U.S. Department of Transportation
Federal Highway Administration

Rijkswaterstaat
Ministerie van Infrastructuur en Milieu

Joint FHWA and Rijkswaterstaat Report 'Resilient Infrastructure'

Assessing vulnerabilities/risks to climate change and incorporating the results into planning, design and asset management

Date	January 2016
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0 Executive summary

From 2013 and onwards the Federal Highway Administration (FHWA) and Rijkswaterstaat have worked together on the theme of 'Resilience to Climate Change and Extreme Weather Events'.

The collaboration has shown there are valuable tools and knowledge on both sides that are worth sharing and implementing. This report provides an overview. The next step, and challenge, is to fully integrate climate adaptation strategies into the working processes of both organizations.

Scope and structure of the report
The goal of this report is to help to improve FHWA and Rijkswaterstaat processes towards resilience of infrastructure to climate change. To that end the report describes strategies, methods, reports and best practices in both the USA and the Netherlands (and where relevant other European countries) to help to increase the resilience of infrastructure to climate change in a better, smarter, and more cost effective way. The process to work towards resilient infrastructure can be divided into three main phases: 1. vulnerability and risk assessment, 2. developing and incorporating adaptation options and 3. managing adaptation options. The report is roughly structured along these phases.

Climate change scenarios
The projections of climate change on the USA and on Europe show both similarities and differences. On both continents we see more intense precipitation and heat waves. In the USA there is more melting of snow and permafrost in the north and drought in the southern parts of the continent. In the USA there is a strong focus on the likely increased reach of storm surge with sea level rise and stronger hurricanes. Hurricanes are not an issue in Europe, although more intense storms and collateral damage are expected.

In the Netherlands, sea level rise is a prominent issue as much of the land elevation is already below sea level, and sea level on the Dutch coast is projected to rise 80 centimeters (2.5 feet) by 2100. The projected sea level rise on the southern and eastern coast of the USA tends to be even higher (by 2100 up to 4 feet, or 6.6 feet under a rapid ice melt scenario). However, the USA also has many inland population centers which will not be affected by sea level rise.

Policies and national strategies
Both the FHWA and Rijkswaterstaat are government agencies responsible for highway networks. However, Rijkswaterstaat authorities also include coastal and riverine flood defense and water quality management. In the US, those authorities are under the purview of agencies separate from FHWA; the US Army Corps of Engineers constructs and manages US flood defenses and the US Environmental Protection Agency is responsible for water quality.

A Presidential Executive Order requires all US federal agencies, including FHWA, to integrate climate risks into agency programs and operations. In the Netherlands, climate adaptation is not a specified criterion yet in maintenance, construction and management of the National Highway System by Rijkswaterstaat. Integration is being worked on at present through the Netherlands National Adaptation Strategy, expected in 2016.

In both the USA and the Netherlands a national strategy and a plan for adaptation to climate change have been or are being worked out, roughly covering the same risks and impacts related to climate change. However, there are some differences in the overall approach.

In the Netherlands, the primary focus is on preventing coastal flooding from sea level rise and extreme weather. This strategy is implemented through the Delta Programme, a one billion Euro per year government program of flood defenses (dykes, levees, etc.) protecting the population and the built environment. The Delta Programme is risk-based; the probability of casualties as a result of flooding must not be higher than 1:100,000 per annum. The effects of the other aspects of climate change (such as heat, drought, and river flooding) are met by making water systems, infrastructure and built-up areas more robust. The National Adaptation Strategy encompasses all climate change effects and covers the fields of health, agriculture, tourism, mobility and infrastructure, energy, international affairs, etc.

The focus in the USA is mainly on managing the effects of extreme weather and climate change to keep the impacts as low as reasonably possible. To do so, federal agencies must consider climate change in their investments. Prevention of flooding through multi-sectoral flood defenses is managed by the US Army Corps of Engineers and local floodplain managers. Risk tolerance in the USA is higher, with many assets built to the 1 in 100 year flood level of protection.

The European Union (EU) is requiring that projects financed under the planned Trans-European Transport Network (TEN-T) must consider climate change risks. Co-financing rates may be increased by up to 10 percentage points for actions enhancing climate resilience.

Climate action is a key priority for the EU. To respond to challenges and investment needs related to climate change, the EU has agreed that at least 20% of its budget for 2014-2020 – as much as €180 billion − should be spent on climate change-related action.

In both the USA and the Netherlands, investments to make transportation systems more robust to climate change and the prevention of flooding in low-lying areas are key issues in the national plans for the adaptation to climate change. The exchange of knowledge and experiences on these issues should help to improve climate change strategies of both FHWA and Rijkswaterstaat.

Vulnerability and risk assessment

Both FHWA and Rijkswaterstaat have the responsibility to provide tools, case studies and best practices for incorporating climate change into decision-making. A lot of work in this respect has been done on vulnerability and risk assessment.

In the USA, FHWA funded 24 pilot studies across the country on transportation resilience to climate change. These studies were carried out by state and local agencies while FHWA provided technical assistance and funding. Based on the lessons learned in the first round of pilots, the FHWA developed the Climate Change & Extreme Weather Vulnerability Assessment Framework. This framework provides an overview of the key steps in conducting vulnerability assessment and gives in-practice examples to demonstrate a variety of ways to gather and process information.

For the Netherlands, most work on vulnerability assessment is being done on a European level in the ROADAPT, RIMAROCC and Blue Spot projects and research programs. The tools and guidelines are based on and tested in only a few pilots concentrated in the Northwestern region of Europe.

The most striking differences and similarities in vulnerability assessments in the different pilot projects in the USA and Europe are listed below:

- The pilots in the USA usually look at the transport system as a whole whereas the pilots in Europe focus on road networks and related systems and services

- In both the US and European pilots, a wide range of climate variables and effects are taken into account. The emphasis is mostly on the risks of flooding and on the effects of extreme rainfall. Due to large differences in climate and geography, the climate data and the stress factors involved in the different pilots can vary widely.
- Guidance in the USA pilots is organized in accordance to the decision making process focussing often on a more qualitative risk assessment, on identifying and prioritizing options and the involvement of stakeholders. The European project and research programs follow a more scientific approach providing technical guidelines on the use of climate data, on vulnerability assessment and on performing a socio economic impacts assessment.
- Both the US and European pilots and guidelines mainly use GIS-aided methodologies for the vulnerability assessment. The availability of correct GIS files and databases greatly influences the results.

An in-depth comparison of the technical approaches and methodologies used for vulnerability assessment in the USA and Europe is hard to carry out. Especially in the US, pilots use different technical approaches and methodologies. The pilots are conducted by the state and local agencies, which have their own goals and emphases. In addition, the availability of data varies for each pilot and this influences the choice of methodology. The European projects and pilots are more centrally coordinated and therefore much more uniform in the methodologies used.

Implementing adaptation options
Both FHWA and Rijkswaterstaat have developed frameworks and guidance documents that focus on the process of developing and integrating climate change and that evaluate methodologies and best practices. These frameworks and guidance documents are meant to help agencies in developing tailor-made solutions for each individual project.

In both the USA and the Netherlands climate change will be a mandatory part of Environmental Impact Assessment (EIA). In the Netherlands, the requirement will come into effect in 2017. The Netherlands does not have examples of climate resilience incorporation into EIA to share. In the USA, the US Council on Environmental Quality has released draft guidance and is expected to release final guidance soon. Though the guidance will not technically require inclusion in EIA, CEQ guidance is usually interpreted as a de facto requirement. At the state level, Washington state department of transportation requires climate adaptation consideration in EIA by state law and as such EIA documents from that state provide examples.

Both agencies in the USA and RWS are dealing with limited financial resources for adaptation to climate change. There is a need for cutting costs and at the same time, mobility is expected to improve, requiring even more funding. This is a major challenge, calling for innovation.

Cost benefit analysis is seen as an important instrument to underpin the need for implementing adaptations options even though there is often no legal obligation for it. The long-term view and the large amount of uncertainty in the effect of climate change provide a problem when estimating the benefits of adaptation options. There is a considerable amount of guidance on this subject in the USA which can be useful for the Netherlands.

Very few design procedures are adapted to the impact of climate change. In the Netherlands and Denmark, design standards on the discharge of run-off have been increased 30 percent to account for more intense precipitation because of climate change. This is based on Dutch meteorology projections of a 27.5% increase with rounding up to account for uncertainty. In the US, pilot projects have taken different approaches to estimating precipitation and streamflow changes from climate change. Some have found that simply using more updated historic data provides a significant improvement to previous practice, which used data from the 1960s. Others have input precipitation projections downscaled from global climate models into local hydrology models to develop estimates for streamflow. Still others have estimated the percent increase in streamflow a bridge or culvert could withstand before being overtopped in order to assess vulnerability to different climate scenarios. On the national level, the US President updated the Federal Flood Risk Management Standard in 2015 to account for climate change. Federal agencies have three options: using best available science; using two to three feet of elevation above the 100 year flood elevation, or using the 500 year flood elevation. FHWA is working on determining how best to incorporate this new requirement into highway design.

In terms of sea level rise, the Dutch Delta Programme incorporates sea level rise estimates. In the USA, the Army Corps of Engineers requires coastal flood protection projects to consider sea level change. The state transportation agencies for California and Washington state require consideration of sea level rise in transportation project development and design.

Given the complexity and uncertainties associated with climate change, much can be gained by a single source where information can be found on climate data, reports, frameworks and best practices. FHWA has already invested in websites, workshops and sessions (e.g. webinar series). Rijkswaterstaat is still at the starting point of unlocking available information, sponsoring of pilot projects and organizing workshops.

Asset management

In both the Netherlands and the USA asset management is considered to be a key element in making the National Highway Network more resilient to climate change. Asset management covers both the maintenance and replacement of existing infrastructure as well as the construction of new infrastructure designed and built to face the effects of climate change.

The main challenge is to cope with the unpredictability of climate change and to work out how to incorporate the unpredictability into a risk based approach in a financially responsible way. Asset management also requires good asset data. Gathering and documenting these data has proven to be a challenge in itself.

In both USA and the Netherlands, implementing climate change in asset management is still in its early stages. Available reports and papers from the USA focus on what elements of climate change can be taken into account in asset management. FHWA's draft asset management regulation would require state DOTs to consider climate risks. Available reports and papers from the Netherlands focus on how climate change adaptation can be implemented in asset management.

The roles of the FHWA and of Rijkswaterstaat in asset management differ. FHWA oversees and supports state DOTs in construction and maintenance of the National Highway System. Rijkswaterstaat itself is responsible for the maintenance, operations, renewal and expansion of the National Highway Network in the Netherlands.

Conclusions

Both countries have benefited from the collaboration on infrastructure resilience to climate change and there are many opportunities for continued collaboration.

FHWA intends to review the ROADAPT guidelines in the update of its Climate Adaptation Framework. At the same time, FHWA's framework and pilot lessons learned may be helpful to the Netherlands in its application of ROADAPT.

The Netherlands experience with large coastal flooding protection projects, protecting land that would otherwise be permanently inundated by the sea, provides useful knowledge that can applied in the USA. Meanwhile, the multiple innovative approaches adopted by pilot projects in the USA for incorporating climate risks into transportation planning and project development offer examples relevant to the Netherlands. Both countries have also expressed interest in additional collaboration on approaches to incorporating precipitation changes into infrastructure design.

1 Introduction

From 2013 and onwards Federal Highway Agency (US DOT) and Rijkswaterstaat have worked together on the theme of 'Resilience to Climate Change and Extreme Weather Events'.
This collaboration has shown there are valuable tools and knowledge on both sides that are worthe to be shared and implemented. This report gives an overview of this. The next step and challenge is to further implemt climate adaptation options fully into the working processes in both organizations.

Scope and goal of the report
The scope of the report is (climate) resilient infrastructure. The goal of this report is to help to improve the FHWA and Rijkswaterstaat processes towards resilience of infrastructure. To that end the report describes strategies, methods, reports and best practices in both the USA and the Netherlands (and where relevant other European countries) to help to increase the resilience of infrastructure to climate change in a better, smarter, and more cost effective way.

Rising temperatures and sea levels as well as an increasing frequency and intensity of extreme weather events (e.g. storms, heat waves, flooding) already have significant impact on the functioning of transport infrastructure. The consequences of climate change are both negative and positive for transport infrastructure such as for rail, road, shipping and aviation, but will differ from region to region. In particular, the projected increase in the frequency and intensity of extreme weather events such as heavy rain (e.g. causing floods), heavy snowfall, extreme heat and cold, drought and reduced visibility can enhance negative impacts on the transport infrastructure, causing injuries and damages as well as economic losses, transport disruptions and delays. Some beneficial impacts on transport can also be expected, such as reduced snowfall.

In Europe for road transport infrastructure, weather stresses represent from 30% to 50% of current road maintenance costs (8 to 13 billion € p.a.). About 10% of these costs (~0.9 billion € p.a.) are associated with extreme weather events alone, in which extreme heavy rainfalls and floods events represent the first contribution. These costs might be reduced in the future by making infrastructure more resilient to climate change. Similar figures for the USA are not yet available but are expected to be in the same range.

Structure of the report
The process to work towards resilient infrastructure can be divided into three main phases: 1. vulnerability and risk assessment, 2. developing adaptation options and 3. incorporating and managing adaptation options.
This report is roughly structured along these phases in the following chapters:
- policies and national strategies (Chapter 2)
- vulnerability and risk assessment (Chapter 3)
- developing adaptation options (Chapter 4)
- management of the adaptation options (Chapter 5).

Each chapter starts with by comparing the practices in the USA and the Netherlands. Following that the strategies, methods, reports and best practices on which the comparison is based, are described in more detail. A summary is given for the reviewed strategies and reports . The methods and best practices are described along following criteria and questions:

1. Description of the method (scope, key steps, how is the analysis conducted, illustrative examples, incorporation in existing processes)
2. How is it applicable to the US/ The Netherlands (how applicable, is it transferable, does it need to be changed/ adapted, can it be used in other countries)

3. How much time/ money/ effort is required

If the reviewed reports and surveys consist of a main project or an overall method with several sub-methods or case-studies (best practices), the sub-methods and case-studies will be discussed separately following the given criteria. For the main project or overall method, a description is given of the relationship between the overall method and the sub-methods or case studies.

2 **Policy and National strategies**

2.1 Comparing policies and strategies USA - The Netherlands

In this chapter, the policies and national strategies with respect to adaptation to climate change in the Netherlands and in the USA are discussed.
This first paragraph summarizes the main similarities and differences found . These are illustrated by the different policies and plans described in the following paragraphs.

In both the USA and the Netherlands, a national strategy and plan for the adaptation to climate change has been or is being worked out, roughly covering the same risks and impacts related to climate change.
As can be expected there are differences in the overall approach. In the Netherlands the first focus is on preventing flooding (as a result of sea level rise and extreme weather), worked out in a risk-based level of protection in the Delta Programme (probability of casualties as a result of flooding not higher than 1:100.000 per annum). In the Delta Programme the effects of the other aspects of climate change (such as heat, drought, pluvial flooding) are met by making water systems, infrastructure and built-up areas more robust. The effects of the other aspects of climate change (such as heat, drought, pluvial flooding) are met by making water systems, infrastructure and built-up areas more robust. Next to this the National Adaptation Strategy deals not only with flooding, but with all effects of climate change, in the fields of health, agriculture, tourism, mobility and infrastructure, energy, international affairs, etcetera.
The focus in the USA is on managing the effects of extreme weather and climate change, whereby the aim is to keep the impacts as low as reasonably possible.

In the USA an adaptation strategy specific for infrastructure has been worked out by the Department of Transportation (ref. policy statement and adaptation plan). In the Netherlands there an adaptation strategy is not available yet. The National Adaptation Strategy is being worked out at present in the Netherlands by several Departments, under the responsibility of the Department of Infrastructure and the Environment. The Strategy is planned to be ready in 2016. Infrastructure and mobility is one of the subjects that we be addressed in the agenda, planning both technical and political measures.

Both the FHWA and Rijkswaterstaat are government agencies responsible for highway networks. However, Rijkswaterstaat authorities also include coastal and riverine flood defense and water quality management. In the US, those authorities are under the purview of agencies separate from FHWA; the US Army Corps of Engineers constructs and manages US flood defenses and the US Environmental Protection Agency is responsible for water quality.

A Presidential Executive Order requires all US federal agencies, including FHWA, to integrate climate risks into agency programs and operations. In the Netherlands, climate adaptation is not a specified criterion yet in maintenance, construction and management of the National Highway System by Rijkswaterstaat. Integration is being worked on at present through the Netherlands National Adaptation Strategy, expected in 2016.

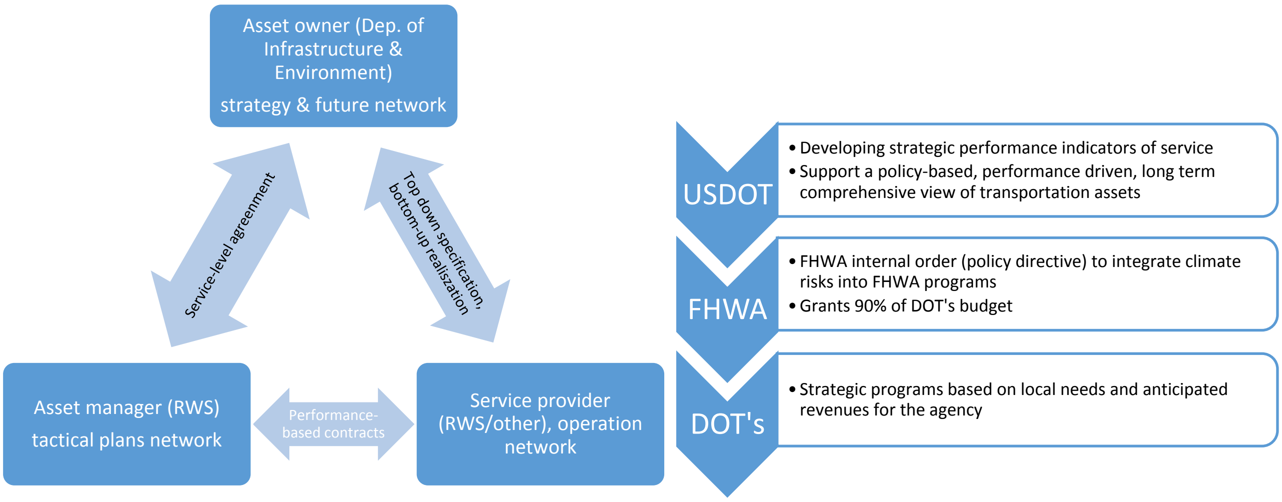


Figure 1: Organization structure in the Netherlands and the USA

This is also reflected in the way climate adaptation for the National Highway System is managed and funded. In the USA, the National Highway System is built and maintained mainly by the State Departments of Transportation. FHWA's role is to oversee federal funds used by the State departments of Transportation or local highway agencies for constructing and maintaining the National Highway System.
Climate adaptation activities are eligible for FHWA funding.
In the Netherlands Rijkswaterstaat is responsible for the maintenance, operations, renewal and expansion of the National Highway Network. Both FHWA and Rijkswaterstaat do not receive specific funding from the Ministry (Department) / DOT for climate adaptation. Measures to improve the resilience of the network have to be paid out of the total budget assigned to a specific project.

In table 3 policies and strategies for climate adaptation in the Netherlands and the USA are compared.

Table 2: Comparing policies and strategies for climate adaptation in the Netherlands and the USA

	USA	NL
Goals and strategies	• Reducing harmful effects • Presidential Executive Orders • USDOT Adaptation strategy on climate change • FHWA internal order to integrate climate risks into their programs • Currently no specific requirements for environmental review of projects under NEPA, though draft guidance has been developed[1] • No specified criteria in the maintenance, construction and management on climate change adaptation.	• Prevention. • Joint effort of national government, provinces, municipalities and regional water boards work together with input from social organizations and the business community in nationwide programs • No specified criteria in the maintenance, construction and management on climate change adaptation. A National Adaptation Strategy in being developed • An important element of the Delta Decision on Spatial Adaptation is that all authorities have agreed that in 2050 the Netherlands must be as climate-proof and water-robust as possible. • 'Soft' pressure by European Commission in the paper "Adapting infrastructure to climate change"

[1] See https://www.whitehouse.gov/administration/eop/ceq/initiatives/nepa/ghg-guidance

	USA	NL
		• EU directive on environmental impact assessments
Organization and funding	• Regulation, supervision, and funding for all aspects of transportation • The majority of roads in the United States are owned and maintained by state and local governments • Climate adaptation activities are eligible for FHWA funding but no additional funding is provided for climate adaptation	• Rijkswaterstaat is responsible for the maintenance, operations, renewal and expansion of the Highway Networks • The national roads (Rijkswegen) are controlled by central government agency Rijkswaterstaat. The country's twelve provinces control the provincial roads and the municipalities control the local roads • Rijkswaterstaat receives no explicit funding from the Ministry for climate adaptation

2.2 Goals and strategies

2.2.1 USA

White house

Obama orders federal agencies to account for rising seas in their investments (E.O 13690: 30 January 2015)

"The Obama administration today ordered federal agencies to account for rising seas and stronger storms when making grants and building infrastructure, one of the most definitive steps it has yet taken to adapt the country to a changing climate. In an executive order released this afternoon, Obama established a new Federal Flood Risk Management Standard that gives agencies a choice of three options for determining where it is safe to invest federal dollars. They can use data and methods based on "best-available, actionable climate science"; they can require buildings to be 2 feet above the 100-year flood elevation; or they can require that infrastructure is built to at least the 500-year floodplain. Most federal investment is currently based on the 100-year floodplain, although federal rebuilding standards for Superstorm Sandy required infrastructure to be a foot higher than that."

Executive-order-climate-preparedness (25 June 2013)

The Executive Order (E.O. 13653) "Preparing the United States for the Impacts of Climate Change," directs Federal agencies to:

- *"Modernize Federal programs to support climate-resilient investments*: Agencies will examine their policies and programs and find ways to make it easier for cities and towns to build smarter and stronger. Agencies will identify and remove any barriers to resilience-focused actions and investments– for example, policies that encourage communities to rebuild to past standards after disasters instead of to stronger standards – including through agency grants, technical assistance, and other programs in sectors from transportation and water management to conservation and disaster relief.

- *Manage lands and waters for climate preparedness and resilience:* America's natural resources are critical to our Nation's economy, health and quality of life. The E.O. directs agencies to identify changes that must be made to land- and water-related policies, programs, and regulations to strengthen the climate resilience of our watersheds, natural resources, and ecosystems, and the communities and economies that depend on them. Federal agencies will also evaluate how to better promote natural storm barriers such as dunes and wetlands, as well as how to protect the carbon sequestration benefits of forests and lands to help reduce the carbon pollution that causes climate change.

- *Provide information, data and tools for climate change preparedness and resilience*: Scientific data and insights are essential to help communities and businesses better understand and manage the risks associated with extreme weather and other impacts of climate change. The E.O. instructs Federal agencies to work together and with information users to develop new climate preparedness tools and information that state, local, and private sector leaders need to make smart decisions. In keeping with the President's Open Data initiative, agencies will also make extensive Federal climate data accessible to the public through an easy-to-use online portal.

- *Plan for climate change related risk*: Recognizing the threat that climate change poses to Federal facilities, operations and programs, the E.O. builds on the first-ever set of Federal agency adaptation plans released earlier this year and directs Federal agencies to develop and implement strategies to evaluate and address their most significant climate change related risks."

To implement these actions, the E.O. establishes an interagency Council on Climate Preparedness and Resilience, chaired by the White House and composed of more than 25 agencies. To assist in achieving the goals of the E.O., these agencies are directed to consider the recommendations of the State, Local, and Tribal Leaders Task Force on Climate Preparedness and Resilience.

Department of Transportation (DOT)
<u>US DOT Policy Statement on Climate Change Adaptation (June 2011)</u>
Even before the "Executive order climate preparedness (June 2013)" the US DOT released a policy statement on Climate Change Adaptation. This policy was based on Executive Order (E.O.) 13514 – Federal Leadership in Environmental, Energy, and Economic Performance. The E.O. includes direction to address climate adaptation planning.

"The United States Department of Transportation (DOT) shall integrate consideration of climate change impacts and adaptation into the planning, operations, policies, and programs of DOT in order to ensure that taxpayer resources are invested wisely and that transportation infrastructure, services and operations remain effective in current and future climate conditions.
The DOT policy is to incorporate climate adaptation strategies into its transportation missions, programs, and operations. Climate change adaptation is a critical complement to mitigation efforts to address the causes and consequences of climate change. Every modal administration has the responsibility to consider climate change impacts on current systems and future investments. Furthermore, planning for climate adaptation assists State and local transportation agencies, and DOT, to identify how climate change is likely to impact their ability to achieve their mission, continue operations, and to meet policy and program objectives.
In implementing this Policy, DOT will adhere to the following guiding principles.

- *Adopt integrated approaches*. Climate change adaptation strategies should be integrated into core policies, planning, practices, and programs.
- *Prioritize the most vulnerable*. Adaptation plans should prioritize helping people, places, and infrastructure that are most vulnerable to climate impacts.
- *Use best-available science*. Adaptation should be grounded in best-available scientific understanding of climate change risks, impacts, and vulnerabilities.
- *Build strong partnerships*. Adaptation requires coordination across multiple sectors, geographical scales, and levels of government and should build on the existing efforts and knowledge of a wide range of stakeholders.
- *Apply risk-management methods and tools*. A risk management approach can be an effective way to assess and respond to climate change because the timing, likelihood, and nature of specific climate risks are difficult to predict.
- *Apply ecosystem-based approaches*. Ecosystems provide valuable services that help to build resilience and reduce the vulnerability of people and their livelihoods to climate change impacts.
- *Maximize mutual benefits.* Adaptation should, where possible, use strategies that complement or directly support other related climate or environmental initiatives,
- *Continuously evaluate performance*. Adaptation plans should include measurable goals and performance metrics to continuously assess whether adaptive actions are achieving desired outcomes.

Each modal administration within DOT shall, in a manner consistent and compatible with its mission:

- Analyze how climate change may impact its ability to achieve its mission, policy, program, and operation objectives.
- Report annually on its accomplishments in implementing climate adaption strategies.
- Coordinate actions with the Senior Official responsible for implementing climate adaptation and the Center for Climate Change Steering Committee member.
- Implement climate change adaptation implementing instructions issued by the Council on Environmental Quality (CEQ)."

U.S. Department of Transportation Climate Adaptation Plan (2014)
"Pursuant to earlier Executive Orders as well as Council on Environmental Quality (CEQ) Implementing Instructions, the U.S. Department of Transportation (DOT) is required to submit a Climate Adaptation Plan. The US DOT adaptation plan is organized into sections based on the guidance from CEQ and describes steps DOT will take to move towards fully integrating considerations of climate change adaptation and resiliency into DOT policies, programs, and operations.
DOT's mission is to serve the United States by ensuring a fast, safe, efficient, accessible and convenient transportation system that meets our vital national interests and enhances the quality of life of the American people, today and into the future. The Department and its modal agencies oversee the safe operation of the United States transportation system including more than 3.9 million miles of public roads, 120,000 miles of major railroads, 25,000 miles of commercially navigable waterways, 5,000 public-use airports, 500 major urban public transit operators and more than 300 coastal, Great Lakes, and inland waterways ports.

Scientists have concluded that some level of climate change is already occurring. Weather patterns are changing, and these changes are expected to continue or accelerate in the future. The Third National Climate Assessment concludes that higher temperatures, increased atmospheric water vapor, rising sea levels, and the frequency of extreme weather events over the past 50 years have resulted from increased levels of greenhouse gases emitted from human activity. Past weather and climate patterns appear to be much less reliable indicators of future weather and climate than in recent decades, which makes greater flexibility in planning and decision-making processes ever more important.

Transportation is and will continue to be affected by climate change. The range of impacts from these threats may include roadway deterioration, flooding, limited waterway access, and weakened structures. Severe conditions may reduce the life of capital assets and increase operational disruptions. Some consequences may require changes in the design, construction, and maintenance of infrastructure.
DOT's modal administrations are taking steps to address the impacts of climate change on their respective missions. DOT modal administrations have committed to implementing the following priority actions:

- *Planning*. DOT will take actions to ensure that Federal transportation investment decisions address potential climate impacts in state-wide and metropolitan transportation planning and project development processes as appropriate in order to protect federal investments. Through such actions, transportation systems will gradually become better prepared for future climate shifts.
- *Asset Management.* DOT will work to incorporate climate variability and change impact considerations in asset management. For example, modal administrations will work with grantees to assure that potential impacts are incorporated into existing grantee asset management systems and their own buildings and operations. Agencies will assess the policy, guidance, practices, and performance measures of its asset management programs to incorporate such considerations.
- *Tools*. DOT will provide tools, case studies, best practices, outreach, and performance measures for incorporating climate considerations into transportation decision-making."

FHWA
FHWA order 5520: Transportation System Preparedness and Resilience to Climate Change and Extreme Weather Events (December 2014)

“The purpose of this directive is to establish the Federal Highway Administration (FHWA) policy on preparedness and resilience to climate change and extreme weather events. It serves to comply with Executive Order 13653, Preparing the United States for the Impacts of Climate Change (EO 13653), dated November 1, 2013, and further the U.S. Department of Transportation (DOT) Policy Statement on Climate Change Adaptation.

FHWA’s policy concerning climate change and extreme weather event preparedness and resilience

- It is FHWA's policy to strive to identify the risks of climate change and extreme weather events to current and planned transportation systems. The FHWA will work to integrate consideration of these risks into its planning, operations, policies and programs in order to promote preparedness and resilience; safeguard Federal investments; and ensure the safety, reliability, and sustainability of the Nation’s transportation systems
- The FHWA will implement these relevant provisions in title 23, EO 13653, EO 13514, and subsequent laws, regulations and policies.
- The FHWA will also implement the principles of the DOT Policy Statement on Climate Change Adaptation by incorporating consideration of climate change and extreme weather event preparedness and resilience in all FHWA programs, policies, and activities within the framework of existing laws, regulations, and guidance
- FHWA managers and staff shall ensure that FHWA programs, policies, and activities for which they are responsible integrate consideration of climate change and extreme weather event impacts and adaptation into its planning, operations, policies and programs, in order to promote climate change and extreme weather event preparedness and resilience

FHWA’s responsibilities

a) Identifying and removing administrative, regulatory, and policy barriers that discourage climate change and extreme weather event preparedness and resiliency or unintentionally increase the vulnerability of transportation systems to these risks.

b) Encouraging State departments of transportation (DOT), metropolitan planning organizations (MPO), Federal land management agencies (FLMAs), tribal governments, and others to develop, prioritize, implement and evaluate risk-based and cost-effective strategies to minimize climate and extreme weather risks and protect critical infrastructure using the best available science, technology and information.

c) Developing and providing technical assistance, research, and outreach, and encouraging the development and use of transportation-specific vulnerability assessment and adaptation tools.

d) Clarifying and informing State DOTs, MPOs, FLMAs, tribal governments, and others of existing funding eligibilities to support resiliency and adaptation in the delivery of title 23 programs.

e) Developing research and tools, providing technical assistance, and building partnerships with State DOTs and MPOs, particularly in development and analysis of adaptation, preparedness, and resiliency options.

f) Encouraging the consideration of climate change and extreme weather event risks, preparedness and resiliency in the delivery of programs, such as in the risk-based asset management plans State DOTs are required to develop under MAP-21.

g) Updating planning, engineering, and operations guidance to include consideration of climate change and extreme weather event resilience.

h) Reporting on progress through the US DOT Adaptation Plan and internal FHWA strategic planning activities.”

2.2.2 Netherlands/Europe

The Netherlands
The development of adaptation policy in The Netherlands follows two parallel interacting tracks:
1) The formulation of a new comprehensive and integrated National Adaptation Strategy (NAS),
2) The implementation of the Delta Programme, which re-evaluates water management in the light of long-term sustainable development and climate change.

Both the development of the NAS and the Delta Programme are nationwide programmes. This implies a joint effort of national government, provinces, municipalities and regional water boards working together with input from social organizations and the business community.
The formulation of both strategies is guided by an integral climate change policy agenda; 'the Climate Agenda'.

<u>Climate Agenda: Resilient, Prosperous, and Green (February 2014)</u>
This Climate Agenda outlines a climate approach focused on assembling a broadly-based coalition for climate measures and on a combined approach to climate adaptation (by designing a resilient physical environment and preparing society for the consequences of climate change) and mitigation (by reducing greenhouse gas emissions). This Climate Agenda translates these themes into eight action lines of which action line 3 is the most relevant for the resilience of infrastructure:
Action line 3: Heading towards vital climate-robust sectors
Being prepared for climate change also opens the door to opportunities: provided that the risks of climate change are clear, it can give a sector an insight into what to expect and provide a form of security. Central government is working on a strategy built around risks and opportunities. The outcomes will be translated into the National Adaptation Strategy that the Cabinet wants to have ready in 2017 at the latest.

<u>NL National Adaptation Strategy (2016)[2]</u>
The new National Adaptation Strategy 2016 (NAS) will update the 2007 National Adaptation Strategy "Make Space for Climate". The formulation of the NAS is guided by the integral (mitigation and adaptation) climate policy agenda: 'the Climate Agenda' (2013). The NAS is to be presented to Parliament by 2016. It will be based on recent insights in climate risks and vulnerabilities and socio-economic developments. It goes beyond the water related focus of the Delta Programme by comprehensively addressing sectors, in particular health, energy and ICT, infrastructure, transport, nature, agriculture and fisheries. Cross-sectoral cascading effects will also be taken into account. Various projects have been initiated to support the development of the strategy. Also the effects of climate change elsewhere, in countries within and outside Europe, which might result in impacts on Dutch society and economy, will be covered in the strategy. The NAS will also contain a Monitoring and Evaluation framework for climate change adaptation. This system will primarily look into progress with the adaptation policies (=process), but also seeks transparency with regards to implementation (=output) and effectiveness (=outcome) of actions.

<u>Delta Programme[3]</u>
The Delta Programme is a nationwide programme. The objective is to protect the Netherlands from (coastal and river) flooding, to work towards climate resilient urban areas and to ensure adequate supplies of freshwater for generations ahead. The legal framework for the implementation of the Delta Programme in the Netherlands is 'the Delta Act on flood safety and freshwater supply' (hereafter: the Delta Act). The Delta Act anchors the Delta Programme, the Delta Fund and the role of the Delta Commissioner. The Delta Act entered into force on 1 January 2012.

1 The Delta Act is formally an amendment of the Water Act
The Dutch Government appointed the Delta Commissioner to direct the development and implementation of the Delta Programme. Every year the Delta Commissioner reports to the Cabinet about progress and advises on necessary steps. On behalf of the Cabinet, the Minister of Infrastructure and the Environment presents the Delta Commissioner's annual report to the Parliament supplemented with an appropriate policy response. The provinces, municipalities and especially the regional water boards are closely involved in developing this annual report.

[2] From: The Netherlands' report under MMR article 15 National Adaptation Actions, 15 March 2015
[3] From: The Netherlands' report under MMR article 15 National Adaptation Actions, 15 March 2015

The Delta Programme comprises plans and provisions to guarantee flood safety and a sufficient supply of freshwater as well as climate resilient urban areas, including the relevant planning and a cost estimate. The Delta Programme uses an integrated and adaptive approach in finding solutions when tackling the issues of safety, water supply and the role that spatial planning can play in resolving those issues. In September 2014 key decisions on policy frameworks and regional strategies were presented to the Parliament in the "Delta Programme 2015". These so-called "Delta Decisions" have wide support:

- Delta Decision on Water Safety: the new flood risk management policy, based on a multi-layered approach to improve protection and reduce the consequences of flooding.
- Delta Decision on the Freshwater Supply: a new nationwide approach to limit water shortages and use the freshwater supply optimally in the economy and public utilities.
- Delta Decision on Spatial Adaptation: a new, targeted approach to water-robust and climate-proof (re)development in the built environment.

In addition, three key decisions are made regarding two complicated geographical areas, where coastal and riverine water systems interact, and the sandy coast, and where measures regarding flood risk, fresh water supply and spatial adaptation are urgent and may interfere with each other:

- Delta Decision on the Rhine-Meuse Delta: choices on the distribution of water from the Rhine across the Waal, Lower Rhine-Lek and IJssel that is of great importance to water safety in the delta region.
- Delta Decision on the IJsselmeer Region: choices on average summer and winter water level of the IJsselmeer to balance water safety and the freshwater supply.
- Strategic Decision on Sand: choices on maintaining the sand balance along the coast

In December 2015 the Delta decisions have been set down in the six-year National Water Plan.
In the new National Water Plan the Minister of Infrastructure and the Environment and State Secretary of Economic Affairs have set down how, for the next 6 years, the Netherlands will protect itself from water, how the water will be made cleaner and how the Netherlands will be designed in a climate-resilient and water-robust manner[4]. The National Water Plan lays down the new water policy for the coming six years, and also looks ahead to 2050.

In the Delta Programme and the Delta Decisions the measures following from the European Water Framework Directive (addressing water quality) and the Floods Directive (addressing flooding risks) are integrated with a long term perspective.

The cabinet has accepted the proposed Delta Decisions as government policy, to be elaborated in national legislation and administrative agreements, starting in 2015. The Delta Decisions are being translated into concrete measures for different parts of the Netherlands.
Solidarity between regions and between generations is a key principle for financing the Delta Programme. The Delta Fund holds money dedicated by the national government for the implementation of measures and research needs. The water boards co-fund the primary flood defense system The fund will be highly significant for credible and timely delta-management in the coming decades. Building on the current investments of a similar order of magnitude, as from 2020, the Delta Fund will be fed with a minimum of €1 billion a year in order to ensure the implementation of the Delta Programme.
Every year the Delta Commissioner will present advice on how to target the budget on necessary measures and supporting research in the annual Delta Programme. The Minister of Infrastructure and the Environment decides and is politically responsible. Interim decisions will take account uncertainties around the future impact of climate change as well as spatial and socio-economic developments. The approach here is the so called 'adaptive delta management', choosing the kind of necessary measures that keep options open for later adjustment. In the process all relevant material, results of research and knowledge programmes ('Knowledge for Climate'), experience from international cooperation (e. g. 'Netherlands Water Partnership', 'Partners for Water', 'Delta Alliance' and Connecting Delta Cities), and assessments by the Netherlands Environmental Assessment Agency (such as the study 'Climate Adaptation in the Dutch Delta - Strategic options for a climate-proof development of the Netherlands') are taken into account. Adaptive

[4] http://english.deltacommissaris.nl/

delta management based on sound knowledge used in a future oriented Delta Programme is essential for cost-effective investments.

The execution of investments in existing programmes (such as 'Room for the River', 'Border Meuse Programme' and 'Flood Protection Programme') and projects (such as Climate buffers) continue. The 'Third Safety Assessment' which looked into the existing primary flood defence systems, acknowledged the importance of the considerable effort devoted to compliance with current, statutory flood protection standards. Reinforcing weak segments of the coastal defence is also work in progress. Meanwhile, new flood protection standards have been proposed in the light of increased population numbers and economic value of assets that will be turned into the legal norms after 2017.

Regional Water Boards make a structural contribution to financing the current Flood Protection Programme. As part of an Administrative Agreement on Water (concluded on 23 May 2011) regional Water Boards became co-financiers for the construction and improvement of primary flood defence systems, as managed by these boards.
The co-financing is equally distributed, the water boards are responsible for funding half of the construction and improvement costs, the other half is funded by the Delta Fund. The agreement also focuses on cooperation in the Delta Programme.
The Administrative Agreement on Water and the recently published policy note on Infrastructure and Spatial Planning designates the responsibilities of parties. The national government is responsible for national interests including flood risk management and the main water system. The provinces act as area-director, organize spatial planning and set out frameworks for the regional water system. The regional Water Boards supervise and manage the regional and the majority of primary defence systems as well as ensure the availability of water as a resource of adequate quality in the regional water systems. The municipalities supervise the public areas within their duty of care under the Water Act and are the initial point of contact in the event of flooding.

Working with the various partners and their responsibilities is an important part of the process in the Delta Programme under the direction of the Delta Commissioner.
In 2009 the Dutch provinces signed an agreement with the national government to mainstream climate adaptation into spatial planning. Today most provinces have written climate adaptation action programmes. Priorities are 'no regret' options and mainstreaming climate adaptation into water management, spatial planning, nature policy, agriculture and economic policy. For spatial planning a specific engagement programme has been set up to stimulate regional and local policy makers, institutes and businesses to create climate proof and water resilient cities from the year 2020. Applicants can receive funds to implement this ambition by joining the programme and they can sign a letter of intent to indicate they are willing to adapt to climate change. The engagement programme focusses on capacity building and mainstreaming spatial adaptation.
Next to these programmes, sector (infrastructure, nature, health etc.) specific adaptation measures are in the process of being created or are already being implemented.

European Union (EU)
<u>EU adaptation strategy</u>
The EU adaptation strategy was presented in the form of a communication from the commission to the European Parliament, the Council, the European Economic and Social Committee of the regions.

Adaptation strategies are needed at all levels of administration: at the local, regional, national, EU and also the international level. Due to the varying severity and nature of climate impacts between regions in Europe, most adaptation initiatives will be taken at the regional or local levels. The ability to cope and adapt also differs across populations, economic sectors and regions within Europe.

The Commission adopted an EU adaptation strategy in April 2013 which has been welcomed by the Member States. Complementing the activities of Member States, the strategy supports action by promoting greater coordination and information-sharing between Member States, and by ensuring that adaptation considerations are addressed in all relevant EU policies.

The EU's role can be particularly appropriate when climate change impacts transcend borders of individual states - such as with river basins - and when impacts vary considerably across regions.

The role of the EU can be especially useful to enhance solidarity among Member States and ensure that disadvantaged regions and those most affected by climate change are capable of taking the necessary measures to adapt.

The Communication stresses that due to the long life span of much of our infrastructure and its great economic value, preparedness for current and increasing future impacts of climate change over the lifetime of infrastructure is critical. Left unmanaged, climate change may significantly affect the operational, financial, environmental and social performance of large fixed assets and infrastructure.

The paper "Adapting infrastructure to climate change" presents the contribution of the European Union to climate change adaptation in selected infrastructure sectors. It covers energy and transport infrastructure as well as buildings in the EU.
This paper is not a binding document but it provides further background material supportive of the narrative and arguments put forward in the Communication. It also presents an outline of actions that the Commission will be undertaking, as announced in the Communication.
The Dutch NAS is likely to partly follow the European Adaptation strategy.

<u>Environmental Impact Assessment (EIA) Directive (2014/52/EU)</u>
A newly amended Environmental Impact Assessment (EIA) Directive (2014/52/EU) entered into force on 15 May 2014. The amended Directive introduces clear references to climate change management, mainly in Article 3 and Annexes III and IV.

- Article 3: The environmental impact assessment shall identify, describe and assess in an appropriate manner, in the light of each individual case, the direct and indirect significant effects of a project on the following factors: (c) land, soil, water, air and climate;
- Annex III: criteria to determine whether the project listed in Annex II should be subject to an EIA: (f) the risk of major accidents and/ or disasters which are relevant to the project concerned, including those caused by climate change, in accordance with scientific knowledge;
- Annex IV: Information for the environmental impact assessment report as referred to in article 5(1): (f) the impact of the project on climate (for example the nature and magnitude of greenhouse gas emissions) and the vulnerability of the project to climate change;

Member States have to apply these rules as from 16 May 2017 at the latest. A guidance document was published to improve the consideration of Climate change in the strategic environmental assessment (SEA). This document is reviewed in paragraph 4.2.2.)

2.3 Organization and funding

2.3.1 USA

The United States Department of Transportation and its divisions provide regulation, supervision, and funding for all aspects of transportation. Each state has its own Department of Transportation, which builds and maintains state highways, and depending upon the state, may either directly operate or supervise other modes of transportation.
The majority of roads in the United States are owned and maintained by state and local governments. Federally maintained roads are generally found only on federal lands (such as national parks) and at federal facilities (like military bases). The Interstate Highway System is partly funded by the federal government but owned and maintained by individual state governments. There are a few private highways in the United States, which use tolls to pay for construction and maintenance.

The Federal Highway Administration (FHWA) is a division of the United States Department of Transportation that specializes in highway transportation. The agency's major activities are grouped into two "programs," the Federal-aid Highway Program and the Federal Lands Highway Program:
- FHWA's role in the Federal-aid Highway Program is to oversee federal funds used for constructing and maintaining the National Highway System (primarily Interstate Highways, U.S. Routes and most State Routes). This funding mostly comes from the federal gasoline tax and mostly goes to state departments of transportation. FHWA oversees projects using these funds to ensure that federal requirements for project eligibility, contract administration and construction standards are adhered to.

- Under the Federal Lands Highway Program, FHWA provides highway design and construction services for various federal land-management agencies, such as the Forest Service and the National Park Service.

In addition to these programs, FHWA performs and sponsors research in the areas of roadway safety, congestion, highway materials and construction methods, and provides funding to local technical assistance program centers to disseminate research results to local highway agencies.

FHWA issued an order (see FHWA E.O 5520) committing the agency to integrating climate risk considerations into the delivery and stewardship of FHWA programs.

- Climate adaptation activities are eligible for FHWA funding, including vulnerability assessments and design and construction of projects or features to protect assets from damage associated with climate change.
- FHWA's updated emergency relief program guidance reflects climate resilience.
- Transportation law passed in 2012 requires states to develop risk-based asset management plans and to consider alternatives for facilities repeatedly needing repair or replacement with federal funding.

2.3.2 Netherlands/Europe

The Netherlands
The Ministry of Infrastructure and Environment is committed to improving quality of life, access and mobility in a clean, safe and sustainable environment. The Ministry strives to create an efficient network of roads, railways, waterways and airways, effective water management to protect against flooding, and improved air and water quality.
The Directorate-General for Mobility and Transport of the Ministry of Infrastructure and the Environment (I&M) focuses on the continued development of the network quality of airways, waterways, railways, the road network, harbours and ports.

Roads are developed and maintained by authorities at all four administrative levels in the Netherlands. The national roads (Rijkswegen) are controlled by central government agency Rijkswaterstaat, and the country's twelve provinces control the provincial roads. Most motorways are national roads, and the remaining national roads are mostly expressways. Only a few motorways are provincial ones, and they are much shorter, serving mainly regional traffic. Municipality roads make up the bulk of the network, they are mostly local roads.

Rijkswaterstaat is the executive agency for all three directorates of the Ministry of Infrastructure and the Environment, responsible for the Dutch main road network, the main waterway network, the main water systems, and the environment in which they are embedded. Rijkswaterstaat facilitates smooth and safe flow of traffic, keeps the national water system safe, clean, user-friendly and protects the Netherlands against flooding.
Rijkswaterstaat is responsible for the maintenance, operations, renewal and expansion of these networks. The annual budget is approximately 5 billion euros. The mission of Rijkswaterstaat is 'to deliver best service to the public at lowest life cycle cost, given public acceptable risk'. There are no specific targets and budgets for the adaptation to climate change.

European Union
Within its competences and building on the 2009 white paper, the European Union is engaged in mainstreaming climate change adaptation in various EU policies and financial instruments including the European Transport Policy (see below TEN-T). The general objective of the 2011 White Paper was to define a long-term strategy that would help the EU transport system achieve the overall goal of the Common Transport Policy, i.e. to provide current and future generations with access to safe, secure, reliable and affordable mobility resources to meet their own needs and aspirations, while minimizing undesirable impacts such as congestion, accidents, air and noise pollution, and climate change effects.

The transport sector fulfils crucial economic and social functions and is highly dependent on the environmental situation. Investment in transport infrastructure is increasingly put at risk by changing climatic conditions and related extreme weather events. Due to the long life span of the majority of transport infrastructure and their great economic value, their preparedness and resilience to future impacts of climate change are critical.

The Trans-European Transport Networks (TEN-T) are a planned set of roads (much like the US interstate highway network), rail, air and water transport networks in the European Union. TEN-T envisages coordinated improvements to primary roads, railways, inland waterways, airports, seaports, inland ports and traffic management systems, providing integrated and intermodal long-distance, high-speed routes.

TEN-T projects, co-financed under the Connecting Europe Facility, are expected to contribute to promoting the transition to a climate- and disaster-resilient infrastructure. All transport modes are eligible for funding. Co-financing rates may be increased by up to 10 percentage points for actions enhancing climate resilience.

Next to adaptation to climate change, the trans-European transport (TEN-T) network should provide the basis for the large-scale deployment of new technologies and innovation, which, for example, can help enhance the overall efficiency of the European transport sector and curb its carbon footprint. This will contribute towards the Europe 2020 strategy and the Transport White Paper's target of a 60% cut in greenhouse gas emissions by 2050 (based on 1990 levels) and at the same time contribute to the objective of increasing fuel security for the Union.

The proposal for the new TEN-T Guidelines includes climate resilience, in particular under article 41: during infrastructure planning due consideration shall be given to risk assessments and adaptation measures adequately improving the resilience to climate change. Additionally, where appropriate, due consideration should be given to the resilience of infrastructure to natural or man-made disasters.

Climate action is a key priority for the EU. To respond to challenges and investment needs related to climate change, the EU has agreed that at least 20% of its budget for 2014-2020 – as much as €180 billion − should be spent on climate change-related action. To achieve this increase, mitigation and adaptation actions will be integrated into all major EU spending programmes, in particular cohesion policy, regional development, energy, transport, research and innovation and the Common Agricultural Policy[5].

[5] http://ec.europa.eu/clima/policies/budget/index_en.htm

3 **Vulnerability and risk assessment**

3.1 Comparing vulnerability and risk assessment USA-NL

In this chapter the vulnerability and risk assessment to climate change in the Netherlands and in the USA is discussed. This first paragraph will summarize the main similarities and differences found between the USA and the Netherlands. These are illustrated by the different reports and studies reviewed in the following paragraphs.

Climate change scenarios
The projections of climate change on the USA and on Europe shows both similarities and differences.
On both continents we see more intense precipitation and the melting of snow and permafrost in the north and more heat waves and drought in the more southern parts of the continent.
In the USA, there is also a strong focus on the likely increase of hurricane intensity. This is not an issue in Europe.
In the Netherlands sea level rise is a very prominent issue with a projected sea level rise on the Dutch coast in 2100 of 80 centimeter (2,5 feet). The projected sea level rise on the southern and eastern coast of the USA tends to be even higher (locally up to 3 to 3.5 feet).

Vulnerability and risk assessment
Presented below is a comparison of vulnerability and risk assessment in USA and in the Netherlands and Europe.

Table 2: Comparing vulnerability assessment in the Netherlands and the USA

	USA	NL/EU
The scope of the pilots and methods used.	• Vulnerability to extreme weather and climate change is assessed for the transport system as a whole in some cases and at particular sub-areas or projects in others. Many pilots focus not only on roads but also at railroads, airports, seaports and ferries. • The pilot studies are carried out and managed by the grant recipients, with overall program management performed by FHWA.	• The assessments that are carried out by Rijkswaterstaat focus mainly on the road network and related systems and services.
The climate variables and effects taken into account	• The framework and pilots take a wide range of variables related to extreme weather into account (sea-level rise, storm surge, extreme winds, changes in temperature, droughts, high intensity rainfall and changes in snowmelt and permafrost) • The pilots are widespread across the USA and cover many climate zones • Due to large differences in climate and geography, the climate data and the stressors involved in the different pilots	• In the RoadApt studies a wide range of variables related to extreme weather is taken into account (Extreme rainfall events, seasonal and annual average rainfall, sea level rise, heat waves, drought, changes in the number of frost, thaw and fog days, extreme winds) • The Blue spot studies focus mainly on the risk of floods and the effects of intense rainfall • The pilots are concentrated in the Northwestern region of Europe (The Netherlands, Germany,

	USA	NL/EU
	can vary widely	Denmark, and Norway). The data bases are therefore not complete for the more arid climate zones
The methodology used	• In most pilots, there is a focus on workshops and the involvement of a wide range of stakeholders. Both to create awareness and to provide know-how and the correct available data • The methodologies used are GIS-aided using available GIS files and databases • Priority setting is based on effects of climate change, consequences (socio-economic impacts) and on governance aspects	• Mostly Road Authorities, Universities and Institutes take part in the studies and pilots • The methodologies used are GIS-aided using available GIS files and databases • Priority setting is based mainly on the effects of climate change and consequences (socio-economic impacts) and hardly involves governance aspects.
Presenting and incorporating results	• There are large differences in the pilots in the way the results are presented and interpreted. This can be explained by the differences in the goals of the pilots. • In most pilots there is an emphasis on the incorporation of the results into decision making (prioritization and planning)	• Studies and pilots are more uniform because they are more centrally coordinated

An in depth comparison of the technical approaches and methodologies used for vulnerability assessment in the USA and European pilot, is hard to carry out. Especially in the US, pilots used different technical approaches and methodologies. The pilots are coordinated by the state agencies, which have their own focus and goal. In addition, the availability of data vary for each pilot and influences the choice of the methodology. The European projects and pilots are more centrally coordinated and therefore much more uniform in the methodologies used for vulnerability assessments.

3.2 Climate change scenarios

3.2.1 USA

Future climate change[6]

Future Temperature Changes

We have already observed global warming over the last several decades. Future temperatures are expected to change further. Climate models project the following key temperature-related changes for the USA.

- By 2100, the average U.S. temperature is projected to increase by about 4°F to 11°F (2-4 °C), depending on emissions scenario and climate model.
- An increase in average temperatures worldwide implies more frequent and intense extreme heat events, or heat waves. The number of days with high temperatures above 90°F (32 °C) is expected to increase throughout the United States, especially in areas that already experience heat waves. For example, areas of the Southeast and Southwest currently experience an average of 60 days per year with a high temperature above 90°F. These areas are projected to experience 150 or more days a year above 90°F by the end of the century, under a higher emissions scenario. In addition to occurring more frequently, these very hot days are projected to be about 10°F (4,5 °C) hotter at the end of this century than they are today, under a higher emissions scenario.

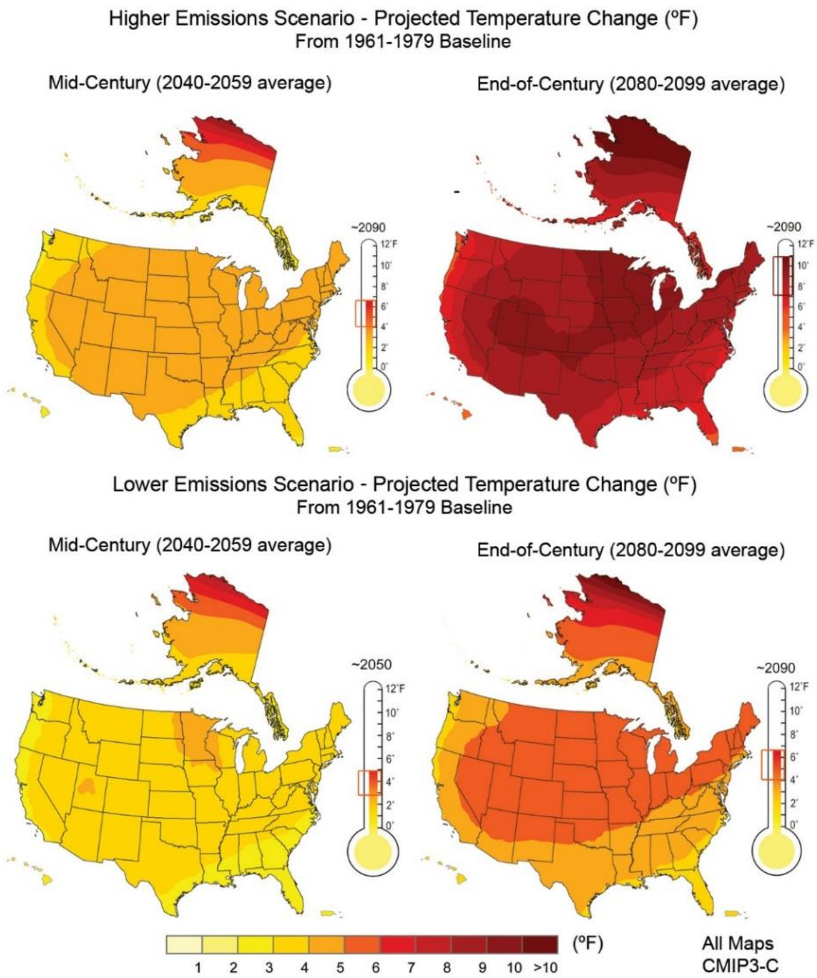


Figure 2 : Projected temperature changes the USA due to climate change

[6] website EPA Future Climate Change

Future Precipitation and Storm Events

Patterns of precipitation and storm events, including both rain and snowfall are also likely to change. However, some of these changes are less certain than the changes associated with temperature. Projections show that future precipitation and storm changes will vary by season and region. Some regions may have less precipitation, some may have more precipitation, and some may have little or no change. The amount of rain falling in heavy precipitation events is likely to increase in most regions, while storm tracks are projected to shift poleward. Climate models project the following precipitation and storm changes for the USA.

- Northern areas are projected to become wetter, especially in the winter and spring. Southern areas, especially in the West, are projected to become drier.
- Heavy precipitation events will likely be more frequent. Heavy downpours that currently occur about once every 20 years are projected to occur about every four to 15 years by 2100, depending on location.
- More precipitation is expected to fall as rain rather than snow, particularly in some northern areas
- The intensity of Atlantic hurricanes is likely to increase as the ocean warms. Climate models project that for each 1.8°F (1°C)increase in tropical sea surface temperatures the rainfall rates of hurricanes could increase by 6-18% and the wind speeds of the strongest hurricanes could increase by about 1-8%. There is less confidence in projections of the frequency of hurricanes, but the global frequency of tropical hurricanes is likely to decrease or remain essentially unchanged.
- Cold-season storm tracks are expected to continue to shift northward. The strongest cold-season storms are projected to become stronger and more frequent.

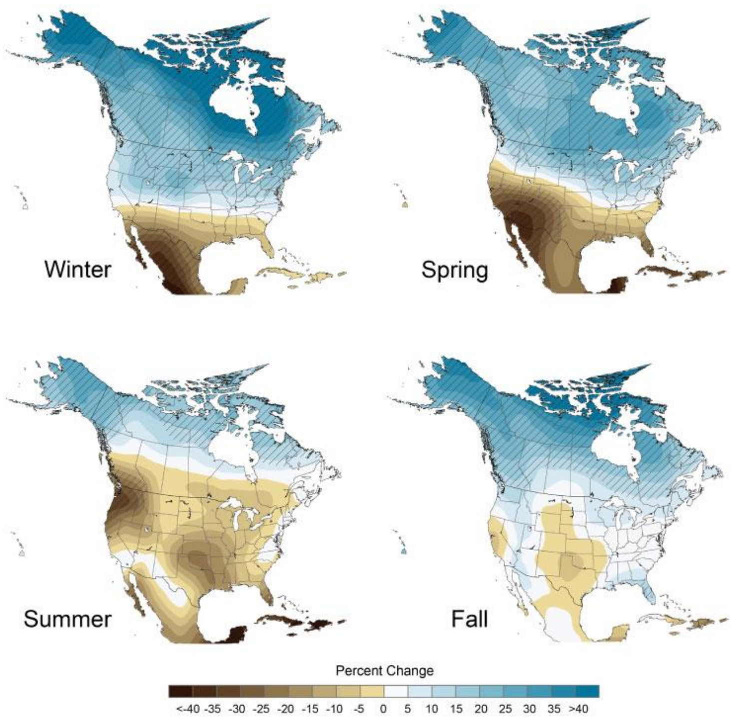


Figure 3: Projected changes in temperature in the USA because of climate change

Future Ice, Snowpack, and Permafrost

Arctic sea ice is already declining. The area of snow cover in the Northern Hemisphere has decreased since about 1970. Permafrost temperature has increased over the last century.

Over the next century, it is expected that sea ice will continue to decline, glaciers will continue to shrink, snow cover will continue to decrease, and permafrost will continue to thaw. Potential changes to ice, snow, and permafrost are described below.

- Northern Hemisphere snow cover is expected to decrease by approximately 15% by 2100
- Models project the snow season will continue to shorten, with snow accumulation beginning later and melting starting earlier. Snowpack is expected to decrease in many regions
- Permafrost is expected to continue to thaw in northern latitudes. This would have large impacts in Alaska.

Future Sea Level Change

Increasing temperatures contribute to sea level rise by: expanding ocean water; melting mountain glaciers and ice caps; and causing portions of the Greenland and Antarctic ice sheets to melt or flow into the ocean. Since 1870, global sea level has risen by about 8 inches. Estimates of future sea level rise vary for different regions, but global sea level for the next century is expected to rise at a greater rate than during the past 50 years.

The contribution of thermal expansion, ice caps, and small glaciers to sea level rise is relatively well-studied, but the impacts of climate change on ice sheets are less understood and represent an active area of research. Thus it is more difficult to predict how much changes in ice sheets will contribute to sea level rise.

Ice loss from the Greenland and Antarctic ice sheets could contribute an additional 1 foot of sea level rise, depending on how the ice sheets respond.

Regional and local factors will influence future relative sea level rise for specific coastlines around the world. For example, relative sea level rise depends on land elevation changes that occur as a result of subsidence (sinking) or uplift (rising). Assuming that these historical geological forces continue, a 2-foot rise in global sea level by 2100 would result in the following relative sea level rise:

- 2.3 feet at New York City
- 2.9 feet at Hampton Roads, Virginia
- 3.5 feet at Galveston, Texas
- 1 foot at Neah Bay in Washington state

Relative sea level rise also depends on local changes in currents, winds, salinity, and water temperatures, as well as proximity to thinning ice sheets.

Several methods, approaches and tools have been created in an attempt to make climate data more usable by practitioners, including transportation.[7] FHWA created the CMIP Tool to help users get downscaled climate projections for precipitation and temperature for their area.[8]

[7] See: http://toolkit.climate.gov/tools
[8] See: http://www.fhwa.dot.gov/environment/climate_change/adaptation/adaptation_framework/modules/index.cfm?moduleid=2

3.2.2 Netherlands/Europe

KNMI'14 climate scenarios

Climate change effects in the Netherlands include higher temperatures, accelerating sea level rise, wetter winters, more intense showers, and drier summers. According to the KNMI'14 (Dutch Meteorological Institute) climate scenarios, these effects need to be taken into account for the future of the Netherlands.

The KNMI'14 climate scenarios (May 2014) translate the research results on the global climate in the IPCC report (2013) to the Netherlands. Together, the KNMI climate scenarios cover the outer points of likely changes in the climate of the Netherlands. They give the change around 2050 and 2085 compared to the climate in the period 1981-2010. The four KNMI'14 scenarios differ in the extent to which the global temperature increases ('Moderate' and 'Warm') and the possible change of the air circulation pattern ("Low value" and "High Value").

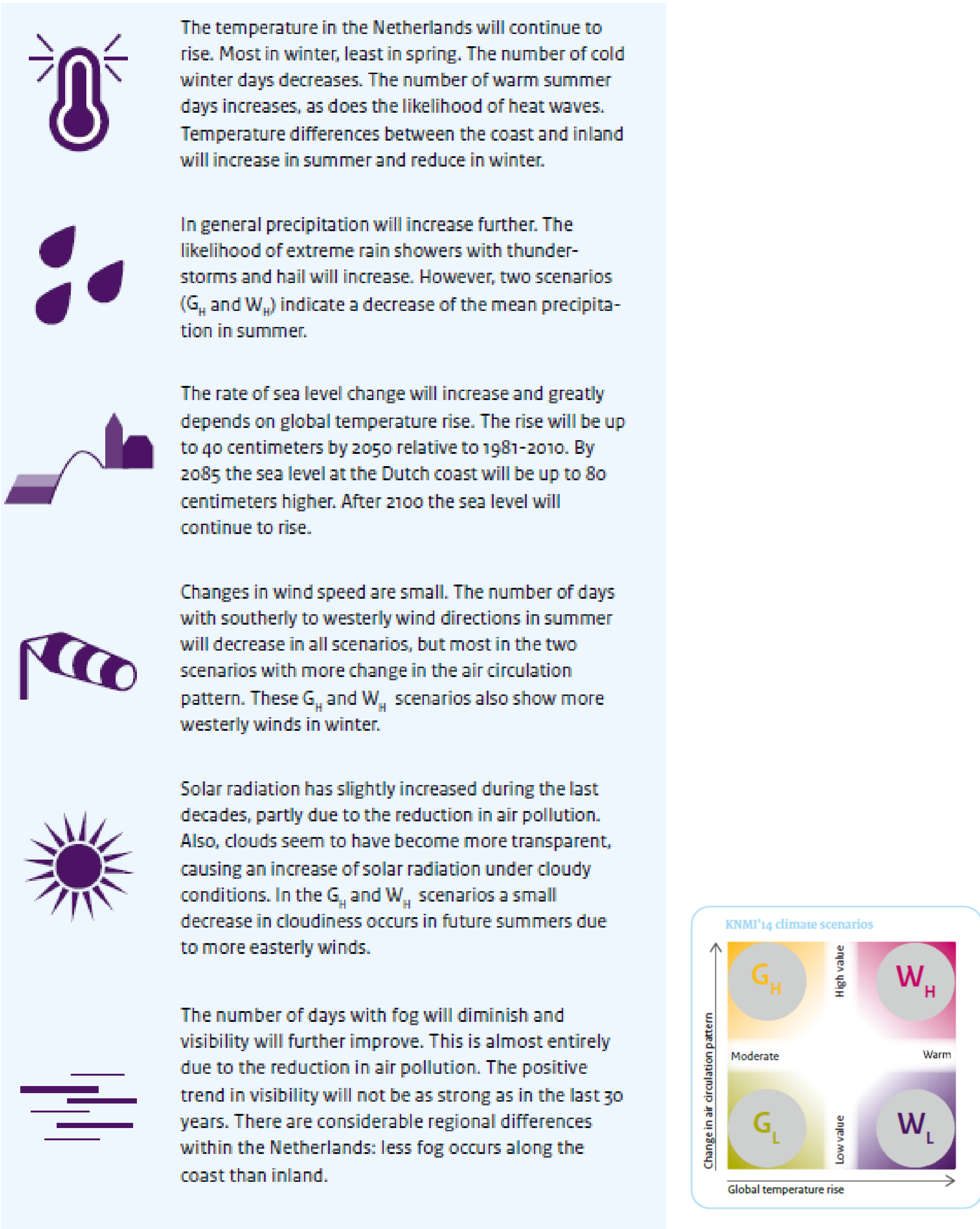


Figure 4: Projected changes in the weather because of climate change in the Netherlands

EU Adaptation strategy

The temperature of the European land area over the last decade (2002-2011) has increased on average 1.3°C (2.3°F) above preindustrial level, meaning that the increase in Europe has been faster than the global average. Some extreme weather events have increased, with more frequent heat waves, forest fires and droughts in southern and central Europe. Heavier precipitation and flooding is projected in northern and north-eastern Europe, with an increased risk of coastal flooding and erosion. A rise in such events is likely to increase the magnitude of disasters, leading to significant economic losses, public health problems and deaths. Impacts vary across the EU depending on climate, geographic and socioeconomic conditions.
All the countries in the EU are exposed to climate change (see Figure 1 below). However, some regions are more at risk than others. The Mediterranean basin, mountain areas, densely populated floodplains, coastal zones, outermost regions and the Arctic are particularly vulnerable. Additionally, three quarters of the population of Europe live in urban areas, which are often ill equipped for adaptation and are exposed to heatwaves, flooding or rising sea levels.
Many economic sectors are directly dependent on climatic conditions and are already facing the impact of climate change in areas such as agriculture, forestry, beach and snow tourism, health and fisheries. Major utilities, such as energy and water providers, are also affected.
Ecosystems and the services they provide are suffering from the adverse impacts of climate change, which is accelerating the decline of biodiversity and reducing their ability to buffer natural extremes. Climatic changes will have consequences for the availability of basic natural resources (water, soil) leading to significant changes in conditions for agriculture and industrial production in some areas.
Global warming may provide opportunities for specific sectors in certain areas, such as increased crop yields and forest growth, more hydropower or less energy needed for heating in northern Europe. However, the potential regional net benefits are highly uncertain.

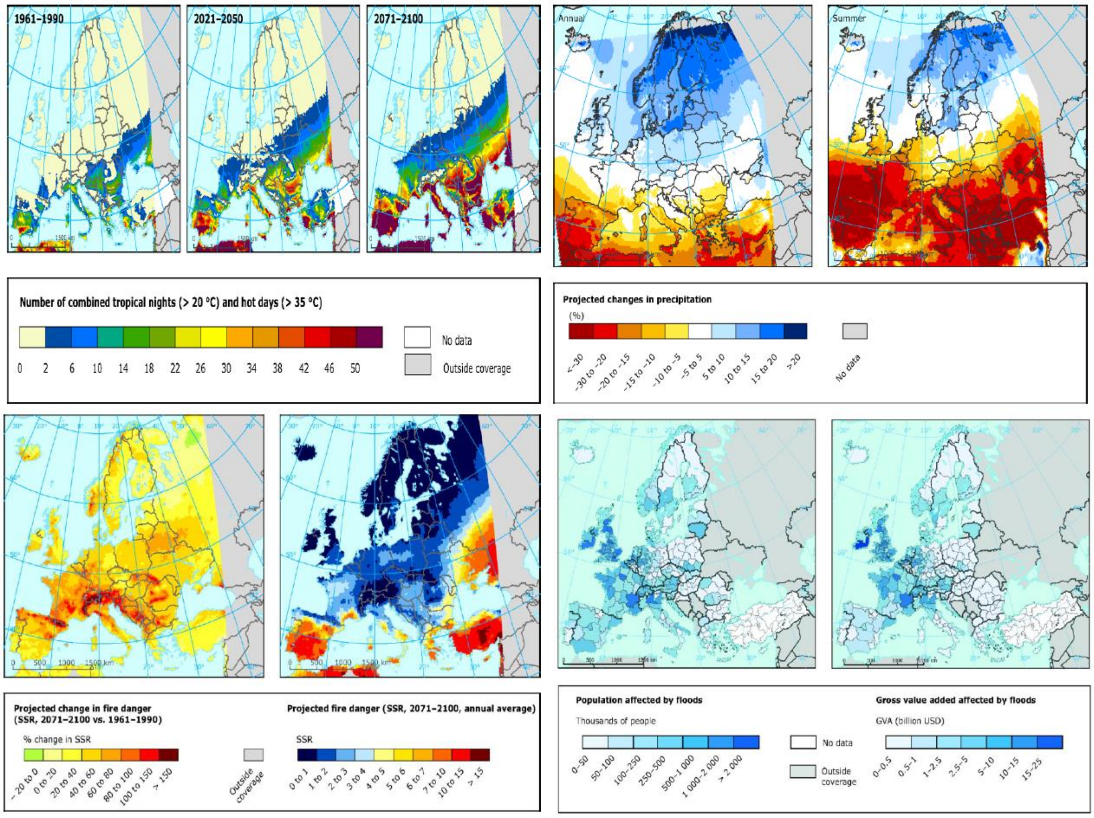


Figure 5: Projected impacts of climate change and associated threats. Based on EEA report Climate Change Impacts and Vulnerability in Europe (2012)

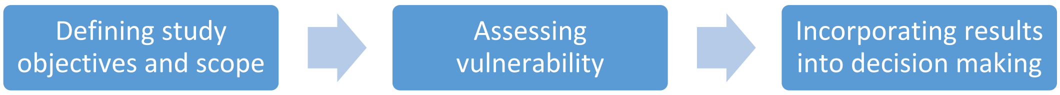
3.3 Vulnerability assessment

3.3.1 USA

FHWA: Climate Change & Extreme Weather Vulnerability Assessment Framework (December 2012)

1. Goal of overall method (scope)

The framework gives an overview of key steps in conducting vulnerability assessments and uses in-practice examples to demonstrate a variety of ways to gather and process information. The framework is comprised of three key steps:



The guide highlights the need for transportation agencies to focus on assets with a high likelihood of climate impact and high consequence.

The range of future changes to the climate that are of importance to a specific transportation agency will vary by region and by study objectives.
For transportation, the most important changes are often not changes to annual or seasonal averages, but to relatively short duration extreme events that can cause significant damage to transportation infrastructure or disrupt transportation operations. The kinds of climate changes included in transportation vulnerability assessments are:

- Temperature (including increase of numbers of very hot days, heat waves, changes to freeze-thaw cycles, and changes to the length of the construction season)
- Extreme precipitation events (both wetter and dryer conditions. May lead to flooding, destabilization of vegetation and wild-fires, increase of rock fall)
- Sea-level and Coastal Storm Surge (causing permanent or periodic inundation of infrastructure, increased coastal erosion, changes in groundwater levels and salinity)
- Permafrost Thaw (damage to infrastructure built on permafrost, mainly in the arctic region of Alaska).
- Snowmelt Hydrology (changes in snow accumulation and snowmelt can lead to flooding and channel instability and cause damage to infrastructure built alongside or across rivers)

2. Background information (context, authors)

The Federal Highway Administration's (FHWA's) *Climate Change and Extreme Weather Vulnerability Assessment Framework* is a guide for transportation agencies interested in assessing their vulnerability to climate change and extreme weather events.

3. Sub-methods/ researches

The framework is based on an earlier version named 'Vulnerability and Risk Assessment Conceptual Model" and the lessons learnt from five pilot project in which this earlier version was implemented.
The five pilot project on which the framework is based are the "New Jersey pilot", the "Oaha MPO pilot", the "San Francisco Pilot", the "Virginia pilot (Hampton Roads)" and the "WSDOT pilot"
(see further on for more information on these pilot projects)
In recent years (2013 and 2014) several more pilots are conducted all over the US. These pilots are mentioned at the end of the paragraph.

4. Relationship between sub-methods & how to use methods

The framework is designed as a guide for all transportation agencies in the US

San Francisco pilot – Adapting to Rising Tides
1. *Description of the method (scope, key steps, how the analysis is conducted, illustrative example, incorporated into existing processes)*
The San Francisco Pilot is a broad study of climate vulnerability, sensitivity, risks and adaptation options. The San Francisco pilot used the first conceptual Risk Assessment model developed by the Federal Highway Administration (FHWA) to assess the climate change–related sea level risks to transportation infrastructure in a select portion of the San Francisco Bay Area. The study selected sea level rise scenarios for mid- and end-of-century that were within the range of values included in the State of California Sea - Level Rise Interim Guidance Document (October 2010). The two sea level rise scenarios were evaluated for three tide/Bay water level conditions (mean higher high water, the 100-year extreme water level, and the 100-year extreme water level with wind-driven waves) by leveraging regional modeling results from USGS and the Federal Emergency Management Agency (FEMA). - Asset Risk Profiles A risk profile summarizes the results of the pilot for a selected asset. The risk profiles are tools for future development and prioritization of adaption strategies. The profiles combine the relevant information on one 'factsheet' that is easy to read for decision makers (see risk profile glossary below). - Prioritizing adaptation options through categorization The project reviewed a list of potential adaptation measures organized in the following categories: structural and nonstructural measures, and asset-specific and regional measures. The project team developed criteria that can be weighed and ranked in evaluating adaptation measures for each of the following groups: Equity, Economy, Ecology and Governance (see example below). These categories and criteria are not specific to the San Francisco area but are relevant for all adaptation options. Therefore, they can be applied elsewhere.

San Francisco pilot – Adapting to Rising Tides

Risk Profile Glossary

Asset Location/Jurisdiction Location of the asset in the region/agency responsible for the asset	
Summary Summarizes the technical information on the risk profile in a couple of sentences	
Characteristics This section lists the functionality of the asset selecting from: • Lifeline route • Mass evacuation plan route • Goods movement • Transit routes • Bike route • Commuter route • Regional importance • Socioeconomic importance: supports transit-dependent populations	
Sensitivity: Low /Medium/High – provides the overall sensitivity rating allocated for the asset	
Year Built	Year
Level of Use	
Peak Hour AADT (Annual Average Daily Traffic AADTT (Annual Average Daily Truck Traffic)	Number
Seismic Retrofit	Yes / No
Annual Operations & Maintenance	Cost $
Liquefaction Susceptibility	VH = very high H = high M = moderate L = low
Exposure: Low /Medium/High – provides the overall exposure rating allocated for the asset	
Maximum Inundation Depths	
16" + MHHW 16" + 100-yr SWEL 16" + 100-yr SWEL + wind waves	ft ft Yes/No
55" + MHHW 55" + 100-yr SWEL 55" + 100-yr SWEL + wind waves	ft ft Yes/No
Inadequate Adaptive Capacity (16" SLR): Rating Notes on alternative routes available if asset is inundation	
Vulnerability Rating (midcentury): Low /Medium Low / Medium/ Medium High / High	

Images shown on each risk profile

- Context map showing where the asset is in the subregion
- Photograph(s) of the asset
- Map thumbnail showing projected inundation with 16-inch SLR + 100-yr SWEL
- Map thumbnail showing projected inundation with 55-inch SLR + 100-yr SWEL
- Map thumbnail showing projected overtopping with 16-inch SLR + 100-yr SWEL (light blue)
- Map thumbnail showing projected overtopping with 55-inch SLR + 100-yr SWEL

*Note that there may be symbols in the thumbnail images that are not explained – for the full legend please see the inundation and overtopping maps in Chapter 6.

San Francisco pilot – Adapting to Rising Tides

Economy	Ecology
- **Protection of functionality**—Although the continued use of the asset may be limited, the function of the system as a whole can be protected if other facilities (e.g., Bay Area Rapid Transit [BART] or ferries, alternative routes) can provide the same or similar functionality. - **Protection of asset**—When the asset is protected, the asset could still be used. - **Economic benefit**—Does the improved flood protection/ climate resiliency spur new investment or growth? - **Cost and time to build**—What are the time and costs associated with implementing the adaptation measures? - **Operation and maintenance cost**—What are the operation and maintenance costs? - **Spatial requirements**—How much land is required to implement the adaptation measure? - **Adaptability**—Can an adaptation measure be designed to adapt to future climatic changes as likelihood increases or new technologies become available? - **Applicability in time**—Which measures are appropriate for the midterm and which for the longer term, given different SLR scenarios?	- **Ecological value**—Does the adaptation measure provide benefits to the natural environment through species or habitat protection? - **Ecological function**—Does the adaptation measure improve ecological function (e.g., wetland vs. flood wall)? - **Sustainability (longevity)**—Do the different adaptation measures provide long-term sustainable solutions (e.g., next 50, 100, or 200 years)? - **Sustainability (materials)**—Are the materials used for the adaptation measure environmentally sustainable? - **Environmental impacts**—What are the environmental impacts of implementing the adaptation measure, can they be mitigated, and do they reduce green house gas emissions?
Equity	**Governance**
- **Safety**—Does the adaptation measure enhance public safety and security? - **Environmental justice**—Does the adaptation measure benefit underserved populations? - **Regional benefit**—Is there a regional benefit to the local community selecting a specific adaptation measure (e.g., systems approach to protect the region vs. asset-specific protection)? - **Awareness**—Does the measure enhance public awareness and technical knowledge about SLR? - **Public access and aesthetic importance**—Can the adaptation measure be integrated into the natural or urban landscape so that it becomes an amenity and (for example) provides public access to the shoreline? - **Unintentional consequences**—Are there beneficial or negative consequences to the surrounding community or other assets by implementing this measure?	- **Institutional (organizational) arrangements, including jurisdiction**—Are governmental bodies and current policies and regulations equipped to ensure or facilitate long-term planning and timely implementation of the adaptation measure? - **Funding**—Which organization is providing the funding for the adaptation measure, and are there funds available? - **Public or private land**—Which entity or individual owns the land, and how does this affect implementation of the adaptation measure? - **Policies**—Does the adaptation measure build on existing policies, and do new policies allow for modifications as new climate change data/insights become available? - **Development**—Does the adaptation measure facilitate (undesired) development in low lying areas (through improving the flood protection level)?

TABLE 7.1 Criteria for Helping Selection of Adaptation Measures

2. *How is it applicable to other countries (how applicable/ transferable, what might need to be changed/ adapted, use in the Netherlands)*

The data and much of the results and findings are specific to the San Francisco context (for example the inundation maps). The lay out of the factsheet (risk profile) and the criteria used for priority setting can be useful and applicable elsewhere

3. *How much time/ money/ effort required*

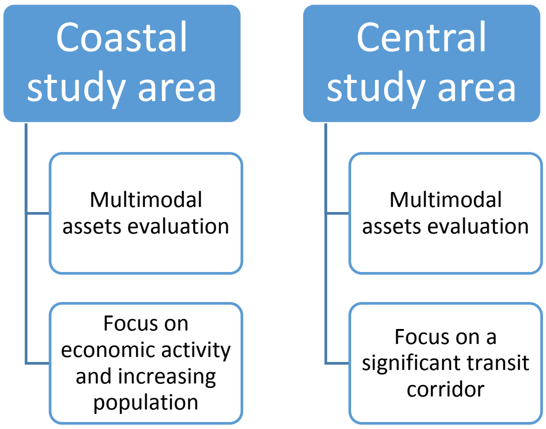
Study took several months

New Jersey pilot

1. *Description of the method (scope, key steps, how the analysis is conducted, illustrative example, incorporated into existing processes)*

The North Jersey Transportation Planning Authority (NJTPA) led the interagency NJ Partnership to assess the vulnerability of transportation systems. Much of the state's infrastructure is ageing and concentrated near major rivers and the coast. The NJ Partnership wanted to understand how to make more strategic capital investments in light of the changing climate. To accomplish this goal, the project team conducted a Geographic Information System (GIS)-

New Jersey pilot
based climate vulnerability assessment on transportation assets in two geographic areas of focus. The New Jersey pilot is based on an evaluating multimodal assets including roadways, bridges, tunnels, rail and bus transit, freight rail, maritime assets, airports and wetlands in two study areas. The first concerns the Coastal Study Area along the Atlantic coast, aiming at the state's economic activity and an increasing population. The latter concerns the Central Study Area, focusing on a significant transit corridor.

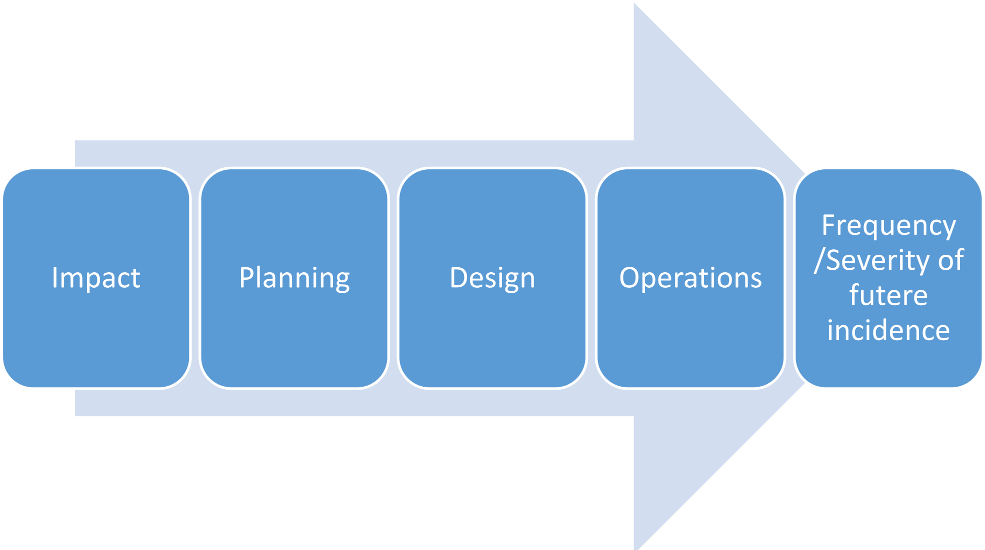


As such, this pilot is conducted by comparing the outcome of two researches.
The New Jersey pilot looked at sea-level rise, storm surge, extreme temperatures and temperature ranges, extreme and average precipitation, drought, and inland flooding. The pilot benefitted from assistance from their State Climatologist, and hired a consultant to develop downscaled climate projections for the study area. The pilot also analyzed future floodplain expansion using a regression model developed in a FEMA-sponsored study (Federal Emergency Management Agency). Inputs to the model included current and future climate variables.

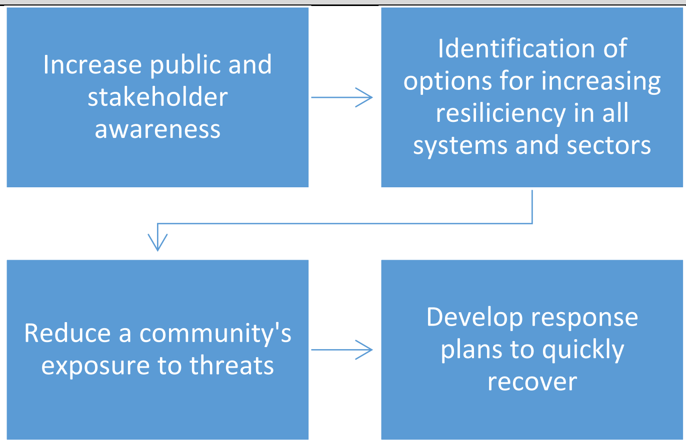
The New Jersey pilot used the first conceptual Risk Assessment model developed by the Federal Highway Administration (FHWA) to assess the climate change–related sea level risks to transportation infrastructure in a select portion of the San Francisco Bay Area. The pilot 'test-drived' the model and the recommendations were used in the FHWA "Climate Change & Extreme Weather Vulnerability Assessment Framework".

2. *How is it applicable to the Netherlands (how applicable/ transferable, what might need to be changed/ adapted, use in other countries)*

While much of the results and findings are specific to the New Jersey context, the method (see below) is applicable in other countries.



New Jersey pilot



The method contains a series of matrices to identify potential adaptation strategies that could be implemented at the planning, design and operations phases of transportation decision making.

IMPACT	STRATEGY Planning	Design	Operations	Frequency/ Severity of Future Incidence
Climate Stressor: Sea Level Rise				
Flooding	• Site future infrastructure out of or above estimated flood impact zone • Identify or create redundant routes • Abandon/ relocate infrastructure (for chronically flooded segments)	• Enhance shoreline infrastructure (sea walls and shoreline armoring) • Elevate infrastructure • Enhance drainage to minimize road closure time and pavement deterioration (pumping infrastructure for tunnels)	• Road closures as necessary • Traveler notification of flooded roadways and alternative routes/modes (ITS)	
Erosion	• Land use policies discouraging development in at-risk zones	• Create/ strengthen seawalls and barriers	• More frequent inspections and maintenance • Beach nourishment • Wetland maintenance	
Corrosion (from chronic sea water		• Design infrastructure to resist salt water corrosion	• More frequent inspections and maintenance	

3. *How much time/ money/ effort required*

Study took several months

WSDOT pilot

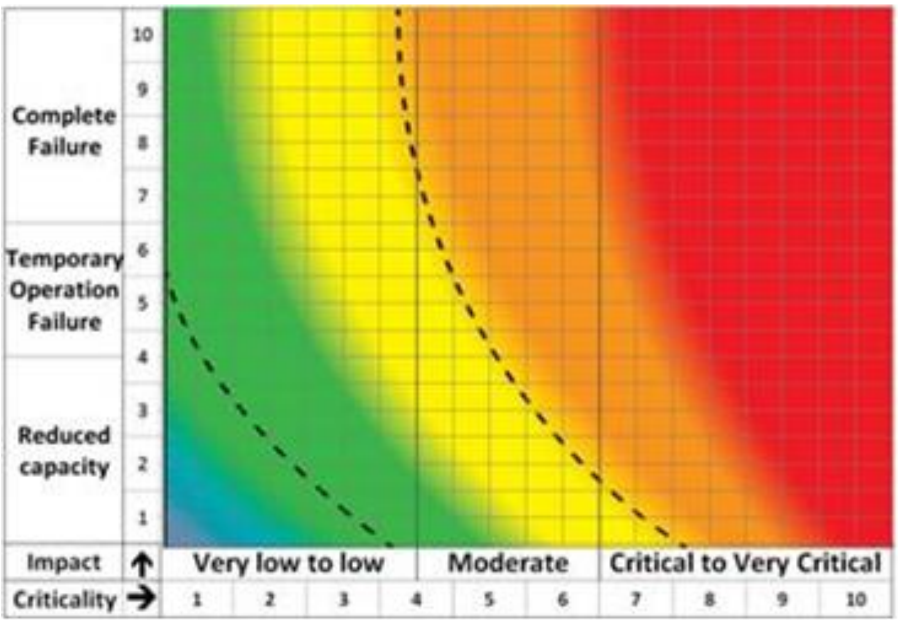
1. *Description of the method (scope, key steps, how the analysis is conducted, illustrative example, incorporated into existing processes)*

As part of the FHWA pilot program, the Washington State Department of Transportation (WSDOT) assessed the vulnerability to climate change of the infrastructure it owns, including roads, rail, ferry facilities, and airports.
The WSDOT pilot considered all known climate threats in the Pacific Northwest: sea level rise, precipitation change, temperature change, and fire risk. The study used climate projections funded and endorsed by an act of the Washington State Legislature for use in adaptation studies, developed by the University of Washington Climate Impacts Group.

WSDOT pilot

The chosen method is a qualitative, climate scenario planning approach. It makes use of the conceptual model for risk assessment, created by FHWA. The WSDOT held 14 workshops around the State, presenting information on climate projections and asking maintenance engineers and other employees with intimate familiarity with the assets, "What keeps you up at night?" to help identify current vulnerabilities that may be exacerbated in the future.

WSDOT's vulnerability assessment considered two factors: asset criticality and the potential impacts of the CIG climate change scenarios. The project team used a 1 to 10 rating scale to articulate the relative criticality and impact for each asset. Workshop participants scored criticality based on the asset's character, its general function, and use. Similarly, participants defined climate impacts based on the anticipated impact of a given climate scenario on a specific asset. The impact-asset criticality matrix in the figure below is a visual representation of the relationship between these two factors.



The findings from the pilot project are used in the Washington State Integrated Climate Change Response Strategy.

2. *How is it applicable to the Netherlands (how applicable/ transferable, what might need to be changed/ adapted, use in other countries)*

While much of the results and findings are specific to the Washington State context. The use and lay-out of the impact-asset criticality matrix can be useful and applicable elsewhere

3. *How much time/ money/ effort required*

The pilot project provides $ 189,500 to partially match WSDOT investments in asset management and sustainability. The timeline indicates it is a yearlong process

Hampton Roads (Virginia pilot)

1. *Description of the method (scope, key steps, how the analysis is conducted, illustrative example, incorporated into existing processes)*

This pilot study is executed for Hampton Roads in Virginia. This is a low-lying, coastal

Hampton Roads (Virginia pilot)

metropolitan region with among others multiple military installations. The study consists of combining climate change variables with other planning factors like population and industrial growth. The objectives are to assess the sensitivity of transportation priorities to climate change scenarios, to develop a prioritization model and to provide recommendations for evolving the FHWA conceptual model.

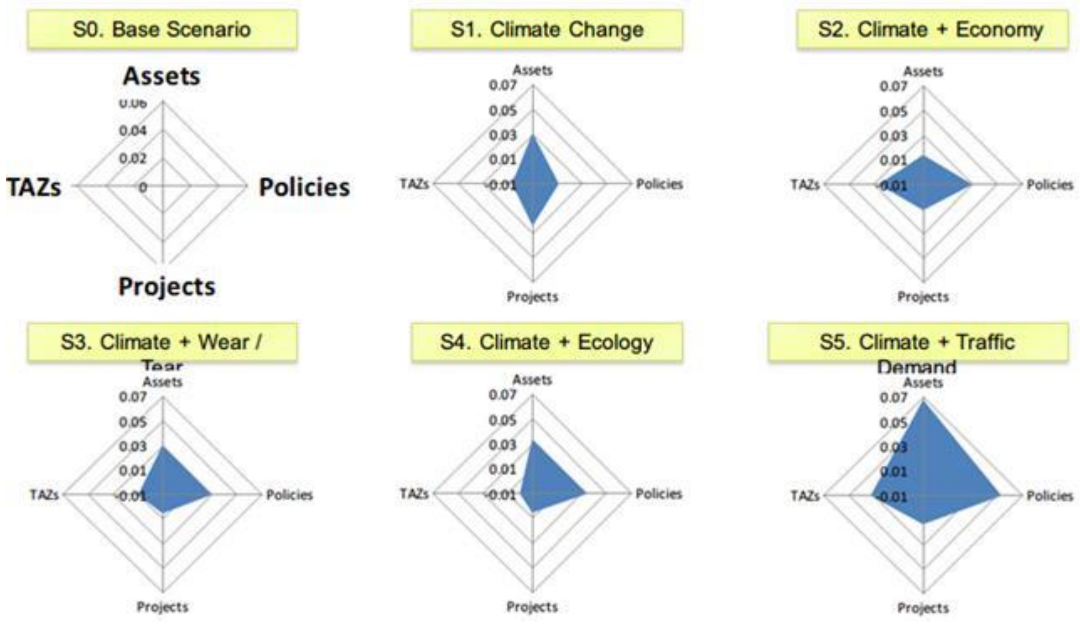
The Virginia Pilot developed a tool for incorporating vulnerability and risk assessment results into the transportation planning process. The decision support tool helps to prioritize projects in a transportation plan based on how they would address various issues, including climate change vulnerability.
The pilot study used an existing decision model to evaluate how the transportation priorities of the region might be influenced by a variety of different scenarios. The methodology is built up by scenario-based preferences and multi-criteria decision analyses. Striking is the combination of physical consequences of climate change and the socio-economic conditions that could interact with these consequences.

A priority analysis was done for four types of transportation planning in the region:

- Major Transportation Projects
- Existing Transportation Assets.
- Transportation Analysis Zones (TAZs)
- Transportation Policies.

Priorities were set using scenarios based on a combination of climate factors and non-climate factors (such as economic conditions, wear-and-tear, travel demand, and environmental/ecological change and regulations).

The pilot found that the most influential scenario for priority-setting was a combination of sea level rise and storm surge with increased traffic demand (see S5 Figure below). This scenario significantly disrupted existing priorities for projects, assets, TAZs, and policies. Interestingly, prioritization of planned projects was most sensitive to the climate-change-only scenario.



2. How is it applicable to the Netherlands (how applicable/ transferable, what might need to be changed/ adapted, use in other countries)

In order to share the method with the broader transportation community, the decision model was transferred into a workbook tool. The report states this model will be applicable to regions across the USA. The model is downloadable from the website. Therefore, it is easy to replicate

Hampton Roads (Virginia pilot)
the method. The methods and the data used are specific to the USA and specifically the Virginia area. The use of a combination climate factors and non-climate factors however can be very relevant and applicable in the Netherlands and other countries
3. How much time/ money/ effort required
Study took several months

The Oahu MPO pilot
1. Description of the method (scope, key steps, how the analysis is conducted, illustrative example, incorporated into existing processes)
The Oahu Metropolitan Planning Organization (MPO) used an interagency, multidisciplinary 2-day workshop to facilitate a climate change dialog and identify five key vulnerable assets for further study. The five assets were then assessed in more detail by transportation experts in three full-day work sessions. The Oahu MPO pilot looked at potential sea-level rise, storm surge, wind, high intensity rainfall, drought, and temperature effects on critical assets on the island of Oahu. The study made use of climate projections from published literature and storm surge modeling from University of Hawaii research conducted for Federal Emergency Management Agency (FEMA). A short list of critical transportation assets was made up, mainly by depending on local knowledge. To visualize these vulnerable assets and locations, GIS was used. Historical climate information over the past (from 1970 till most recent) was gathered and projections for 2050 and 2100 were formed. By assuming a worst case and best case scenario a range of both social and economic impacts is defined. For both storm surge and sea level rise Light Detection and Ranging-based inundation maps were developed. The team used a three-tier ranking system to classify asset risk for the two planning horizons years of 2050 and 2100 (see Figure below). The three categories for ranking integrated risk were: • Low: Repair of asset needed, but can work around it • Medium: Asset is temporarily unusable and in need of repair • High: Total catastrophic loss

The Oahu MPO pilot

Asset	Period	Sea Level Rise		Storm Surge		High Intensity Rainfall	
		Vulnerability	Impact	Vulnerability	Impact	Vulnerability	Impact
Honolulu Harbor	**2050**	Low	Low	High	High	Low	Low
	2100	Moderate	Moderate	High	High	Moderate	Moderate
Honolulu International Airport							
TheBus (811 Middle Street)	**2050**	Low	Low	Moderate	Moderate	Low	Low
	2100	Low-Moderate	Low-Moderate	High	High	Moderate	High
Oahu Baseyard (727 Kakoi Street)	**2050**	Low-Moderate	Low	High	High	Low-Moderate	Low
	2100	High	High	High	High	Moderate	High
Honolulu International Airport and Access	**2050**	Low	Low	High	High	Low	Low
	2100	Low	Low	High	High	Low	Low
Kalaeloa Barbers Point	**2050**	Low	Low	High	High	Low-Moderate	Low-Moderate
	2100	Low-Moderate	Low-Moderate	High	High	Low-Moderate	Low-Moderate
Three Waikiki Bridges							
Ala Moana Boulevard	**2050**	Low	Low	High	High	Low	Low
	2100	High	High	High	High	High	High
Kalakaua Avenue	**2050**	Moderate	Moderate-High	Moderate	High	Moderate	Moderate
	2100	High	High	High	High	High	High
McCully Street	**2050**	Low-Moderate	Low	Moderate	Moderate	Moderate-High	Moderate-High
	2100	High	High	High	High	High	High
Farrington Highway on Waianae Coast	**2050**	Moderate-High	High	High	High	Drought: High Rain: Moderate	Drought: High Rain: Moderate
	2100	High	High	High	High	High	High

The method provides a sufficient first step but a more detailed risk assessment is required to guide transportation planners in developing the Long Range Transportation Plan (LRTP).

2. *How is it applicable to the Netherlands (how applicable/ transferable, what might need to be changed/ adapted, use in other countries)*

The data used and therefore the results and findings are very specific to the Oahu context. The focus on the link with asset management however is very useful and applicable elsewhere.

3. *How much time/ money/ effort required*

Cost are claimed to be low but no detailed information is available on the required effort to use this method (time/money)

<u>Recent ongoing pilots on climate adaptation</u>:

Tennessee Department of Transportation (TDOT)

TDOT, in conjunction with the MPOs throughout the state, will conduct a systematic evaluation of the vulnerability of the State's multimodal infrastructure. They will consider both existing and planned transportation assets.

Michigan Department of Transportation (MDOT)

MDOT will conduct a vulnerability assessment to identify at risk assets, identify a method for incorporating risk information into their asset management systems, and identify maintenance and operational activities needed to address climate change risk.

Capital Area Metropolitan Planning Organization (CAMPO)

CAMPO, the Austin area MPO, will use FHWA's framework to conduct a vulnerability assessment of transportation infrastructure in their region. They will consider temperatures and extreme heat, extreme precipitation and flooding, drought, and wildfire. At the conclusion of the study they will conduct a regional symposium to share the report findings broadly.

North Central Texas Council of Governments (NCTCOG)

NCTCOG will conduct a vulnerability and risk assessment for critical roadway and rail facilities in the Dallas-Fort Worth region. The region is subject to extreme heat and drought followed by flash flooding events. Near the beginning of their study, NCTCOG will hold a meeting for partners and/or other interested parties to finalize a list of infrastructure to include in the assessment and to determine whether to focus on both drought and flooding or just one type of weather event.

Maine Department of Transportation (Maine DOT)

The Maine DOT will assess the vulnerability of state-owned transportation infrastructure to extreme precipitation events and projected sea level rise in six coastal Maine communities. This project will dovetail with a Project of Special Merit (PSM) recently funded by NOAA entitled "Integrating Science into Policy: Adaptation Strategies for Marsh Migration," thus providing the transportation infrastructure component of interest to municipalities as well as Maine DOT's asset management and maintenance programs.

Arizona Department of Transportation (ADOT)

ADOT will assess the vulnerability of state-owned transportation infrastructure, based on findings from their recently completed study: Preliminary Study of Climate Adaptation for the Statewide Transportation System in Arizona. ADOT will focus on a transportation corridor connecting Nogales, Tucson, Phoenix and Flagstaff as a case study. ADOT will analyze impacts of extreme surface temperatures, floods, dust storms, and species migration on pavement, drainage, bridges, and roadside vegetation/stabilization/habitat.

Alaska Department of Transportation & Public Facilities (ADOT&PF) and Alaska Federal Land Management Agencies (FLMAs)

ADOT&PF and the Alaska FLMAs (BLM, FWS, NPS, and USFS) will identify transportation assets that are adversely affected by climate change, identify engineering and other strategies to make infrastructure more resilient and adaptable, and identify priority-based work plans for addressing the most vulnerable assets first.

Connecticut Department of Transportation (ConnDOT)

ConnDOT will conduct a systems-level vulnerability assessment of bridge and culvert structures six to twenty feet in length from inland flooding associated with extreme rainfall events. The assessment will evaluate the existing storm-event design standards, the recent (ten year) historic actual rainfall intensity and frequency, and evaluate the hydraulic capacity of these structures using the projected increases in rainfall. The study area is in the northwest portion of the state.

Massachusetts Department of Transportation (MassDOT)

MassDOT focus on the Central Artery system in Boston. They will work with UMass and others to conduct detailed flood impact assessment for the project area with ADCIRC modeling, using this information to identify where and how the Central Artery is vulnerable to flooding. They will then investigate adaptation options including a cost-benefit analysis based on both current and future conditions in order to determine when various options become costs-effective.

Minnesota Department of Transportation (MNDOT)

MNDOT will conduct a systems-level vulnerability assessment to flash flooding events in two districts to better understand the type, location, and reason for asset risks from flash floods. They will then conduct a focused adaptation analysis of specific high-risk facilities identified in the system assessment.

New York State Department of Transportation (NYSDOT)

This study will look at the New York portion of the Lake Champlain Basin in northern New York. Working with the Nature Conservancy, which recently predicted climate change impacts to the basin through 2100, NYSDOT will: identify and prioritize culverts and road segments that are most vulnerable to changing precipitation; develop engineering-based design options; create an economic tool to evaluate the full benefits and cots of adaptation options (including costs to non-DOT entities); and incorporate climate vulnerability assessments into existing NYSDOT standards, guidelines, and tools.

Metropolitan Transportation Council (MTC)

MTC will build on their previous FHWA pilot, looking more in depth at three focus areas within the study area to develop multimodal adaptation options and an implementation strategy.

Broward Metropolitan Planning Organization

This effort focuses on Palm Beach, Broward, Miami-Dade, and Monroe Counties in South Florida. The project will include some vulnerability assessment work, but it is mainly focused on developing a consistent methodology and decisions support and screening tool for incorporating climate change impacts into transportation decision making.

Oregon Department of Transportation (ODOT)

ODOT will develop a corridor level Coastal Hazards Adaptation Implementation Plan for Highway 101 in the northwest area of the state. ODOT will develop a set of effective adaptation measures to reduce risk and improve the resilience of transportation assets vulnerable to climate change and extreme weather, conducting an engineering and technical review for building adaptive capacity. The project has a focus on landslide risk and flood warning.

California Department of Transportation (Caltrans)

Caltrans will develop a range of adaptation strategies at four specific locations on the state highway system in the northwest corner of the state (District 1). They will determine vulnerability of these segments due to sea level rise, coastal bluff erosion, high precipitation, and the resulting flooding. They will work with regional transportation partners, several Native American Tribal Governments, federal agencies, and a university.

Hillsborough Metropolitan Planning Organization (Hillsborough MPO)

Hillsborough MPO, of the Tampa area, will identify potential adaptation/mitigation projects in the MPO's 2040 Plan to improve resiliency of key transportation facilities. They hope to incorporate results into Florida DOT's EDTM.

Washington State Department of Transportation (WSDOT)

This study builds on WSDOT's earlier pilot to examine adaptation options in an identified highly vulnerable area, the Skagit River Basin, which includes I-5. The U.S. Army Corps of Engineers is preparing a DEIS for a Skagit River General Investigation Study, and the WSDOT study would feed into that effort. Outcomes of WSDOT's study would include:

- A set of site specific adaptation strategies for the state owned and managed transportation infrastructure
- A replicable evaluation process, including life-cycle cost analysis of multiple engineering and non-structural adaptation options to reduce risk to infrastructure.
- A plan of action for flooding and weather related closures to improve public safety and enhance continuity of international freight flow along this corridor that considers future climate impacts.

Iowa Department of Transportation (IDOT)

IDOT will assess the vulnerability of highway structures in Iowa due to climate change impacts on extreme weather events. The project will monitor, predict, assess and provide alerts when vulnerable highway infrastructure assets are at risk from extreme rainfall events.

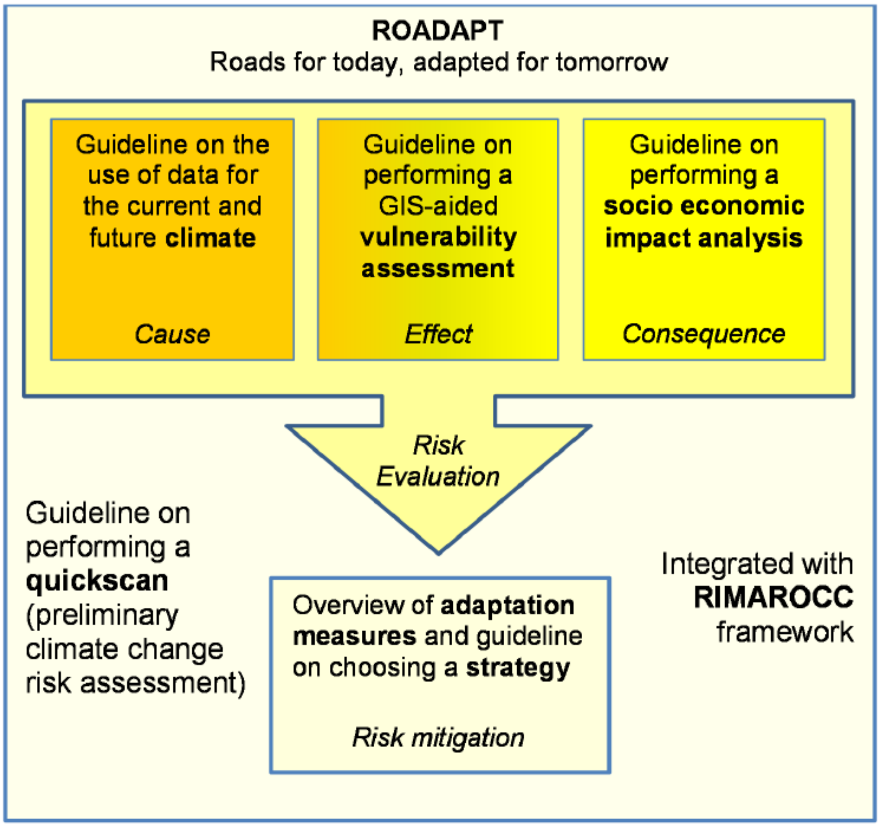
Maryland State Highway Administration (SHA)

SHA will conduct, in partnership with appropriate agencies and jurisdictions, an assessment of asset resilience to climate change effects and extreme weather. SHA will focus on the Eastern Shore before broader analysis of the entire state is completed. SHA will identify the types of drainage asset issues being seen now and evaluate how to address them now and in the future. SHA will consider adaptation options and best management practices, standards, or other ways to support the adoption of adaptive design

3.3.2 Netherlands/Europe

ROADAPT – overall
1. Goal of overall method (scope)
ROADAPT (Road owners adapting to climate change) aims at providing methodologies and tools, applicable in Europe, enabling tailored and consistent climate data information, a good communication between climate researchers and road authorities, a preliminary and fast QuickScan for estimating the climate change related risks for roads, a vulnerability assessment, a socio economic impact analysis and an action plan for adaptation with specific input from possible adaptation techniques related to geotechnics and drainage, pavements and traffic management. The last step, actual choice of mitigating measures and their implementation is not covered by ROADAPT.
2. Background information (context, authors)
ROADAPT has an integrated approach following the RIMAROCC (Risk Management for Roads in a Changing Climate) framework that was developed for ERA NET ROAD in 2010 The research within the ROADAPT project has been carried out as part of the CEDR Transnational Road research Programme Call 2012. It was developed by Deltares (coordinator), SGI, Egis and KNMI.
3. Sub-methods/ researches
The ROADAPT guidelines consist of: Integrating main guidelines A. Guidelines on the use of climate data for the current and future climate B. Guidelines on the application of a QuickScan on climate change risks for roads C. Guidelines on how to perform a detailed vulnerability assessment D. Guidelines on how to perform a socio economic impact assessment E. Guidelines on how to select an adaptation strategy The guidelines can be downloaded on the CEDR-site.[9]

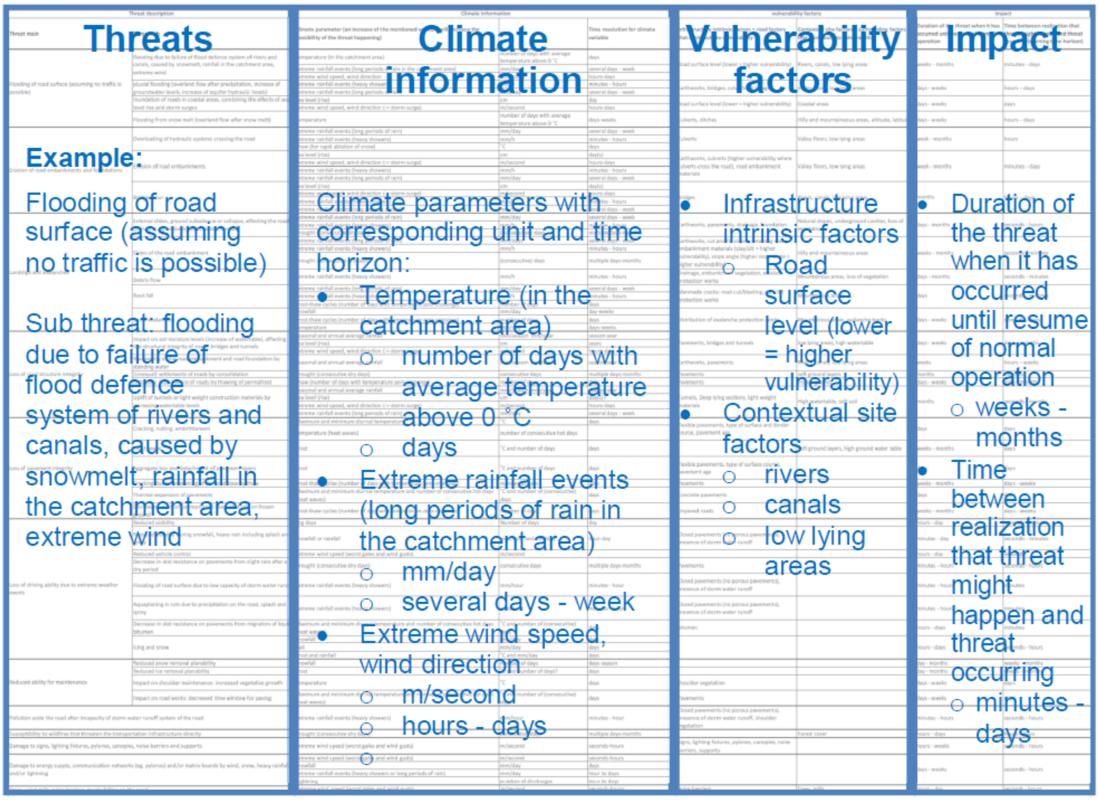
9 http://www.cedr.fr/home/index.php?id=wwwcedreuresearchcall2012&dlpath=CEDR%20Call%202012%20Climate%20Change&cHash=b7531baf0fcaae6a738248fb6aed77b5

ROADAPT – overall
4. Relationship between sub-methods & how to use methods
The structure of ROADAPT is as follows:    With regard to the above, the project resulted in the development of 5 guidelines which can be used in unison or separately. Although the guidelines are primarily written for European National Road Authorities to gain insight into the steps to be taken for a climate change risk assessment on roads, these guidelines may be beneficial to a broader range of professionals, including road managers, climate change adaptation professionals, innovation managers, and project managers. Also the topics and methodology are applicable to other infrastructure assets like railways or electricity networks and for other areas outside of Europe also. The final reports for the ROADAPT project will be available on the CEDR website

ROADAPT Integrating main guidelines
1. Description of the method (scope, key steps, how the analysis is conducted, illustrative example, incorporated into existing processes)
This provides the context and scope of the ROADAPT research and provides the main conclusions. An overview table is given that may be used as a starting point for all risk and vulnerability studies to the effects of extreme weather on roads. This overview can be used in studies both for present and future situations and links most known threats to climate factors and factors

ROADAPT Integrating main guidelines

which determine the vulnerability of the infrastructure.



General structure of ROADAPT overview table

The first part of the overview shows a list of ‘all possible’ threats to infrastructure, specifically roads. Although this list is as complete as possible, there are probably threats missing, especially when other types of infrastructure and/ or other (non-European countries) are regarded. The second part shows relevant climate information, linked to the type of threat. Subsequently vulnerability factors are given. The last part of the overview shows how much time may be present between the moment of realization that a threat will occur and to a threat actually occurring and also indicates the duration of the unwanted event.
The overview, together with the climate information provides insight into the probability of a threat occurring and it’s potential extent. By performing a socio-economic impact analysis, insight is gained in the consequences of the threat if it happens at a certain vulnerable location.

2. *How is it applicable to the US (how applicable/ transferable, what might need to be changed/ adapted, use in other countries)*

To be used together with the ROADAPT guidelines, and could be used in update of FHWA framework

3. *How much time/ money/ effort required*

Not applicable to this document

ROADAPT A. Guideline on the use of climate data for the current and future climate
This sub-method consists of 2 guidelines.

1. *Description of the method (scope, key steps, how the analysis is conducted, illustrative example, incorporated into existing processes)*

This guideline covers climate and climate change parameters. They provide information on climates and climate change, the expected climate changes for Europe, how to use climate change information and -scenarios, and numerous other (user) questions. The guidelines A were developed by KNMI (Dutch Meteorological Institute) specifically for this project. Prior to writing the guidelines, user questions were collected and addressed in these reports. As such, this guideline is not so much a description of a methodology but provides background information, necessary to interpret and use information provided by a meteorological institute (or other).
The user is provided with guidance how to use climate data. ROADAPT assumes climate data are provided by a meteorological institute. The guideline then helps a Road authority or consultant with the interpretation of the data and/ or put it in the proper context.

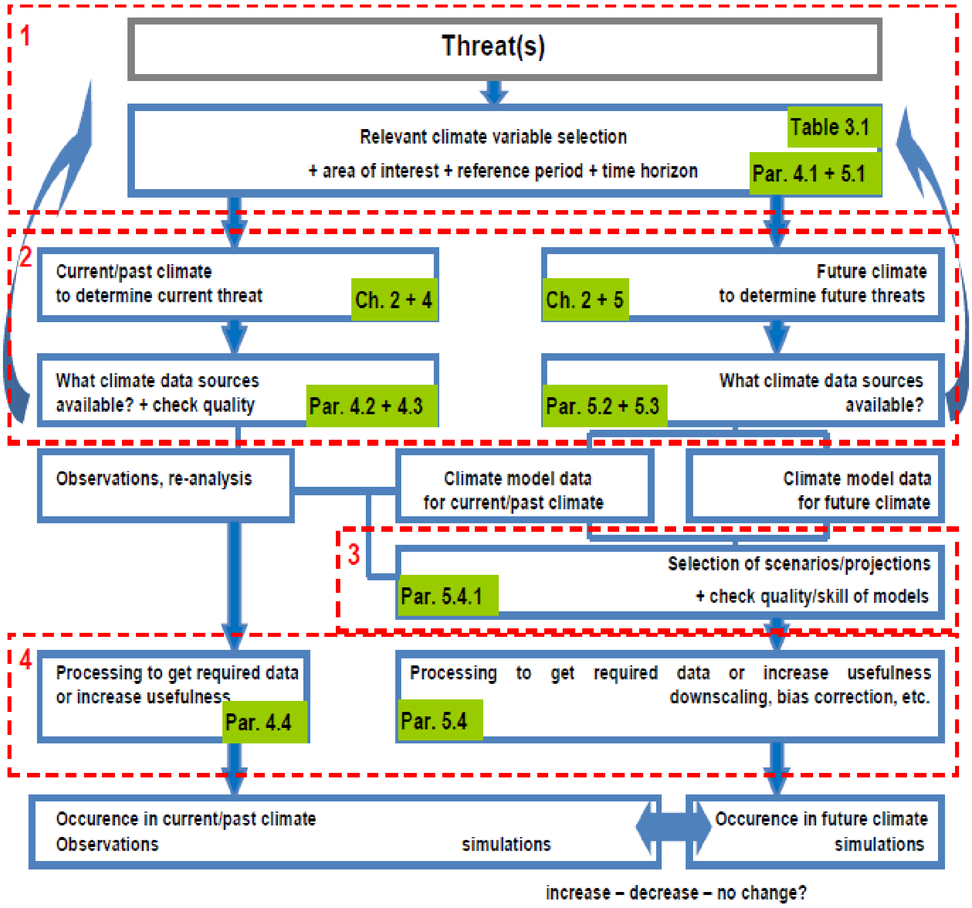


Figure: How to use climate data (the red dashed boxes indicate specific explanations given in the guidelines)

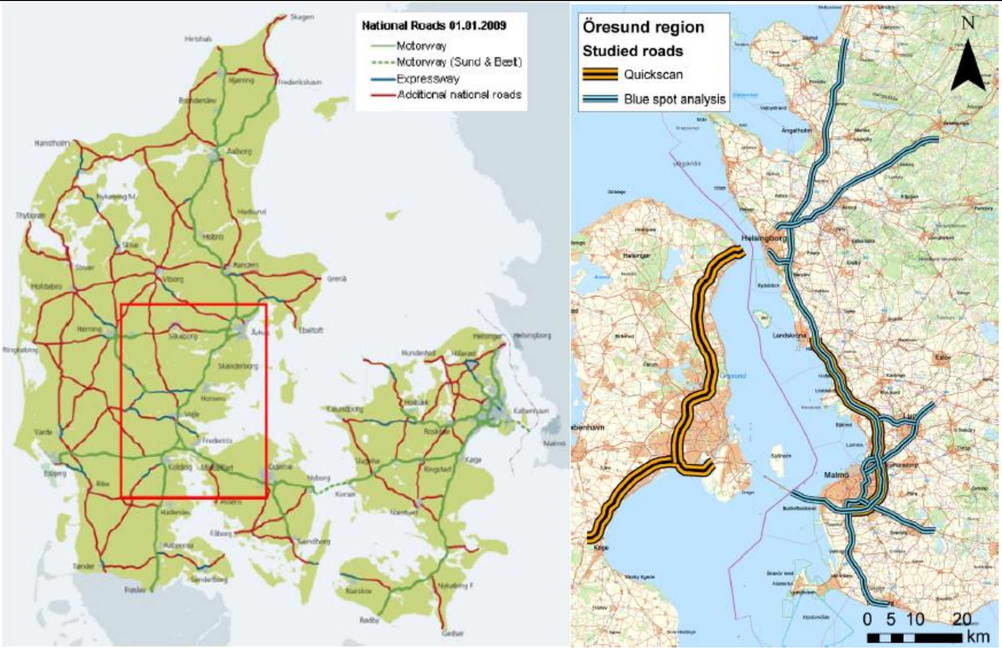
2. *How is it applicable to the US (how applicable/ transferable, what might need to be changed/ adapted, use in other countries)*

The provided climate data and climate change information are focused on the European situation. As such, this information is not applicable in the USA. However, the information on how to use climate information, what are the pitfalls, etc. are generic and may be used outside

ROADAPT A. Guideline on the use of climate data for the current and future climate This sub-method consists of 2 guidelines.
of the European context.
3. How much time/ money/ effort required
Not applicable for this document

ROADAPT B. Guidelines on the application of a QuickScan on climate change risks for roads
1. Description of the method (scope, key steps, how the analysis is conducted, illustrative example, incorporated into existing processes)
The ROADAPT method may be carried out in a 'full/ robust' manner as mentioned above, providing deeper insight and more objective results. The alternative is to make a Quickscan, with (possibly less detailed) results earlier. How to perform the Quickscan is outlined in guideline B. Workshops are the core of the QuickScan method. The QuickScan starts with looking at all possible threats and continuously narrows the focus in an ongoing process. The QuickScan is carried in semi quantitative manner. Recommended criteria to be judged are: availability, safety, surroundings, direct technical costs, reputation and environment. Stakeholders are brought together in around-the-table sessions and are asked to provide input regarding the consequences and probabilities. - Workshop 1, determine consequences - Workshop 2, determine probabilities, top risks and locations - Workshop 3, determine action plan for adaptation The QuickScan results in an overview of the top risks and possible adaptation strategies. The quality of the results strongly depends on the people present during the workshops. Their attendance (agendas) may influence the speed at which the QuickScan may be carried out. Once the appointment(s) have been made, the QuickScan will take days – a weeks' worth of effort. As with the other guidelines, this also depends on the amount of data present and the detail required. The QuickScan was tested on three pilot cases (Oresund between Denmark and Sweden, A24 Portugal and the Rotterdam – Ruhr corridor).

ROADAPT B. Guidelines on the application of a QuickScan on climate change risks for roads



The Oresund pilot focused on the E55 between Helsingor and Copenhagen and the E20 from Amager to Koge in Denmark and the E20/E6 in Sweden between the Oresund bridge and Landskrona.

The pilot identified depressions and low-lying areas where there is a danger of flooding due to heavy precipitation or sea level rise (compare to Blue Spot analysis). The analyses were conducted using national Digital Elevation Models in combination with climate scenarios for precipitation in 2100. The concept seems to be a useful tool in identifying sections at risk. Note: the workshops did not completely follow the guidelines (one specific type of risk was targeted, sequence of workshops changed according to situation and personal preference). Both Danish and Swedish road authorities may use these results, however the analysis was primarily used to check if the provided steps work.

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ROADAPT B. Guidelines on the application of a QuickScan on climate change risks for roads

The A24 case in Portugal focused on the A24 motorway between Viseu and Chaves

The case followed the proposed Quickscan steps. Various types of hazards were identified:

- Landslips, avalanches – external slides
- Landslips, avalanches – slides of road bed
- Landslips, avalanches – rock fall
- Loss of driving ability due to fog
- Reduced ability for maintenance due to snow
- Susceptibility to wild fire

Mitigating measures were suggested. As a result, a new section will be added to the 5-year repair and investment plan for dealing with climate related risks.

The Rotterdam – Ruhr case focused on the main routes from the Rotterdam harbor to the German Ruhr area (heavy industry). Due to unforeseen circumstances, only the Dutch part of these routes were analyzed. The Quickscan steps were followed. It was determined that the main hazards were:

- Bridge scour
- Impact on soil moisture levels, affecting the structural integrity of roads, bridges and tunnels

ROADAPT B. Guidelines on the application of a QuickScan on climate change risks for roads
- Weakening of the road embankments by standing water - Reduced visability during snowfall, heavy rain including splash and spray - Tress, noise barriers or windmills falling on the road due to strong winds An action plan was formulated however the current status of the plan is unknown.
2. How is it applicable to the US (how applicable/ transferable, what might need to be changed/ adapted, use in other countries)
The QuickScan methodology is applicable to other infrastructures and may be used outside of Europe without reservations. It could be added to FHWA framework.
3. How much time/ money/ effort required
Each workshop has an approximate duration of half a day. The desktop work required prior and between the workshops adds up to approximately 2 days, excluding the final reporting and depending on the amount of data available. The total time required to perform a QuickScan depends on how the workshops are organized (back to back or with a few days/ weeks in between).

ROADAPT C. Guidelines on how to perform a detailed vulnerability assessment
1. Description of the method (scope, key steps, how the analysis is conducted, illustrative example, incorporated into existing processes)
This guideline suggests a GIS based method to determine the spatial distribution of the vulnerability of infrastructure for all climate related threats. The output of the method is spatially distributed vulnerability index scores in the form of a GIS dataset. The guideline is based on, and compatible with RIMAROCC and can be used integrated with RIMAROCC or stand alone. The method assumes it is known which threats are relevant and need to be analyzed. These may follow from the QuickScan results (see Guidelines on the application of a QuickScan on climate change risks for roads’) or from another source e.g. RIMAROCC steps 1.1 and 1.2. For a given threat, contributing vulnerability factors are identified either by experts or in a group session and represented spatially via GIS (see example below). The Vulnerability assessment does not provide a list of vulnerability factors. The method lists Transnational GIS datasets which may be used in this step.

ROADAPT C. Guidelines on how to perform a detailed vulnerability assessment

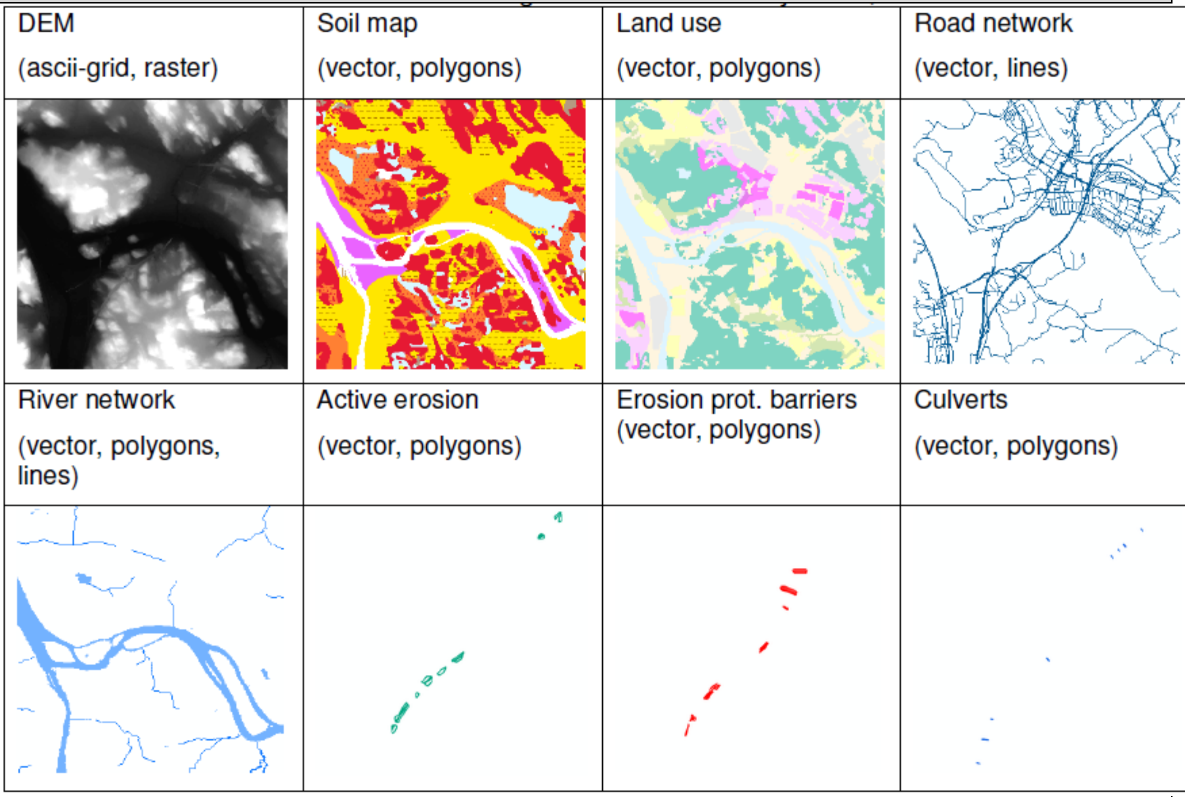


Figure. Example of vulnerability factors

GIS datasets are assumed to be present, however missing information may be added via experts making the method robust. The vulnerability factors are then scored (0, +1, +2 i.e. no increase, small increase and considerable increase) and rasterized. Subsequently, vulnerability scores are summed up and normalized and represented on a vulnerability index map.

Note that the vulnerability is independent of the probability of climate actually resulting in a threat.

2. *How is it applicable to the US (how applicable/ transferable, what might need to be changed/ adapted, use in other countries)*

The method is applicable to other countries outside of Europe, including the USA. However, it is not known if/ which GIS datasets are available.

3. *How much time/ money/ effort required*

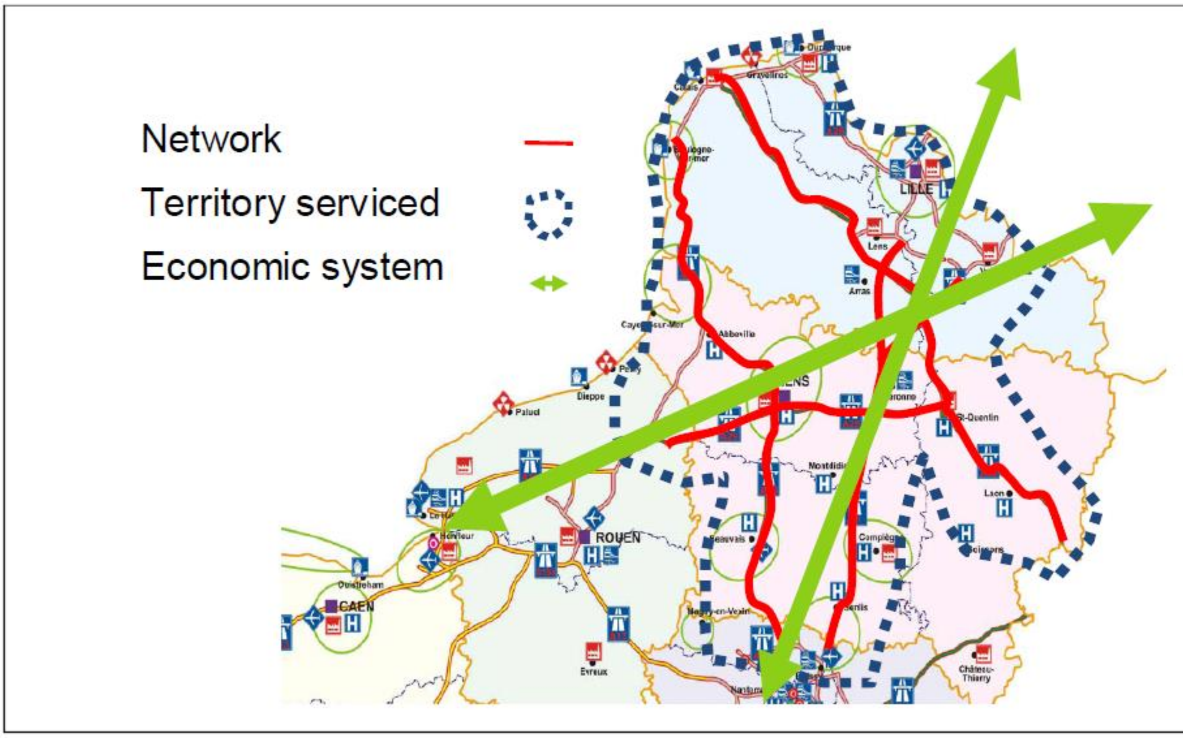
The amount of time/ effort required to execute such a Vulnerability analysis may vary, depending on the amount of threats that are to be taken into account, the scale of the project, amount of detail required and the amount of data present. For a European country, with a good coverage of GIS data sets this method is expected to take 1- several weeks of work by one or two people.

ROADAPT D. Guidelines on how to perform a socio economic impact assessment.

1. *Description of the method (scope, key steps, how the analysis is conducted, illustrative example, incorporated into existing processes)*

This guideline describes how to perform a socio-economic analysis. Although the costs for repair to infrastructure are mentioned, the method focuses on the disruption (impact) of the traffic system and it's consequences.

The impact may be assessed at three geographical levels:
- The network level
- Local territory level
- Economic system as a whole



The guideline provides a methodology of how to perform such an analysis at different levels and gives examples for the Oresund area/ case.

The required steps for a small network are:
- Determine the events (scenarios) that are to be evaluated
- Choose a traffic model (for a small network a rough estimation can be made of the time lost by all network users. However for larger events e.g. regional weather systems and/ or complex networks, a traffic model is required)
- Implement the traffic event(s) in the model and run with- and without the events
- Calculate the main indicators of total travel time loss and additional travelled distance
- Do a global Cost Benefit Analysis (use HEATCO* reference data)
- Compare the two scenarios

* HEATCO [http://heatco.ier.uni-stuttgart.de/] provides Estimated Travel Time Savings for the European

ROADAPT D. Guidelines on how to perform a socio economic impact assessment.
situation. It is not clear if/ how these may be used outside of Europe. For an analysis at local territory scale, the method was developed in France. It is composed of 4 steps: - Definition of relevant socio-economic themes - Geographical analysis of relevant themes (synthesis map of territory characteristics - Analysis of territory accessibility - Evaluation of the impact of the network incident The analysis on the economic system as a whole is based on a (theoretical) model that evaluates the accessibility to the various economic poles in a territory, based on the logarithm of product supply at each destination. For this analysis the situation before network disruption is compared to the situation during disruption. The difference between the two situations shows the impact per zone of the modeled incident
2. How is it applicable to the US (how applicable/ transferable, what might need to be changed/ adapted, use in other countries)
All analyses types rely on traffic/ transport modeling tools and therefore it is recommended that tools already in use in the country/ region are used.
3. How much time/ money/ effort required
It is unknown how much time/ money is required to execute such an analysis. The presence of (validated) traffic models will have a major impact: should these not be present than a lot of effort is required to set up such a model.

ROADAPT E. Guidelines on how to select an adaptation strategy
1. Description of the method (scope, key steps, how the analysis is conducted, illustrative example, incorporated into existing processes)
This guideline provides an overview of adaptation measures and helps in selecting an adaptation strategy. The guideline deals with the following climate change threats: flooding of the road surface (assuming no traffic is possible), erosion of road embankments and foundations, landslips and avalanches, loss of road structure integrity, loss of pavement integrity, loss of driving ability due to extreme weather events, reduced ability for maintenance. Selection of an adaptation strategy is done via a 10 step approach that makes use of an interactive (excel) database of adaptation techniques. It is applicable to various climate change threats. - Steps 0 – 3 provide background information on the road owner's needs, impacts and current and future resilience - Steps 4 – 8 deal with the selection of adaptation measures and strategies - Steps 9, 10 provide an outlook on research that will help climate change adaptation, also estimating the time to support compilation of research road maps. The approach uses the following policy matrix (steps 4 – 8, next page) to identify combinations

ROADAPT E. Guidelines on how to select an adaptation strategy

of measures – policies – that are the building blocks of an adaptation strategy.

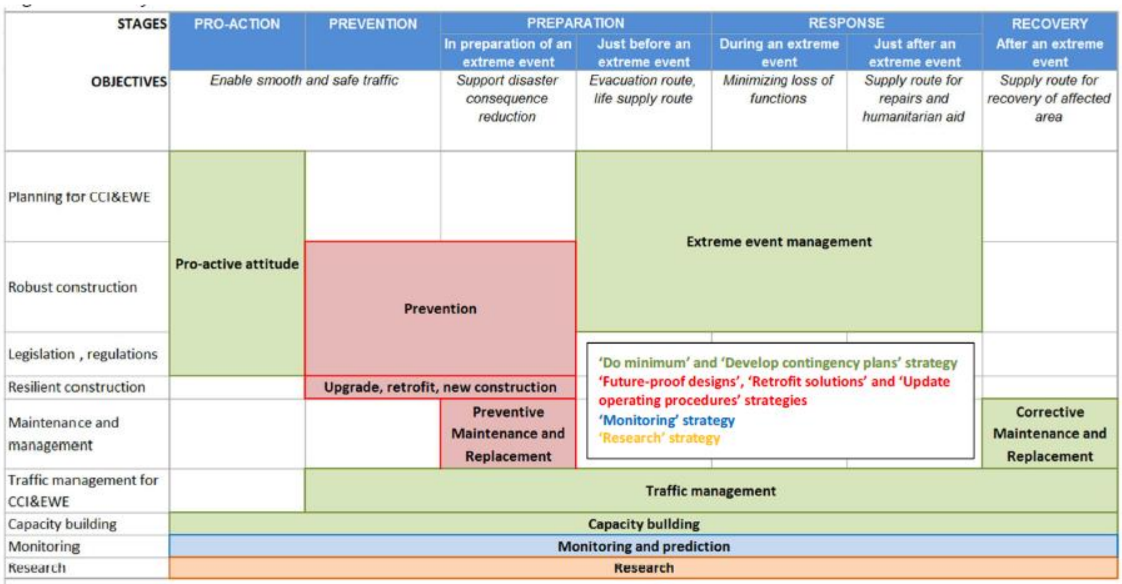


Figure. Policy matrix

A database of more than 500 adaptation measures supports the use of the Part E of the guideline. Selection of measures in a specific context would proceed along the following lines:

- Select relevant measures via the tick box menu (ROADAPT step 4).
- Present the selected measures in the policy matrix (ROADAPT step 5).
- Narrow down the selected measures according to the qualitative consequence criteria (Availability, Safety, Impact on network, Direct cost, Reputation, Sustainablility) Costs and benefits of measures are not given in absolute terms as these are specific for each case/ situation (ROADAPT step 6).
- Select a policy or a combination of policy from the policy matrix (ROADAPT step 7).

2. How is it applicable to the US (how applicable/ transferable, what might need to be changed/ adapted, use in other countries)

The method is applicable for other countries outside of Europe also. The database is robust for all threats common in cold & temperate climates (Europe). However for hot/ arid climates the database should be checked for completeness.

3. How much time/ money/ effort required

The time/ effort needed for this method depends on the amount of data present and how many threats need to be considered. A general estimation is that time needed lies in the order of days – one or two weeks.

Blue Spot research projects
1. Goal of overall method (scope)
The goal of the Blue Spot research projects was to determine the vulnerability to flooding of the Dutch Highway Network system.
2. Background information (context, authors)
The Blue Spot research projects were conducted for Rijkswaterstaat in 2012 and following years. The projects were conducted by Deltares.
3. Sub-methods/ research-projects
Original project: - Investigation of the blue spots in the Netherlands National Highway Network (1205568) - 2012 Following the results of the original project, a number of **subsequent surveys** were initiated. Part of these surveys were reported in the Dutch language. - Determination of flooding duration for highways (1206082-001) [translation of 'Bepaling duur van overstromingen voor autosnelwegen'] - 2013 - Risks of flooding for the functioning of the main highway network (1207849) [translation of 'Risico's van overstroming voor het functioneren van het hoofdwegennet' :] – 2013 - Climate related (geotechnical) construction challenges of geotechnical constructions (1207839) [translation of Klimaatbestendigheid geotechnische constructies] – 2014 - Vulnerability of road embankments during and after flooding – Increasing insight into possibilities of evacuations and assistance via the main highway network (1209380-005) [translation of 'Kwetsbaarheid van weglichamen tijdens en na overstromen – vergroten inzicht in mogelijkheden evacuatie en hulpverlening via het hoofdwegennet'] – 2014 - Indepth insight into the availability of the highway network during evacuations – robustness of special objects (1209380-005) [translation of Verdiept inzicht in de beschikbaarheid van hoofdwegennet tijdens evacuaties – robuustheid van speciale objecten]- 2014 - Opportunities for using the main highway network – determination of possible quick wins (1209380-005) [translation of 'Kansen voor benutting hoofdwegennet bij evacuatie en hulpverlening tijdens overstromen – vaststellen van mogelijke quick wins'] - 2014
4. Relationship between sub-methods & how to use methods
The different analyses may be subdivided into several categories: **Determination of vulnerability (and location)** • Investigation of the blue spots in the Netherlands National Highway Network (1205568) - 2012 **Impact** • Determination of flooding duration for highways (1206082-001) [translation of 'Bepaling duur van overstromingen voor autosnelwegen'] - 2013 • KPP Aanlegvraagstukken Klimaatbestendigheid geotechnische constructies (1207839) [translation: Climate related construction challenges of geotechnical constructions] – 2014 • Indepth insight into the availability of the highway network during evacuations –

Blue Spot research projects

robustness of special objects (1209380-005) [translation of Verdiept inzicht in de beschikbaarheid van hoofdwegennet tijdens evacuaties – robuustheid van speciale objecten]- 2014

Risk

- Risks of flooding for the functioning of the main highway network (1207849) [translation of 'Risico's van overstroming voor het functioneren van het hoofdwegennet] – 2013

Mitigating measures

- Vulnerability of road embankments during and after flooding – Increasing insight into possibilities of evacuations and assistance via the main highway network (1209380-005) [translation of 'Kwetsbaarheid van weglichamen tijdens en na overstromen – vergroten inzicht in mogelijkheden evacuatie en hulpverlening via het hoofdwegennet'] – 2014
- Opportunities for using the main highway network – determination of possible quick wins (1209380-005) [translation of 'Kansen voor benutting hoofdwegennet bij evacuatie en hulpverlening tijdens overstromen – vaststellen van mogelijke quick wins'] - 2014

Investigation of the blue spots in the Netherlands National Highway Network (1205568) - 2012[10]

1. *Description of the method (scope, key steps, how the analysis is conducted, illustrative example, incorporated into existing processes)*

The goal of the original Blue Spot investigation was to determine which spots in the Dutch National Highway network are vulnerable to flooding (called Blue spots) due to different hazards. These hazards comprise:

Type of flooding			Influence parameter	Physical effects
A	Failure of flood defences	Flooding from sea and large rivers	Sea and river levels at certain frequencies	Flooding of the road Uplift / Heave Instability
		Flooding from small rivers/canals		
B	Water system in the area around the road is not capable for drainage / discharge of water	Pluvial flooding (overland flow after precipitation)	Intense rainfall Long period of rain	Flooding of the road Uplift / Heave Instability
		Increase of groundwater levels	Intense rainfall / long periods of rain	Uplift / Heave Instability
		Increase of aquifer hydraulic heads	Intense rainfall / long periods of rain / sea level rise	Uplift / Heave
C	Road surface not capable for enough drainage / discharge of water	Run-off on the road	Intense rainfall	Flooding (waterfilm) of the road
		Flooding of the storm water drainage system		

Table. Types of flooding, as investigated for the Dutch national highway network

The resulting effects of the various types of flooding on the infrastructure or its use was not

[10] In the fall of 2015, the survey was updated for the purpose of evacuation strategies giving same results in general.

Investigation of the blue spots in the Netherlands National Highway Network (1205568) - 2012[10]

looked at in this project, nor were the effects for Rijkswaterstaat as owner of the roads. That was done in following projects (also presented in this Joint Report).
A general description of steps carried out for all types of flooding is given below. In the figure one can see a graphical presentation of this methodology.

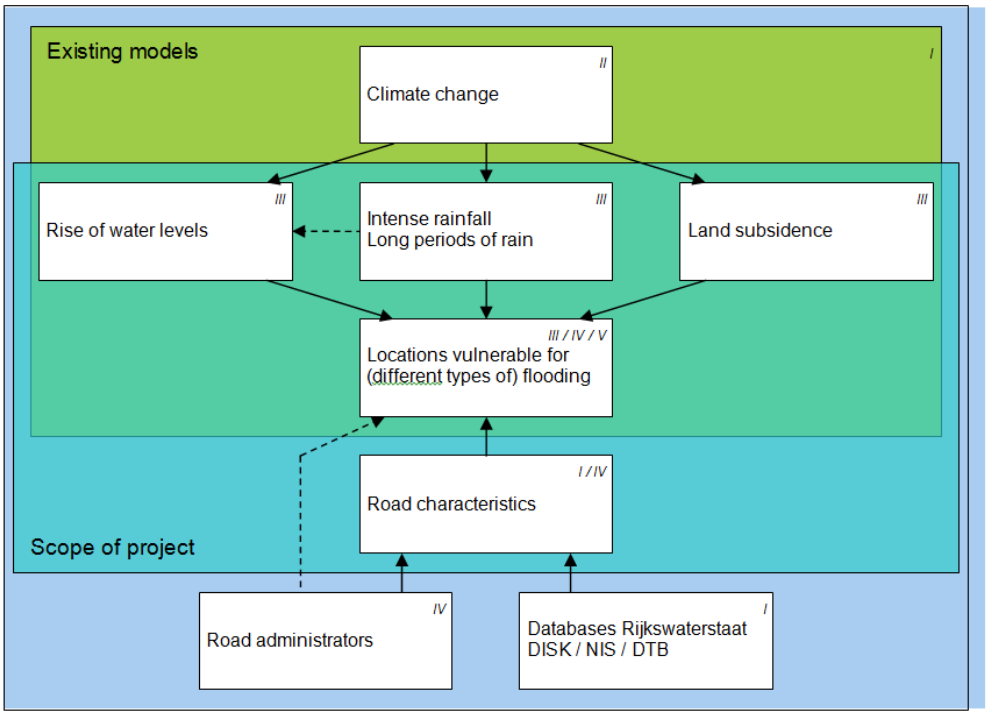


Figure. Methodology of blue spot investigation

I. Collecting data and existing models
A lot of data were collected to identify the blue spots. These data dealt with the road, climate change and the existing regional modeling results for the types of flooding A and B .

II. Determination of climate change scenarios for the different analyses
The relevant worst case scenario for the different types of climate change in 2050 were taken into account for this project.

III. Phase 1: determination of locations on road network, vulnerable to flooding
The knowledge with the road information and climate change was combined in order to gain a first insight in potential blue spots. An analysis was performed to identify locations where water heights were higher than road heights. Subsequently information about the construction of the roads was used to identify other vulnerable spots, also for locations where water heights do not exceed road heights.

IV. Phase 2: calibration of results with road administrators of road districts
The previous results were calibrated by comparing these results to the experience of road administrators by interviewing the road administrators of different districts.

V. Phase 3: analysis of the identified potential blue spots
Phase 3 zoomed in on the identified potential blue spots from the previous steps in order to filter out the 'not vulnerable spots' from the potential blue spots, resulting in a list of more likely, vulnerable blue spots. These more likely blue spots can later (outside the scope of this project) be analyzed to be sure whether it will be a blue spot or not.

Information about the Dutch National Highway Road infrastructure was provided by Rijkswaterstaat in GIS files. This includes location information as well as elevation data.

Investigation of the blue spots in the Netherlands National Highway Network (1205568) - 2012[10]
The presence of special objects (Expanded polystyrene (EPS), MSW slags, piled embankments and foamed concrete) vulnerable to excess water tables was acquired via telephone conferences with consultant specialists as these were not otherwise available. Information concerning the drainage capacity of the road surface during periods of intense rainfall was derived from the database IVON, the RWS information system for pavement maintenance planning. Climate data was derived from the KNMI climate scenarios. For each type of flooding the worst scenario was used for the analysis. How the investigation was carried out is described per type of flooding, below: ***Flooding due to failure of flood defense systems*** The method used to determine the Blue spots following from failure of flood defense systems (both primary- as well as regional-; flooding type A in table 1.1) makes use of existing water depths that follow from the projects FloRis, Flood Risks in the Netherlands, (in Dutch: Veiligheid Nederland in Kaart, VNK) and Flood protection for the 21st century (in Dutch: Waterveiligheid 21^{e} eeuw, WV21). These water depths were then combined with the level of the highway (lowest level for a 500m section), resulting in a water depth per highway section. Water depths are mapped according to the Risk map, which is expressed in terms of availability of the road for normal traffic or for military traffic. Note that the resulting risk map is a compilation (worst case) of several flooding events, which in reality are highly unlikely to occur at the same time. Differentiation by cause of flooding, by analyzing the individual flood scenarios, has provided more insight. Moreover, specific local provisions that prevent roads from flooding are not being taken into account. For instance flooding of tunnels and deep lying sections can be prevented by the use of dikes at the entries (kanteldijken in Dutch).

Investigation of the blue spots in the Netherlands National Highway Network (1205568) - 2012[10]

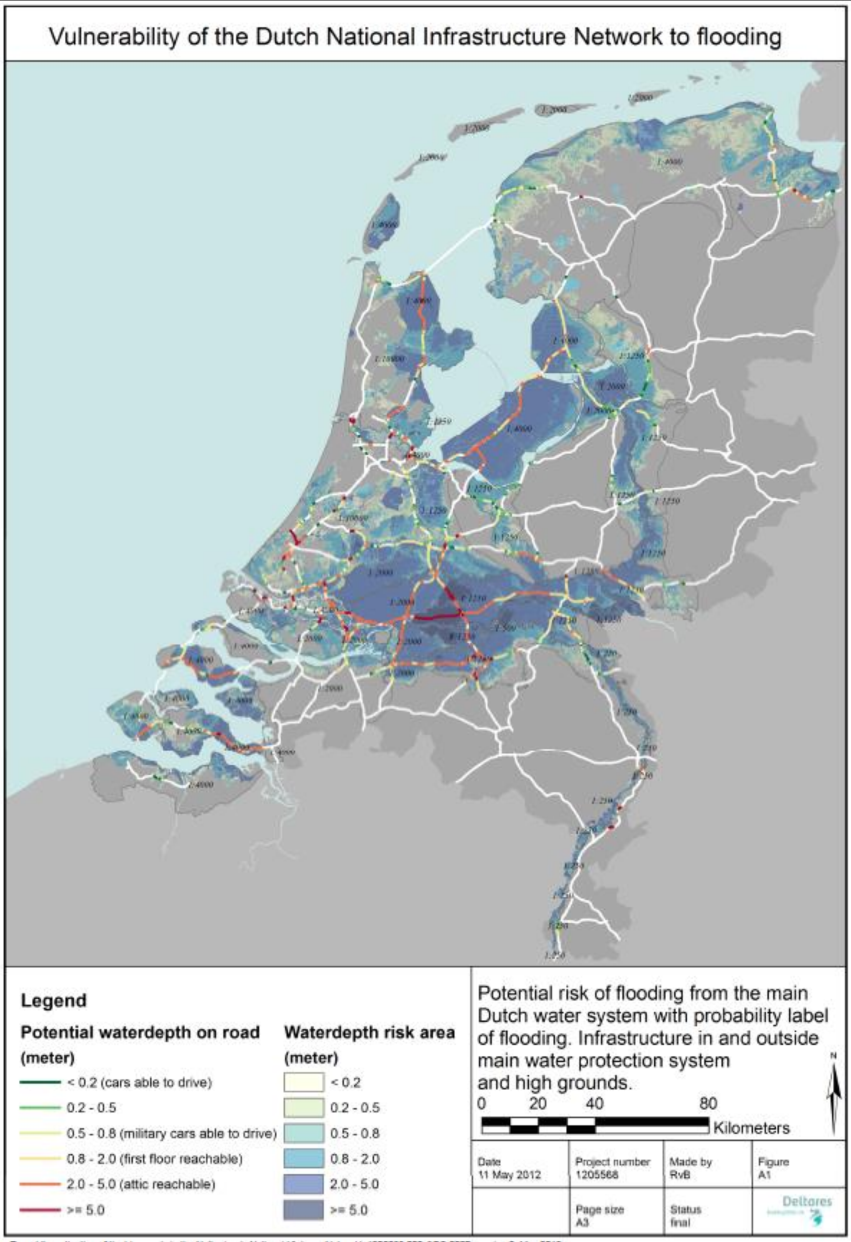


Figure. Typical map showing the water depth on highways due to flooding caused by failure of primary flood defences

Pluvial flooding

Flooding by intense rain (pluvial flooding; type B) flooding originates from the surroundings of the road and not the road itself. This analysis was carried out by updating previous research by Alterra, that was itself also based on former research by Future Water (both Dutch research Institutes). The main reason to perform an update of the Alterra analysis was that the exact elevation of roads was not considered with sufficient detail.

The Alterra analysis made use of

- Surface elevation and slope
- Seepage and infiltration of subsurface
- Groundwater levels: soil map and observation well data

Investigation of the blue spots in the Netherlands National Highway Network (1205568) - 2012[10]

Decision rules were then applied to derive a sensitivity index (range 0-100%), which was subsequently combined with land use and climatic data to quantify the risk of pluvial flooding. For this analysis, road elevation details were taken more into account. The result of this analysis is a comparison with the Alterra study.

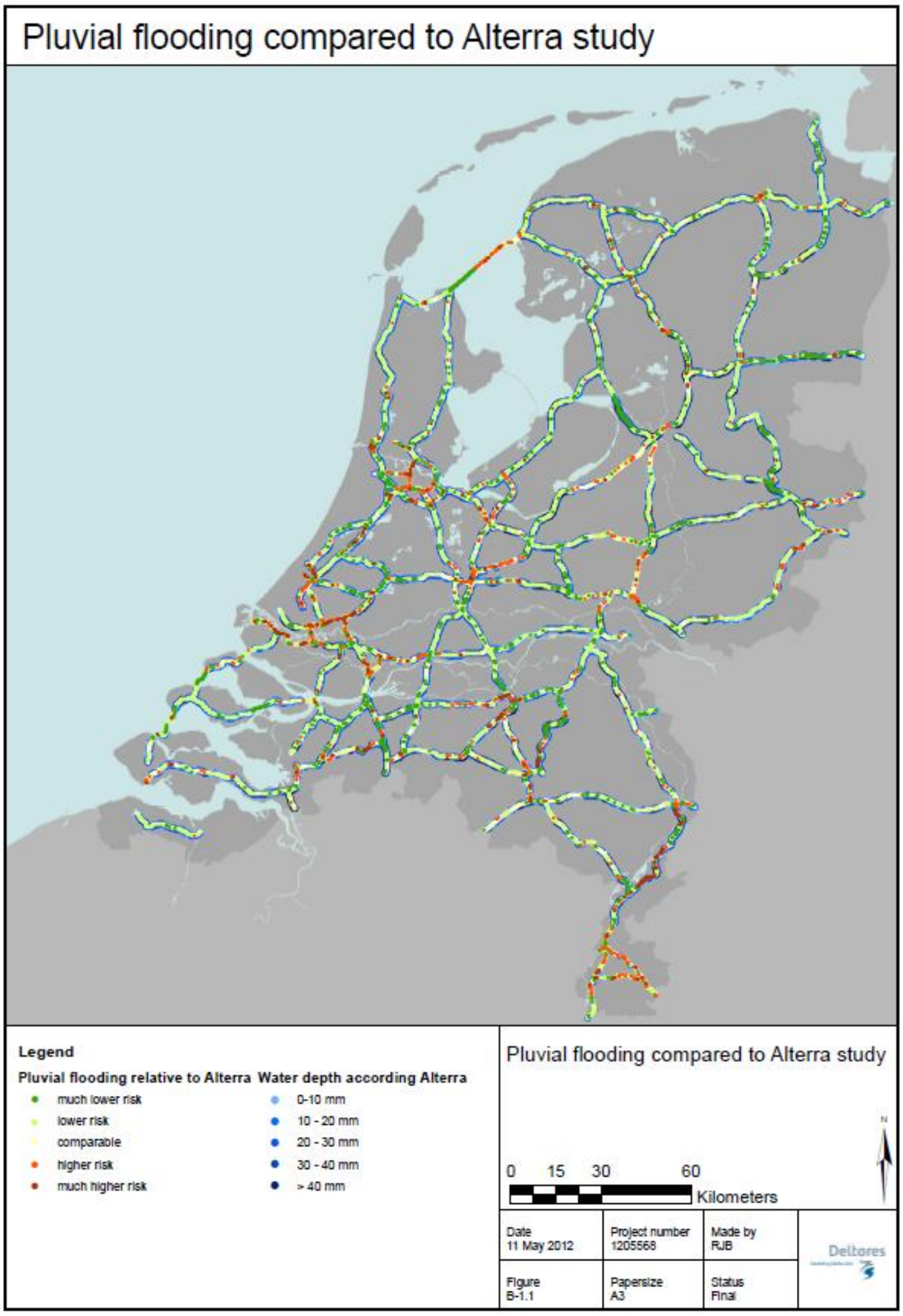


Figure. One of the pluvial flooding maps showing the comparison to the Alterra results

Excess groundwater tables

Possible effects of excess groundwater levels are uplift and heave of roads in excavation, loss of bearing capacity, uplift of roads with an EPS foundation and leaching of pollution.

Investigation of the blue spots in the Netherlands National Highway Network (1205568) - 2012[10]

Therefore, a nationwide analysis was carried out by intersecting the “mean highest phreatic groundwater depth” map by NHI with the highway road network geometry, (using the lowest point on the road). NHI is the Dutch national hydrological instrument (www.nhi.nu). The NHI map is available for the Netherlands with the exception of South Limburg, and includes urban areas.
For the situation for the Groundwater level in 2050, the NHI provides groundwater level calculations that also take land subsidence due to both natural- as well as man-made causes into account. As the most critical climate scenario was not provided for, the groundwater levels in the worst calculated scenario were doubled and compared to highway levels, as above.

Further to the above analyses concerning Groundwater levels, critical locations (based on building method/ -materials) were further reviewed. The inventory of special objects, tunnels and deep lying sections shows a variety of situations with different vulnerability. The analysis of the vulnerability of these special objects proceeded as follows:

1. Eliminate locations that are not vulnerable because of geometrical characteristics, such as distance between the base level of the object and groundwater table. This step requires detailed design information that is currently available only for a number of locations.
2. Eliminate locations that are not vulnerable after analysis of the general design rules that were used at the time of construction, and the expected groundwater rise due to climate change.
3. Prioritize locations according to importance. The importance decreases from applications in the main lanes, applications in entries and exit ramps, applications in secondary roads crossing highways to applications in auxiliary structures such as noise barriers.
4. Prioritize locations based on expected groundwater table rise due to climate change.
5. Eliminate locations that are not vulnerable after detailed analysis of the original design. This step can be very time consuming, depending on the number of locations and accessibility of the data and was not executed within current project

Excess hydraulic heads

Possible effects of excess hydraulic heads, in the aquifer directly below the (mainly Holocene) cover deposits, are uplift and heave of roads in excavation and in deep-lying polders.
The methodology applied was essentially the same as the procedure followed for excess phreatic groundwater levels, except that the results for NHI model layer 2 are used instead of layer 1, where Model layer 2 represents the ‘deep’ aquifer directly below the cover deposits in the major part of the Netherlands.

Soil subsidence

The type of soil subsidence addressed here is caused by regional surface water level adjustments in peat and clay areas. Local subsidence caused by e.g. a leaking sewer is not considered. The effects of oxidation of organic components, irreversible shrinkage of organic soil, and compaction of the soft layers was considered. Worst case calculations have shown that a typical highway embankment will subside less than 1 mm in 10 years following a 0.10 m drop in groundwater table, compared to 0.05 to 0.10 m subsidence of the surrounding area. In other words, the relative elevation of the highway will increase under soil subsidence
Subsidence caused by mining from deep aquifers or rock layers is different in that it may cause an entire area to subside with uniform rate, highways as well as their surroundings. In these areas, pluvial and groundwater flooding risks remain unchanged.
National subsidence maps were used that take into account the effects of water management (and resulting subsidence) as well as the effect climate change under the W+ scenario, and the influence of gas mining in the province of Groningen.
The conclusion of this analysis was that land subsidence is not expected to lead to an increase of the risks of pluvial flooding, rise of groundwater tables and rise of aquifer hydraulic heads on the Dutch highways.

Investigation of the blue spots in the Netherlands National Highway Network (1205568) - 2012[10]

Development of a waterfilm on the road surface during heavy rainfall

According to the Dutch New Guidelines for Design of Motorways (NOA) it should be prevented that a water film layer with thickness larger than 2.5 mm develops during periods of heavy rain.

With increasing rainfall intensity and amounts expected due to climate change, vulnerable spots were identified in the main highway network.

At present the following criteria for design of motorways are valid in the Netherlands:

- Intensity of rainfall 36 mm/hr (0.6 mm/min).
- Duration of rainfall 5 minutes.
- Thickness of water layer maximally 2 to 3 mm.
- Length of ponding about 10 m at maximum in one of the road tracks.

For this analysis increased rainfall intensity was taken into account as well as the effect of Porous Asphalt (PA).

The analysis makes use of the empirical formula of Manning The parameters are:

- WD = Water Depth
- S = Pavement cross slope and grade
- L = Drainage path length or Width of pavement [m]

Wider roads require a higher cross slope to achieve the same degree of drainage.

- I = Rainfall intensity [m/s]
- k_M = Manning's coefficient for surface type, in notated as 1/n or 1.486/n but depending on the unit system.

It appears that the number of blue spots more than doubles due to climate change, being present at 3,3% of the total road length. Blue spots are mostly present at locations with a change of transverse slope, many lanes and closed pavements.

Road drainage system incapable for draining during periods of intense rainfall

As a rule, runoff from the pavement will freely flow into the verge and infiltrate in the embankment. In most cases, horizontal drains installed in the embankment will transport the water to the ditches alongside the highway. The ditches are connected to the surface water system of the surrounding area.

In a number of situations surface flow and infiltration into the verges is impossible or restricted and drainage is provided by a system of gutters and sewers e.g. tunnels, roads in excavation without possibilities for gravity drainage, bridges, etc.

All locations with gutters could be considered potential blue spots. This approach however is rather rough and produces a relatively large amount of potential blue spots. Additional analysis therefore is required to assess the actual vulnerability. Therefore this was refined by

- reviewing if existing pumping systems have any over- or spare capacity that is sufficient to cope with more intense rainfall
- For locations where the transverse slope is directed to the center verge, an analysis was made of the infiltration and storage capacity of the center verge during the actual events. This capacity is spare capacity that can be used to temporarily store the additional rainfall due to climate change, assuming the capacity of the drainage system is sufficient for the present day rainfall.
- For locations with danger of erosion of the embankment top layer, a more detailed analysis was made of the actual discharges that could occur for different pavement widths. These were compared to the discharges allowed for overtopping of waves over flood defenses. Thus, the proper design rules for erosion resistance of the top layer were selected, and compared to typical conditions in road embankments.
- For all other locations, the design of the sewer system was reviewed. The first step is the analysis of general design rules at the time of construction, giving general conclusions for systems of a certain age.

For all mechanisms, inspection and maintenance of drainage systems, verges and embankment slopes will become more critical. Poor maintenance may reduce the capacity of drainage systems to such extent that even present day extreme events cannot be adequately processed. Thus, poor maintenance may be the cause of water related problems at locations

Investigation of the blue spots in the Netherlands National Highway Network (1205568) - 2012[10]
not identified as blue spots.
2. How is it applicable to the US (how applicable/ transferable, what might need to be changed/ adapted, use in other countries)
Using the Blue Spot investigation method always requires customization. The original SWAMP (ERANET ROAD – project) method seems to fit well for the Danish situation and consequently is expected to fit also for the US situation. For Holland there is largely a different geographical situation (below sea level) than in Denmark and the US so a custom method is used. The method used for Flooding type A i.e. from sea and main rivers, as well as from secondary rivers and canals, can be used in the USA also. However, it relies heavily on flooding information that is already present. It is not known to what extent this is also present outside of Europe/ the Netherlands. The method used for pluvial flooding cannot be used in the USA in the same manner as for this study, as this analysis was based on former research. Should insight be required in pluvial flooding threats, than an updated version of the Alterra/ Future Waters research, combined with this analysis is advised. If groundwater data is present for both the present and the future than the given method for vulnerability to high groundwater levels may be conducted in a similar fashion in the USA also. This also applies to excess hydraulic heads. The method used to calculate the depth of the waterfilm on the road during heavy rainfall is applicable to other countries, including the USA. As both run- off from the road and overloading of storm water systems are mainly mathematical analyses, the methods used are also applicable in the USA.
3. How much time/ money/ effort required
The analyses were conducted in approximately 3 months time by several people.

Determination of flooding duration for highways (1206082-001) [translation of Dutch : *Bepaling duur van overstromingen voor autosnelwegen*] - 2013
1. Description of the method (scope, key steps, how the analysis is conducted, illustrative example, incorporated into existing processes)
Not being able to use a main highway due to flooding may cost up to 1billion Euros per year. This report therefore looks at what influences the inundation duration and provides an indication of the duration itself. Key factors include: - Elevation of the area: the report makes a distinction between low laying areas that will always be inundated during a flooding event (type A), areas that are only inundated during extremely high water levels (type B) and areas that are not prone to flooding (type C). The water depth/ -volume has a direct correlation with the duration of inundation - Available drainage method and capacity: for areas of type A, pumping seems the only solution to lower water levels. Pumping capacity is generally speaking low and therefore pumping off large volumes of water will take a considerable amount of time. For areas type B natural run off may lower water levels faster. However levees may hinder natural run off

Determination of flooding duration for highways
(1206082-001) [translation of Dutch : *Bepaling duur van overstromingen voor autosnelwegen*] - 2013

(these may be temporarily removed to facilitate faster drainage). Areas type C will be free of water relatively quickly due to natural run off

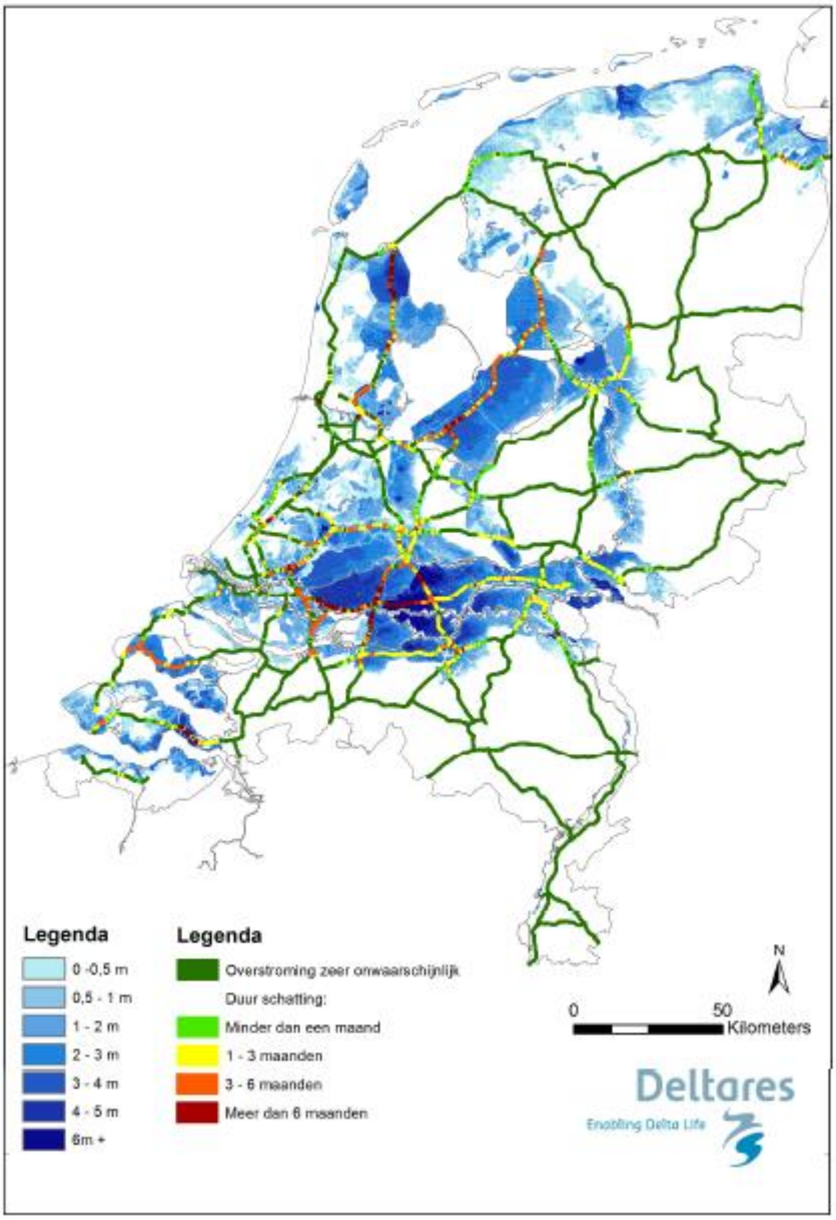
- The volume of water that enters an area
- Duration of the high water event at the source of the flood: this may high water levels due to extreme rain run off or elevated water levels due to wind (slanted water levels)
- Time needed to close the breach
- Elevation of the point of interest within the inundated area

Furthermore, larger volumes of water may be expected from the sea and main waterways, whereas smaller rivers and canals will generally lead to less flooding water. Moreover, for flooding from smaller rivers and canals, there are more opportunities to influence the flood and pumping is more effective. As such, the duration of a flood originating from smaller rivers and canals is thought to be in the order of magnitude of hours to days.

Lastly, roads, embankments and special objects e.g. tunnels may need repairing after being inundated. This will also influence the amount of down time for the highway. This may actually take longer than for normal repair work. Also a waiting period may be necessary to allow embankments to fully drain before repair work may commence.

The analysis was based on maximum water depth maps that are (publically) available [WV21, De Bruijn et al, 2011]. The elevation of the roads was taken into account in this analysis. The division of the Netherlands in flooding areas types A, B and C (see above) allows for an estimation of the speed at which the water level may be lowered (based on the method and capacity of drainage method). By combining the water depth information with the drainage speeds, a duration of inundation was made.

Determination of flooding duration for highways
(1206082-001) [translation of Dutch : *Bepaling duur van overstromingen voor autosnelwegen*] - 2013



Estimation of maximum inundation durations

Finally, in the report the results of the inundation duration map were verified with a case study of one dike ring.

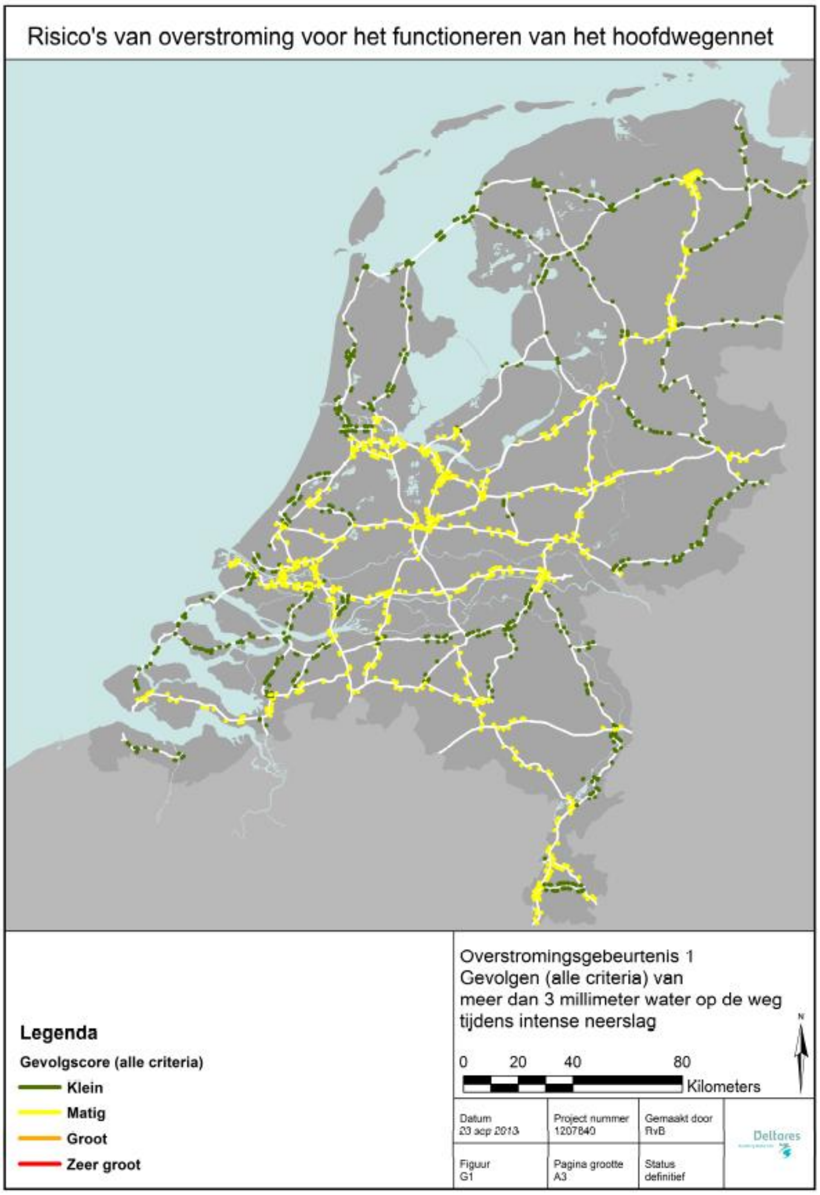
2. *How is it applicable to the US (how applicable/ transferable, what might need to be changed/ adapted, use in other countries)*

The key factors that influence inundation duration are expected to be similar in the USA. Therefore, the method may be applicable in the US also. However, information used such as the water depth maps may not be readily available. In such a case the analysis of the water depth will precede the inundation duration analysis.

Determination of flooding duration for highways (1206082-001) [translation of Dutch : *Bepaling duur van overstromingen voor autosnelwegen*] - 2013
3. How much time/ money/ effort required
The amount of time required to execute such an analysis is expected to lay in the order of days – a couple of weeks by one or two people depending on the amount of information present and the amount of detail required.

Risks of flooding for the functioning of the main highway network (1207849) [translation of ‘Risico’s van overstroming voor het functioneren van het hoofdwegennet’ :] – 2013
1. Description of the method (scope, key steps, how the analysis is conducted, illustrative example, incorporated into existing processes)
With the original Blue Spot study, the vulnerability (and probability) for flooding and other (ground)water related events was determined. This analysis zooms in on the risk of these events: how will flooding influence the functioning of the main highway network? The impact on the surrounding areas is not taken into account. The analysis makes use of the currently used highway importance categories (A, B, C, D, TEN-T). Based on this division, a questionnaire was circulated within experts of Rijkswaterstaat who scored 5 criteria for each importance category. Scores ran from 1 (very low) to 4 (very high); definitions were provided per score and per criterion. The criteria are based on a slightly adapted version of the RAMS/RAMSSHEEP criteria: 1. Availability 2. Safety (for road users; not for surrounding area) 3. Surroundings (effect on surrounding network) 4. Euro (direct technical costs) 5. Reputation damage An average score per threat, per criterion and per road importance category was calculated of all experts was made. The question to be answered was: assuming threat XX happens, what would be the effect for a highway with importance YY with regards to criterion ZZ. Subsequently, the probabilities that follow from the original Blue Spot analysis were categorized from 1 – 4. Multiplication of impact (expert scores) with probabilities gave risk scores from 1 – 16. These were then visualized, per threat, on a map.

Risks of flooding for the functioning of the main highway network
(1207849) [translation of ‘Risico’s van overstroming voor het functioneren van het hoofdwegennet’ :] – 2013



Example of map made for risk of flooding (>3mm water on highway due to intense rainfall)

2. *How is it applicable to the US (how applicable/ transferable, what might need to be changed/ adapted, use in other countries)*

The method used can be transferred to other countries outside of the Netherlands.

3. *How much time/ money/ effort required*

The amount of effort required to execute such an analysis depends on the amount of threats to be regarded and not in the least, if vulnerability maps are already present of the relevant threats. Assuming this is case, then putting out the questionnaire and analysis of the results could be done within a week. Filling in the questionnaire is in itself not necessarily a lot of work (order of magnitude: hours – half a day), however the experts need to find this time, causing

Risks of flooding for the functioning of the main highway network
(1207849) [translation of 'Risico's van overstroming voor het functioneren van het hoofdwegennet' :] – 2013

a-synchronicity and thus delays.
Also, different interpretations of the definition of threats and criteria may lead to delays. From a time perspective and to guarantee maximum unambiguous responses, a collective scoring session is advised. The RoadApt Quick scan method evolved from this project, therefore for future analyses use of the RoadApt method is advised.

Climate related (geotechnical) construction challenges of geotechnical constructions
(1207839) [translation of Klimaatbestendigheid geotechnische constructies] – 2014

1. *Description of the method (scope, key steps, how the analysis is conducted, illustrative example, incorporated into existing processes)*

This research expands on the results of the original Blue Spot research (2012), specifically flooding types A (flooding from sea and main rivers, flooding from smaller rivers and canals) and type B (pluvial flooding and high groundwater levels). The aim of the research is to:

- Make a (geotechnical) model that describes the mechanisms that influence stability and strength of an embankment (with and without traffic loading) for flooding situations
- Perform analysis with the model to determine safety factors for stability and strength
- Determine the effects of the most relevant mitigating measures, including the waiting time for an embankment to sufficiently drain any water overpressures after a flooding event.

Several failure mechanisms were looked into:

- Loss of bearing capacity
- Failure of asphalt layer
- Failure of slope of embankment (macro stability, Bishop)
- Failure of slope of embankment due to liquefaction
- Instability of slope of embankment due to water flow out of the embankment (micro stability) – not regarded in analysis due to practical condition of slow lowering of water levels
- Erosion of slope of embankment (not taken into account due to lack of key parameters)

Following the results of the Blue Spots study (2012), several critical locations and profiles were chosen as case studies and analyzed.

Generally speaking loss of bearing capacity and failure of the asphalt layer may only play a role in specific cases. Also, failures due to liquefaction are deemed unlikely. Macro stability issues may be expected.

2. *How is it applicable to the US (how applicable/ transferable, what might need to be changed/ adapted, use in other countries)*

The mechanisms regarded are relevant in other countries also. Possibly other theoretical models may be used but this is not necessary. As such the method may be used in the USA. However both assumptions why not to take a certain failure mechanism and actual results of the analysis may differ from the Dutch situation due to different geometry, embankment characteristics and subsurface conditions.

Climate related (geotechnical) construction challenges of geotechnical constructions (1207839) [translation of Klimaatbestendigheid geotechnische constructies] – 2014
3. How much time/ money/ effort required
Approximately 3 weeks by two – three people are required to execute this analysis.

Vulnerability of road embankments during and after flooding – Increasing insight into possibilities of evacuations and assistance via the main highway network (1209380-005) [translation of ‘Kwetsbaarheid van weglichamen tijdens en na overstromen – vergroten inzicht in mogelijkheden evacuatie en hulpverlening via het hoofdwegennet’] – 2014
1. Description of the method (scope, key steps, how the analysis is conducted, illustrative example, incorporated into existing processes)
This research provided input to determine the availability of highways during and after a flooding event. By means of case studies, geometrical assessment criteria were determined and subsequently used on highway cross sections to come to an appraisal of the stability. Assessments were executed for a number of situations: • No damage to roads and driving lanes • Damage limited to a width of less than 6m (driving lane + shoulder) This was done for two failure mechanisms: • Failure of slope of embankment (macro stability, Bishop) • Failure of slope of embankment due to liquefaction Assumptions were made for both embankment (sand) and subsurface (clay and peat). This lead to a general relationship regarding critical slope steepness and embankment height. This relationship was then used to identify potentially vulnerable spots in the highway network.
2. How is it applicable to the US (how applicable/ transferable, what might need to be changed/ adapted, use in other countries)
The applied method may be used in the USA. However, underlying assumption of a clay/ peat subsurface may prove too inaccurate. Therefore input parameters should be assumed that are relevant to the region/ area of interest.
3. How much time/ money/ effort required
This analysis takes approximately two – three weeks by two – three people.

Indepth insight into the availability of the highway network during evacuations – robustness of special objects (1209380-005) [translation of Verdiept inzicht in de beschikbaarheid van hoofdwegennet tijdens evacuaties – robuustheid van speciale objecten]- 2014
1. *Description of the method (scope, key steps, how the analysis is conducted, illustrative example, incorporated into existing processes)*
This report focusses on the vulnerability of the special objects e.g. tunnels, bridges, culverts, section of highway constructed with special building materials, etc, during and after a flooding event. Steps taken: • Inventory which special objects are present (+location) • For each special object a generic failure analysis was executed based on a flooding event, chain effects were taken into account when necessary • The generic results should be validated (when possible) by means of a local analysis, however due to time constraints, the robustness (per special object) was determined based on the number and type of required case studies necessary for validation. • Also, a first inventory of special object owners was performed, contact was sought after and as-built information requested as well as current/ ongoing operational agreements • Possible mitigation measures were determined that may increase the availability during and after a flooding event
2. *How is it applicable to the US (how applicable/ transferable, what might need to be changed/ adapted, use in other countries)*
Other special objects and failure mechanisms may be relevant outside of the Netherlands. Therefore, the steps taken may be copied but should be checked and completed for the American situation.
3. *How much time/ money/ effort required*
This analysis takes about one to two months by two or three people.

Opportunities for using the main highway network – determination of possible quick wins (1209380-005) [translation of 'Kansen voor benutting hoofdwegennet bij evacuatie en hulpverlening tijdens overstromen – vaststellen van mogelijke quick wins'] – 2014
1. *Description of the method (scope, key steps, how the analysis is conducted, illustrative example, incorporated into existing processes)*
The goal of this research was to determine which highway sections might easily be made more available before and during a flooding event. The previous Bluespot research shows that generally speaking mostly large sections of highway are inundated. As a result, mitigating measures cannot 'easily' be taken. Relative 'quicks wins' are: • short sections (approximately <2km length) i.e. bottlenecks that are flooded in a larger network A number of these were analyzed using local information. Local analyses of specific cases show that the previously performed (regional) analyses cannot always be used at a local scale e.g. actual height of the road sometimes leads to incorrect water depths. Therefore the selected short sections were re-analyzed based on local information. This lead to the understanding that: • Some roads may only partially be submerged or that the water level was limited, thus

Opportunities for using the main highway network – determination of possible quick wins (1209380-005) [translation of 'Kansen voor benutting hoofdwegennet bij evacuatie en hulpverlening tijdens overstromen – vaststellen van mogelijke quick wins'] – 2014
allowing for special vehicles (military) to still use the highway sections. • For some roads, only half of the road may be submerged, thus allowing transport over the non-flooded half. • Arrival times of some flood events were sufficiently long to allow for transport to continue beyond the initiation moment of the flooding event (previously some dike-rings assumed that no transport was possible from the moment flooding started). The report suggests to increase the elevation of critical portions of the highways during extensive maintenance activities. Additional costs must be regarded with respect to the costs of alternatives that increase the availability of the section.
2. How is it applicable to the US (how applicable/ transferable, what might need to be changed/ adapted, use in other countries)
The method used in the analyses may be used outside the Netherlands.
3. How much time/ money/ effort required
This analysis takes about two weeks for two – three people. Note that collection of the information might take quite some (calendar) time.

4 **Developing adaptation measures**

4.1 Comparing developing adaptation measures USA-NL

In this chapter, the development of the adaptation measures to climate change in the Netherlands and in the USA is discussed. This first paragraph will summarize the main similarities and differences found between the USA and the Netherlands. These are illustrated by the different reports and studies described in the following paragraphs.

When developing and implementing adaptation measures both FHWA and RWS face similar problem:

- Each project is unique and there can't be one blueprint for the adaptation to climate change. Therefore, both FHWA and RWS have developed frameworks and guidance documents which focus on the process of developing and integrating climate change and which evaluate methodologies and best practices that can be used. The frameworks and guidance documents are meant to support agencies in developing tailor-made solutions for each project.
- The legal basis for the adaptation to climate change is not solid, the obligation to take into account climate change is indirect in many cases. This means it is not sure that the correct starting points are taken into account in projects, and attention of those responsible for climate resilience is always needed.
  In both USA and the Netherlands/Europe climate change is or will be a mandatory part of the Environmental Impact Assessment. Guidelines and guidance document are available or are being prepared to assist in considering the effects of climate change. There is an agreement in the Netherlands (based on the Delta Progamme, the Climate Agenda and the National Adaptation Strategy which is being worked on at present, to be finished in 2016) that the vital infrastructure will have to be robust to climate change by 2050. In general it is essential to start taking measures now to be resilient as a whole in e.g. 2050.
- In the Netherlands, the impact of climate change on water management is part of the Water Assessment (Watertoets) which is an obligatory part of the spatial planning process. However the right climate scenarios are not always used yet.
- Both agencies in the USA and Rijkswaterstaat are dealing with limited financial resources for the adaptation to climate change. There is a need for cutting costs and at the same time mobility is expected to improve, requiring even more funding. This is a major challenge, calling for innovation. It is essential to take into account climate change from the beginning of the planning process of projects (regarding both new infrastructure and maintenance).
- Cost benefit analysis is seen as an important instrument to underpin the need for implementing adaptations options even though there is often no legal obligation for it. The long-term view and the uncertainty in the effect of climate change provide a problem when estimating the benefits of adaptation options. There is a considerable amount of guidance on this subject in the USA which can be useful for the Netherlands.
- In both USA and the Netherlands, officials from many agencies and different stakeholders are involved in decision-making. Sharing information on climate change and on the costs and benefits of adaptation options is a great challenge. In many of the FHWA pilot studies discussed is the previous chapter on vulnerability assessment, providing information for decision-making and the involvement of officials and stakeholders, were an important part of the work. Also in these cases solutions proved to be site or project specific.
- Very few design standards are adapted to the impact of climate change. In the Netherlands and Denmark design standards on the discharge of run-off have been corrected to more intense precipitation as a result of climate change.

- Given the complexity and uncertainties associated with climate change, much can be gained by a single source where information can be found on climate data, reports, frameworks and best practices. FHWA has already invested in websites, workshops and sessions (e.c. webinar series). Rijkswaterstaat is still at the starting point of unlocking available information, sponsoring of pilot projects and organizing workshops.

4.2 Identifying and prioritizing adaptation measures

4.2.1 USA

<u>Revised DRAFT NEPA Guidance on Consideration of the Effects of Climate Change and Greenhouse Gas Emissions (December 2014)</u>
The Council on Environmental Quality (CEQ) issued this guidance to provide Federal agencies direction on when and how to consider the effects of greenhouse gas (GHG) emissions and climate change in their evaluation of all proposed Federal actions in accordance with the National Environmental Policy Act (NEPA) and the CEQ Regulations Implementing the Procedural Provisions of NEPA (CEQ Regulations).
This guidance explains that agencies should consider both the potential effects of a proposed action on climate change, as indicated by its estimated greenhouse gas emissions, and the implications of climate change for the environmental effects of a proposed action. The guidance also emphasizes that agency analyses should be commensurate with projected greenhouse gas emissions and climate impacts, and should employ appropriate quantitative or qualitative analytical methods to ensure useful information is available to inform the public and the decision-making process in distinguishing between alternatives and mitigations.

Climate change adaptation and resilience — defined as adjustments to natural or human systems in response to actual or expected climate changes — are important considerations for agencies contemplating and planning actions with effects that will occur both at the time of implementation and into the future. The current and expected future state of the environment without the proposed action represents the reasonably foreseeable affected environment that should be described based on available climate change information, including observations, interpretive assessments, predictive modeling, scenarios, and other empirical evidence. The temporal bounds for the future state of the environment are determined by the expected lifespan of the proposed project.
Agencies should remain aware of the evolving body of scientific information and its clarification of climate impacts at a more localized level.
The analysis of impacts on the affected environment should focus on those aspects of the human environment that are impacted by both the proposed action and climate change. Climate change can affect the environment of a proposed action in a variety of ways. Climate change can increase the vulnerability of a resource, ecosystem, human community, or structure, which would then be more susceptible to climate change and other effects and result in a proposed action’s effects being more environmentally damaging. Climate change effects should be considered in the analysis of projects that are located in areas that are considered vulnerable to specific effects of climate change, such as increasing sea level or other ecological change, within the project’s anticipated useful life.

<u>Assessment of the Body of Knowledge on Incorporating Climate Change Adaptation Measures into Transportation Projects (December 2013)</u>
This report issued by the FHWA highlights adaptation actions that transportation agencies around the world are already pursuing and articulates a growing set of best practices for implementing adaptation. The report also discusses strategies, examples, and best practices for evaluating the costs and benefits of adaptation. The purpose of the report is to provide transportation practitioners with a guide to the current “state of practice” in this field. Since many transit agencies have actively pursued adaptation strategies, this report also covers relevant adaptation initiatives from transit agencies.
The report therefore is useful for all transport agencies in Europe as well although European references (i.e. RoadApt and Blue Spot investigation) are part of the review.

The report focuses exclusively on adaptation. Adaptation is considered to be any activity that reduces the vulnerability of transportation systems to future changes in climate.

Common examples of adaptation include shoreline protection to reduce exposure to coastal hazards, design updates to reduce sensitivity, and building additional redundancy into the system to increase adaptive capacity.

The report is organized into the following sections.

- The first section provides an overview of existing research and literature on adaptation. Each of the nine studies highlighted in this section has contributed significantly to the field transportation adaptation field.
- Next, the report identifies common adaptation actions occurring in the disciplines of transportation asset management, long range transportation planning, design and construction, operations and maintenance, and emergency management. Examples are discussed of how adaptation is being mainstreamed into existing decision-making processes, including asset management, long-range transportation planning, design and construction, operations and maintenance, and emergency management. A summary of adaptation activities identified and information about the adaptation activities is included in Appendix A.
- The following section highlights common best practices emerging across these adaptations, such as recognizing adaptation as a co-benefit and tracking data on extreme weather.
- Next, the report transitions to discussing methods of evaluating costs and benefits of adaptation options. Estimating the costs and benefits of adaptive measures can be tricky. Costs of adaptation can be very project- or site-specific. Benefits of adaptation are sometimes associated with a large amount of uncertainty. Although economists have well-developed methodologies for estimating costs and benefits of a variety of actions, cost-benefit analyses are still not always used in developing climate adaptation plans due in part to the challenges of quantifying costs and benefits. This section focuses on these issues from several perspectives, and is organized as follows:
    1. an overview of how costs and benefits are defined;
    2. a discussion of traditional methods for estimating costs and benefits;
    3. example "real-life" efforts to estimate costs and benefits of climate change adaptation in the transportation sector; and
    4. best practices moving forward.
- The final sections of the report describe common barriers to adaptation, methods of overcoming those barriers, and ongoing research in the field. The following key challenges are discussed.
    - *Resource constraints*. Agencies are dealing with limited financial and human resources, including assets that are well beyond their anticipated useful life.
    - *Regulatory or programmatic roadblocks to modifying guidelines and practices to mitigate risk*. Some policies may not support or may even discourage rebuilding to projected conditions rather than historically observed conditions.
    - *Information availability and applicability to local decision making*. The amount of projected climate data available can be overwhelming, making it difficult for transportation officials to determine which climate scenarios, models, and data to use for assessing vulnerability and adaptation options.
    - *Stakeholder engagement*. Lack of coordination and information sharing among stakeholders can hinder the implementation of adaptation.
    - *Interdependencies of transportation and other sectors* (e.g., health and human services, power, telecom, disaster response).
      Transportation systems do not operate in isolation and some of the most critical impacts will most effectively be addressed by considering the interdependencies and engaging other sectors in developing solutions.

FHWA Adaptation Peer Exchanges Final Report (August 2012)
The purpose of the peer exchanges was to facilitate an exchange of ideas among transportation officials regarding strategies to assess and reduce the vulnerability of their transportation assets and services to projected changes in climate.

- The Midwest Peer Exchange focused on integrating climate change adaptation into emergency management from both an MPO and DOT perspective.
- During the West Coast Peer Exchange, California DOT (Caltrans), Oregon DOT (ODOT), and Washington State DOT (WSDOT) collaborated and discussed strategies for assessing climate change risks, incorporating adaptive strategies into asset management and operations, and communicating climate change adaptation.
- The New England Peer Exchange provided an opportunity for Metropolitan Planning Organizations (MPOs) and Regional Planning Commissions (RPCs) in New England to discuss methods of assessing vulnerability and potential opportunities for collaboration and partnership.

The report synthesizes the key themes and lessons from the peer exchanges, including examples of effective practices presented by participants. It includes the following sections:

- Section 2 – **Best Practices and Strategies for Overcoming Common Challenges** summarizes the common challenges identified during these peer exchanges as well as the solutions that participants proposed for overcoming these challenges. Common challenges are:
  - *Developing Guidance and Information for Climate Vulnerability Assessments.* There are not yet established best practices for evaluating climate change vulnerability or integrating climate change considerations into existing risk mitigation efforts. DOTs and MPOs often struggle with identifying the climate change impacts that will matter at a local scale and understanding the alignment of climate change impacts with decision making. In addition, the amount of projected climate data available can be overwhelming, and it is difficult for agencies to determine which scenarios, models, and data to use in assessing vulnerability.
  - *Managing Resource Constraints and Streamlining Processes*. Transportation agencies manage multiple, interacting stressors while planning, programming and designing, projects. Often, resources are barely sufficient for maintaining the status quo for transportation operations and investments. Participants from each exchange noted the challenge of considering climate change as a new risk at a time when agencies are currently struggling to maintain existing operations.
  - *Communicating and Coordinating with Stakeholders*. Participants mentioned the need for increased collaboration between MPOs, DOTs, federal agencies, universities, and other stakeholders engaged on this issue. Relevant climate change adaptation information needs to be directed to a wide range of staff across disciplines and offices, making frequent discussions challenging. Communicating the need for climate change adaptation is challenging for several reasons. First, people often assume that "climate change" issues refer exclusively to mitigation. Second, it is difficult to communicate the range of uncertainty associated with climate projections.
- Section 3 – **Future Needs and Participant Recommendations** provides an overview of the needs and recommendations made during the peer exchanges. They also recommended the following potential next steps for the Federal Highway Administration and other federal agencies interested in supporting state and local adaptation efforts:
  - *Single Source for Adaptation Best Practices and Technical Resources*. There is currently no single place that MPOs and DOTs can visit in order to get information on best practices in the field, case studies, and frameworks for planning the vulnerability assessment and adaptation process.
  - *Guidance on Evaluating Adaptation Options*. Very few resources exist to help DOTs and MPOs evaluate and compare adaptation options. Participants at all three peer exchanges highlighted the need for information on the costs of adaptation and emphasized that very little cost information is currently available.

- *Collaboration and Leadership on Implementing Adaptation*. One of the major barriers to adaptation efforts across the region is lack of collaboration among local, state, and federal agencies. Proactively building partnerships among these agencies is an adaptation best practice because it helps agencies integrate climate change considerations across different types of planning.

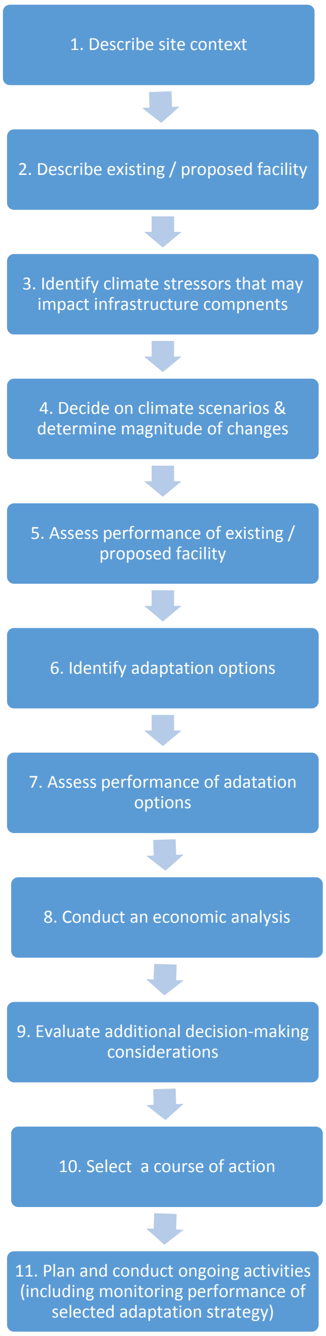
Hydraulic Engineering Circular U.S. Department of No. 25 – Volume 2: Highways in the Coastal Environment: Assessing Extreme Events (FHWA, October 2014)
The circular provides technical guidance and methods for assessing the vulnerability of coastal transportation facilities to extreme events and climate change, focusing on sea level rise, storm surge, and waves. Approaches are based upon using risk-based, data driven concepts manifested by three different levels of effort ranging from use of available data to original numerical modeling.
The manual also contains a method for computing relative sea level rise based on local tidal gages and likely impacts of climate change. The FHWA anticipates that there will be multiple uses for this guidance including risk and vulnerability assessments, coastal floodplain management, planning activities, and design procedure development.
HEC-25 v2 aligns with current and anticipated FHWA policy and programmatic guidance in areas of extreme events, extreme weather events, climate change, adaptation, and resilience.

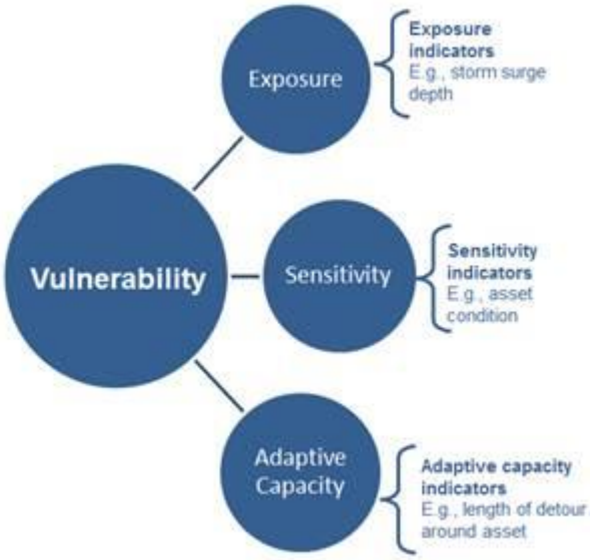
Methods and tool for developing adaptation options

Gulf Coast study Phase 1 and 2
1. *Description of the method (scope, key steps, how the analysis is conducted, illustrative example, incorporated into existing processes)*
To better understand potential climate change impacts on transportation infrastructure and identify adaptation strategies, the US DOT is conducting a comprehensive, multi-phase study of climate change impacts in the Central Gulf Coast region. This region is home to a complex multimodal network of transportation infrastructure and several large population centers, and it plays a critical national economic role in the import and export of oil and gas, agricultural products, and other goods. Phase 1 (completed in 2008) examined the impacts of climate change on transportation infrastructure at a regional scale, investigating risks and impacts on coastal ports, road, air, rail, and public transit systems in the central Gulf Coast, with a study area stretching from Houston/Galveston, Texas, to Mobile, Alabama. Phase 2 focuses on the Mobile, Alabama, region -- with the goal of enhancing regional decision makers' ability to understand potential impacts on specific critical components of infrastructure and to evaluate adaptation options. New, downscaled projections of temperature and precipitation for the study area were developed for the study. Several temperature and precipitation values were chosen to be projected, including a range of annual, seasonal, and extreme values. Sea level rise scenarios were developed based on literature reviews of global sea-level rise scenarios and an assessment of historic subsidence/uplift rates specific to the area, and hurricane scenarios were developed using historic storms as a base source of data. The study identified appropriate "indicators" of three components of vulnerability (exposure, sensitivity, and adaptive capacity, see figure below). These indicators are characteristics of an asset that may suggest how exposed, sensitive, or the adaptive capacity of each asset is to the projected changes in climate. The project team scored indicators on a scale of 1 through 4 and then calculated a composite vulnerability score for each asset.

Gulf Coast study Phase 1 and 2

In the Gulf Coast study, a flexible 11-step "General Process for Transportation Facility Adaptation Assessments" (the Process) was used as a framework for conducting detailed engineering assessments.





2. How is it applicable to the Netherlands (how applicable/ transferable, what might need to be changed/ adapted, use in other countries)

Phase 2 of the Gulf Coast Study was designed to develop analysis methods that can be replicated in other areas. While the analysis is still quite applicable to localities across the United States, each community should begin by determining its most important climate

Gulf Coast study Phase 1 and 2
hazards and modes. The data used and therefore the results and findings are very specific to the Gulf Coast context. The focus on the link with asset management and the use of the "indicators" of three components of vulnerability however are very useful and applicable elsewhere.
3. How much time/ money/ effort required
No detailed information available, study took several years

Virginia pilot: decision support tool
1. Description of the method (scope, key steps, how the analysis is conducted, illustrative example, incorporated into existing processes)
The results of the Hampton Roads study (the Virginia pilot, see chapter 3.1) where used to create a decision support tool that can be adapted to the situations of other regions. This model is being made available via a website. The Virginia decision support tool contains four workbooks in which priority setting is the objective: - The first sets priority for transportation vulnerable to climate, - the second for multimodal policies, - the third for infrastructure assets - and the fourth, for traffic analysis zones (TAZ's). The model developed is built in Microsoft Excel. There are 8 steps involved in using the workbook for transportation project prioritization: 1. The first step is to define the criteria and assign the maximum score (indicating relative importance) for each criterion. Criteria such as congestion levels, safety and security, cost effectiveness. 2. The second step is to define the list of projects to be prioritized 3. The third step is to give baseline ratings to projects defined in step 2 over the criteria defined in step 1 4. The workbook will calculate the aggregated score of each project via built-in multicriteria value function based on the inputs from step 1 to step 3. 5. Scenario-based analysis, up to five scenarios can be constructed by checking corresponding checkbox 6. adjustment to new scenarios, a worksheet is used to record expert opinions on the changes of criteria relative importance across the scenarios constructed in step 5 7. Projects scores and prioritization under the Climate Change scenarios, After all inputs above are collected, users can navigate to a worksheet to look at the scenario-informed results 8. Top influential scenarios: a worksheet quantifies and shows the influence of each individual scenario defined in step 5, in terms of the changes on rankings comparing to the baseline rankings
2. How is it applicable to the Netherlands (how applicable/ transferable, what might need to be changed/ adapted, use in other countries)
The workbook is specific to the situation in the USA and Hampton Road area. Especially the policy-based criteria for priority setting cannot easily be transmitted to the European situation.
3. How much time/ money/ effort required
No detailed information available

4.2.2 Netherlands/Europe

Water Assessment (in Dutch: Watertoets)
An important tool for the national, provincial and municipal government to prepare the Netherlands for climate change effects is the Water Assessment. This assessment is now an obligatory part of the spatial planning process. It assures the involvement of the water managing authority (mostly the water board) from the start-up to guarantee the integration of water management interests in the spatial planning process in order to limit negative effects of climate change effects.

The objectives of Water Assessment are to guarantee that water interests are taken into account in spatial and land use planning, so that negative effects on the water system are prevented or compensated for elsewhere. This integration of water in spatial planning works in two ways: a plan is assessed on its implications for the water system and the restraints that the water system puts on land use are made explicit.

Water management includes flood control, water quantity management, and water quality management. Flood control is meant to keep dikes, dams, and dunes in good condition. Water quantity management includes water level management, for which often pumping stations are needed. Water quality management includes waste water treatment and monitoring water releases, and is meant to meet ecological and water quality standards, required for recreation, agriculture etc.

In Water Assessment there are no fixed criteria. In the initial phase of Water Assessment the spatial planning authority and water authority together agree on the criteria to be met in the plan. Thus the criteria are tailor-made for each individual plan and can concern all aspects of the water system: susceptibility to flooding, groundwater levels, soil subsidence, sewage, water quality and ecology. The criteria are based on knowledge of the water system at hand, on all relevant legislation and policies and on existing spatial plans of a higher authority.
The likely impacts of climate change also have to be considered. However, the right climate scenarios are not always used yet. The level of detail of the criteria has to fit to the level of detail of the plan. The more the accent shifts from the choice of location to actual design, the more detailed the criteria must be.

Methods and tool for developing adaptation options

RWS Framework for Climate Adaptation and Mitigation (in Dutch: Rijkswaterstaat NL)
1. *Description of the method (scope, key steps, how the analysis is conducted, illustrative example, incorporated into existing processes)*
The Framework describes how climate change is incorporated by Rijkswaterstaat in the decision-making process of projects on infrastructure and water management. There is a Guideline for incorporating climate change in the spatial planning process and the Strategic Environmental Assessment. There is a Directive for incorporating climate change in the process of project design and the Environmental Impact Assessment. The framework only applies to RWS projects. Climate adaptation is not approached as a problem on its own but as a part of other themes and topic that are influences by climate change. Topics such as water safety, navigation and mobility, soil and water management. The effects of a wide range of climate variables are taken into account (flood risk, more intense rainfall, drought, increase in temperature) Climate mitigation is considered a part of sustainable development. The emphasis is on travel patterns and CO2 emissions from transport and on the energy demands and CO2 emissions related to building materials and construction. The framework supports the integration of climate change into the spatial planning process (Guideline) and into the process of project design (Directive). The frame work is not meant to make new regulations but aims to help to take climate change into account in the process of planning and preparing for new infrastructure. For the most important steps in the process a description is given of the actions that have to be taken and who is accountable for taking these actions.

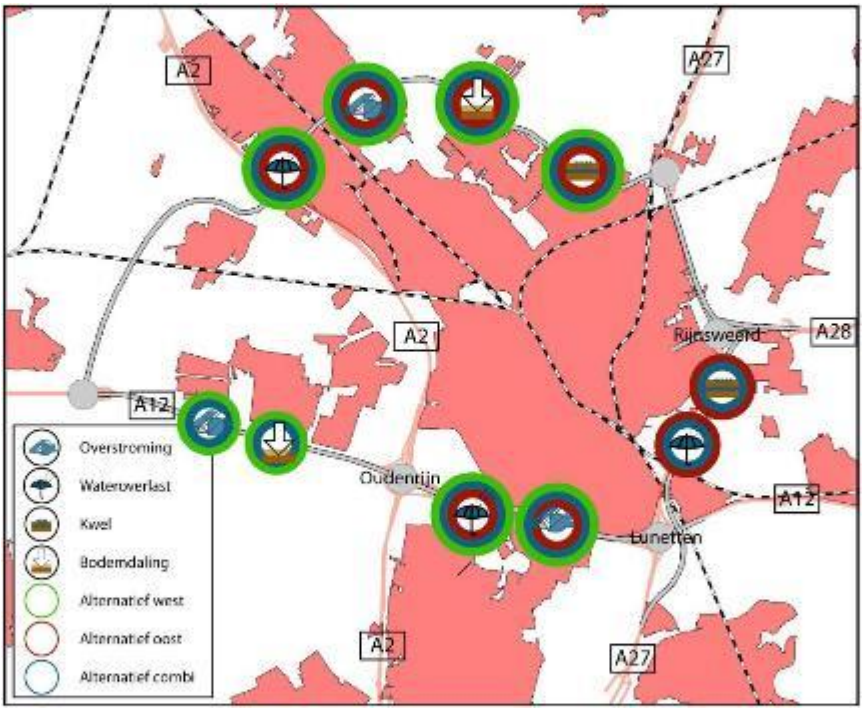
RWS Framework for Climate Adaptation and Mitigation (in Dutch: Rijkswaterstaat NL)
An overview is provided on available tools and methods to analyze the effects of climate change in projects Steps in the Guideline for the spatial planning process – Step 1: problem analysis and definition of the scope of the effects of climate change on the project – Step 2: identifying the spatial effects of climate change on the project and identifying possible measures to compensate or mitigate these effects – Step 3: identifying the costs and other consequences of measures to compensate or mitigate climate change – Step 4: reporting and recommendations on climate change for decision-making. Steps in the Directive for the process of project design – Step 1: reconsideration of the problem analysis and scope of the effects of climate change in the project – Step 2: quantifying the effects of climate change on the targets/goals of project – Step 3: Identifying the possible changes in de design of the project to cope with climate change – Step 4: calculating the costs of the possible changes in the design of the project to compensate or to mitigate for climate change – Step 5: formulating the specifications for project procurement to compensate or mitigate climate change – Step 6: reporting and recommendations on climate change for decision-making. Parts of the methodology were already available in other frameworks and directives
2. *How is it applicable to the US (how applicable/ transferable, what might need to be changed/ adapted, use in other countries)*
The method is focus on planning and decision-making. It can be used in similar decision-making processes in the USA.
3. *How much time/ money/ effort required*
Costs are not yet clear. The method can be integrated into the normal decision making process. At the moment (August 2015) several pilot project are planned to further work out the framework to optimize t for use in the process of planning and preparing for infrastructure.

Pilot case Framework for Climate Adaptation and Mitigation (ring Utrecht)
1. *Description of the method (scope, key steps, how the analysis is conducted, illustrative example, incorporated into existing processes)*
How can climate change be taken into account in the construction of a new highway? This question was the focus of a pilot, which was part of the project Ring Utrecht. The KNMI climate scenarios are applied to four different construction alternatives that were tested in the study. For construction of dry infrastructure, Rijkswaterstaat applies to climate change the worst case the KNMI'06 climate scenarios. The reason for this is that the additional costs for a climate robust construction are relatively low with respect to the heads of damage that can cause climate change at a later stage. Various climate variables were taken into account such as extreme rainfall, seepage and groundwater, land subsidence, floods and heat and frost. The results are in the image projected on the Ring Utrecht. To solve current problems different alternatives are under study. The alternatives consist of different combinations of possible solutions such as adding new lanes and creating bypasses to existing infrastructure and creating new infrastructure. The conclusion of the pilot is that climate adaptation play a distinctive role in the selection of

Pilot case Framework for Climate Adaptation and Mitigation (ring Utrecht)

the preferred alternative. Especially for water issues good technical solutions exist. Climate proof-design, however, means considerable cost. The pilot project has shown that it is possible to give a first indication of impacts in the exploration phase.

The results of the pilot were presented as input for the decision making process. Since decision making is not yet completed, is not yet clear whether climate adaptation will actually play a part in the selection of alternatives and design of the project.



2. *How is it applicable to the US (how applicable/ transferable, what might need to be changed/ adapted, use in other countries)*

The context of the pilot is specific to the city of Utrecht. The methodology and the result however are similar to those of pilot studies in the USA

3. *How much time/ money/ effort required*

Costs are tens of thousands of euros

EU Guidance on Integrating Climate Change and Biodiversity into SEA

1. *Description of the method (scope, key steps, how the analysis is conducted, illustrative example, incorporated into existing processes)*

The aim of this Guidance document is to improve the consideration of Climate change in strategic environmental assessments (SEAs) carried out across the EU Member States under the recently amended Environmental Impact Assessment (EIA) Directive (2014/52/EU) (see paragraph 2.2.2.). The guidance document has a broad scope and is not focused on infrastructure.
Since it is the first such type of guidance issued by the European Commission, and climate change and biodiversity scientific base, policies, and SEA practices constantly evolve, it should be considered as a pilot guidance document.

EU Guidance on Integrating Climate Change and Biodiversity into SEA

The Guidance document supports both the screening and scoping stages in the SEA process. Therefore, a wide range of climate variables is discussed.

Climate change mitigation	Climate change adaptation
• energy demand in industry	• heat waves (including impact on human health, damage to crops, forest fires, etc.)
• energy demand in housing and construction	• droughts (including decreased water availability and quality and increased water demand)
• Green House Gas (GHG) emissions in agriculture	• flood management and extreme rainfall events
• GHG emissions in waste management	• storms and high wind (including damage to infrastructure, buildings, crops and forests)
• travel patterns and GHG emissions from transport	• landslides
• GHG emissions from energy production	• sea level rise, extreme storms, coastal erosion and saline intrusion
• land use, land-use change, forestry and biodiversity	• cold spells
	• freeze-thaw damage

The guidance is arranged in a way that will encourage users to think about how important climate change and biodiversity — as assessment issues — are likely to be for a specific SEA. The focus is on answering the following questions:

- How will plans and projects influence climate change and biodiversity and how it will be influenced by climate change and biodiversity?
- What is it about climate change and biodiversity that poses a challenge to the assessment process?
- How does that affect the information needs — what type of information, what sources and what stakeholders will hold information and specific knowledge in these areas?
- What are the key aspects to cover in the detailed assessment and how important will those issues be in decision making?

The guidance document also gives advice on:

- How to address climate change effectively
- Critical challenges for addressing climate change
- How to identify climate change
- How to assess the effects related to climate change

An overview is provided on documents on climate change which have already been issued by Member States or other organizations.

2. *How is it applicable to the US (how applicable/ transferable, what might need to be changed/ adapted, use in other countries)*

Yes, the method is applicable in most other regions and countries in similar temperate climate zones

EU Guidance on Integrating Climate Change and Biodiversity into SEA
3. How much time/ money/ effort required
Not specified, there are no examples yet. The methodology however can be integrated into the normal process of the environmental impact assessment

4.3 Analyzing costs and benefits of adaptation measures

4.3.1 USA

Economics of Climate Adaptation (ECA). Shaping Climate-Resilient Development: A Framework for Decision Making
1. Description of the method (scope, key steps, how the analysis is conducted, illustrative example, incorporated into existing processes)
The goal is to develop a practical framework – grounded in robust analysis – that would allow national and local decision-makers to assess the "total climate risk" facing their economies, and to minimize the cost of adapting to that risk through climate-resilient economic development strategies. The report is looking at all climate change impacts within the IPCC and other widely accepted academic research as the basis for the assessments of current and future climate risk. A quantitative decision-making framework has been built around two sets of tools. 1. First, the framework provides tools to quantify a location's "total climate risk". Included in this quantification is an assessment of the expected annual loss to the location's economy from existing climate patterns; a projection of the extent to which future economic growth will put greater value at risk; and finally, an assessment of the incremental loss that could occur over a twenty-year period under a range of climate change scenarios based on the latest scientific knowledge. 2. Second, the framework uses cost-benefit discipline to evaluate a selection of feasible and applicable measures to adapt to the expected risk – spanning infrastructural, technological, behavioral and financial solutions. The output of this cost-benefit exercise provides one key input – along with policy, capacity, and other considerations – for a country, region or city assembling a comprehensive adaptation strategy. Because any such strategy will need to be closely integrated with the location's broader economic development choices, many of the measures evaluated will be economic development steps. The methodology was applied in eight on-the-ground test cases in China, Guyana, India, Mali, Samoa, Tanzania, the UK, and the US, conducted in partnership with local governments and stakeholders. The cases focused on selected climate-sensitive regions and cities in each of these countries, and tested the methodology against a sample of climate hazards, economic impacts, and development stages. There were four overarching findings from the test cases. 1. The first is that, despite much uncertainty about the possible effects of global warming on local weather patterns, society knows enough to build plausible scenarios on which to base decision-making. This is true even in developing countries, where historical longitudinal climate data may be limited. 2. The second finding is a sobering one: significant economic value is at risk. If current development trends continue to 2030, the locations studied will lose between 1 and 12 percent of GDP as a result of existing climate patterns, with low income populations such as small-scale farmers in India and Mali losing an even greater proportion of their income. 3. Thirdly, however, the cases found that a portfolio of cost-effective measures can be put together to address a large part of the identified risk. In principle, between 40 and 68 percent of the loss expected to 2030 in the case locations – under severe climate change scenarios – could be averted through adaptation measures whose economic benefits outweigh their costs. These measures include infrastructure improvements, such as strengthening buildings against storms or constructing reservoirs and wells to combat

Economics of Climate Adaptation (ECA). Shaping Climate-Resilient Development: A Framework for Decision Making
drought. 4. Finally, the cases reinforced the view that adaptation measures are in many cases also effective steps to strengthen economic development – especially in developing countries.
2. *How is it applicable to the Netherlands (how applicable/ transferable, what might need to be changed/ adapted, use in other countries)*
Yes, it was designed for use all over the world
3. *How much time/ money/ effort required*
No detailed information available

FEMA Benefit-Cost Analysis Tool
1. *Description of the method (scope, key steps, how the analysis is conducted, illustrative example, incorporated into existing processes)*
To evaluate proposed hazard mitigation projects prior to funding, the Federal Emergency Management Agency (FEMA) requires a Benefit-Cost Analysis (BCA) to validate cost effectiveness. BCA is the method by which the future benefits of a mitigation project are estimated and compared to its cost. The end result is a benefit-cost ratio (BCR), which is derived from a project's total net benefits divided by its total project cost. The BCR is a numerical expression of the cost effectiveness of a project. A project is considered to be cost effective when the BCR is 1.0 or greater, indicating the benefits of a prospective hazard mitigation project are sufficient to justify the costs. The tool consists of guidelines, methods and software modules for estimating the benefits and costs of mitigation strategies to a range of major natural hazards, including wildfire, floods, hurricanes, and tornadoes. The benefits of hazard mitigation are the avoided losses, i.e., those losses that would have occurred (in a probabilistic sense) if the mitigation activity had not been implemented. Mitigation costs are incurred primarily during a short period, such as during construction, and are relatively certain. Mitigation benefits, however, accrue over the useful life of the project or process activity and are highly uncertain because they are usually realized only if natural hazard events occur. The Federal Emergency Management Agency (FEMA) has developed standardized loss estimation models that could be used by nontechnical hazard specialists. Various categories of hazard mitigation benefits are addressed such as: 1. Reduced direct property damage (e.g., buildings, contents, bridges, pipeline); 2. Reduced direct business interruption loss (e.g., factory shutdown from direct damage or lifeline interruption); 3. Reduced indirect business interruption loss (e.g., ordinary economic "ripple" effects); 4. Reduced (nonmarket) environmental damage (e.g., wetlands, parks, wildlife); 5. Reduced other nonmarket damage (e.g., historic sites); 6. Reduced societal losses (deaths, injuries, and homelessness); 7. And Reduced emergency response (e.g., ambulance service, fire protection).
2. *How is it applicable to the Netherlands (how applicable/ transferable, what might need to be changed/ adapted, use in other countries)*

FEMA Benefit-Cost Analysis Tool
Although the tool was developed specifically for the USA, separate elements of the tool can be useful for the situation in the Netherlands and other European countries.
3. How much time/ money/ effort required
No detailed information available

4.3.2 Netherlands/Europe

RWS frameworks for LCC (Life Cycle Costs) and KBA (Cost Benefit Analysis)
Rijkswaterstaat is working with a multi-year infrastructure, spatial planning and transport program (MIRT). A RWS framework describes the use of LCC in the exploration, plan development and realization phase of MIRT process. Another document describes the use of the Cost Benefit analysis in the MIRT process.

Climate change however is not a specified element of the LCC or the Cost benefit Analysis. Both LCC and KBA are based on the cost (and benefits) of management and maintenance during the total lifespan of infrastructure. Therefore climate change is implicitly part of both the LCC and KBA.
The main problem in integration climate change in LCC and KBA is the unpredictability of climate change. This problem is recognize but not dealt with yet.

4.4 Design and construction

4.4.1 Best practices Netherlands/Europe

Danish Road Directorate Drainage Standards
The Danish Road Directorate (DRD) bases its climate predictions on the A1B scenario from the IPCC. Based on this scenario, annual rainfall in Denmark is predicted to increase by 11 percent by 2050 and by 22 percent by 2100. In addition, the number of days experiencing more than 20mm is projected to increase from two to five days by 2050 and seven days by 2100. The increase in precipitation levels and rates increases the risk of floods that exceed the capacity of the drainage infrastructure.

The DRD recognizes that integrating climate considerations into the design and construction of a project is less expensive than having to adapt a project at a later stage. As such, the agency continuously analyzes and updates road regulations to account for the changes in climate. In addition, for a considerable time now, the agency has made a standard practice of planning new roads away from locations that have a high risk of flooding or by creating structures with higher barriers.

Current design standards require that infrastructure be built to withstand a 25-year return period for precipitation. Under current conditions, a 25-year return period corresponds to 58 mm of rain. Analysis by the Danish Meteorological Institute predicts that in 2100, a 25-year event will equal 74 mm of rain. At present, this amounts to a 100-year event (see Table 3).

Present time	Return pattern	Return pattern 2050	Return pattern 2100
Mm	*Years*	*Years*	*Years*
45	5	2	1
47.5	10	5	2
54.6	20	10	5
58	25	20	10
65.2	50	25	20
74	100	50	25
97.3	500	100	100
142.8	1000	500	500

Table 3: Changes in Precipitation Pattern. Source: Danish Meteorological Institute

The agency employs a cost-benefit approach to determine the appropriate adaptation response. For example, a number of emergency pumps are located across the country to alleviate road flooding. Based on the Blue Spot analysis, the agency is, as an example, planning to increase the number and capacity of pumps at road stretches particularly prone to flooding in order to ensure that roads are re-opened as quickly as possible and that material damage is kept to a minimum.

<u>Normative intensity of precipitation (Maatgevende bui) in the RWS framework for "run-off discharge" (Richtlijn afvoer hemelwater RWS-NL)</u>
According to the RWS framework for "runoff" the order of preference for dealing with road water runoff from (national) roads and works as follows:
1. controlled infiltrate the soil; drain through to roadside ditches;
2. discharge into a surface water body;
3. alternative discharge

The water storage capacity of the drainage system has to meet certain specifications depending on the drainage situation and the intensity of precipitation. The normative intensity of precipitation (maatgevende bui) depending on the drainage situations are as follows:

- 1x in 10 years occurring shower for the situations in which sufficient space for water storage and infiltration is available next to the pavement.
- 1x 50 per year occurring shower for the situations in which only limited space is available next to the pavement. This could include major intersections, roundabouts, bridges and viaducts.
- 1 x 250 years occurring shower where no space is available next to the pavement for infiltration of run-off. For example, tunnels

The normative intensity of precipitation on which the drainage system has to been designed are based on the so-called rain duration lines (regenduurlijnen) of Buishand en Wijngaard (KNMI, 2007) increased with 30% to account for the impact of climate change in 2050. The increase of 30% is based on an analyses of the increased likelihood of extreme rain showers in the climate scenario's.
These lines representing the cumulative precipitation over a certain period of time, are presented in the figure below. The dotted lines represent the original rain duration lines and the drawn lines represent the precipitation corrected for climate change in 2050 (blue 1 x 10 years, green 1 x 50 years and red 1 x 250 years)

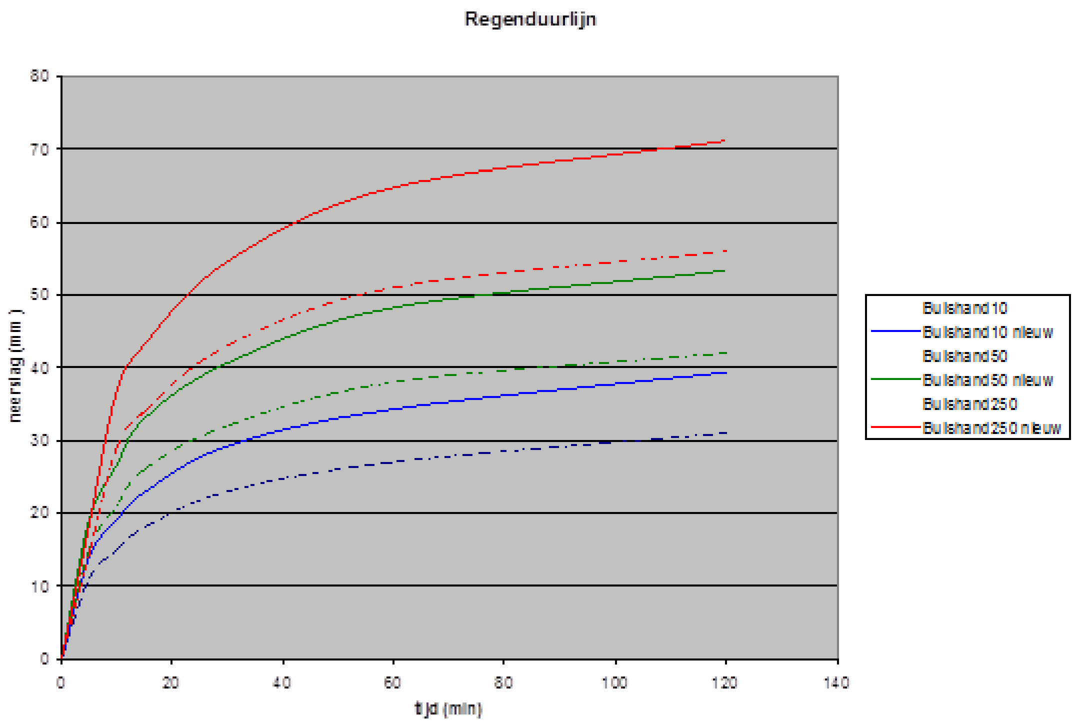


Figure 6: Rain duration lines (regenduurlijnen) corrected for climate change (Buishand en Wijngaard, KNMI, 2007)

The intensity of precipitation (including the correction for climate change) on which the drainage system has to be designed are also given in the table below.

Time (in minutes)	Precipitation (mm)		
	1x in 10 yr	1x in 50 yr	1x in 250 yr
0	0	0	0
5	14	20	19
10	20	27	38
15	23	34	44
30	30	42	56
60	35	49	66
120	40	55	73
>120	30+5mm/h	43+6mm/h	59+7mm/h

Table 4: **The intensity of precipitation (including the correction for climate change)**

5 Asset Management and adaptating to climate change

5.1 Comparing asset management of the adaptation to climate change USA-NL

In this chapter the asset management of the adaptation to climate change in the Netherlands and in the USA is discussed. This first paragraph will summarize the main similarities and differences found between the USA and the Netherlands. These are illustrated by the different reports and studies described in the following paragraphs.

In both the Netherlands and the USA asset management is considered to be a key element in making the National Highway Network more resilient to climate change. There are many similarities in the way asset management is viewed upon:

- Asset management covers both the maintenance and replacement of existing infrastructure as the construction of new infrastructure designed and built to face the effects of climate change.
- The main challenge is to cope with the unpredictability of climate change and to work out how to incorporate the unpredictability into a risk based approach in a fiscally responsible manner.
- Asset management requires the linking of different hierarchical levels: network level, object class level and object-element-component level.
- Asset management requires good asset data. Gathering and documenting these data can be a challenge in itself.

In both USA and the Netherlands, implementing climate change in asset management is still in its early stages. Available reports and papers from the USA focus on what elements of climate change can be taken into account in asset management. Available reports and papers from the Netherlands focus much more on how climate change can be implemented in asset management.
The role of the FHWA and of RWS in asset management is different. FHWA oversees and supports the state DOT’s in constructing and maintaining the National Highway System. RWS itself is responsible for the maintenance, operations, renewal and expansion of the National Highway Network in the Netherlands.

5.2 Asset Management

5.2.1 Best practices USA

U.S. Department of Transportation Climate Adaptation Plan (2014)
U.S.DOT will work to incorporate climate variability and change impact considerations in asset management. For example, modal administrations will work with grantees to assure that potential impacts are incorporated into existing grantee asset management systems and their own buildings and operations. Agencies will assess the policy, guidance, practices, and performance measures of its asset management programs to incorporate such considerations.

U.S. DOT identified three general vulnerabilities to climate change, which its climate change adaptation and resilience actions will address. Addressing these general vulnerabilities will foster a resilient transportation system.

1. *Existing Infrastructure Resilience*: Existing transportation infrastructure is owned and operated by various public agencies and private firms, and covers an enormous range of ages, service life and levels of sophistication. Existing infrastructure has been built to many different design standards, and its current and future environmental risk is similarly varied. As environmental risks change, the probability of unexpected failures may increase. Further, as existing infrastructure approaches the end of its service life, decisions about replacement or abandonment should, but may not currently, take into account changing future risks.

2. *New Infrastructure Resilience*: Similarly, newly constructed infrastructure should be designed and built in recognition of the best current understanding of future environmental risks. In order for this to happen, understanding of projected climate changes would need to be incorporated into infrastructure planning and design processes, across the many public and private builders and operators of transportation infrastructure.

3. *System Resilience*: Transportation systems are more than just the sum of their individual parts. Some elements are of particular importance because of their vital economic role, absence of alternatives, heavy use, or critical function. The National Airspace System, for example, plays a vital economic role, while hurricane evacuation routes perform a critical function. Transportation systems are potentially vulnerable to the loss of key elements. Therefore, selectively adding redundant infrastructure may be a more efficient strategy than hardening many individual facilities on the existing system. System resilience is best viewed across transportation modes and multiple system owners. While some key elements are obvious, other dependencies may be less well recognized. For example, some airports rely on petroleum pipelines, which may depend, in turn, on electric power for pumping. Transportation systems are also interdependent when passengers or freight carriers rely on multiple transportation modes to reach their destination.

Managing External Threats through Risk-based Asset Management (FHWA March 2013)
This is one of the five reports published by the FHWA that examine how risk management complements asset management. This report examines how physical, climatic, seismic and other external threats can be addressed in risk-based asset management programs. These risks generally are external, and while highly probable over a long period of time, are difficult to predict in the short term. Randomness and variability complicate planning for them.
Asset management assists agencies to sustain desired infrastructure conditions for the lowest cost over a number of decades. While asset management seeks to achieve reliable, predictable highway system conditions, risk management seeks to identify and mitigate the unpredictable threats to infrastructure, while identifying opportunities created by uncertainty or new opportunities. Climate change, increased flooding, terrorist attacks, earthquakes and other unpredictable events clearly create risks to infrastructure. Many of these risks are negative but some could be positive such as warmer winter temperatures or the lessons learned from minor seismic events. A risk-based asset management program includes a "learning function" in which risks such as these are identified, evaluated, and categorized. They can be rationally treated, tolerated, transferred, terminated or taken advantage of depending upon the risk analysis.

As such, asset management becomes a key component of a resilient agency by creating robust infrastructure, complete asset inventories and prioritization processes that allow agencies to quickly respond to changed conditions. An agency with a mature asset management program not only has stronger physical assets, it also will have better information systems and is more likely to have a culture of resiliency that will serve it well in times of crisis.

Planning for Systems Management and Operations as Part of Climate Adaptation (FHWA March 2013)
The paper begins to explore the effects of climate change on operations. Effects are going to manifest both due to specific weather events/phenomena but also long term trends in air temperature. The link between weather events and climate is not simplistic, but recent severe weather events point to the challenges posed to operations. The scale, frequency, and intensity of events will change how operation agencies are organized and function in the country.
The major challenge to agencies is how to plan for operations an uncertain future in a fiscally responsible manner. The relationship between the probability of an impact and the severity of impact versus the cost of investment continues be a difficult equation for agencies to solve. Given the latency from planning to implementation inherent in transportation operations (i.e., future operations are dependent on plans being considered today), there is an urgency to include climate change considerations in transportation plans today.

Recent guidance and best practices are starting to emerge for planning for operations with an emphasis on system performance and driven by regional objectives. Driven by policy objectives such as congestion, safety, economic competitiveness, agencies are starting to better integrate operations into the planning process.

Into this paradigm of objective-driven performance-based planning, climate change considerations have to be included. While many questions remain, two main actions are worth investigation as part of planning for operations efforts

Introducing risk assessment in transportation operations planning – Risks are an inherent part of transportation planning. However, assessing the risk posed by climate change to operations is new to the field. Climate change risks vary across regions and times, they vary in scale of impacts, and there is inherent natural and modeling uncertainty in future climate scenarios. The assessment approaches may vary from qualitative assessments to quantitative but primarily needs to answer questions regarding levels of likelihood and levels of consequence of the event. Good examples for such risk assessments in transportation that might translate to this field may be found in States with high seismic activity such as *California and Washington.*

Integration with other adaptation efforts – An immediate approach for operating agencies is to be part of statewide climate change action plans and adaptation efforts. Integration of operations considerations such as evacuation procedures, alternate routings, monitoring systems all are worthwhile considerations as part of the larger State climate change action plans.

FHWA draft Asset Management Rule
On February 20, 2015, the Federal Highway Administration (FHWA) published a Notice of Proposed Rulemaking (NPRM) to propose a process for the development of State risk-based asset management plans. A State asset management plan shall, as a minimum, include:

a) A summary listing of the pavement and bridge assets on the National Highway System in the State, including a description of the condition of those assets;
b) Asset management objectives and measures;
c) Performance gap identification,
d) Lifecycle cost and risk management analysis,
e) A financial plan, and
f) Investment strategies

Each State is required to develop a risk-based asset management plan for the National Highway System (NHS) to improve or preserve the condition of the assets and the performance of the system. The risk-based asset management plans should include the risks of climate change and extreme weather. It also requires states to conduct an evaluation of reasonable alternatives to repeated repairs due to emergency events.

5.2.2 Best practices Netherlands/Europe

A Holistic Approach to Asset Management in the Netherlands (article by Jenne van der Velde, Leo Klatter and Jaap Bakker published in Structure and Infrastructure Engineering Vol. 9, No. 4, April 2013, 340–348)
In 2009, Rijkswaterstaat started to implement asset management. In this program five subprograms are defined:

1. Reliable and accurate asset data
2. Stable long-term maintenance programmes
3. Clear objectives and transparent requirements
4. Transparent procurement procedures
5. Life cycle costing

1. Reliable and accurate asset data

Asset data management calls for a network oriented approach. One part of the solution was the introduction of a sector wide normalization process for the decomposition on the levels 'element' and 'component'. This project is realised by the NEN institute, the Dutch Centre for Standardization. A condition assessment code, originally developed for buildings is used as a base for this process.

2. Stable long-term maintenance programmes

Development of the stable long-term maintenance programmes (including prioritisation) is another important development at Rijkswaterstaat. The classical bridge management process for example, resulted in a list of damages to be repaired. This list was prioritized to fit into the (limited) available budget.

Sometimes this process resulted into a programme, based on network related objectives. Such programmes contain elements for strategic and operational planning, but they were not integral and not based on strategic goals on a network level.

3. Clear objectives and transparent requirements

Clear objectives and transparent requirements are important to justify the maintenance programmes. Each hierarchal level in the decomposition needs a specific description. Also requirements should be connected throughout the hierarchical levels. Elements required for these are as follows:
. At network level a network strategy.
. At element and component levels technical requirements, (design) codes and regulations.
System engineering (SE) principles are used to connect all these requirements and to assure compliance within the different levels.

4. Transparent procurement procedures

The policy in the Netherlands is to outsource activities to private parties to an extent as high as possible. All maintenance and construction works are contracted out to private companies, contractors and engineering firms. This means that 100% of the final output and outcome is realized through these contracts. This asks for a well balanced mix of responsibilities and skills of the government agency and the private parties.

5. Life Cycle Costing

Previous sections dealt with asset management in the operational phase, once the infrastructure has been constructed. This section describes the asset management aspects of new construction. The functional need for new infrastructure originates from the asset management process, when existing infrastructure falls short in complying with demands. For new infrastructure Rijkwaterstaat uses the so-called MIRT (Dutch acronym) procedure. LCC is being implemented as integral part of the MIRT process. In the early phase of the process, exploration, a LCC calculation will be made for the solutions developed. In addition to the results of the cost–benefit analysis the cost of construction, the LCC prognosis (discounted present value) and the cost of future maintenance are determined.

The experience in the Netherlands with the introduction of an asset management programme learned that asset data are the first barrier to be taken. Next, a stable multiannual maintenance programme based on network level prioritisation rules is a big effort. Not only to draw up the programme, but maybe even more difficult to keep it stable in its execution. Ensure we are still looking at the same picture that was taken at the beginning of the year, after this year has passed, in terms of scope, costs and planning. Documentation is a third field of the mega operation. The changes in the operational practice, originally organised in object classes, can be characterised as an intercultural integration process. Further the interlinking of the different hierarchical levels is difficult. In practice three domains are distinguished: network level, object class level and object-element-component level.

Simulation Framework for Asset Management in Climate Change Adaptation of Transport Infrastructure (Srirama Bhamidipati, Faculty of TPM, Delft University of Technology, The Netherlands, AET 2014)

With climate change gaining prominence, asset management is now starting to look at vulnerabilities of infrastructure assets especially with a focus on robustness and availability of the asset. Asset managers of a particular domain, most often, are interested only in their specific assets. Such an approach may be appropriate for general purposes, but in the context of climate change, it creates a mismatch in two main aspects.

- First, events of climate change have a large area impact and affect an array of assets in their wake. This is unlike the damage of one or a few assets that can be predicted by their established deterioration profiles. The impact of a weather event on an area is irrespective of the category of an asset, or the asset in concern of a particular asset manager. The array of assets affected can be of one category (transportation or sewer-lines or underground cables etc.) or a combination of these categories in that area.

- Secondly, most reports and literature dealing with asset management and climate change deal with a static framework, in a sense that they recreate a most possible/probable scenario of an impact and analyse the outcomes. This may be appropriate for short-term measures or disaster preparedness, but are less useful for long-term asset management strategies.

Addressing these two shortcomings, a framework is presented that is dynamic in nature and includes an integrated approach by involving interconnected assets. Agent-based simulation technique are used to handle the dynamics of both short-term and long-term consequences and the logic of causal interactions between collocated infrastructures to handle assets of other sectors that may affect the transportation assets.

The model presented is divided into three stages. The following sections describe this model building progression and procedure.

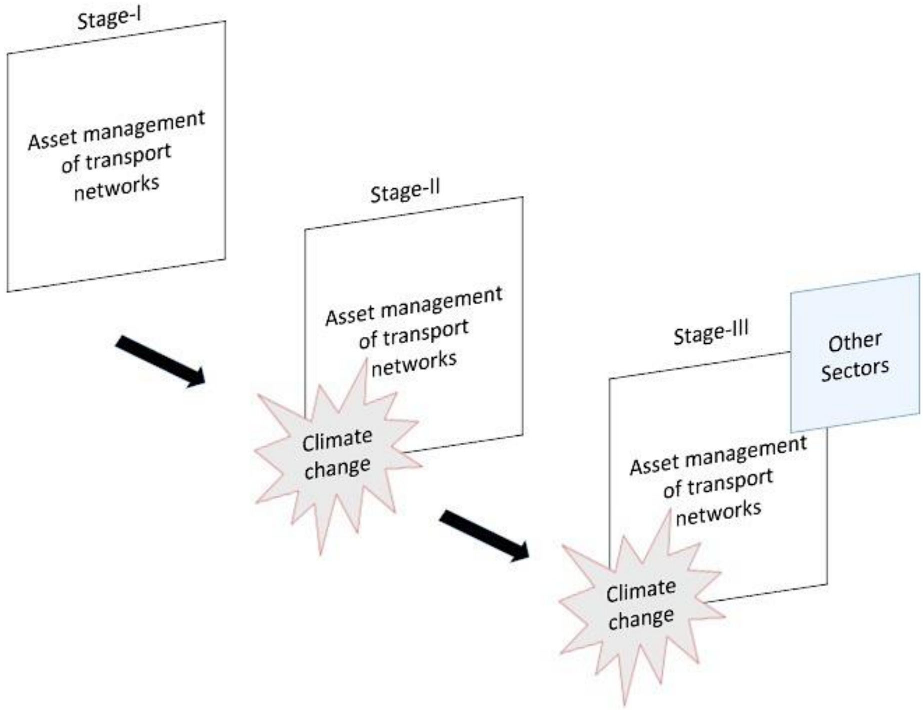


Figure 7: Model building progression and procedure

All in all, if all the three stages of the model are put together, it gives a very powerful decision support tool especially for planning future risk and budget profiles of transportation assets and their maintenance activities.

Tipping point analysis (Deltares)

Tipping Point Analysis was developed for the Dutch Delta programme to provide the Netherlands with long-term protection from flooding. A number of Dutch water authorities use it as a support tool for strategic decisions. International interest is on the rise. The approach is now introduced in Colombia to properly prepare the country for climate change in the future and for managing the impact on the water system. The approach may differ from the Roadapt studies which focus mainly on infrastructure instead of water management.

In climate change adaptation, policy making methods promoting a bottom up approach are gaining ground. Climate change is not the leading argument for taking action, but rather the key vulnerabilities of the area, sector, management practices and policies under consideration. Basically the question is asked under what amount of change will we start missing achieving our objectives or will we start to perform unacceptably?

The analysis consist of several steps:

1. Definition of thresholds or critical performance criteria. If these are exceeded policy and management need to improve or change.
2. Estimate/calculate how the performance changes with climate change and with what amount of change thresholds or critical performance criteria will be exceeded.

3. Timing: use a climate/socio-economic scenario to assess when the change will lead to a the exceeding of a threshold (tipping point). At that point in time alternatives should be ready.

Climate change will alter the river's hydrological regime which may lead to an increase of droughts and floods in the future, causing at a certain moment in time that objectives can no longer be met. Current management and policy have to be reconsidered, and new measures might need to be taken. In scientific literature (Kwadijk et al. 2010, Haasnoot et al. 2012) these moments are called adaptation tipping points. Their future occurrence depends heavily on the uncertainty in the speed and amount of climate change and on the definition of a critical level or acceptable risk level which may also change in time due to socio economic development and changing societal risk perception.

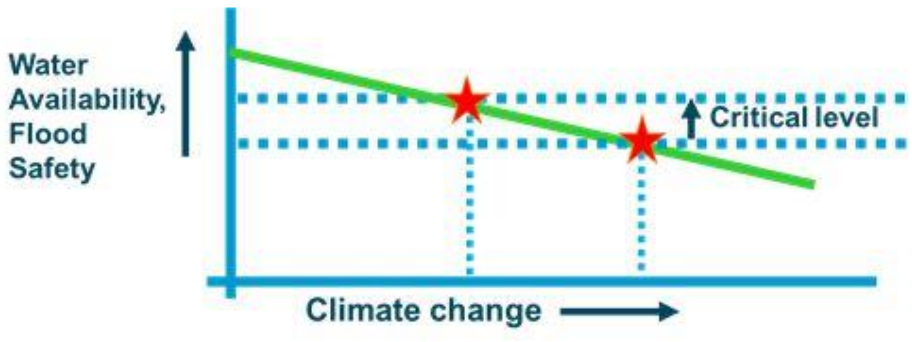


Figure 8:Tipping point analysis

Tipping Points Analysis has been used, among others, by the Delta Commission in order to establish the urgency of the various consequences of climate change. The next stage is to set up alternative strategies that could be used after the current management and policy are no longer feasible, for example the Dynamic Adaptive Policy Pathways.

In the climate adaptation program in the Netherlands (The Delta Program) this way of thinking was applied to define priorities for adaptation to climate change in water management. To give two examples:

- Critical levels for flood risk management in the Netherlands are defined by flood protection standards that depend on the potential damage and victims in an area. The standards define a protection level as a discharge debit and water level that should be accommodated with a certain probability. For instance in a large part of the Dutch Rhine river basin the flood protection system should be able to withstand discharges and water levels that occur once every 1250 years, corresponding with a current critical discharge of 16.000 m3/s. With help of multiple climate scenarios, past rainfall statistics, hydrological and hydraulic models it was calculated that this critical discharge could increase to 17.000 or 18.000 m3/s in 2050. The current flood risk management practice (including planned room for river and dike reinforcement projects) which is designed to accommodate 16.000 m3/s should be reconsidered to incorporate possible future climate meaning additional investments over the course of time.

- Agricultural areas in the west of the Netherlands depend on the external supply of fresh water from the main rivers during summer. The national water authority is guiding (by sluice operation) river water to the main water intake points where the regional water authority is directing it further over regional waterways to water users. Based on water use criteria, the regional authority has defined goals for salinity of the water which is around 250 mg/l Chlorine.

  Due to sea level rise and decreasing summer discharges, salt water will intrude further upstream and cause the salinity to increase near the intake point of freshwater, causing intake stops. Ultimately this leads to drought damage in different, mostly agricultural sectors. By using climate scenarios and river models it was analyzed how often the situation, currently happening once every 10 years, which was considered acceptable based on economic analysis, could occur under climate change. The range of outcomes given by the analysis was so large that in one scenario action (like different supply routes, increasing local water buffers) would be needed within twenty years and in another scenario this might not be needed before the end of the century. This forced the decision makers to avoid making large investments on the short term (uncertain if needed) but they started making small investments in already existing solutions such as expanding the capacity of alternative routes for freshwater distribution.

References