damage curves for the status quo scenario, optimization level 1 and optimization level 2

The risk density curves are illustrated in Figure 3.5. Risk density at any given point on the curve is interpreted as the damages associated with that point, weighed by the probability of the occurrence. As illustrated in Figure 3.5 it is a rain event corresponding to an intensity of around a 25-year event that has the highest risk density in this example.

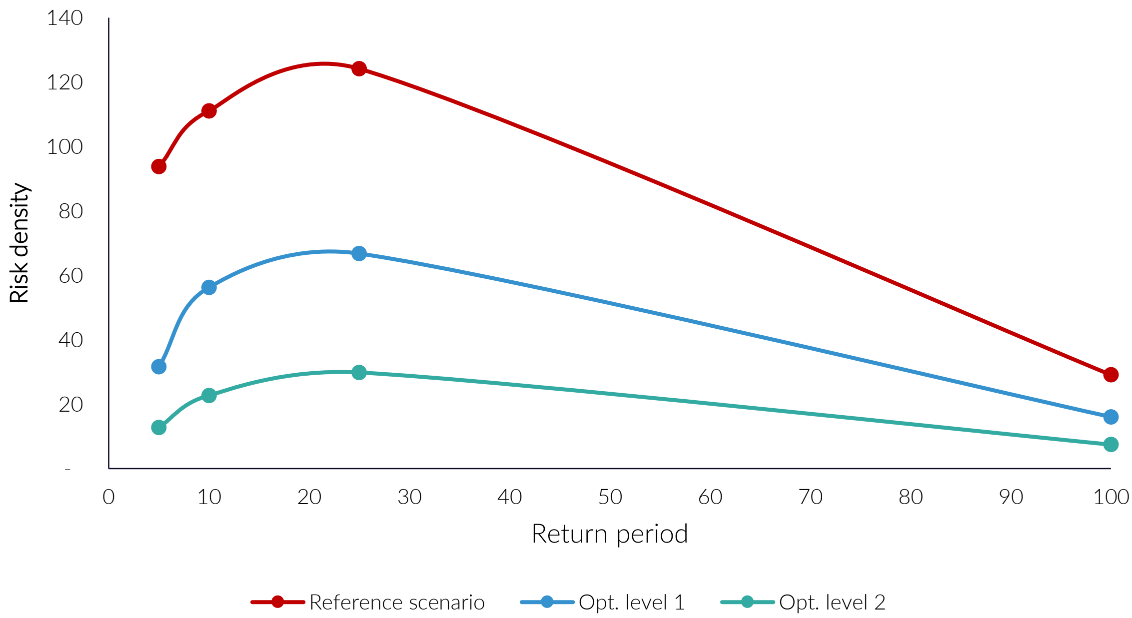


Figure 3.5: Risk density curves for reference scenario, optimization level 1 and optimization level 2

The damage curves can be used to estimate a cash flow for the *expected annual damages* (EAD) over the 50-year project period for all three scenarios. An elaborate description of how this is done is included in appendix 7.2. The EAD is an expression of the damage costs, which the NRA should expect to experience, for a given drainage capacity. The EAD therefore accounts for all of the probable rain intensities that might cause damage and their associated probabilities combined.

An EAD is calculated for two points in time for all three scenarios (reference scenario, optimisation level 1 and optimisation level 2); an EAD for today (project start) and for the assumed end of the project period. By interpolating linearly between these two points, the EAD cash flow for the whole project period is estimated. An elaborate description including the estimation details is included in appendix 7.2.

EAD cashflows are calculated for both the reference scenario, optimisation level 1 and optimisation level 2. These are depicted over the 50-year project horizon. The EADs are increasing over time since the probability of experiencing extreme rain events will increase in the future. Therefore, a climate factor has been applied in the estimation of the cash flow. Ideally, the sensitivity analysis on the results from varying the climate factors should be conducted. This is however left out of this example for simplicity.

Figure 3.6 illustrates that the reference scenario has the highest EAD cash flow, and the EAD for optimization level 2 has the lowest. Based on the EAD, it is possible to calculate the total benefits of increasing the drainage capacity from the reference scenario to optimisation levels 1 and 2, respectively. By deducting the cashflows from each other, two benefit cashflows are estimated for the project period:

$$\boldsymbol{Benefit_{opt.level\,1}} = EAD_{Reference\ scenario} - EAD_{Opt.level\,1}$$

$$\boldsymbol{Benefit_{opt.level\,2}} = EAD_{Reference\ scenario} - EAD_{Opt.level\,2}$$

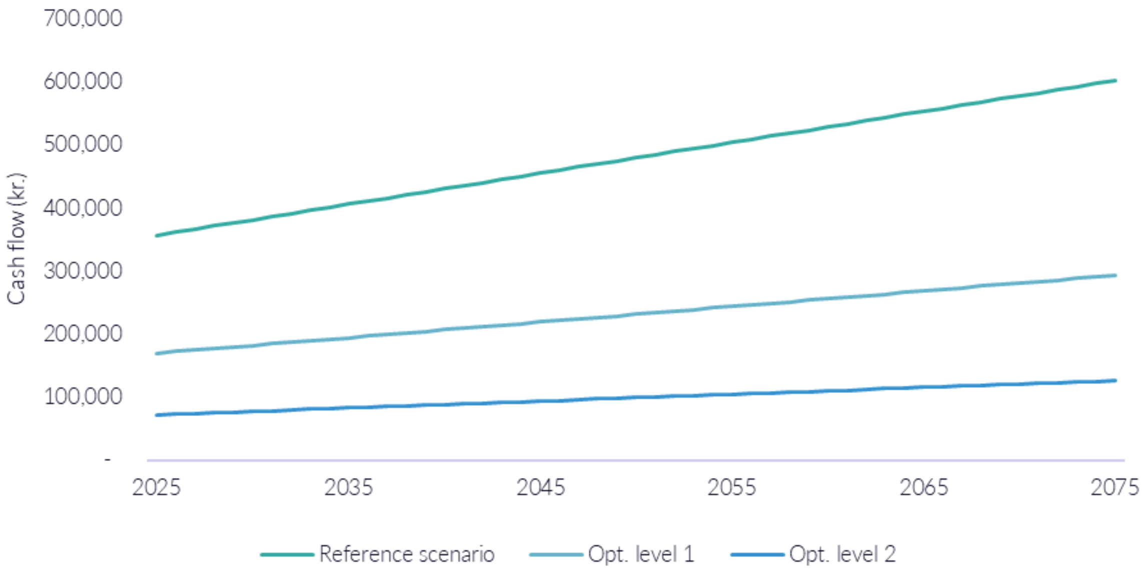


Figure 3.6 Expected annual damage for the three scenarios; status quo, optimization level 1 and optimization level 2

The calculated benefit cash flows are included in appendix 7.2. with two benefit cashflows for our two optimization options, it is necessary to discount the cashflows to be able to compare all costs and benefits of the project in the later stages. Conducting a CBA usually involves comparing costs and benefits that occur at different points in time. This is also the case in this example, where all benefits and costs occur over a 50-year project horizon. To account for this all future cashflows of both costs and benefits are *discounted* using a discount rate and thereby expressed as their *present value* (their value today). In essence, we discount our cashflows to account for the fact that a monetary value today is not equal to that same value tomorrow[10].

Table 3.4: Recommended discount rate for CBA in Denmark, Danish Ministry of Finance (2021).

Recommended discount rate for cost-benefit analyses, Danish Ministry of Finance 2021		
	0-35 years	36-50 years
Real discount rate	3.5 pct	2.5 pct.
(Risk-free real interest rate)	(2 pct.)	(1.75 pct.)
(Risk premium (non-diversifiable risk))	(1.5 pct.)	(0.75 pct.)

The Danish Ministry of Finance determines the discount rate to be applied e.g., in CBAs. The Danish discount rate is presented in Table 3.4. The discount rate is made up of two main components; the risk-free real interest rate, and a risk premium. A brief description of the rationale behind how this is determined is provided in Textbox 3.3.

Textbox 3.3: Description on how the discount rate set by the Danish Ministry of Finance is determined.

As illustrated in Table 3.4 the recommended discount rate for CBAs in Denmark declines after 35 years. This means that for the first 35 years of a project, a discount rate of 3.5 pct. should be used. For cashflows occurring later than the 35 years a discount rate of 2.5 should be used.

The discount rate from years 0-35 is set to reflect two elements: the idea that people, in general, put a higher value on consumption today than tomorrow (due to the presence of risk) and the fact that growth in society overall makes people richer combined with typically assumed diminishing marginal utility of consumption.

A declining discount rate for project horizons exceeding 35 years is intended to reflect that when longer time horizons are considered, the CBA becomes more sensitive to the value of the discount rate. The declining discount rate set by the Danish Ministry of Finance is based on the economic theory of declining discount rates and that prediction of future development of parameters of importance to the discount rate, becomes increasingly more uncertain. Moreover, the risk-premium reflected in the discount rate (non-diversifiable risk) is assumed to be trending towards zero.

The declining discount rate is of particular importance in relation to climate adaptation projects since such projects usually are reflected as projects with (potentially high) investment costs today, but with benefits that occur (potentially far out) in the future. With a declining discount rate, higher weight is placed on benefits and costs that occur e.g., from year 35-50.

Using the discount rate presented in Table 3.4, results in the present value of benefits arising from increasing the drainage capacity from the reference scenario to optimization levels 1 and 2. These net-present values of benefits are depicted in the figure below and amount to

- 6.3 million kr. for optimization level 1
- 9.6 million kr. for optimization level 2.

[10] In other words, if a person is presented with the possibility of receiving 100 kr. today or in a year, that person would (should) rationally not be indifferent between those two options. People tend to prefer the option of receiving the 100 kr. today since the future is uncertain. Thus, it is necessary to compensate people to postpone receiving they payment, e.g., for a year. Another way of viewing this is that 100 kr. in a year do not have the same value as 100 kr. today.

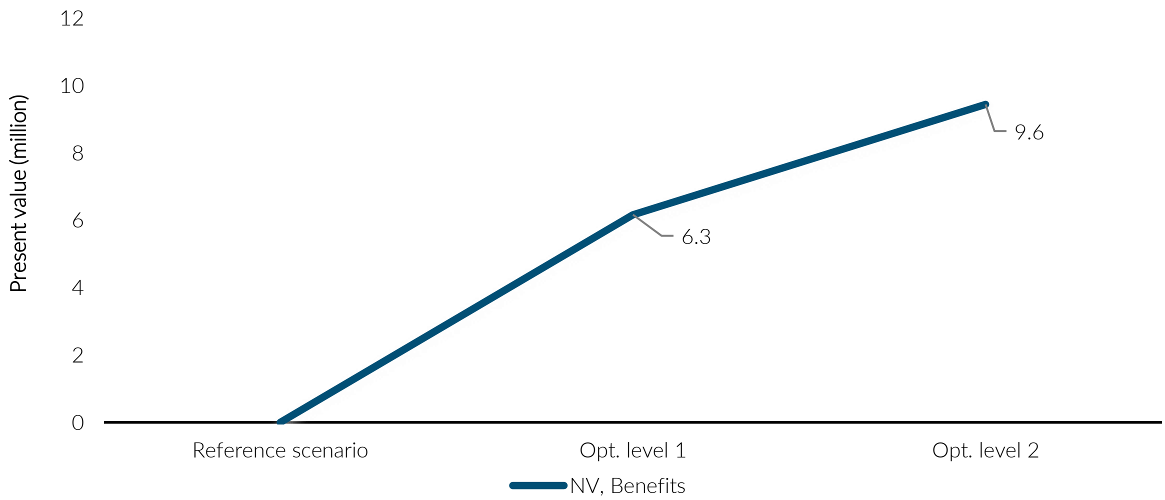


Figure 3.7 Net present value associated with the benefits of the two adaptation options.

It is assumed that the benefits are the same for the two climate adaptation strategies (increase in size of culvert and Nature-based Solution). In the following, the process of estimating the co-benefits associated with implementing a Nature-based Solution in the area is described.

Recreational value of applying a Nature-based Solution

As briefly touched upon in previous sections, a Nature-based climate adaptation option will increase the recreational value of the nearby catchment area in addition to increasing the external drainage capacity.

Currently, the areas both upstream and downstream of the stream crossing the road are inaccessible due to the surrounding areas being overgrown and swampy areas. The adaptation solution is based on the principles of retention. The flow directed downstream of the stream and the culvert under the highway is reduced by creating a large natural basin that the flow is diverted into during periods of high rainfall. The excavated soil is used to create the banks of the basin and a system of small footpaths to make the river and surrounding areas accessible for recreational purposes. A total of three hectares are made accessible for recreative purposes.

The Danish National Environmental Agency provides a catalogue for key figures of unit values on environmental economic assessments, including recreative values per hectare. Based on the catalogue, the specific value is chosen based on nature type and the region. Furthermore, the unit value is inflation-adjusted. The applied unit value for the increase in recreational options is 26.000 kr./year/ha. for the specific region.

This means that the total value of increasing the recreational area with 3 hectares will be 78.000 kr./year. It is assumed that the value is the same for both optimization levels 1 and 2.

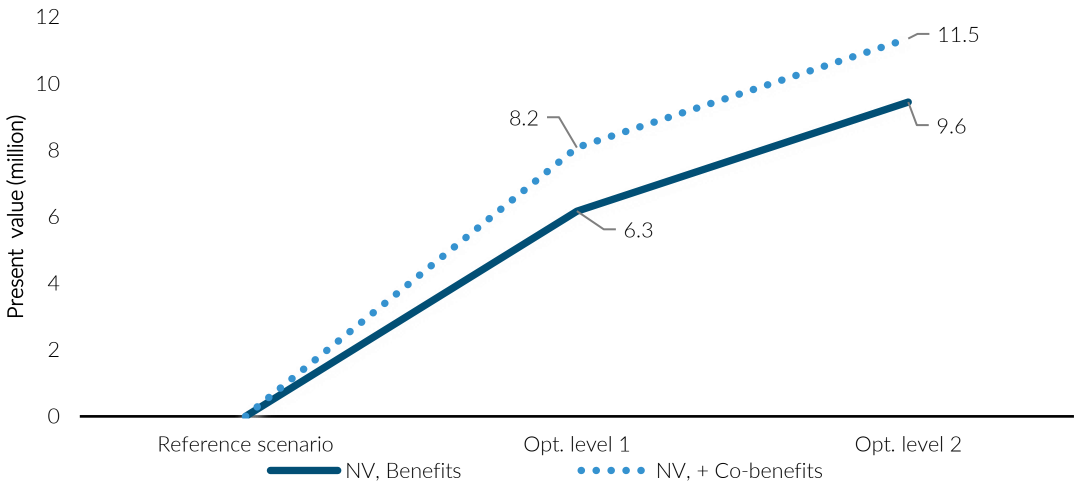


Figure 3.8 Net present value of co-benefits associated with implementing Nature-based Solutions

Cost-estimation

Now that all (co-) benefits associated with the two adaptation options are known, the NRA gathers information to estimate the adaptation costs associated with implementation of the two options. The NRA does this by gathering both current knowledge and historical data on cost estimates.

Both cost estimates are based on previous Danish projects regarding implementation of similar adaptation options.

The costs of increasing the size of the culvert are the estimated construction costs and there will be no maintenance costs over the project period. Based on figures from previous experience, increasing the drainage capacity to optimization level 1 by increasing the size of the culvert is estimated to be 6 million kr. Raising the capacity to optimization level 2 is estimated to be 11 million kr.

The adaptation cost of the Nature-based Solution is also based on cost estimates from previous projects. This indicates a construction cost of around 50 kr./m^3 drainage needed for projects around 100.000 m^3 and a construction cost of around 60 kr./m^3 drainage needed for projects around 150.000 m^3. The higher costs stem from typically higher costs associated with environmental investigations associated with larger projects. Optimization level 1 requires a drainage capacity of 114,000 m^3 and thus has an adaptation cost of an estimated 5.1 million kr., based on a cost of around 45 kr./m3. For optimization level 2, a drainage capacity of 145,000 m^3 is needed generating an adaptation cost of around 9 million kr. based on a rate of 62 kr./m^3.

Costs are estimated for both options and for both levels 1 and 2. The total cost estimates for the two adaptation options over the lifetime of the project are now discounted and represented as a net present value of the costs. This is done for each of the options and both optimization level 1 and optimization level 2.

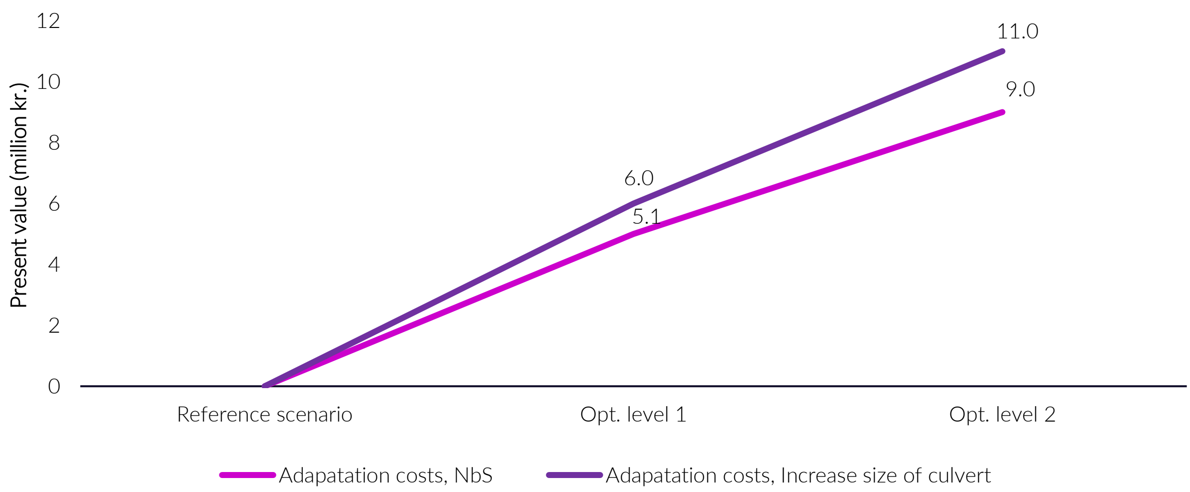


Figure 3.9 Net present value of the climate adaptation costs for the two adaptation options

3.3.5 Choice of adaptation option for based on costs and (co-)benefits optimization

Now all the calculations from the previous steps are gathered, so that all considered costs and benefits are compared to make the case for adaptation. The decision has two dimensions, which optimization level to choose and which adaptation option to choose.

For the Nature-based Solution the net present value of benefits including co-benefits and the cost curve. Subtracting the cost curve (pink) from the (co-)benefit curve (dotted blue) results in the net gain curve (green) for increasing the drainage capacity. As seen in Figure 3.10 the net gain from increasing the drainage capacity to optimization level 1 is 3.0 million kr., and 2.4 for optimization level 2. Based on this result, increasing the drainage capacity to optimization level 1 is the more optimal choice, when applying the Nature-based Solution as an adaptation option.

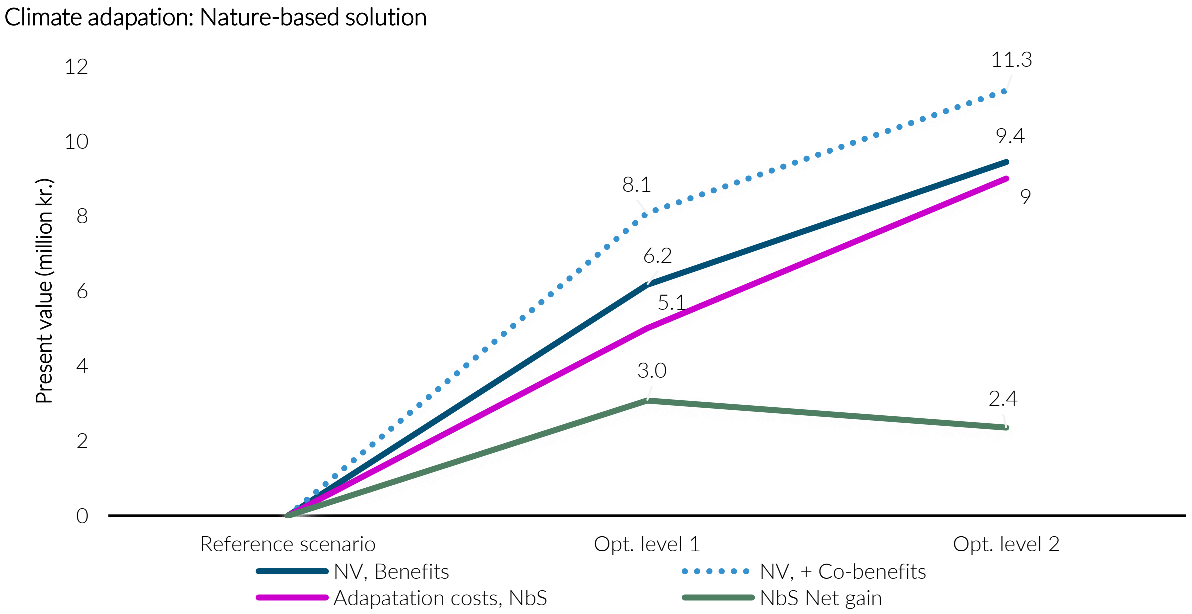


Figure 3.10 Benefits and costs of climate adaptation on the road stretch using a Nature-based Solution. Note: the numbers in the figure are rounded to nearest hundred thousand.

Increasing the size of the culvert does not include any co-benefits that will materialize in the local area, and thus the benefit curve (not including co-benefits) is maintained in the figure. Since the adaptation costs are significant for this option, the net gain is small or even negative, as visualized in Figure 3.11. For optimization level 1 the net gain amounts to 0.2 million kr. and for optimization level 2 to -1.6 million kr.

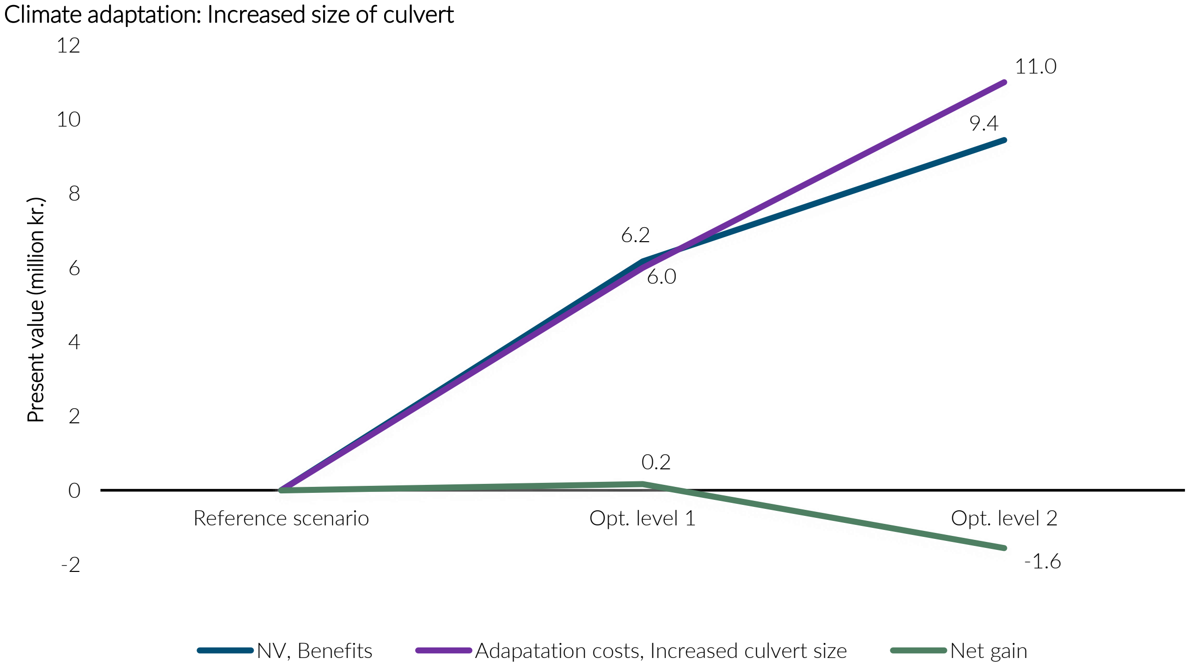


Figure 3.11 Benefits and costs of climate adaptation on the road stretch by increasing the size of the culvert

Going through all the previous steps and combining the results gives the following conclusion of the optimal choice; the drainage capacity should be increased to optimization level 1, using the Nature-based Solution as an adaptation strategy, since this is the climate adaptation option that yields the highest net present value over the considered project period.

3.3.6 Adapting the guidelines

Here, we present one example where an optimum has been found for two adaptation options. In practical situations, there are two ways of adapting the guidelines. The first option is to adapt the guidelines and then based on the changed guidelines implement this in projects. However, the more logical way is to apply the adaptation options for several case studies and projects and based on these experiences jointly, integrate this in the guidelines. In this example, we used the guideline for the design of drainage structures which covers the dimensioning, design, construction and maintenance of common drainage structures[11].

[11] Guideline, Danish Road Directorate

3.3.7 Recommendations

Chapter 3 has aimed to illustrate the fundamental principles of defining optimum service levels for appropriate climate adaptation options, using an example. This example is built on simplified assumptions to facilitate a clear understanding of the core concepts. Below are some considerations and recommendations for applying these principles while implementing them within the NRA.

For successful implementation, we recommend the following:

- Number of adaptation options and combination of adaptation: The example has exemplified two adaptation options for demonstration purposes. In reality, more options should be taken into consideration. Also, combinations of adaptation options should be considered, because these could result in a higher combined effectiveness.
- Number of optimisation levels: In this example we made use of two optimisation levels. It is recommended to use multiple optimisation levels, likely result in a more clearly defined optimum. When no optimum is achieved it is recommended to increase the number of optimisation levels being considered.
- Account for uncertainty.
    - This example shows how cost-benefit assessments can assist in choosing the optimum service levels that should be thrived for. At the same time, climate change is very uncertain and will lead to different possible optimum situations. The example only includes the use of one climate scenario. In reality, more scenarios should be considered to understand the sensitivity of different adaptation options to various scenarios for the future climate. The climate change scenarios to consider should be in line with the national policy and/or the scenarios that are used by the IPCC. For each climate change scenario, the same approach can be used as explained in this section, which will provide a bandwidth of optimum service levels. Taking this approach will also help in identifying solutions that perform well across a range of plausible future climate conditions.
    - In reality, the life span of adaptation measures does not necessarily compare to the road's expected service life. For options with shorter lifetimes than the road, the annual maintenance or replacement costs can be incorporated and/or net present value analyses used to ensure comparability in economic analyses.
    - Using approaches for decision-making under (deep) uncertainty is recommended to account for these uncertainties. For example, the Dynamic Adaptive Policy Pathways (DAPP) approach is outlined in deliverable D2.1 Chapter 2. This method involves developing a set of adaptation pathways under uncertain future conditions, enabling decision-makers to pivot as circumstances evolve.
- The discount rate: Most countries have officially agreed upon discount rates for calculating the net present values (NPV) of projects involving costs and benefits that accrue over time. As such, national guidelines should be adhered to. However, it is crucial to recognize the significance of the discount rate applied over extended project durations. The further into the future the project's costs and benefits are realized, the more impactful the chosen discount rate becomes.
- When performing the economic evaluation OPEX costs should also be considered in relation to the lifespan and investment of the measure.

3.4 Slow Onset Processes

Next to sudden events that are caused by extreme conditions, infrastructure can also be under threat from drivers which result in a slow but constant increase of pressure on the infrastructure, causing a steady degradation in the performance of the asset. An example is the uneven settling of the road embankment by soil subsidence that slowly but steadily degrades the road and affects the evenness of the road surface. The following section discusses ways that this decrease in performance can be economically appraised while supporting the decision-making process.

3.4.1 Determining optimum service levels for slow onset processes

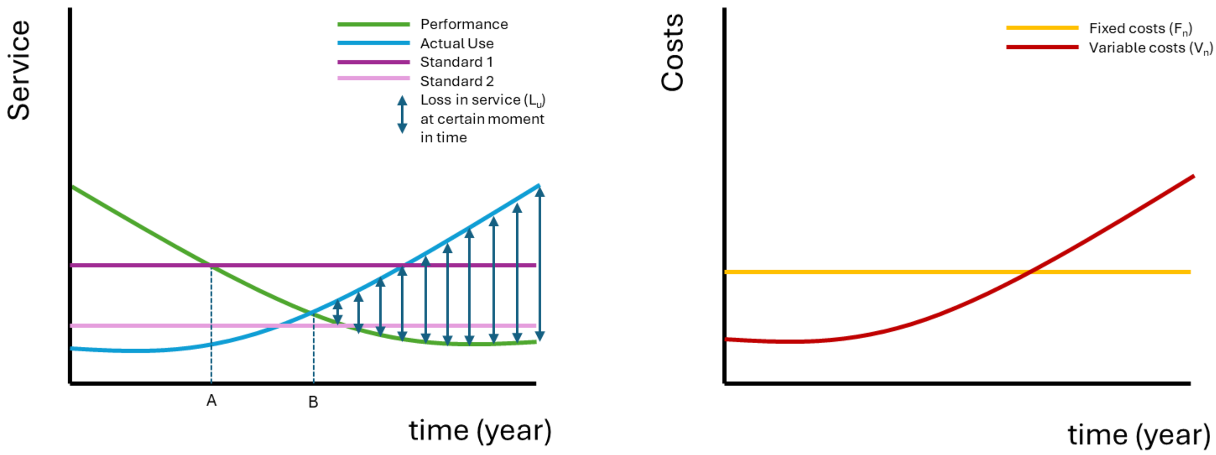


Figure 3.12 Illustration of performance, use and associated costs of a road. ***Left figure****: The green line depicts the functioning of the road which decreases over time due to slow onset processes. The blue line depicts the actual use, which is assumed to increase, because of higher traffic demands. The two purple lines demonstrate two standards the road would need to achieve with standard 1 being a higher standard than 2. Up until Point A the performance of the road does meet Standard 1 and at Point B the performance of the road and demand based on actual use are equal. Losses (arrows) occur when the demand is higher than the service the road can deliver ..* ***Right figure****: The yellow line depicts assumed annual fixed costs (depreciation over the planned lifespan of the road) and the red line depicts variable (increasing) annual costs for operation and maintenance.*

In Figure 3.12 we illustrate a situation for a road with known annual fixed costs (depreciation over the planned lifespan of the road) and the variable (increasing) annual costs for operation and maintenance (O&M). The decreasing performance of the road is illustrated by the green line “Performance”. The standard that is applied by the NRA for the specific road is represented by the purple line “Standard 1” (e.g. a certain number of cars should be able to pass the stretch of road with a certain velocity, say 100 km/h). Point A represents a trigger point where the performance of the road decreases to the point that intervention is now required, since performance drops below the standard. The appropriate course of action from an economic perspective would depend on the actual use of the specific stretch of road, and not by only looking at costs for the NRA but also for the user. Here, we assume that the actual use of the road is expected to increase over time, as traffic intensity will increase with socio-economic developments, while performance of the road will normally decrease due to degradation of the road over time. There are two situations that are explained: (i) the actual use of the road (illustrated by the blue line “Actual use”) is currently below the standard or (ii) the actual use of the road is above the standard.

Scenario (i); actual use is below the standard and below performance

In this scenario, performance has dropped below standard 1, but actual use of the road is also below the standard. An economically driven decision would be to lower the standard to "Standard 2", as this would for the time being not influence the requested performance of the road. With growing actual use, usually as a consequence of increased economic activities with increased demand for transport, at some point in time the performance of the road could be equal to the actual demand of the road users (i.e. "Point B"), after which the economic evaluation would move to the scenario (ii) Actual use above the performance.

Scenario (ii); Actual use is above the performance

In scenario (ii) the choice would be between accepting (some) losses for the road user or rehabilitation of the road, which would require a possible early rehabilitation with increased costs for the NRA. The costs for the NRA consist of the fixed costs associated with the investment (i.e. depreciation) and the variable costs associated with annual (slowly increasing) costs for O&M. Fixed costs are considered constant over the life span of the road, illustrated by the orange line "Fixed annual costs" and are constant in time from year 1 (F_1) to year n (F_n). The variable costs, illustrated by the red line "variable annual costs O&M" will slowly increase over time from year 1 (V_1) to year n (V_n). In the case when actual performance would drop below actual demand a limitation of use would be imposed (e.g. a speed reduction for traffic). This would result in a loss for the road user. This loss (L_u in €) could be calculated by the value of time (VoT) and the time lost (expressed as vehicle loss hours) through the speed reduction for the stretch of road. From an economic point of view, the road should be rehabilitated when;

$$V_n + L_u > F_1 + V_1$$

At this point, the total costs for the NRA and the road user combined are larger than the costs for a rehabilitation of the road (which will result in improved performance and reduced costs for O&M) making the rehabilitation the best choice from an economic point of view. In case the road is not rehabilitated would lead to a general loss of welfare for society because of the costs invoked by all stakeholders combined.

3.4.2 Example

To illustrate the above mechanism, a fictitious but realistic example is being introduced dealing with a stretch of road that is susceptible to subsidence. This example is used to explain the comparison between different types of interventions. In this example we describe three different situations; the standard practice (the baseline); the situation with increased maintenance (Alternative 1) and the situation with an improved road (Alternative 2). For all alternatives, we consider an evaluation period of 40 years. The economic calculations make use of a discount rate of 3%.

Baseline;

In the reference we assume that a road will be constructed without a special foundation, be resurfaced after 10 years and replaced after 20 years. In this baseline situation, a speed limit needs to be imposed 5 years after resurfacing (from 120 km/h to 100 km/h) to keep the same level of risk for accidents. This speed reduction will result in a loss for the road user that will have an increased travel time.

Alternative 1

In Alternative 1 the interval for resurfacing of the road is reduced to once every 5 years, thus there is no need for a reduction in speed on the road.

Alternative 2

In Alternative 2 the road is constructed with an improved foundation giving the road a lifespan of 40 years and an interval for resurfacing of the road every 10 years, without the need for a reduction in speed after 5 years.

Costs

The costs for the construction of a normal road are € 10 million per kilometre while resurfacing costs € 2 million per kilometre. The cost for a road with an improved foundation is € 20 million per kilometre. The losses for the road users in case of a speed reduction are calculated by the increase in travel time, multiplied y an average VoT of € 25/h. For this example, we use a speed reduction of 20 km/h.

The total costs for the alternatives are given in Table 3.5 for a time horizon of 40 years. However, as investment costs and costs for O&M vary between the different scenarios, we use the present value to compare the alternatives. Furthermore, losses that occur in the reference situation are presented as benefits in the two alternatives since these are avoided losses in both alternatives. The benefits depend on the number of vehicles that use the road daily (intensity); a higher intensity gives higher benefits from the avoidance of time (and money) lost. The effects on total costs of the two alternatives are illustrated in Figure 3.13.

In Table 5.1 in Deliverable 2.2 of ICARUS there is also mention of wider benefits that can be the result of an intervention on the road. For example, a reduced speed can have reduced fuel consumption for the road user and a reduced CO_2 emissions. Assuming a 10% reduction of fuel consumption this could result in savings of € 60,000 – 90,000, for fuel consumption, depending on fuel prices and 20,000 vehicles per day. Benefits from reduced carbon emissions for an intensity of 20,000 vehicles a day range between € 4,000 and € 8,000 depending on the price of Carbon credits and actual emissions. Furthermore, differences in road safety, noise and air quality could also result in potential benefits. These types of benefits are however often difficult to quantify and need modelling in order to be quantified and priced. In this specific example the potential values would not influence the decision on the preferred alternative, as the costs of the identified alternatives are dominant in the decision.

Table 3.5 Costs and benefits associated with reference and alternatives in € million over a 40-year time period

	Amounts in million €		
	Reference	Alternative 1	Alternative 2
Costs			
Costs (cash flow)	24.0	32.0	26.0
Costs (PV)	17.8	22.5	23.4
Benefits			
Avoided losses (per 5,000 vehicles/day)		0.75	0.75

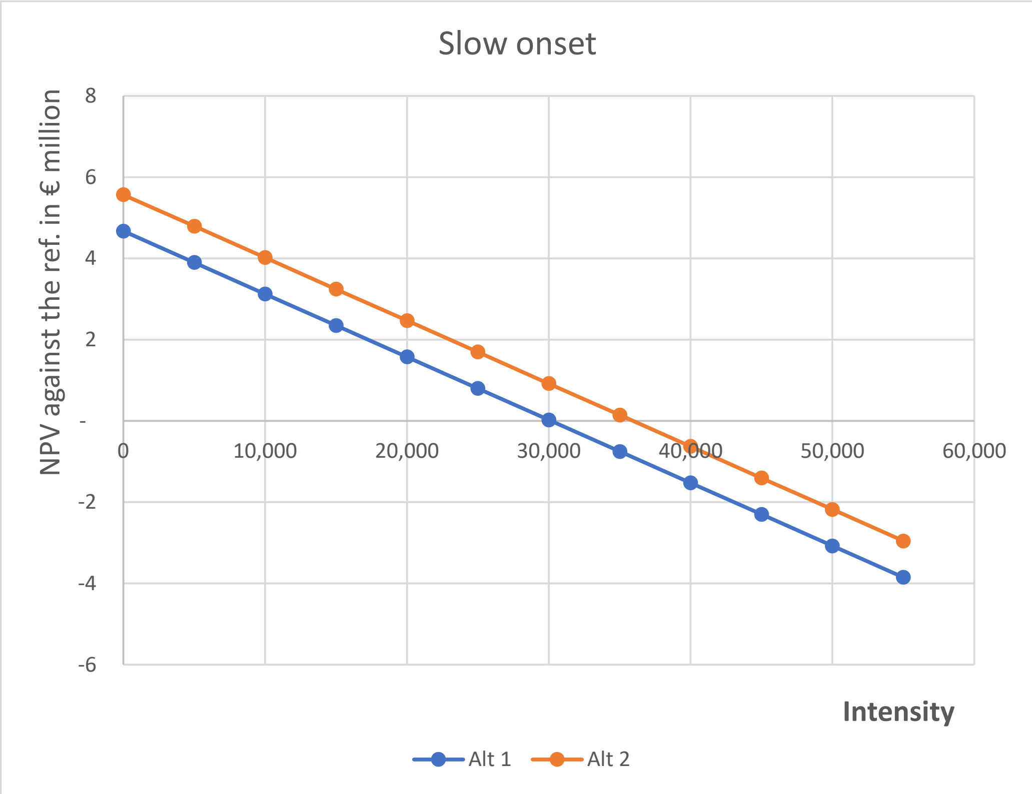


Figure 3.13 Graph showing NPV of alternatives against the reference for different intensities (period of 40 years)

Conclusions

As can be seen from the Figure 3.13 in which the net present value of the alternatives are presented for different traffic intensities as provided in Table 3.5, in which the alternatives are compared to the baseline (the *reference*), Alternative 1 (increased O&M) has less costs than Alternative 2 (improved foundation of the road), mainly due to the higher upfront investment costs for an improved foundation of the road. Since expenses for increased cost for O&M are later in time, this results in lower total costs in *present value* than an initial more robust investment for the road. Furthermore, for lower intensities of use of the road, the introduction of a use limitation of the road (i.e. the introduction of a lower speed limit) has lower costs. Only for roads with high intensities the increase of expenses for O&M as compared to the reference situation is justified from an economic point of view. In this example, this means that doing more frequent O&M (Alternative 1) only makes sense for roads with a user intensity higher than 30,000 vehicles per day (Figure 3.13), as with lower intensities the costs of alternatives are higher than the baseline (here the line crosses the x-axis in the graph). When also considering wider benefits such as safety or sustainability, results may become different. An example of this could be differences in traffic safety, carbon emissions or fuel saving of the different alternatives that can be valued from Value of a Statistical Life, differences in carbon emissions or reduction in fuel consumption between the alternatives. In this example these types of benefits would not change the order of economic performance of the alternatives, as the costs are the dominant factor (reference is made to Table 5.1 in Deliverable 2.2 of ICARUS for further examples of wider benefits).

4 DEMONSTRATING THE USE OF THE IMPLEMENTATION PROCESS DIAGRAM

In Deliverable D2.3, the concept of the ICARUS adaptation implementation process was introduced (below); a step-by-step process showing how resilience assessment and adaptation planning can be processed by a highways administration, including where various parts of the organisation (strategic, tactical and operational) will be mainly responsible for the various steps.

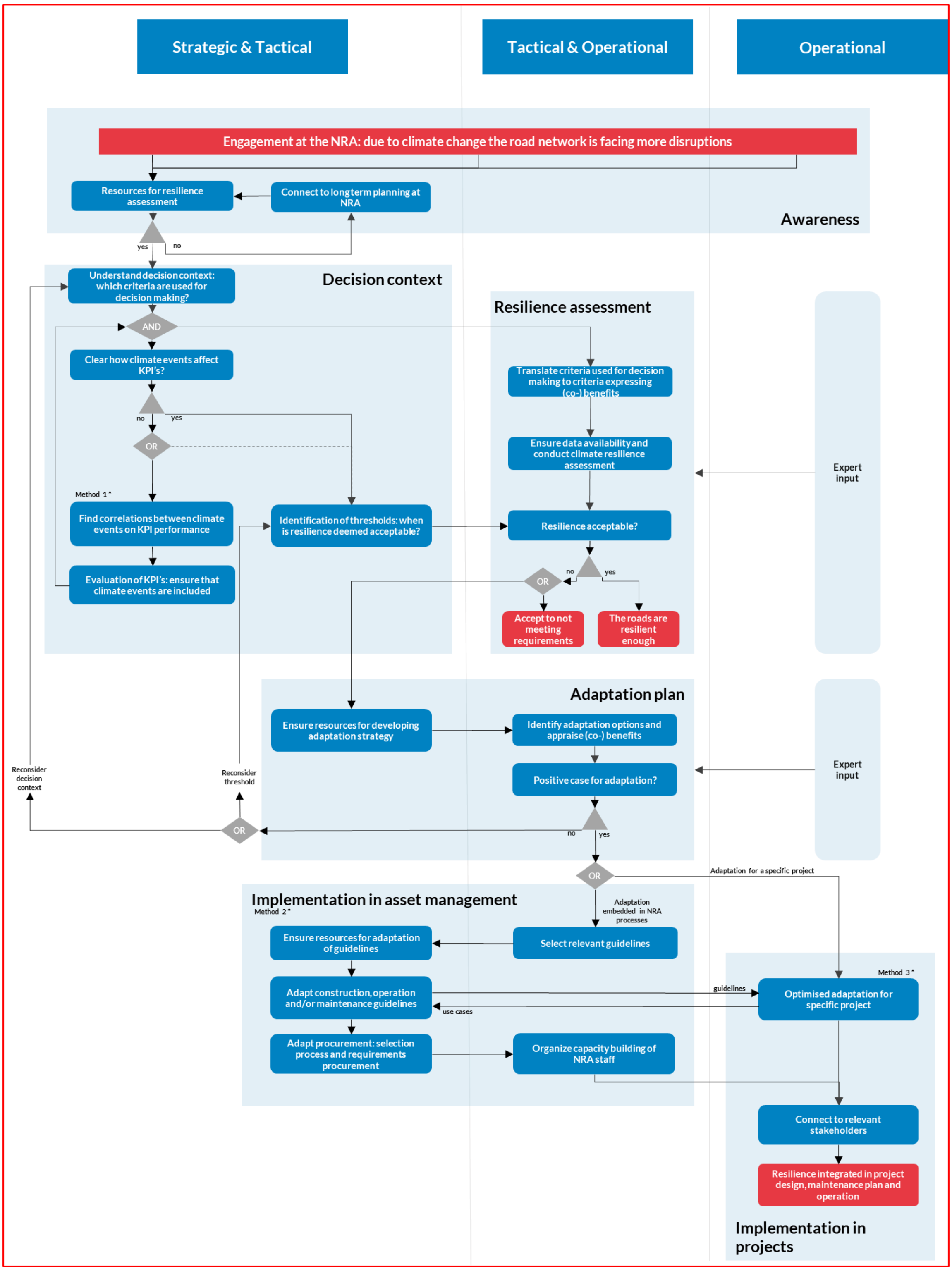


Figure 4.1 ICARUS adaptation implementation process

4.1 Introduction

The process is designed to help road owners and operators understand the steps needed to integrate climate change adaptation into their daily processes and consists of five main building blocks. These are:

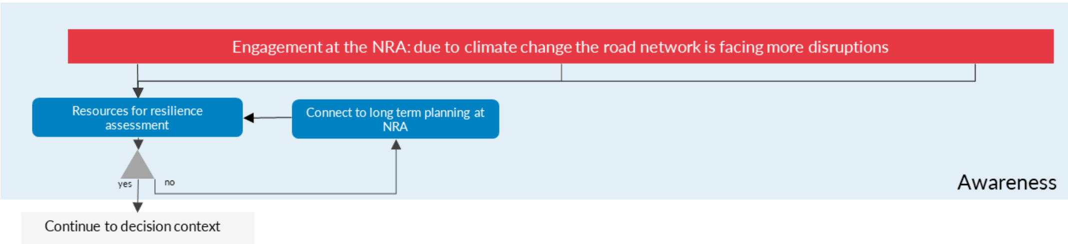
1. Awareness
2. Decision Context
3. Resilience Assessment
4. Adaptation Plan
5. Implementation (at asset management or project level)

Given the fictional example outlined in the previous section, this section will focus primarily on the final option of implementation at a project level. However, it is first useful to briefly consider the levels required to get to that stage.

4.2 ICARUS Implementation Process

This section describes how the ICARUS adaptation implementation process can be used in practice. This is illustrated (in blue text boxes) using the example introduced in the previous section.

4.2.1 Awareness



The road operators are aware that there is an issue with a culvert on the highway that is likely to be undersized to cope with future projected rainfall events. This could lead to flooding on the motorway on a connection between two major conurbations, causing delay or requiring diversions onto local roads, also causing disruption, delay and impacting local communities.

At a strategic level, there is concern that there could be similar culverts or other weak points on the network and that the network will have insufficient resilience for future rainfall events.

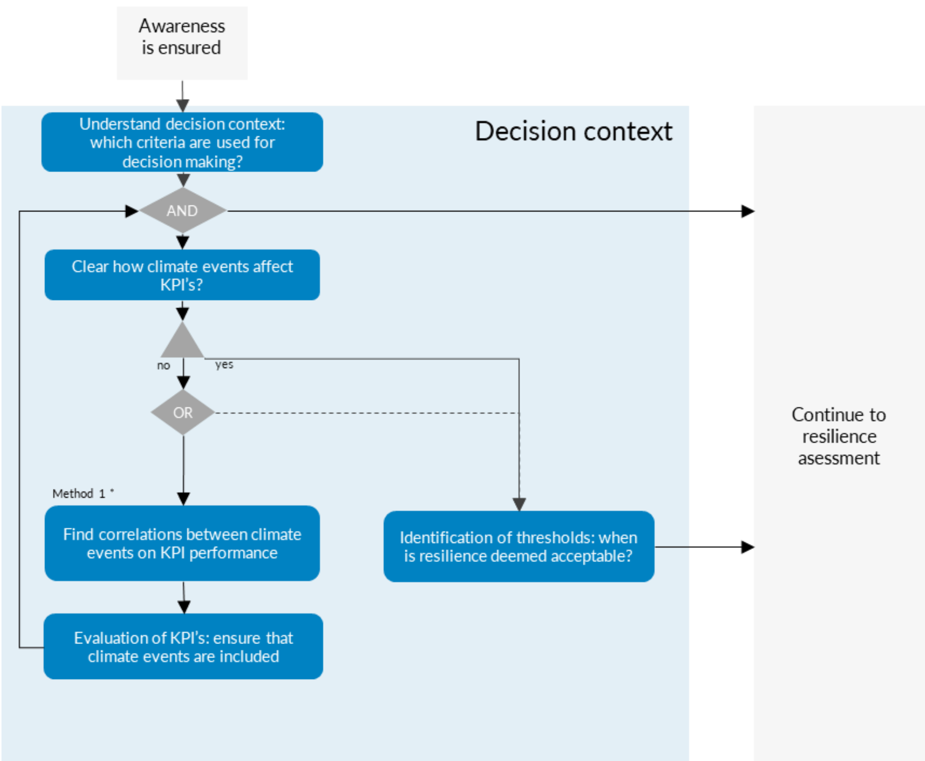
This represents the first step in the process, with the NRA becoming aware of an issue and climate change potentially increasing the risk of disruptions. Depending on the organisational maturity and pre-existing plans, the issue in question (the culvert in the example) may be recognised as part of an existing resilience assessment regime, or it could have been raised by local operational level staff as a potential weak point. At this stage, there should be engagement between all levels of the NRA (strategic, tactical and operational), it identifies roles and ensures the resources to conduct a resilient assessment (to be undertaken later) are available.

The next stage is to make resources available to undertake a resilience assessment. This moves the issue on from general awareness of the issue to quantification of the resilience level. Funding will be required to appoint an external consultant, for internal technical liaison and internal project management.

Should funding not be available to undertake the resilience assessment, there is a requirement for further internal engagement, to further make the investment case and to address climate change as a part of the long-term technical strategy. Once this iteration is complete, a funding request can be made again.

In this example, the assumption is that funding has been made available, either initially, or following one or more iterations, and the process moves to the next stage of the decision context.

4.2.2 Decision context



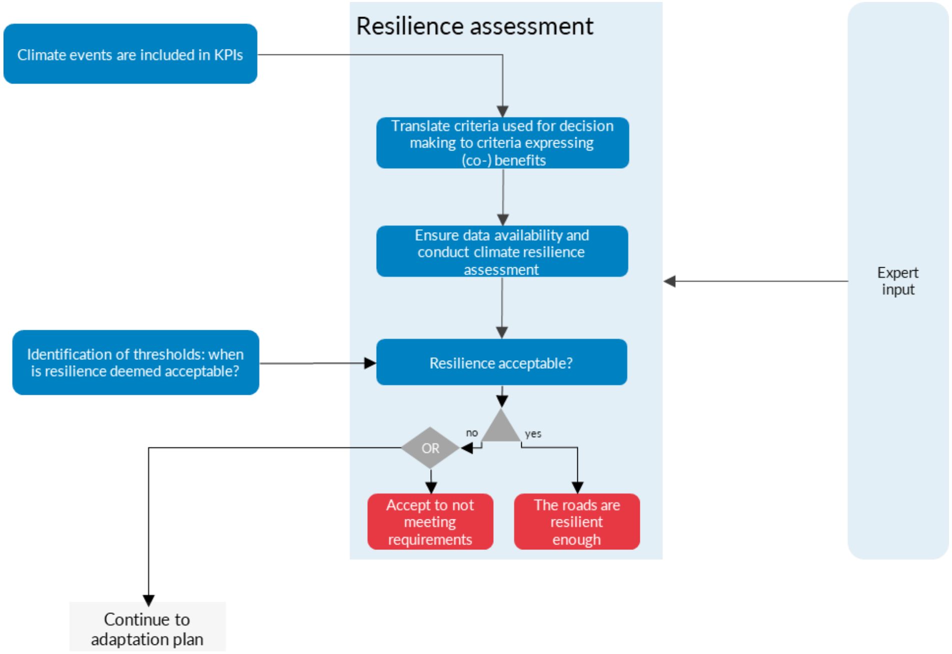
Before the resilience assessment is undertaken, it must first be understood the decision context within which the NRA assesses climate events. The NRA must first be clear on what measures it will use to define resilience. This will be informed in part by the KPIs the NRA uses to measure performance.

All NRAs have KPIs against which they measure specific performance levels, for example, availability and safety are two key measures, whilst there are also other considerations around maintenance and environmental measures such as air quality, noise, and water run-off quality. Depending on how recently the KPIs have been updated, there may be a lack of clarity on how climate events will impact KPIs.

In this specific example, it is known that the design of the culvert as built 15 years previously, did not provide adequate resilience for current rainfall events now or in the future. In such cases, correlations between existing KPIs and climate events must be determined; an obvious target would be to consider the percentage of availability in a defined return period, such as a 1 in 10-year rainfall event. An NRA may have an availability target such as >99% availability for normal conditions, and this could be amended for specific climatic conditions. Targets could also be set for recovery to normal levels following extreme rainfall and floods. Other KPIs to consider could be around maintenance, given the importance of the culvert in removing rainwater – there might be a KPI to clear drains of leaves and debris annually, but this could be set to two or three times for specific 'high risk' culverts, to ensure they remain clear.

Once the link between climate events and their effects on KPIs used by the NRA has been established, then thresholds for resilience can be set. Should availability in normal conditions be set at >99%, then a KPI of 95% availability might be set during flood conditions. With KPIs linked to climate events and thresholds for resilience set, the basis is set for the resilience assessment to be undertaken.

4.2.3 Resilience Assessment



The first step in the resilience assessment is to translate the criteria used by NRAs in decision-making to the valuation of benefits and co-benefits, which essentially means monetising decision criteria.

In this example there is a question on how to translate specific criteria into Euros – this could be the value assigned to availability (or lack of availability) or the financial implication of a reduction in safety during flood events represents the financial impact of travel delays and so on. It is known that the culvert being overloaded could cause flooding that could result in delays closed lanes or potentially sever the link between two important cities. Consequently, the values assigned to this will be much higher than for a less critical link e.g. a minor road between two villages.

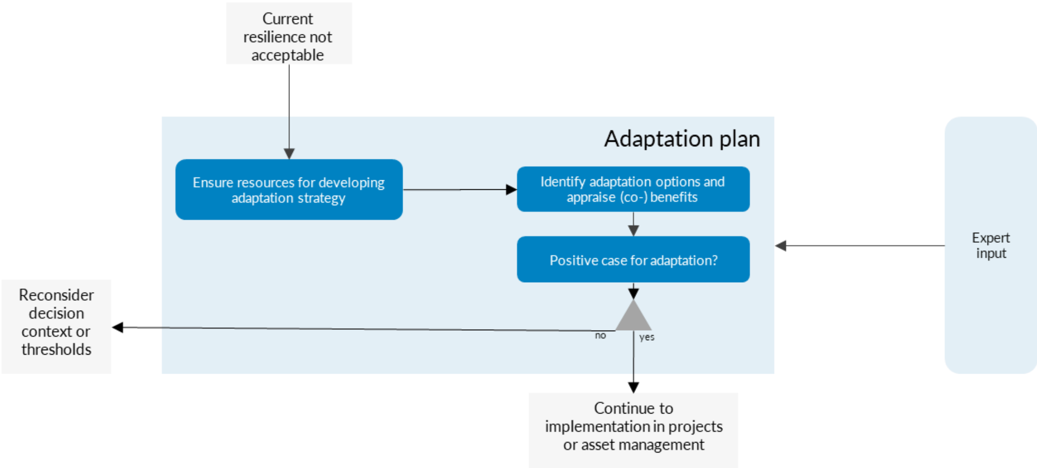
A baseline should then be established against which the effects of adaptation options can be described. Generally, this should be a *business-as-usual* scenario which incorporates expected future changes to the current situation, to consider potential future climate scenarios. The resilience assessment can consider future situations with a changing climate, for example by making use of hazard scenarios based on future climate. This may require external expertise to support this step.

In the example of the culvert, this would consider its suitability now and under future climate conditions. It is known that the design did not consider future climate scenarios, and what might have been a 50-year event at the time, might be a 10-year event in future.

The final step in this stage is to determine whether the level of resilience that was identified in the resilience assessment, probably for both the current and the future situation, is acceptable or not. To do this, the thresholds stemming from the decision context are combined with the outcomes of the resilience assessment. For example, if >95% availability in flood events is a criterion and the resilience assessment indicates that availability would fall below the value set under future climate conditions, then a decision would need to be made to either develop an adaptation plan or choose not to meet the requirements.

In the example , given the importance of this section of motorways in terms of the traffic loads and connection between the two cities, it was decided that choosing not to meet the requirements was not an option. Had the assessment determined that the network would meet criteria set in future climates, then no further action would be required, although periodic reviews would be advisable.

4.2.4 Adaptation plan



As described, in the example of the culvert, it has been determined that the level of future resilience of the culvert is unacceptable and that choosing not to meet resilience thresholds is not an option they wish to consider.

The first step in this stage will be to ensure that the resources required to develop the adaptation strategy are available. These could be financial resources, or human resources in the form of internal and/or external experts. It is likely that for at least some of this stage, external input would be required.

At this point, the individual adaptation options can be appraised for defined benefits and potential co-benefits. In section 3.2.1, two levels of resilience, Optimisation level 1 and Optimisation level 2, were identified to prevent water accumulation on the highway for a one in five year and one in ten year event respectively in 2045. From there, a long list of adaptation options which would achieve this can be assessed and the results of the assessment will determine whether there is a positive case for adaptation. The aim is to prevent flooding on this section of road and any of the adaptation options considered must achieve this objective. This could be achieved by traditional 'hard' engineering solutions, which could include changes in maintenance, raising the embankment, increasing the size of the culvert or adding one or more culverts nearby to divert some rainfall. These benefits of any of the solutions can be appraised based on criteria such as cost, constructability, future maintenance requirements and practicality/disruption, based on this being an active motorway.

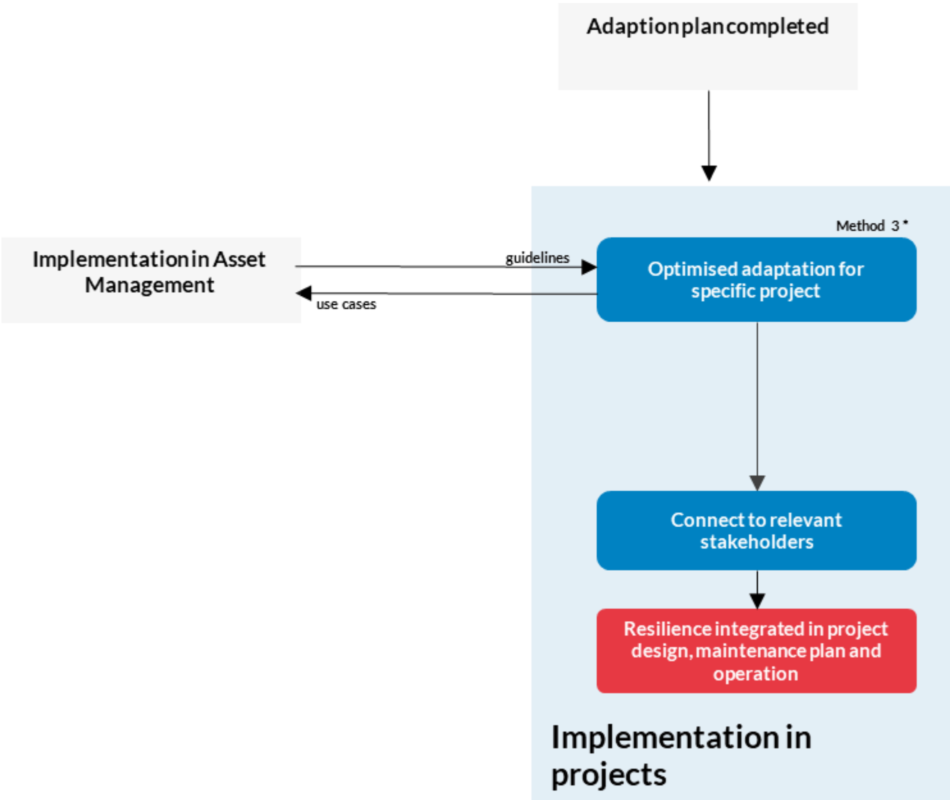
Should Nature-based Solutions (or hybrid solutions) be considered, the benefits would need to be appraised as above in terms of cost, maintenance requirements etc. The co-benefits would also need to be assessed – should a wetland area be chosen as an adaptation option. Co-benefits would include increased recreational value, biodiversity and potentially carbon capture.

When deciding whether there is a positive case for adaptation, i.e. whether it makes sense to invest in adaptation options, the adaptation needs to be compared to the *business-as-usual* situation as used in the resilience assessment.

When there is no positive case for adaptation, for example when the costs don't outweigh the benefits, the NRA can decide to go back to the decision context to either change the criteria or KPIs to include climate effects in decision-making or reconsider the thresholds, which may result in less investments or maybe an acceptable level of resilience in the Resilience assessment stage. For example, it may be that the costs of achieving >95% availability in flood conditions are unaffordable, but affordable solutions exist that would achieve >90% availability.

The methods of assessing options for the culvert and an alternative NbS have been explained in detail in Chapter 3.

4.2.5 Implementation at the project level



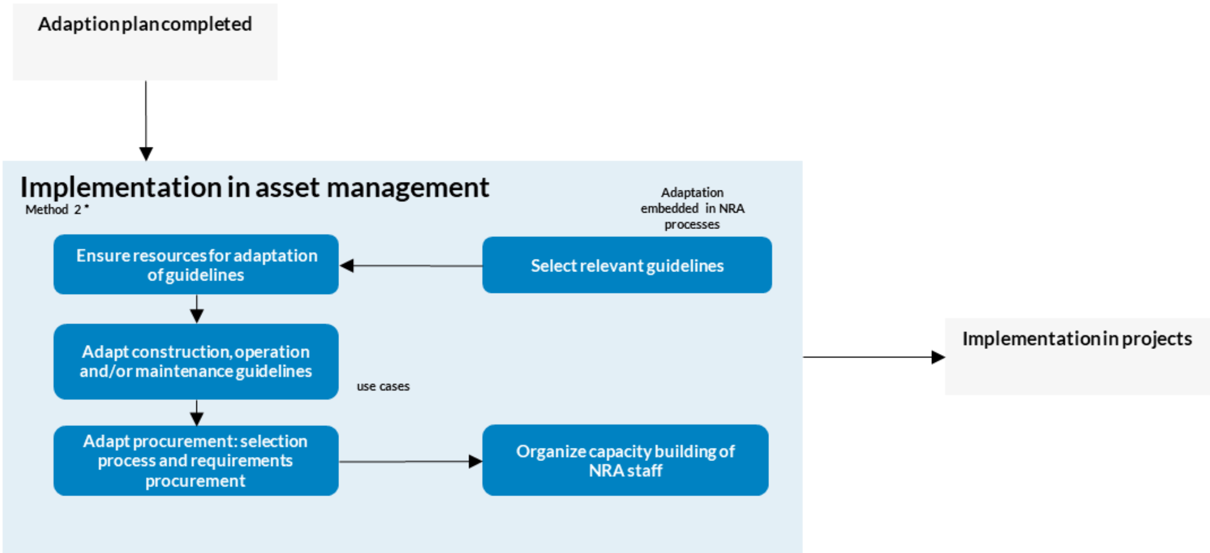
Once the Adaptation Plan has been completed, there is a choice to implement adaptation either at the asset management level or at the project level.

For the culvert example, the adaptation plan has been completed and the optimised solution (based on benefits, co-benefits and cost-effectiveness) has been identified. Actual construction of the solution will be a matter to be put out to tender, whilst potentially planning permission and environmental permits will need to be secured, and depending on the solution chosen, potentially some land purchase will be required. This will require wide stakeholder consultation; for Nature-based Solutions in particular, there should be public consultation to design schemes that best address their needs. In some cases, there could be multiple parties providing funding for a scheme with many co-benefits, which increases affordability but also the complexity of delivery.

The discrete nature of an individual project simplifies some elements of the process. This will generally be undertaken mostly at an operational level, with potential expert input, although liaison will be required at the strategic and tactical levels. Procurement at a project level may be easier to achieve and can serve as an evidence base to make changes to the procurement processes.

Project level implementation simplifies some elements of the process. However, if the process is undertaken before implementation at the asset management level, the asset management guidelines, standards and procurement will not be updated to support the implementation. This may be a valid exercise for NRAs to undertake a trial (or series of trials) to build capacity and provide an evidence base from the individual projects to inform guidelines and future implementation in asset management guidelines, as is covered in the following section.

4.2.6 Implementation in Asset Management Processes



Whilst the fictional example is to be implemented at a project level, the alternative scenario is to implement the adaptation plan into NRA asset management processes. There is not necessarily a 'correct' order in which to achieve this. Some NRAs may have implemented adaptation schemes on projects and now want to make this the 'new normal' by updating their asset management guidelines. Others may choose to update or develop processes to support future adaptation of schemes or as part of their maintenance regime. The asset management processes entail all NRA processes from planning, to design, construction, rehabilitation, maintenance and operation, as well as procurement. As such, this process is somewhat more complex than implementing at a project level as it requires potentially significant changes to operational processes.

The initial step here would be to select which guidelines are relevant for review and potential amendment and ensure that there are resources in place (internal and potentially external experts) to undertake the review. At a technical level, the construction, operation and maintenance guidelines should be reviewed and adapted as necessary to embed climate change solutions to be included as options. Here, the development of case studies may be useful, and this is where the learnings from the Pathfinder projects (of which the culvert example may be one) could be insightful. The next stage will be to amend the procurement processes to ensure that climate resilience and climate change adaptation are appropriately considered for new and existing schemes. The engagement of all NRA areas at the outset (strategic, tactical and operational) should help ensure that common goals in this area are agreed.

5 Communication of Results

Whilst the ICARUS project will have training as part of the deliverables, ultimately, many of the results of the projects and the learnings will need to be communicated internally within NRA organisations. As the internal structure of NRAs is different, and some NRAs will be at varying stages of their journey towards climate adaptation, a one-size-fits-all approach will not be appropriate. Rather, what follows are some key considerations as to what should be communicated, to whom and by whom.

5.1 Objectives

Whilst there is a library of ICARUS deliverables and multimedia training materials, the communication of the ICARUS outcomes within NRAs, will be by the NRAs themselves. It is first important to understand what the overriding objectives of this will be to different audiences within and outside of the NRA.

Within the NRA, three different audiences have been identified previously and are included in the implementation plan; these are strategic, tactical and operational. The key objective is to ensure that there is awareness of the ICARUS project, the resources available and links to other resources (e.g. previous CEDR projects, PIARC, national strategies).

At a broader level, there is a requirement to raise the profile of resilience assessment and climate adaptation at the strategic level and with policymakers to make them aware that there are tools and strategies that can be used to make the business case for this and to integrate into longer-term planning.

NRAs will need to communicate the key messages to their supply chain of consultants and contractors about how they plan to address the challenges faced by a changing climate, how they will assess the resilience of their network and what tools and solutions they will use to address the risks.

Finally, there will need to be communication at a basic level to the NRAs 'customers' who can be broadly categorized as users of the highway, neighbours of the highway and workers on the highway. The main purpose here will be awareness raising and engagement about the risks to highway operations posed by climate change and the measures the NRAs are taking to address this.

5.2 People Involved

There are two aspects when considering the people being involved within an NRA. The first is who will be responsible for leading the communication, and the second is, who are the audiences receiving it. The information to be communicated and means of communication are covered in subsequent sections.

In terms of the person leading the communication, this does not mean they have to be the ones to undertake all, or indeed any, of the communication, but there should be someone in charge of the entire process. This will likely be someone within the organisation who has responsibility for climate resilience and they are from the tactical level. This person should also be responsible for any data collected, any assessments performed, and take ownership of outcomes and results. Storage and maintenance of said data and information should also be the responsibility of this person.

The specific audiences within the organisation that will be targeted have been identified previously in Work Package 4 and Deliverable 4.1. The level of information provided, and the means of communication will need to be appropriate to the individual audiences, and with respect of the organisational maturity regarding climate change adaptation, i.e. the extent to which it is embedded within the NRA. The audiences and suggested messages are as follows:

Strategic

The strategic level covers the higher management level of the organization, with responsibility for the overall direction and strategic objectives. The level of detail needs to be high-level, demonstrating the longer-term impact of climate change on the network, that there are adaptation options available, how they align with organisational goals and strategies, and that there are means to develop the business case. It is suggested that this should be delivered in no more than 1 – 2 pages of information or potentially a small slide deck or video.

Tactical

At the tactical level, greater detail will be required as to how this would be delivered in practice. Information on the business case and implementation process should be provided with adaptation options and case studies of successful delivery. Given that there are many different functions at the tactical level, not everything will be relevant to all. Case studies and climate change implementation options should be presented at this level to allow colleagues to explore options for their departments. For this, consideration could be given to a presentation deck and/or executive summary with links to further information and ICARUS training materials.

Operational

At the operational level, the information to be provided should concentrate on practical examples of implementation as well as available guidelines from ICARUS and elsewhere. These could include case studies from the ICARUS website and other sources such as PIARC. The case studies available on the website will be converted to an eBook upon project completion.

The messages to be delivered will depend, to a certain extent, on the maturity of the organisations' experience in climate change. Three levels are suggested on the next page.

Overall, the training material should filter down from a high-level overview of climate change adaptation at the strategic level to detailed guidelines and business case conceptualisation at the tactical level, and finally to practical examples and guidelines for the operational level. This will enable various personnel from each audience within each NRA to focus on the training material of specific relevance to them, based on their division as well as their position on the journey toward climate change adaptation.

Getting Started — Making case for resilience assessment

- Seeking budget to undertake resilience assessment
- Understanding current risk
- This relates to stage 1 of the Implementation Process presented in D2.3
- Message should focus on raising awareness of climate risk within the organisation and developing strategy

Embedding Processes — Making the case for adaptation

- A resilience assessment has been undertaken
- The existing state and risks have been identified
- Adaptation options have been explored
- This relates to stage 2 of the Implementation Process presented in D2.3
- Message should focus on making the case for adaptation and building business cases

Processes Embedded — Implementing in practice

- Resilience assessments have been undertaken and are reviewed regularly
- Adaptation is being implemented in Asset Management and/or projects
- Lessons learned are fed back into the process
- Message should focus on on fully embedded processes and disseminating good practice.

5.3 Results to be communicated

The information to be communicated will be linked to the implementation process developed in Chapter 4 of ICARUS Deliverable 2.3 (de Paor et al, 2024). The results of each stage of the implementation process will need to be communicated to colleagues and stakeholders. At each stage, perhaps additional information is required to progress to the next stage, or maybe approval for additional budget is required to progress to the next stage so it is essential to communicate the right information to the appropriate audience to progress with the implementation process. The information to be communicated at each stage is shown in Table 5.1.

Table 5.1 Results to be communicated at each stage of the implementation process

Stage	Results to be Communicated
Awareness	If climate change adaptation awareness is already good at the organisation, and resources are already in place to implement climate change adaptation, then no further communication is required. However, if resources are required, then awareness in the organisation should be increased at the Strategic level of the organisation. Support and training materials from the ICARUS project can be used to communicate to do this.
Decision Context	If resources are available to proceed with resilience assessment, first the KPIs being used in the assessment should be determined. Each level of the organization (strategic, tactical, operational) may have different priorities, and so a variety of KPIs should be presented to colleagues to determine the most appropriate before moving to the assessment stage.
Resilience Assessment	Once the resilience assessment is performed, if it is deemed acceptable then there is no need to progress to the next stage. Results of the assessment may be communicated to all levels of the organisation using

	materials provided in ICARUS. The Resilience Impact Score for various elements of the network or various climate impact drivers may be used to demonstrate the results depending on the organisation's priorities. If the result is not deemed acceptable, then results should be communicated to the Tactical and Operational levels to inform them that implementation is planned, and to prepare them to start assessing implementation options.
Adaptation Plan	An adaptation plan should be developed with input from experts at operational and tactical levels who know what might be feasible. Complete the adaptation plan with input from economic experts who can help appraise the different adaptation options. The results of this should be communicated at the tactical and operational levels so that operations teams can prepare for implementation.
Implementation in Practice	Results from this will be communicated to the NRA asset management teams at all levels (strategic, tactical and operational), with more specific detail given to those at the operational level who will be responsible for implementation.

In every organisation, even the most mature NRAs, there will be some scenarios where uncertainty exists. Throughout the adaptation implementation process, there may be some uncertainties such as a lack of information, uncertainty surrounding what climate scenarios to select, or a lack of asset management information. These uncertainties may present many barriers to implementation, however, some solutions to these have been proposed in Chapter 3 of ICARUS Deliverable 2.3 *(in preparation)*, which may assist organisations in overcoming uncertainties. It is important that decision-making still proceeds in the presence of uncertainties, and that the best decision possible is made with the information available. This should also be communicated within the organisation for transparency.

If the results link to strategic objectives of the organisation around Sustainability or Climate, for example, this link should be demonstrated and communicated. Similarly, if infrastructure performance is a KPI or part of the organisation's mission/goals, the link should also be emphasised. If results align with organisational goals or strategy, this can also help improve the business case for funding or resources at the strategic level if needed.

5.4 Means of Communication

The type of communication as well as the information being communicated will depend on the audience. Some proposed means of communication at each level of the organisation are provided in 5.2, with additional guidance on how to present the information provided here.

Generating a narrative or storyline can be an effective way to present information. If presenting the stages of the implementation process, present in a sequential manner, explaining progress from one stage to the next. Create a storyline to explain why you did what you did for example. Explain how the assessments were performed and why it is important. How does this help the organisation achieve their long-term strategies?

Visualisation tools such as flow charts, graphs, and heat maps may also be used for both printed and digital media and presentations.

Heat maps and traffic light colour coding (red, orange and green) may be used to demonstrate critical hotspots or the most critical climate impact drivers which have been identified by resilience assessments. These can be effective in showing what climate impact drivers or what infrastructure elements are of most concern. See example in Figure 5.1.

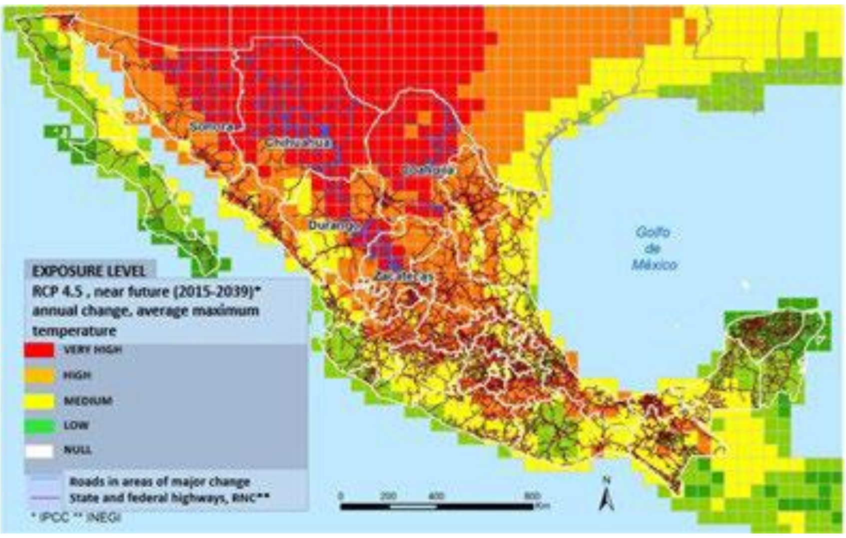


Figure 5.1 Heatmap with degree of exposure to increased temperature, PIARC (2023)

When communicating information about climate change scenarios, there are many tools available such as Climate Impact Atlas or Klimaateffetatlas developed by the Climate Adaptation Services department of Rijkswaterstaat (Rijkswaterstaat, 2024), which allows the user to select different climate scenarios predicted for the year 2050 for the Netherlands, and shows them graphically. The impact of the climate change events on the infrastructure has been calculated using resilience assessment and this is also presented. See example shown in Figure 5.2. This is particularly useful in identifying and communicating the most critical climate change threats at each location. A similar tool has also been developed for Denmark by the Danish Meteorological Institute (Danish Meteorological Institute, 2022).

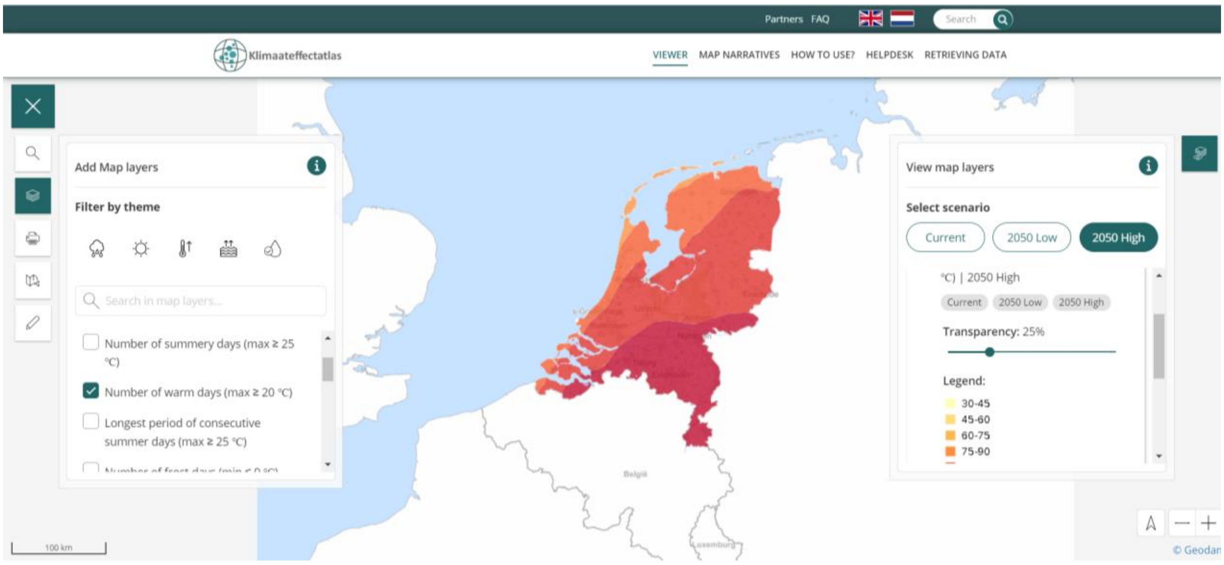


Figure 5.2 Example of climate change map extracted from Klimaateffectatlas (2024)

Impact chains as developed in ICARUS Deliverable 1.2 and re-produced in Figure 5.3 may be used to demonstrate the connection between climate change events and the impact on road infrastructure (Garcia-Sanchez et al., 2023). These impact chains establish causal relationships (asset/ component/ sub-component level) with the Climate Impact-Drivers (CID) identified in ICARUS Deliverable 1.1 (Garcia-Sanchez et al., 2022).

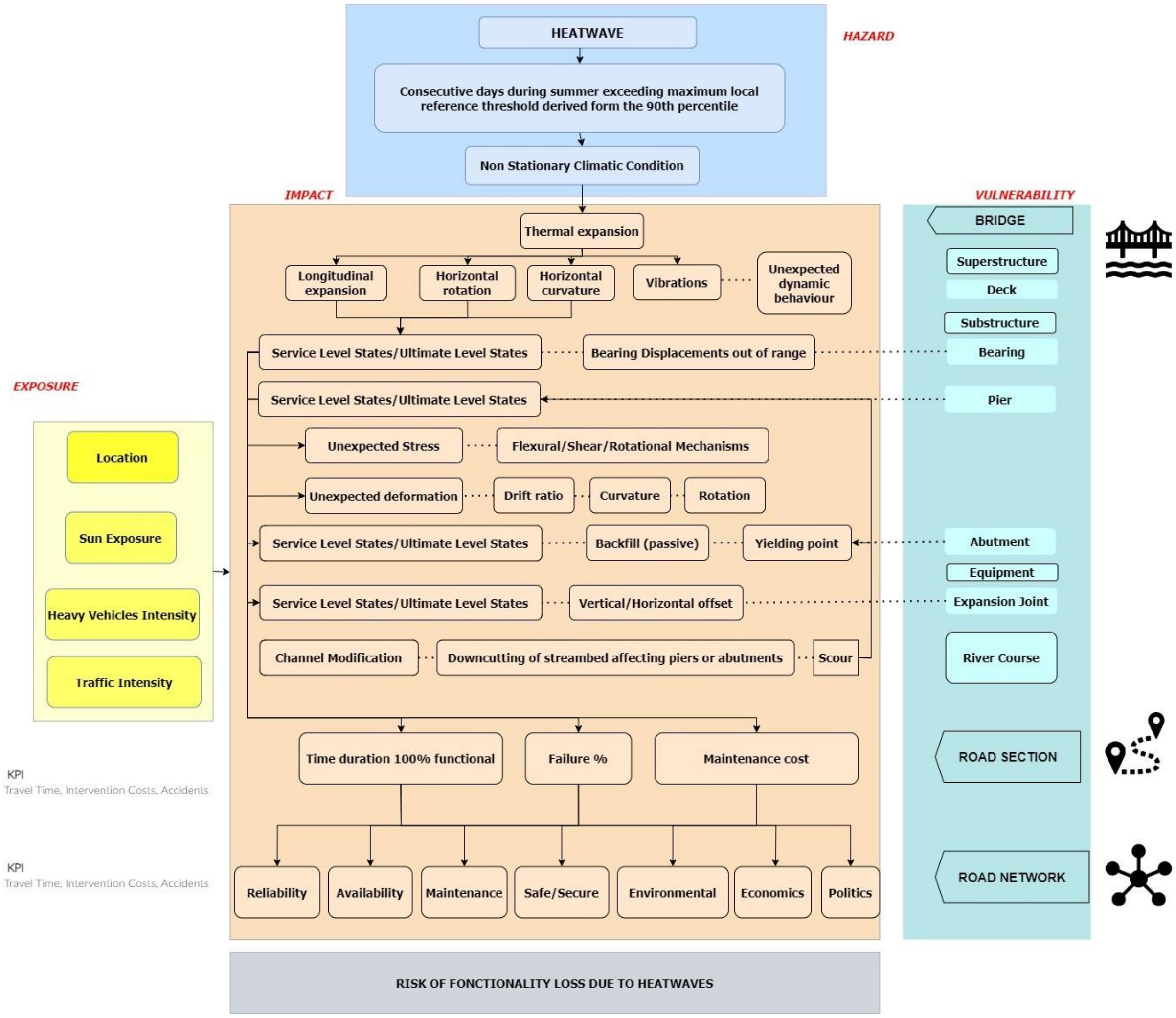


Figure 5.3 Example of Impact Chain for a Heatwave (Garcia-Sanchez et al., 2023)

Some additional guidance may be found in the PIARC International Climate Change Adaptation Framework document (PIARC, 2023).

Another way of visualising and explaining the results can be based on storylines or narratives and visualised in a storymap with a narrative. For example, the visualisation of cascading impacts of flooded infrastructure in Broward County also included the identification of adaptation options. Such a storymap can be informative for decision-makers, emergency responders, as well as users of the infrastructure.

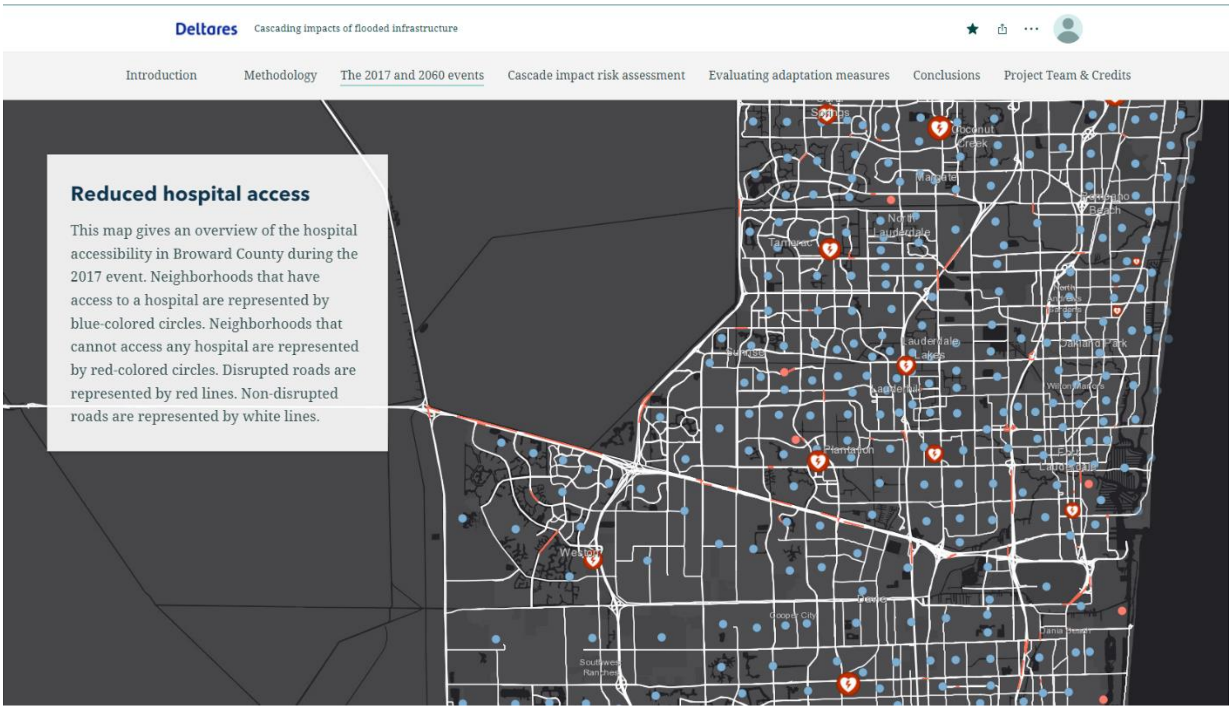


Figure 5.4 Example of the use of story maps for the identification of cascading impacts of flooded infrastructure in Broward County (Deltares, 2022)

5.5 Summary

In summary, to effectively communicate information about the implementation of climate change adaptation, it is important to consider who the audience is. Different communication strategies including the means of communication, and also the type of information communicated should be considered for different audience types. For example, those at the strategic level will require more longer-term information for planning, whereas, at an operational level, information on how to effectively implement climate change adaptation with case studies and examples is required.

6 REFERENCES

Allard, M., et al., (2024), Chapter 6. Permafrost and climate change in Nunavik and Nunatsiavut: Importance for municipal and transportation infrastructures, 2012, Accessed: Feb. 09, 2024. [Online]. Available: https://www.researchgate.net/publication/264454915

Bles, T., Fonseca, A., Lamb, M., Van Marle, M., Dybkjaer, S., De Jonge, A., Toft Andersen, T., de Bel, M., Madsbjerg, K., Bulow Gregersen, I., O'Connor, A., & de Paor, C. (2023). ICARUS Deliverable D2.2: Guidelines on Using Performance Metrics to Make the Case for Adaptation. https://icarus.project.cedr.eu/wp-content/uploads/2023/09/D2.2-ICARUS-Guidelines-on-using-performance-metrics-to-make-the-case-for-adaptation.pdf.

Boike et al., (2021), Standardized monitoring of permafrost thaw: a user-friendly, multiparameter protocol, Arct Sci, vol. 8, no. 1, pp. 153–182, 2021, doi: 10.1139/AS-2021-0007/ASSET/IMAGES/LARGE/AS-2021-0007F14.JPEG.

Brice, C., Brunelle, M., Mauricio, C., Christophe, B., & Clémence, C. (2022, June). Identification of sensor technologies with the potential to support roadside ecosystem services. In 2022 IEEE 28th International Conference on Engineering, Technology and Innovation (ICE/ITMC) & 31st International Association for Management of Technology (IAMOT) Joint Conference (pp. 1-9). IEEE.

Carder, D (2002) PPR302, Performance of Interseasonal Heat Transfer for collection, storage and re-use of solar heat from the road surface

Casartelli V, Mysiak J (2023). Union Civil Protection Mechanism - Peer Review Programme for disaster risk management: Wildfire Peer Review Assessment Framework (Wildfire PRAF - Google Search. (n.d.). Retrieved March 8, 2024, from https://www.google.com/search?q=Casartelli+V%2C+Mysiak+J+(2023).+Union+Civil+Protection+Mechanism+-+Peer+Review+Programme+for+disaster+risk+management%3A+Wildfire+Peer+Review+Assessment+Framework+(Wildfire+PRAF

CIRIA C731 The International Levee Handbook RP957. (2013).

Cortés, C., Rios, C., Cadenas, J. M., García, C., Pascual, P., Castro, D., Vega, A., & Potti, J. J. (2012). SUSTAINABLE ASPHALT PAVEMENTS-PAS. 13–15.

Chu, C.-R., et al., (2013), Windbreak protection for road vehicles against crosswind, 2013, doi: 10.1016/j.jweia.2013.02.001.

Danish Meteorological Institute. (2022). Climate Atlas. https://www.dmi.dk/klima-atlas/data-i-klimaatlas.

Davidsen, S., Asmussen, M. F. 2021. Manual til anvendelsen af Skrift 31. Af Rambøll for Miljøstyrelsen. Accessed at: Accessed at: https://www2.mst.dk/Udgiv/publikationer/2018/manual.pdf

Doré, G., et al., (2022), An Overview of Major Engineering Challenges for Developing Transportation Infrastructure in Northern Canada, The School of Public Policy Publications, vol. 15, no. 1, May 2022, doi: 10.11575/SPPP.V15I1.73187.

Deltares, FIU, ICF, SFWMD, and Broward County (2022) Cascading impacts of flooded infrastructure: Economic quantification for evaluating cascading risks and adaptation solutions. ArcGIS storymap. https://storymaps.arcgis.com/stories/14ed7fcf649648aa98c07d868b80d99b

De Paor, C., Connoloy, L., Bles, T., Woning, M., Van Marle, M., De Jonge, A., Bülow Gregersen, I., Dybkjaer, S. Vicente, S., Lamb, M. (2024). ICARUS Deliverable D2.3: Guidelines providing an overview of and characterisation of adaptation options, with recommendations on implementation.

Garcia-Sanchez, D., De Paor, C., Turienzo, E., Connolly, L., & Paz, J. (2023). *ICARUS Deliverable D1.2 Report on impact chains, vulnerability and hazard classification*. https://icarus.project.cedr.eu/wp-content/uploads/2023/09/D1.2-ICARUS-Report-on-impact-chains-vulnerability-and-hazard-classification.pdf

Garcia-Sanchez, D., Paz, J., Puig, M., Turienzo, E., Connolly, L., & de Paor, C. (2022). *ICARUS Deliverable D1.1 Baseline report on determining impacts and risks due to climate change*. https://icarus.project.cedr.eu/icarus-resources/

Glendinning, S., et al., (2015), Asset-management strategies for infrastructure embankments, https://doi.org/10.1680/ensu.2009.162.2.111, vol. 162, no. 2, pp. 111–120, May 2015, doi: 10.1680/ENSU.2009.162.2.111.

Guo, L. et al., (2021), Changjiang Delta in the Anthropocene: Multi-scale hydro-morphodynamics and management challenges, Earth Sci Rev, vol. 223, p. 103850, 2021, doi: 10.1016/j.earscirev.2021.103850.

Highways England (2022). CG501 'Design of highway drainage systems'. Version 2.1.0

Jiang, G., et al., (2020), Thermal influences of road engineering on permafrost underneath different surface condition in the Qinghai-Tibet Plateau, 2020, doi: 10.1016/j.coldregions.2020.103028.

Johnsson, J (2019) Low-temperature de-icing of road infrastructure using renewable energy

Kocur-Bera et al., (2024), (PDF) Roadside vegetation - The impact on safety. Accessed: Feb. 09, 2024. [Online]. https://www.researchgate.net/publication/282680798_Roadside_vegetation_-_The_impact_on_safety K. Kocur-Bera and M. Dudzinska, ROADSIDE VEGETATION-THE IMPACT ON SAFETY.

Louis Specht, R., & Specht, A. (2013). Australia, Biodiversity of Ecosystems. Encyclopedia of Biodiversity: Second Edition, 291–306. https://doi.org/10.1016/B978-0-12-384719-5.00285-9

Mitchell, A. L., Rosenqvist, A., & Mora, B. (2017). Current remote sensing approaches to monitoring forest degradation in support of countries measurement, reporting and verification (MRV) systems for REDD+. Carbon Balance and Management, 12(1), 1–22. https://doi.org/10.1186/S13021-017-0078-9/TABLES/2

Ministry of Finance. 2021. Den samfundsøkonomiske diskonteringsrente. Accessed at: https://fm.dk/media/18371/dokumentationsnotat-for-den-samfundsoekonomiske-diskonteringsrente_7-januar-2021.pdf

Morales, J. et al., (2018), Beaches of Huelva, The Spanish Coastal Systems: Dynamic Processes, Sediments and Management, pp. 335–359, Sep. 2018, doi: 10.1007/978-3-319-93169-2_15/COVER.

OBrien, Eugene J., and Connolly, Lorcan. Call 2016 Biodiversity Final Programme Report: 'Measures to Enhance Biodiversity and Address Invasive Species in Road Verges'. No. CR2022-12. 2022.

Oras, K. (n.d.). Recreation ecosystem service, calculation of the contributions from different ecosystems Introduction and the scope of the paper. 1. https://doi.org/10.4462/annbotrm-11807

Osterkamp et al., (2000) Observations of thermokarst and its impact on boreal forests in Alaska, U.S.A., Arct Antarct Alp Res, vol. 32, no. 3, pp. 303–315, 2000, doi: 10.2307/1552529.

O'Sullivan, O. S., Holt, A. R., Warren, P. H., & Evans, K. L. (2017). Optimising UK urban road verge contributions to biodiversity and ecosystem services with cost-effective management. https://doi.org/10.1016/j.jenvman.2016.12.062

Olsen, A.S., Zhou, Q., LInde, J.J. Linde, Arnbjerg-Nielsen, K. 2015. Comparing methods of calculating ex-pected annual damage in urban pluvial flood risk assessments. In Water 2015,7, 255-270. Doi: 10.3390/w/7010255

Payo et al., (2015), Experiential Lock-In: Characterizing Avoidable Maladaptation in Infrastructure Systems, *Journal of Infrastructure Systems*, vol. 22, no. 1, p. 02515001, Sep. 2015, doi: 10.1061/(ASCE)IS.1943-555X.0000268.

Phillips, C. A., Rogers, B. M., Elder, M., Cooperdock, S., Moubarak, M., Randerson, J. T., & Frumhoff, P. C. (2022). Escalating carbon emissions from North American boreal forest wildfires and the climate mitigation potential of fire management. Sci. Adv, 8, 7161. https://www.science.org

PIARC. (2023). *PIARC International Climate Change Adaptation Framework - 2023 Version*. http://www.piarc.org

Rijkswaterstaat. (2024). *Klimaateffectatlas*. https://www.klimaateffectatlas.nl/en/

Rosbjerg, D. 2016. Optimal adaptation to extreme rainfalls in current and future climate. In Water Re-sources Research, 52, 535-543. Doi: 10.1002/2016WR019718

Scheer, J., et al., (2024), Thaw settlement susceptibility mapping for roads on permafrost - Towards climate-resilient and cost-efficient infrastructure in the Arctic, Cold Reg Sci Technol, p. 104136, Feb. 2024, doi: 10.1016/J.COLDREGIONS.2024.104136.

Serda et al., (2013), Synteza i aktywność biologiczna nowych analogów tiosemikarbazonowych chelatorów żelaza, Uniwersytet śląski, vol. 7, no. 1, pp. 343–354, 2013

SIREN Policy Brief EJP SOIL https://ejpsoil.eu › fileadmin › projects › ejpsoil PDF Jan 9, 2023 — Problem: To evaluate the state of our environment, including soils, concepts of soil health, ecosystem services and sustainable land use need ... 6 pages - Google Search. (n.d.). Retrieved March 8, 2024

Steenbergen, F., et al., (2019), Green Roads for Water Guidelines for Road Infrastructure in Support of Water Management and Climate Resilience.

Summary-of-July-2023-Climate-Smart-Forestry-Report-final.docx. (n.d.). Retrieved March 8, 2024, from https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Flaw.stanford.edu%2Fwp-content%2Fuploads%2F2023%2F07%2FSummary-of-July-2023-Climate-Smart-Forestry-Report-final.docx&wdOrigin=BROWSELINK

Tamang, B., et al., (2009), Windbreak Designs and Planting for Florida Agricultural Fields: FOR227/FR289, 8/2009, EDIS, vol. 2009, no. 9, Oct. 2009, doi: 10.32473/EDIS-FR289-2009.

TII (Transport Infrastructure Ireland) (2012): "Guidelines on the Implementation of Landscape Treatment on National Road Schemes in Ireland". GE-ENV-01103

TII Publication (2015). DN-DNG-03022 'Drainage Systems for National Roads'

Trencanová, B.; Proença, V.; Bernardino, A. Development of Semantic Maps of Vegetation Cover from UAV Images to Support Planning and Management in Fine-Grained Fire-Prone Landscapes. Remote Sens. 2022, 14, 1262. https://doi.org/10.3390/rs14051262

(9) (PDF) Development of Semantic Maps of Vegetation Cover from UAV Images to Support Planning and Management in Fine-Grained Fire-Prone Landscapes. Available from: https://www.researchgate.net/publication/359067492_Development_of_Semantic_Maps_of_Vegetation_Cover_from_UAV_Images_to_Support_Planning_and_Management_in_Fine-Grained_Fire-Prone_Landscapes [accessed Mar 22 2024].

Trofimenko Y V et al., (2017), NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/). Peer-review under responsibility of the scientific committee of the International Conference on Transportation Geotechnics and Geoecology ScienceDirect Functional Loss Risks of Highways in Permafrost Areas Due to Climate Change, Transportation Geotechnics and Geoecology, vol. 189, pp. 258–264, 2017, doi: 10.1016/j.proeng.2017.05.041.

US (2003), Climate Change, Permafrost, and Impacts on Civil Infrastructure U.S. Arctic Research Commission Permafrost Task Force Report.

Varlamov, S., et al., (2022), Monitoring the Permafrost Conditions along Pipeline Routes in Central Yakutia, Russia, Land 2022, Vol. 11, Page 2331, vol. 11, no. 12, p. 2331, Dec. 2022, doi: 10.3390/LAND11122331.

Wieczorek, G.F., et al., (2009), Monitoring slope movements, Geological Monitoring, Oct. 2009, doi: 10.1130/2009.MONITORING

Zhang, L., Zeng, G., Guo, S., Li, D., & Gao, Z. (2017). Comparison of traffic reliability index with real traffic data. EPJ Data Sci., 6, 19. https://doi.org/10.1140/epjds/s13688-017-0115-7

Zeng D., Zhang, H., et al, (2022) Scalable risk assessment of large infrastructure systems with spatially correlated components, Volume 101, vol. 101, Jan. 102311, doi: 10.1016/j.strusafe.2022.102311.

Zhou, Q., Mikkelsen, P. S, Halsnæs, K., Arnbjerg-Nielsen, K. 2012. Framework for economic pluvial flood risk assessment considering climate change effects and adaptation benefits. In Journal of Hydrology, pp. 539-549. Doi: 10.1016/j.jhydrol.2011.11.031.

7 Appendix

7.1 Applied unit costs and estimated damage costs

Table 7.1: Unit costs of personnel-related accident costs

Personnel-related accident costs	
Killed	39.717.831 kr.
Severely injured	6.212.052 kr.
Minorly injured	798.316 kr.
Average	5.125.234 kr.

Table 7.2: Unit costs of delay (kr./person-hour)

Kr./person-hour	Commuting	Business	Other	Weighted average
Value of delay	176,6	733,8	249,9	283,8

Table 7.3: Presentation of the calculated damage costs associated with availability, safety and maintenance costs associated with extreme rain events for the reference scenario, optimization level 1 and 2.

	Status quo			Optimization level 1			Optimization level 2		
	Availability	Safety	Other	Availability	Safety	Other	Availability	Safety	Other
5-year event	602,375	29.000	-	-	-	-	-	-	-
10-year event	1,204,750	38.667	-	602,375	29.000	-	240,950	14.500	-
25-year event	2,409,500	48.334	-	1,204,750	38.667	-	481,900	19.334	-
100-year event	4,818,999	-	1,000,000	2,409,500	48.334	750,000	963,800	24.167	500,000

In addition to the damage costs associated with the KPIs, availability and safety, the table includes cleaning and repair costs in the category 'Other'. This damage cost is estimated based on historical data from the NRA and will only occur for a 100-year event.

7.2 Derivation of expected annual damages

The outset of the estimation of the EAD is to model the relationship between the return periods and their associated damages. Experience has shown that this relationship by approximation can be exemplified by the relationship illustrated below in Figure 7.1. The damage curve visualizes the damage costs as a function of the return period, and previous estimations have proven this to usually take the form of a logarithmic relationship (Olsen et al. 2017; Rosbjerg 2016; Zhou et al. 2012). As seen in Figure 7.1, the curve increases at the beginning whereafter it flattens. The curve flattens, because the spreading of water in case of flooding is not a linear relationship of higher volume, due to irregularities and dips in the terrain. The dots on the curve in Figure 7.1. are added to illustrate the practical approach most often taken to construct the damage curve. Because it is time-consuming to conduct hydraulic simulations and estimate the costs for enough rain events and their associated damages to form a nearly continuous relationship between them, the practical approach most often taken, is to use at least three to four return periods, and then interpolate between the points and assume a logarithmic functional relationship, as also shown in figure 2.4 (Davidsen & Asmussen 2021).

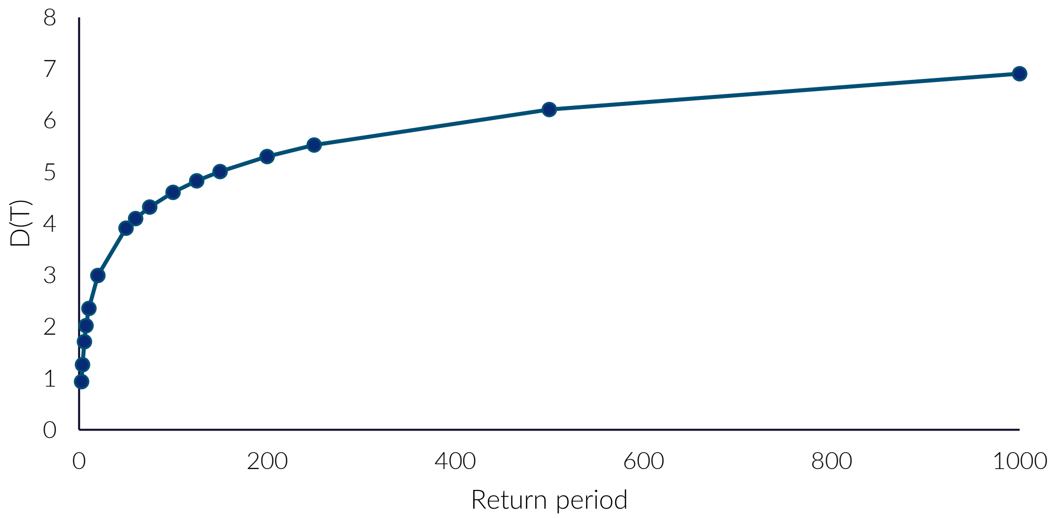


Figure 7.1: Illustration of the typical relationship between return period (rain events) and damages.

Based on the constructed damage curve it is possible to derive the *risk density curve*. The risk density curve is a product of the damage costs as a function of the return periods, weighted by the probability of the occurrence of these return periods. If the damage cost function is defined as $\boldsymbol{D(x_T)}$, where $\boldsymbol{x_T}$ is a series of maximum yearly rainfall, from which we can infer the *T*-year rain event, and $\boldsymbol{F(x_T)}$ is a cumulative distribution function of x_T. Then the EAD is given by

$$\boldsymbol{EAD = \int_{x_{t_s}}^{\infty} D(x_t)dF(x_t)dX}$$

The cumulative density function is differentiated to get the probability density function, and x_{Ts} is the lowest level of rain intensity that implies damage costs. The exceedance probability[12] of a given maximum rain series is given by $\boldsymbol{p = 1 - F(x_T)}$ and therefore, $\boldsymbol{dF(x_t) = -dp}$. As the yearly probability of a *T*-year event is given by $\boldsymbol{p = \frac{1}{T}}$ we get that $\boldsymbol{dp = -\frac{1}{T^2}}$.

We can now write the EAD as

$$EAD = \int_0^p D(p)dp = \int_{T_s}^{\infty} \frac{D(T)}{T^2}$$

Where we have simply replaced the argument in the damage function, to be more conveniently expressed by the return period (or as the inverse of this).

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[12] The exceedance probability is often used in relation to planning and projection of hazards and extreme events. In cases where observations of previous events exist (like historic observations of rain series), the exceedance probability is expressed as $P\big(F(X_T)_{max,N} > F(X_T)_{max,n}\big) = 1 - F(X_T)_{max,n}$ where *n* is the largest value among the existing observations, and $P\big(F(X_T)_{max,N} > F(X_T)_{max,n}\big)$ is the probability that the largest value among *N* future observations is larger than *n*. The exceedance probability thus expresses the probability of experiencing an event, just exceeding the larges value among the existing observations (Frangopol & Kim, 2014).

$\frac{D(T)}{T^2}$ is referred to as the risk density curve and graphically illustrates the return periods that add the most to the risk (and thus the EAD). Importantly, it enables the calculation of EAD over a specified range of return periods (Rosbjerg, 2016). When conducting calculations manually, the EAD can conveniently be approximated by numeric integration by

$$EAD = \sum \frac{D(p_n) + D(p_{n+1})}{2} (p_n - p_{n+1})$$

The function essentially interpolates between the chosen points of calculation (probabilities of the included return periods and their damage costs) and sums the area under the damage curve for each respective probability. This is also illustrated in Figure 7.2 (Assmussen & Davidsen, 2021).

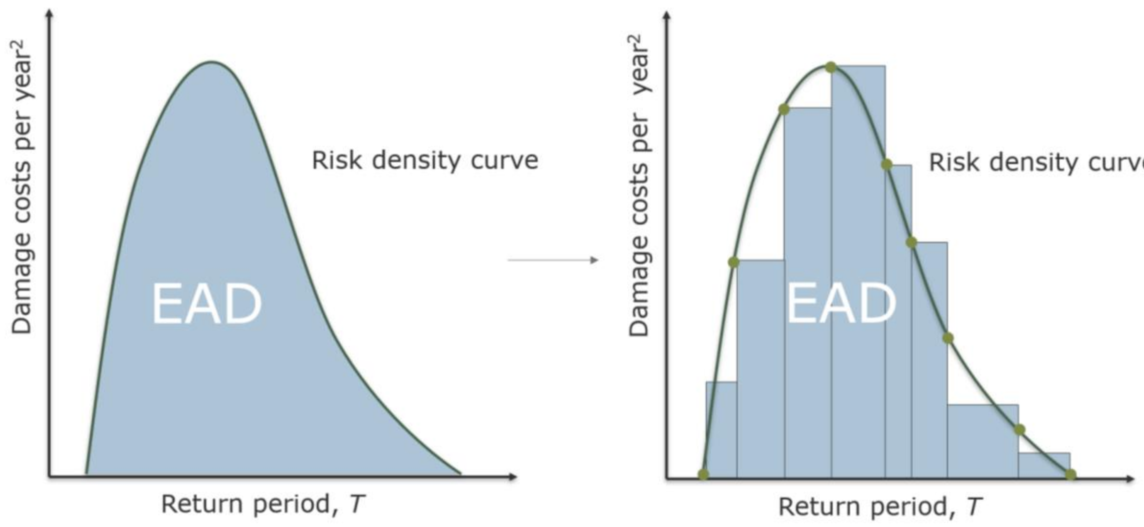

Figure 7.2: Figure to the left illustrates the, in theory, perfectly continuous relationship to form the risk density curve. The figure to the right shows the EAD estimation in practice and as calculated in the demonstration case.

As stated, the most accurate EAD stems from interpolating between at least 4 return periods. Adding to that, it is important to consider what return periods to include in the analysis to most accurately reassemble the damage curve. Furthermore, is it important to note that the EAD is very sensitive to the lower return periods due to their higher probability of occurrence and therefore adds more to the EAD. For example, if a 5-year event causes damages of 10.000 over a 100-year period it will amount to a total of 200.000. If a 100-year event results in damages of 100.000, it will amount to 100.000 in total over the 100-year time horizon (Davidsen & Asmussen, 2021).

The calculations presented in section 3.3 are estimated by calculating the risk densities from the four return periods (5-year event, 10-year event, 25-year event and 100-year event) and are approximated by summing the area of the blocks between the return periods, as illustrated to the right in Figure 7.2. Results of all damage costs, risk densities and calculation of EADs for the three scenarios are presented in Table 7.4 and Table 7.5 below.

Table 7.4: Calculation of EAD in 2025. Calculated damage costs of availability (value of delay), costs of safety (including both increase in number of fatalities, minor injuries and severe injuries) and cleaning and repair costs from road damages. The risk densities are calculated as is calculated as D(T)/T^2 and risk densities by the numeric integration formula provided above and as visualized in Figure 7.2

Reference scenario						
Return period	Probability	Cost, availability	Cost, Safety	Cost, road damages	Risk density	Risk
5	0.200	602,375	29,000	0	25.255	93.740
10	0.100	1,204,750	38,667	0	12.434	111.038
25	0.040	2,409,500	48,334	0	3.933	124.152
100	0.010	4,818,999		1.000.000	582	29.095
					EAD =	358.025
Optimization level 1						
Return period	Probability	Cost, availability	Cost, Safety	Cost, road damages	Risk density	Risk
5	0.200			0		31,569
10	0.100	602,375	29,000	0	6,314	56,244
25	0.040	1,204,750	38,667	0	1,989	66,769
100	0.010	2,409,500	48,334	7,500,000	321	16,039
					EAD =	170,620
Optimization level 2						
Return period	Probability	Cost, availability	Cost, Safety	Cost, road damages	Risk density	Risk
5	0.200	-				12,773
10	0.100	240,950	14,500		2,555	22,701
25	0.040	481,900	19,334		802	29,838
100	0.010	963,800	24,167	500,000	149	7,440
					EAD =	72,751

Table 7.5: Calculation of EAD in 2075. Calculated damage costs of availability (value of delay), costs of safety (including both increase in number of fatalities, minor injuries and severe injuries) and cleaning and repair costs from road damages. The risk densities are calculated as is calculated as D(T)/T^2 and risk densities by the numeric integration formula provided above and as visualized in Figure 7.2

Reference scenario						
Return period	Probability	Cost, availability	Cost, Safety	Cost, road damages	Risk density	Risk
3,3	0,30	602,375	29,000	-	57,978	135,266
6,3	0,16	1,204,750	38,667	-	31,328	131,414
11,4	0,09	2,409,500	48,334	-	18,912	274,968
47	0,02	4,818,999	-	1.000.000	2,634	61,904
					EAD =	603,553
Optimization level 1						

Return period	Probability	Cost, availability	Cost, Safety	Cost, road damages	Risk density	Risk
3,3	0,30			0	-	45.554
6,3	0,16	602,375	29,000	0	15.908	66.565
11,4	0,09	1,204,750	38,667	0	9.568	147.877
47	0,02	2,409,500	48,334	7,500,000	1.452	34.126
						EAD = 294,122
Optimization level 2						
Return period	Probability	Cost, availability	Cost, Safety	Cost, road damages	Risk density	Risk
3,3	0,30	-			-	18.431
6,3	0,16	240,950	14,500		6.436	26.866
11,4	0,09	481,900	19,334		3.857	66.084
47	0,02	963,800	24,167	500,000	674	15.829
						EAD = 127,210

Table 7.6 below illustrates a section of the estimated EAD cashflows as well as benefit cashflows from increasing the drainage capacity from the reference scenario level to the capacity level of optimization levels 1 and 2, respectively. Figure 7.3 illustrates this step.

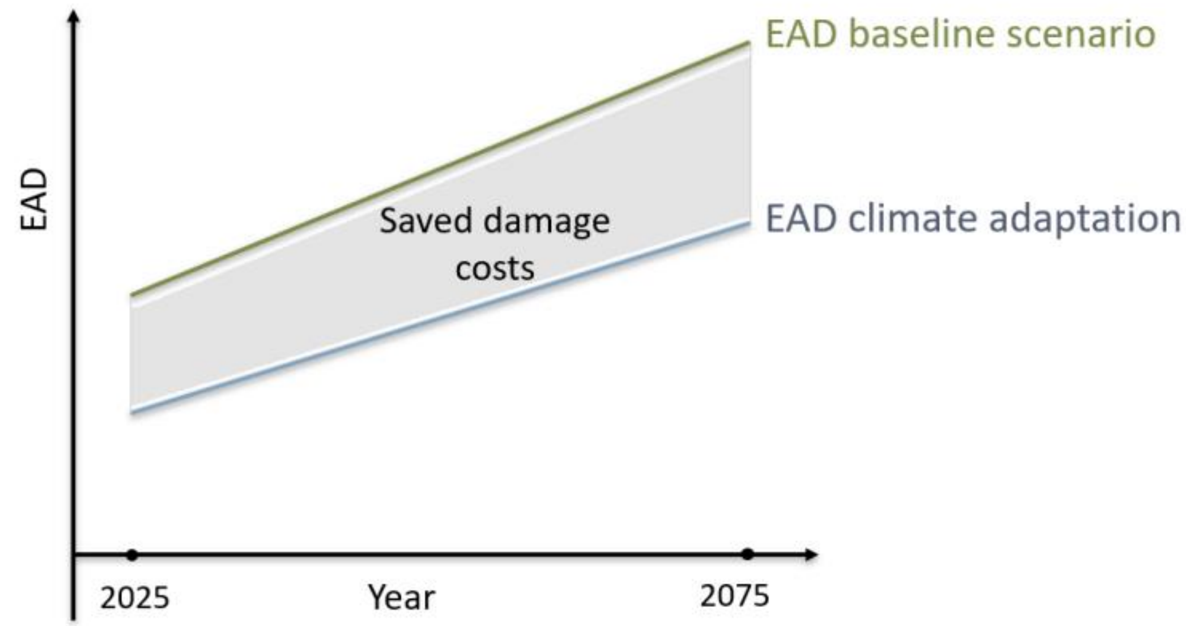

Figure 7.3: Illustration of how the EADs are used to estimate the benefit of climate adaptation.

Table 7.6: Estimated EAD cashflows for the reference scenario, optimization level 1 and 2, as well as the benefit cashflows and discounted present value of these benefits.

Year	EAD Reference scenario	EAD Opt. level 1	Benefit	Present value of benefits	t
2025	358,025	170,620	187,404	187,404	-
2026	362,935	173,090	189,845	183,425	1
2027	367,846	175,561	192,285	179,500	2

….	….	….	….	…	….
….	….	….	….	…	….
2073	593,732	289,181	304,550	93,092	48
2074	598,642	291,652	306,991	91,549	49
2075	603,553	294,122	309,431	90,027	50

Year	EAD Reference scenario	EAD Opt. level 2	Benefit	Present value of benefits	t
2025	358,025	72,751	285,274	285,274	-
2026	362,935	73,840	289,095	279,319	1
2027	367,846	74,929	292,917	273,441	2
….	….	….	….	….	….
….	….	….	….	….	….
2073	593,732	125,032	468,699	143,268	48
2074	598,642	126,121	472,521	140,913	49
2075	603,553	127,210	476,342	138,588	50