Transportation Resilience in the United States and the Netherlands: Summary of Collaboration on Nature-Based Solutions and Application of Infrastructure Resilience Tools, 2016-2022

Summary Report
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13. ABSTRACT (Maximum 200 words) Since 2014, the Federal Highway Administration (FHWA) and Rijkswaterstaat, the government agency responsible for transportation and water infrastructure in the Netherlands, have been collaborating on the topic of infrastructure resilience. From 2016 through 2018, the agencies conducted an applied comparison of a suite of resilience tools developed and/or used by the respective agencies: the FHWA Vulnerability Assessment and Adaptation Framework, and Roads Today, Adapted for Tomorrow (ROADAPT). From 2019 to 2021, FHWA and Rijkswaterstaat - along with Washington State Department of Transportation (WSDOT) and North Carolina Department of Transportation (NCDOT) - participated in a collaboration to explore nature-based solutions that reduce flood hazards to highways and provide environmental benefits. Through monthly conference calls and occasional topic-specific webinars, the partners discussed resources and strategies for nature-based resilience and specific transportation projects that incorporated nature-based strategies. The partners shared lessons learned that could be relevant for transportation projects under consideration by the other agencies. They also shared information on climate resilience strategies more broadly.			
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Contents

Acronyms and Abbreviations

Acronym	Definition
A58	Highway A58 in the Netherlands
C5a	Cluster for Cloud to Coast Climate Change Adaptation
CEDR	Conference of European Directors of Roads
CEN	European Committee for Standardization
CMIP	Coupled Model Intercomparison Project
DeTECToR	Decision Support Tools for Embedding Climate Change Thinking on Road (CEDR project)
DOT	Department of Transportation
EU	European Union
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
HEC	Hydraulic Engineering Circular
I-5	Interstate 5
KNMI	Royal Dutch Meteorological Institute
LCA	lifecycle cost assessment
MPO	Metropolitan Planning Organization
NC24	North Carolina Highway 24
NCDOT	North Carolina Department of Transportation
NNBF	Natural and Nature-Based Features
PA	Porous Asphalt
RFQ	Request for Quotations
RIMAROCC	Risk Management for Roads in a Changing Climate (CEDR project)
ROADAPT	Roads Today, Adapted for Tomorrow (CEDR project)
ROK	Richtlijnen Ontwerpen Kunstwerken (Netherlands technical document on bridge design standards)
RRP	Riparian Restoration Program
SGR	Green Space Structure Scheme
SR 167	State Route 167
TAMP	Transportation Asset Management Plan
TEACR	Transportation Engineering Approaches to Climate Resiliency
USACE	U.S. Army Corps of Engineers
WATCH	Water Management for Road Authorities in the Face of Climate Change (CEDR project)
WSDOT	Washington State Department of Transportation
VA	Vulnerability Assessment
VAST	Vulnerability Assessment Scoring Tool

1 Introduction

Both the United States and the Netherlands face flood hazards in coastal and riverine environments that can damage and disrupt highway infrastructure. With climate change, these hazards are becoming more common and severe. Both countries have developed and tested tools to assess transportation infrastructure vulnerability to flooding and other hazards. They have also pioneered efforts to use nature-based solutions such as marsh and dune restoration to reduce flooding, protect transportation infrastructure, and improve water quality and habitat.

Since 2014, the Federal Highway Administration (FHWA) and Rijkswaterstaat, the government agency responsible for transportation and water infrastructure in the Netherlands, have been collaborating on the topic of infrastructure resilience. In the first phase of the collaboration, between 2014 and 2016, the two agencies shared information on strategies, methods, and best practices from both countries to increase the resilience of infrastructure to extreme weather in better, smarter, and more cost-effective ways.

In the second phase of the collaboration, from 2016 through 2018, FHWA and Rijkswaterstaat, along with the Washington State Department of Transportation (WSDOT), implemented and compared climate resilience tools developed by each agency on one transportation project in each country. The tools compared and tested as part of this effort were 1) Roads Today, Adapted for Tomorrow (ROADAPT), a risk-based climate adaptation framework and associated tools developed under sponsorship of the Conference of European Directors of Roads (CEDR) and 2) the FHWA Vulnerability Assessment and Adaptation Framework, a guide and set of associated tools for transportation agencies interested in assessing vulnerability and integrating resilience considerations into transportation decision-making. U.S. and Dutch analysts applied the frameworks and tools to one ongoing transportation infrastructure project in each country: InnovA58, a project to widen a congested highway in the southern part of the Netherlands, and the State Route 167 (SR 167) Completion Project to complete a missing freeway link to Interstate 5 and the Port of Tacoma, Washington.

From 2019 to 2022, FHWA and Rijkswaterstaat continued to collaborate on infrastructure resilience, exploring nature-based solutions that reduce flood hazards to highways and provide environmental benefits. In the United States, highway planning and design primarily takes place at the State level, so the collaboration included two State departments of transportation (DOTs) – WSDOT and North Carolina DOT (NCDOT) – who shared their experience with nature-based resilience strategies on transportation projects. Through monthly conference calls and occasional topic-specific webinars, the partners discussed resources and strategies for nature-based resilience and specific transportation projects that incorporated nature-based strategies. The partners shared lessons learned that could be relevant for transportation projects under consideration by the other agencies. They also shared information on climate resilience strategies more broadly.

1.1 Report Overview

This report summarizes the collaboration on infrastructure resilience between FHWA and Rijkswaterstaat from 2016 to 2022. Part I focuses on the collaboration on nature-based resilience between FHWA, Rijkswaterstaat, WSDOT, and NCDOT and includes the following sections:

- Section 2 provides a brief overview of nature-based solutions and how they are implemented in transportation projects.
- Section 3 discusses overarching climate resilience work at each agency, particularly as it relates to nature-based resilience strategies.
- Section 4 provides case studies of transportation projects in each country that use nature-based strategies to reduce flooding and improve resilience.
- Section 5 documents related topics that were discussed during monthly conference calls and webinars as part of the collaboration, including asset management, sea level rise, and sustainability.

Part II of the report focuses on the comparison of vulnerability assessment and resilience tools from 2016-2018. It includes the following sections:

- Section 6 provides an overview of the collaboration on resilience tools.
- Section 7 describes each of the tools tested and discusses key similarities and differences.
- Section 0 describes the two pilot projects on which the tools were tested, including the ways in which extreme weather is affecting the project locations.
- Section 9 describes the experiences of Rijkswaterstaat and WSDOT in implementing the tools, as well as other approaches to climate resilience applied to the pilot projects. It also discusses benefits and challenges of using each tool and recommendations to improve the tools.
- Section 10 covers related collaboration among the agencies, including sharing information on specific resilience topics through webinars and site visits and the agencies' plans for future infrastructure resilience strategies.

Section 11 concludes the report and discusses next steps for the collaboration.

The Appendix: Planning and Environmental Topics in the Netherlands provides additional information about transportation planning and regulation in the Netherlands, focusing on several topic areas for which the approach to climate resilience or environmental planning differs between the Netherlands and the U.S.: coastal flood defenses, bridge design standards, and nature compensation.

Part I: Nature-Based Solutions for Transportation Resilience

2 Nature-based Resilience for Transportation

Nature-based solutions – also referred to as natural infrastructure, green infrastructure, and engineering with nature – mimic characteristics of natural features and processes but are created by human design and engineering.[1] Nature-based solutions can help reduce erosion, storm surge, and flood risk, and the resulting damage to transportation infrastructure in coastal areas. They also offer ecological benefits such as restored habitat and improved water quality and can enhance recreational opportunities.

Examples of nature-based solutions include conservation, restoration, or construction of beaches, dunes, marsh, mangroves, maritime forests, and reefs.[2] These strategies are typically used as alternatives to traditional shoreline stabilization strategies (i.e., gray infrastructure).

Transportation agencies in both the United States and the Netherlands have pursued nature-based solutions to mitigate flooding, and this area has grown in recent years as flooding risks from climate change have become more prevalent and severe. Focusing on nature-based resilience strategies for this collaboration gave the partners the opportunity to share their experiences, troubleshoot common challenges, and identify ways to expand the use of nature-based strategies in the future.

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[1] FHWA. "Nature-based Resilience for Coastal Highways." https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/green_infrastructure/

[2] FHWA. "Nature-Based Solutions for Coastal Highway Resilience: An Implementation Guide." 2019. https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/green_infrastructure/implementation_guide/

3 Approaches to Transportation Resilience in the United States and Netherlands

FHWA, Rijkswaterstaat, WSDOT, and NCDOT all have agency-wide programs and activities to prepare for the impacts of climate change and enhance the resilience of transportation infrastructure. This section discusses some of this overarching climate resilience work for each agency, particularly as it relates to nature-based resilience strategies.

3.1 FHWA

FHWA supports State DOTs and regional transportation planning agencies in increasing the resilience of their transportation systems. FHWA provides research and technical assistance on assessing vulnerabilities, incorporating resilience into transportation planning and asset management, addressing resilience in project development and design, and considering sea level rise and other factors in hydraulic engineering. It has produced several resources on nature-based solutions in coastal settings to improve the resilience of transportation systems. These resources include:

- An Implementation Guide: Nature-based Solutions for Coastal Highway Resilience, which is designed to help transportation practitioners understand how and where nature-based solutions can be used to improve the resilience of coastal roads and bridges.
- Four regional peer exchanges to facilitate information exchange between transportation practitioners and coastal engineers and ecologists on nature-based solutions to protect roads from coastal flooding, and a summary report that includes project examples, successful approaches, and challenges in planning, permitting, design, and maintenance.
- Partnerships with State DOTs and others on five pilot projects to assess the potential for natural infrastructure to protect specific locations along coastal roads and bridges.

3.2 Rijkswaterstaat

Assessing Vulnerability and Determining Risk

To map and understand vulnerabilities to climate change and extreme weather, Rijkswaterstaat undertook a “stresstest” of the road network. The stresstest considered:

- Pluvial flooding (effect of flooding due to rainfall, including puddles on the road, poor visibility, erosion and instability of road embankments, and uplift of tunnels)
- Fluvial (riverine) and coastal flooding
- Heat
- Drought

Rijkswaterstaat mapped the vulnerability of the road network to each hazard (see Figure 1). They then considered the risk of the hazards expressed in annual expected costs (damages and losses) for both present day and 2050. To verify the results of the stresstest and identify measures to reduce risk, Rijkswaterstaat held a series of regional risk dialogues with asset managers and other regional stakeholders. The goal of the risk dialogues was to confirm the most important climate risks, identify hotspots for each risk, identify the acceptable level of resilience by developing a risk matrix (see Figure 2), and identify adaptation measures and where to start implementing them.

Figure 1: Map of highway stress test results showing risk of pluvial flooding (Source: Rijkswaterstaat)

Change	Effect			
	1: Negligible	**2: Limited**	**3: Huge**	**4: Severe**
1: Negligible	Acceptable	Acceptable	Acceptable	Acceptable
2: Small	Acceptable	Acceptable	Undesirable	Undesirable
3: Average	Acceptable	Undesirable	Undesirable	Undesirable
4: Huge	Acceptable	Undesirable	Undesirable	Unacceptable
5: Certain	Undesirable	Undesirable	Unacceptable	Unacceptable

Figure 2: Example risk matrix from regional risk dialogues. The table cells are categorized by risk; low change and low effect leads to acceptable risk, while high change and high effect leads to unacceptable risk. (Source: Rijkswaterstaat)

C5a project

Rijkswaterstaat is leading an initiative of the Interreg North Sea Region Programme called Cluster for Cloud to Coast Climate Change Adaptation (C5a). The aim of the C5a project is to enable greater integration and innovation in the adaptation to the physical, economic and social impact of flooding taking into account climate change. The C5a project includes case studies of ongoing projects in the North Sea region to make sure that the approach developed is evidence-based and practical.

Cloud-2-Coast approach

The C5a project aims to create a "Cloud-2-Coast" approach for adaptation, focusing on integrating different systems (catchment, coasts, cities, and infrastructure networks). The Cloud-2-Coast approach promotes the adoption of a whole-system and long-term perspective to climate change adaptation that is purposeful, collaborative and builds on the principles of social justice, ecosystem health, and resilience.

The Cloud-2-Coast approach has been in development since 2021 and is based on four pillars to deliver a resilient society: 1) adaptive approach, 2) inclusive process, 3) whole system response that works with natural processes, and 4) an ongoing, continuous dialogue to make it happen (see Figure 3).

The C5a project team also reviewed and summarized a series of supporting tools from across the contributing Interreg North Sea Region Programmes, which have been added to interactive webpages.

Looking ahead

All partners worked together towards the concluding event in May 2022 in Sweden. After finishing developing the Cloud-2-Coast approach, the focus will be on the uptake of the approach. The project team will also discuss how this approach can be helpful in the U.S. context.

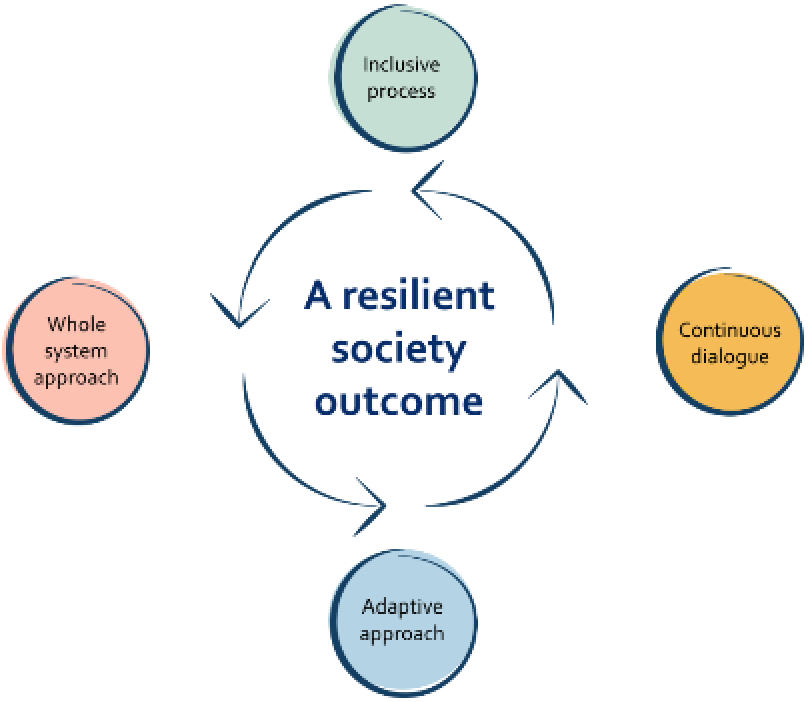

Figure 3: Four pillars of the Cloud-2-Coast approach to achieve an outcome of a resilient society (Source: Rijkswaterstaat)

3.3 WSDOT

WSDOT completed a statewide climate impacts vulnerability assessment in 2011 with support from FHWA. Since then, the agency has worked to incorporate its understanding of climate change impacts and ways to improve resilience across all of its transportation projects and programs. A resilient and sustainable transportation system is part of WSDOT's strategic plan and statewide asset management plans.

WSDOT's Resiliency Workgroup was chartered in 2020. The workgroup is the nexus of all the agency resilience activities. It unites the efforts of emergency management, seismic, safety, cyber security, and asset management. The workgroup's purpose is to coordinate and collaborate across programs to ensure a resilient system is prepared for and adaptable to changing conditions and able to withstand and recover rapidly from disruptions. The workgroup brings recommendations to the asset management executive steering committee and to senior leaders for decision making. Under the umbrella of the workgroup, WSDOT created the Climate and Natural Hazards Subgroup in May 2021. Also in 2021, the State legislature passed significant new laws related to enhancing resilience. These include the Climate Commitment Act, the Healthy Environment for All (HEAL) Act and the addition of resilience to the state's transportation system policy goals, RCW 47.04.280.

Some of WSDOT's design-level guidance integrates projections of climate impacts, including the water crossings chapter (7-4) of the WSDOT Hydraulics Manual (M 23-03.07) and Washington State Ferries Terminal Design Manual (M3082.05). WSDOT also considers climate change and future conditions in the design of new culverts to facilitate fish passage (see Section 4.2 for more information on the design of specific projects).

3.4 NCDOT

In 2020, North Carolina released its Climate Risk Assessment and Resilience Plan. The plan was developed in response to the State's Executive Order 80, which requires all cabinet agencies to evaluate the impacts of climate change and integrate climate change mitigation and adaptation practices into their programs and operations.

The Resilience Plan includes:

- Climate projections specific to North Carolina that will be used statewide
- Climate justice considerations
- Vulnerability, risk, and resilience strategies for addressing climate-related hazards for key sectors, including transportation
- Recommendations for nature-based solutions to resilience

Chapter 7 of the Resilience Plan mapped a path forward to a climate resilient North Carolina and provided guiding principles from which to frame the state's future actions on climate resilience. Building off of this statewide plan, NCDOT published its first annual Resilience Strategy Report in March 2021. This report documents the department's resilience-related activities of the past year and describes future objectives, studies, and projects. In preparation of this first annual report, NCDOT recognized that to develop organization-wide resilience, the Department needed to deploy a coordinated approach. To amalgamate all its resilience efforts, a Resilience Policy was adopted that defined resilience for NCDOT and directs all business units to be resilient to disruption.

3.5 Collaborative Efforts

The U.S. Army Corps of Engineers (USACE) and Rijkswaterstaat have been collaborating on water management issues for many years. Building off a memorandum of understanding signed in 2004, the agencies have worked together on topics including flood control, water resources management, and resilience.

In September 2021, a collaborative effort led by USACE in partnership with Rijkswaterstaat, the Environment Agency in the United Kingdom, and numerous other organizations, released the International Guidelines on Natural and Nature-Based Features (NNBF) for Flood Management. The guidelines were developed through five years of collaboration and knowledge sharing with subject matter experts and practitioners from around the world. They provide practitioners with information on the conceptualization, planning, design, engineering, construction, and maintenance of NNBF to support resilience and flood risk reduction for coastlines, bays, and estuaries, as well as river and freshwater systems. The aim of the guidelines is to inform efforts to increase the performance of flood risk management systems and achieve long-term risk mitigation, increase water infrastructure resilience and sustainability, reduce infrastructure maintenance and repair costs, and increase the value produced by flood risk management infrastructure investments.[3]

Over the course of the FHWA/Rijkswaterstaat collaboration on nature-based solutions, representatives from Rijkswaterstaat provided updates on the development of the international guidelines and their relevance to project partners.

[3] Bridges, T. S., J. K. King, J. D. Simm, M. W. Beck, G. Collins, Q. Lodder, and R. K. Mohan, eds. 2021. Overview: International Guidelines on Natural and Nature-Based Features for Flood Risk Management. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

4 Projects Incorporating Nature-Based Strategies

Throughout the collaboration, the partners discussed specific transportation projects in each country that incorporated nature-based strategies to improve resilience and address flooding. These included the Houtribdijk dam project in the Netherlands, fish passage projects and the State Route (SR) 167 Completion Project in Washington State, and North Carolina Highway 24 and the Neuse River Basin study in North Carolina.

Discussing nature-based strategies through the lens of these projects allowed the partners to share best practices, troubleshoot any issues on the projects, and discuss how similar projects could be implemented in other locations.

4.1 Rijkswaterstaat

The Houtribdijk dam is located in between two lakes in the northeast part of the Netherlands. It is essential for flood management and regulating the water levels in Lake Marken and Lake IJssel. A road (N307) and a bicycle path are located on top of the dam; if the road did not exist, vehicles would need to make a 200-kilometer (124-mile) detour to get across the lakes.

In 2006 the levee failed an assessment of flood risk protection, necessitating reinforcement required by law. To reinforce the dam, the project team considered natural and nature-based features and determined that this approach was cost effective and feasible. They developed a sandy shore nature preserve to provide flood protection and benefit ecosystems in the area (see **Error! Reference source not found.**). This was the first constructed sandy shore project in a non-tidal freshwater lake system to ensure protection from flooding. The project was designed to withstand a 10,000-year storm event. Design was based on assumptions derived from previous projects in the coastal environment along with expert judgement. An adaptive management approach will be followed to determine how to manage changes and to inform engineering of similar projects in the future. A monitoring and research program to evaluate the performance of the sandy shore project, in collaboration with Delft University of Technology, will last from 2018 to 2023.

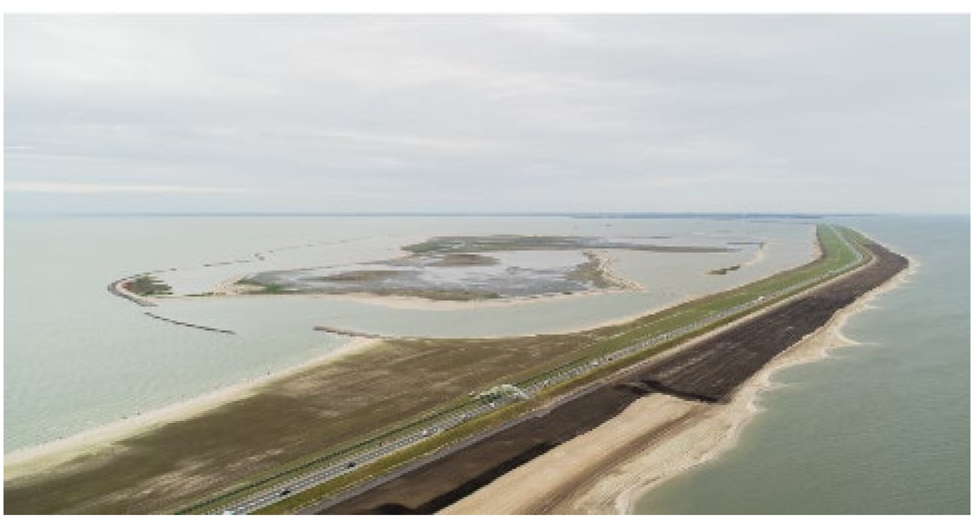

Figure 4: Houtribdijk sandy shores project (Source: Rijkswaterstaat)

The initiation of this innovative project and its adaptive management method led to two other levee reinforcement projects using the same principles. One of these projects, Markermeerdijken, is currently under construction, and the other, IJsselmeerdijk: Leystand-Ketelbrug, is in the final stage of decision making.

4.2 WSDOT

Fish Passage Projects

WSDOT is retrofitting numerous culverts to facilitate fish passage. These projects are designed based on anticipated future changes in precipitation. The fish passage design is more resilient to increased debris flow as well as more intense rain events. Examples of fish passage projects that also enhance climate resilience include:

- SR3 Chico Creek – Bremerton, WA: This project fixes five culverts that are barriers to fish passage. The narrow culverts also change the angle of how Chico Creek flows into Chico Bay and Dyes Inlet. The project will provide access to about 21 miles (34 kilometers) of habitat. It will also reduce future maintenance costs due to culvert blockages by removing undersized culverts and minimize the risk for upstream flooding. The completed project replicates natural conditions for fish while providing more resilient water crossing structures for transportation users and the community.
- SR 101 Coffee Creek – near Shelton, WA: The objective of the project was to replace an existing fish barrier. Using a stream realignment, the project reduced the number of crossings down to one resulting in a significant reduction in maintenance costs. The habitat and channel complexity features provided a more resilient stream for long-term habitat. The new stream alignment was designed to accommodate flood flows with minimal risk to the surrounding area.
- SR 203 Loutis Creek – near Duvall, WA (see Figure 5): The objective of the project was to replace an existing fish barrier as well as provide for historic floodplain connectivity in the area. The culvert used in this project was the first of its kind using fiberglass arch tubes filled with concrete. This was an innovative way to design a resilient structure that can achieve the project objectives. The floodplain within the project limits was also restored with habitat features to ensure resiliency of the crossing.
- Tahlequah Ferry Terminal Slope Stabilization - Vashon Island, WA (see Figure 6): Washington State Ferries completed a project to restore 700 feet (213 meters) of shoreline for habitat for

Figure 5: Fish passage project at SR203 Loutis Creek (Source: WSDOT)

Figure 6: Tahlequah slope stabilization project (Source: WSDOT)

forage fish and restore fish passage to nearly 5,000 feet (1,524 meters) of stream through Tahlequah Creek. The project site is just west of the Tahlequah Ferry Terminal, on Washington State Ferries' southernmost route in Puget Sound. The project involved removing concrete bulkhead, retaining wall, and creosote-treated timber piles, adding natural materials such as anchored logs, boulders, beach sediment, and planting over 2,400 plants.

SR 167 Completion Project

The SR 167 Completion Project will build the remaining four miles (6.4 kilometers) of SR 167 between Meridian and Interstate 5 (I-5), completing a long-planned connection to I-5. WSDOT has completed the initial phase of this project (stage 1a); construction on the next phase (stage 1b) will occur from 2021 to 2026, and the final phase (stage 2) will be constructed from 2024 to 2028.

Parts of this project are within the Hylebos Creek watershed area, where habitat and water quality have been degraded by development. This area also frequently faces flooding, particularly in the wet season (October to April). In addition, expected sea level rise in Commencement Bay, to the west of the project site, will increase tidal backwatering in the creek. Therefore, WSDOT designed the new highway segment to provide extensive restoration of degraded wetland and low-quality agricultural land through an effort called the Riparian Restoration Program (RRP) (see Figure 7). WSDOT expects that the RPP will measurably decrease future flood risk in the area, improve floodwater conveyance, reduce peak flood levels, and prevent flooding on I-5. It will also eliminate the need for traditional stormwater flow control facilities. The RRP is also a climate adaptation strategy, as the expanded floodplain will provide more space for the creek floodwater and tidal backwater to occupy as sea levels rise.

The SR 167 Completion Project was used as a pilot project during the previous collaboration between FHWA and Rijkswaterstaat to test tools for evaluating climate vulnerability. This project was also included in a U.S. Government Accountability Office report, [Climate Resilience: Options to Enhance the Resilience of Federally Funded Roads and Reduce Fiscal Exposure], as an example of a project that used FHWA resilience resources and climate projection information to plan or implement resilience enhancements.

Figure 7: Riparian Restoration Program design (Source: WSDOT)

4.3 NCDOT

NC24 Nature-based Design

NCDOT has developed a living shorelines nature-based design for a project on North Carolina Highway 24 (NC24). The project is located on a causeway in the coastal eastern North Carolina. Partial funding for the improvements using a nature-based design came from a grant from the Fish and Wildlife Service and the North Carolina Coastal Federation. Environmental coordination and permitting with both State and Federal agencies highlighted some regulatory obstacles that need to be addressed. While the USACE offers more streamlined Nationwide Permits under the Clean Water Act for living shoreline projects, initial impact levels triggered a more complicated Individual Permit. NCDOT had to modify the design of the living shoreline – the initial design extended up to 200 feet (61 meters) from the causeway, and the modified design extends only approximately 60 feet (18 meters). Agency coordination on this project has helped define important project regulatory parameters, such as Purpose and Need, so that future projects will experience easier implementation.

Neuse River Basin Study

NCDOT funded a North Carolina State University study to evaluate nature-based approaches to reduce impacts of riverine flooding in the Neuse River basin in eastern North Carolina. This area of the State has experienced severe riverine flooding due to hurricanes and storms in recent years. The study used modeling to assess the impact on flooding of implementing natural infrastructure, including reforestation, water farming, and flood storage wetlands. The study also evaluated the costs and secondary economic benefits of implementing these natural infrastructure strategies.

The study identified approximately 112,737 acres (456 square kilometers), constituting 10.5 percent of the middle Neuse Basin, as suitable for these natural infrastructure measures. In areas with a high density of natural infrastructure adoption, the study found that damage to structures and associated repair costs could be substantially reduced.

5 Other Topics Explored During the Collaboration

Information sharing was an integral part of the collaboration between FHWA, Rijkswaterstaat, NCDOT, and WSDOT. Through monthly conference calls and webinars, the agencies exchanged information on nature-based resilience strategies and explored other topics related to resilience, including asset management, sea level rise, and sustainability/sustainable materials.

5.1 Resilience in Asset Management

FHWA encourages State DOTs to address risk within their investment strategies as they develop their required Transportation Asset Management Plans (TAMPs) and provides technical assistance and resources to State DOTs to help them do so. Between 2017 and 2019, FHWA supported pilots in six States to integrate resilience considerations into their asset management processes. FHWA is also developing a handbook to assist State DOTs in addressing resilience in asset management processes, particularly TAMPs. The handbook covers:

- developing asset inventories informed by natural hazard/vulnerability assessments,
- identifying and managing risks,
- conducting life cycle planning that considers climate change risks, and
- establishing resilient investment strategies and financial plans.

WSDOT is considering risk and resilience in its asset management practices in several ways. In 2021, each of the WSDOT Programs and Modes updated their asset management plans at the request of WSDOT Executives. The Statewide Asset Management group prepared instructions, including adding a resilience section to the risk chapter. The asset management plan updates will inform future budget development processes.

NCDOT is incorporating resilience in asset management by focusing on flood risk. Asset management covers all phases of a project life cycle, from long range planning to design to maintenance and operations. NCDOT considers flood risk and resilience at each stage of the process. They also have a Statewide asset management plan that includes a risk management analysis.

Rijkswaterstaat considered resilience in asset management as part of its highway stresstest and regional risk dialogues. For example, adaptation measures identified in the risk dialogues involved mainstreaming adaptation into performance management, maintenance, and the replacement and renovation program.

5.2 Sea Level Rise

Washington State Ferries, a division of WSDOT, began to design for sea level rise in 2016. Based on sea level rise projections from the University of Washington's Climate Impacts Group, they used a 13-inch (33-centimeter) sea level rise projection for Puget Sound in 2100 for two recent projects: reconstruction of the Seattle Ferry Terminal and construction of the Mukilteo Ferry Terminal. Based on more recent projections noted below, sea level is projected to rise approximately 24 inches (61 centimeters) over the same time frame (based on a 50 percent probability of exceedance).

In 2018, the Climate Impacts Group released a series of sea level rise projections for Washington State. In addition to sea level rise, the model also considers vertical land movement, an important factor in seismically active western Washington. Washington State Ferries is currently working to incorporate these projections in combination with storm wave modeling into a Sea Level Rise Vulnerability Assessment tool. This tool will determine impacts to sea level rise on existing and new structures. Sea level rise risk on existing terminals will be included in the Washington State Ferries Terminal Asset Management Plan to define the asset State of Good Repair and to aid in future prioritization of projects. Strategies for the design of new structures include modifying moveable span lengths, raising support elevations, and armoring utilities. New structures will be designed with an adaptive management approach to prepare for future sea level rise. For example, a structure would be designed for a 30-year sea level rise and, based on the actual rise after 30 years, would be raised or otherwise adapted for the subsequent 30-year projection. Washington State Ferries may explore the use of floating structures for movable bridges to accommodate both daily tidal fluctuations and future sea level rise.

In North Carolina, the Coastal Resources Commission developed sea level rise reports starting in 2010. The North Carolina General Assembly limited the projections to 30 years in the future and required updating the projections every five years. More recently, the North Carolina Climate Science Report released in 2020 by the North Carolina Institute for Climate Studies looked at projections for the next 100 years. In addition to sea level rise, NCDOT is looking at the impact of the combination of sea level rise and storm surge. NCDOT has developed a Coastal Roadway Inundation Simulator that overlays projected inundation levels with a roadway map, providing a resource for planners (see Figure 8).

Figure 8: North Carolina Coastal Roadway Inundation Simulator Tool (Source: NCDOT)

NCDOT also conducted a probabilistic sea level rise study for NC24. The results of this study will be used for future adaptive management strategies on the roadway. NCDOT has also done analyses specific to certain assets, such as the Alligator River Bridge. This 3-mile-long coastal bridge is being rebuilt, and NCDOT is considering sea level rise and storm surge modeling to design the bridge for a 100-year lifespan.

The Netherlands Sea Level Rise Research Program takes a long-term approach, looking at projections for sea level rise from 0.5 up to 5 meters (1.6 to 16.4 feet). Rijkswaterstaat is working on a research project, part of the larger Sea Level Rise Research Program, to evaluate:

- The physical impact of sea level rise on current flood risk management strategies of the national Deltaprogramme,

- At what point current strategies are still applicable, and
- How to “stretch” the current strategies and explore other strategies.

The goals of the Dutch coastal policy are to provide equal protection to flooding for everyone in the Netherlands, to grow with sea level rise, and to maintain coastal functions to support recreation, ecological value, and drinking water supply. The Netherlands is already facing impacts from sea level rise and coastal erosion and aims to maintain its current “reference coastline” by adding sand (see Figure 9).

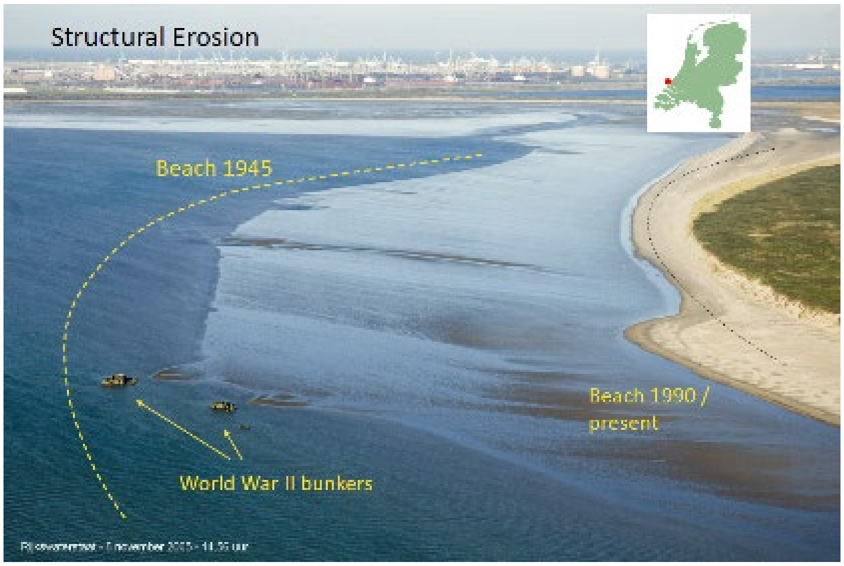

Figure 9: Coastal erosion between 1945 and 1990 in the Netherlands. Since 1990, they have been adding sand to maintain the coastline. (Source: Rijkswaterstaat)

5.3 Sustainability and Sustainable Materials

Rijkswaterstaat’s sustainability goals include:

- Becoming a carbon neutral organization by 2030
- 100 percent circular work (staying within planetary boundaries for material use) by 2050
- Sustainable land use

These goals are translated into sustainability focus areas around sustainable business operations, sustainable infrastructure and procurement, sustainable land and water management, and contributing to the energy transition by producing renewable energy. On the topic of sustainable procurement, Rijkswaterstaat aims to procure sustainable materials for road pavements, structures, waterway and coastline maintenance, and construction. They also use sustainability as a criterion when awarding contracts. Innovation is a key aspect of sustainable procurement, and one role of Rijkswaterstaat is to act as a “launching customer” for innovative companies.

In the U.S., several States, including California and Colorado, have State-level green purchasing initiatives. Through the Sustainable Pavements Program, FHWA works closely with States on building knowledge around lifecycle cost assessment (LCA) and sustainable purchasing. FHWA developed a pavement LCA tool that can be used to assess environmental impacts of pavement material and design decisions.

Part II: Collaborative Application of Transportation Infrastructure Resilience Tools

6 Tools Comparison Overview

From 2016 to 2018, FHWA and Rijkswaterstaat conducted an applied comparison of a suite of resilience tools developed and/or used by the respective agencies. The tools compared as part of this effort were:

- Rijkswaterstaat resilience tools: Roads Today, Adapted for Tomorrow (ROADAPT), a risk-based climate adaptation framework and associated tools developed under sponsorship of the Conference of European Directors of Roads (CEDR).[4]
- FHWA resilience tools: FHWA Vulnerability Assessment and Adaptation Framework, a guide and set of associated tools for transportation agencies interested in assessing vulnerability and integrating resilience considerations into transportation decision-making.

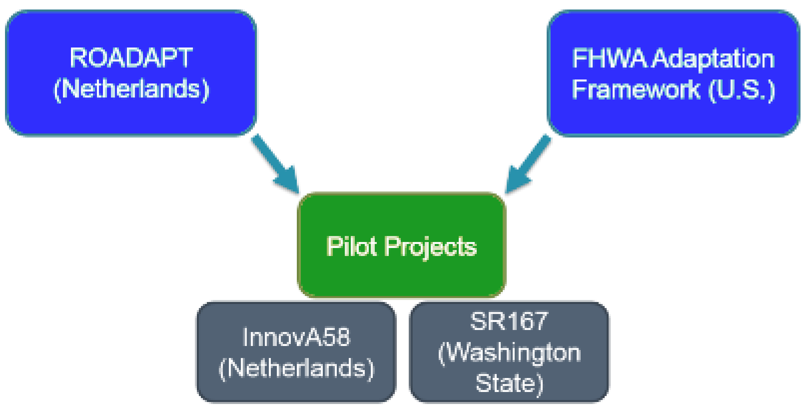

Figure 10: Structure of the tools comparison project

The frameworks and tools were applied to one ongoing transportation infrastructure project in each country (see Figure 10). Rijkswaterstaat applied the tools on the InnovA58, a project to widen a highway in the southern part of the Netherlands. FHWA, in coordination with WSDOT, applied the tools on the State Route 167 (SR 167) Completion Project, which will construct the last remaining 6.4 kilometers (4 miles) of highway to connect with the Interstate 5 highway near Tacoma, Washington and an additional 3.6 kilometer (2.2 mile) segment to State Route 509 that serves the Port of Tacoma. In implementing the tools, the agencies aimed to both improve the resilience of those transportation projects and identify potential enhancements to the tools that would make them easier to use and more effective for other infrastructure projects.

[4] CEDR is an organization that serves as a platform for the European Directors of National Road Authorities to cooperate and promote improvements to the road system and infrastructure in Europe.

7 Resilience Tools

Climate resilience tools have been developed in both Europe and the United States to help transportation agencies find and analyze relevant data, identify vulnerabilities to extreme weather, and develop adaptation strategies. Such tools allow transportation agencies to:

- Follow established methodologies developed by experts.
- Reduce the need to devise new processes for their analysis.
- Simplify and automate some of the analysis required for conducting a vulnerability assessment, such as processing downscaled climate model data or calculating vulnerability scores.
- Build a shared understanding of vulnerabilities and adaptation strategies (for example, by helping an agency compare vulnerabilities across multiple assets using consistent data and methodologies).

The suite of tools tested as part of this project assist transportation agencies in conducting vulnerability assessments and assessing strategies to build resilience. Vulnerability assessments involve analyzing the impact of climate and extreme weather on transportation infrastructure, and can focus on particular assets or classes of assets, or on a region's transportation system as a whole. Agencies can use the results of a vulnerability assessment to develop strategies to address the vulnerabilities identified and to increase resilience.

This section provides an overview of the Rijkswaterstaat and FHWA resilience tools and discusses key similarities and differences.

7.1 ROADAPT

Roads for Today, Adapted for Tomorrow (ROADAPT) was developed in response to the CEDR 2012 research program "Road owners adapting to climate change." The ROADAPT tool consists of five parts:

- Part A provides guidelines for producing focused and consistent climate data and information with which to determine the impact of extreme weather and climate change on national and international motorways in Europe.
- Part B was designed to quickly and efficiently determine the effects of climate change on infrastructure using an approach called Quickscan. In the Quickscan methodology, groups of stakeholders filter relevant threats from a comprehensive list, identify the risks those threats pose to transportation assets, and identify potential adaptation strategies.
- Part C offers methods for determining vulnerability to extreme weather and climate change using a geographic information systems (GIS) approach.
- Part D helps determine the socio-economic impact of the consequences of extreme weather and climate change on roads.
- Part E provides a 10-step process for selecting adaptation strategies for limiting the impact of extreme weather and climate change, as well as a list of potential adaptation measures for different climate threats.

The intended audience of ROADAPT is a broad spectrum of professionals within national road authorities, including road engineers, asset managers, climate adaptation professionals, and project managers. It follows a risk-based approach using the Risk Management for Roads in a Changing Climate (RIMAROCC) framework, a risk management framework familiar to road owners in Europe.[5]

7.2 The FHWA Vulnerability Assessment and Adaptation Framework and Related Tools

The FHWA Vulnerability Assessment and Adaptation Framework (FHWA Framework) is a guide for transportation agencies interested in assessing their vulnerability to extreme weather events and integrating the results into decision-making. The FHWA Framework discusses the key steps in conducting a vulnerability assessment and provides options for how the process can be conducted with varying levels of effort and resources – for example, through a stakeholder-based assessment or a project-level engineering analysis.[6] In addition to the Framework, FHWA developed several associated tools and resources[7] that support transportation practitioners with conducting particular aspects of the vulnerability assessment process. These tools and resources include:

- The Sensitivity Matrix is a spreadsheet tool that documents the sensitivity of roads, bridges, airports, ports, pipelines, and rail to 11 climate impacts. Sensitivity refers to how an asset or system fares when exposed to a climate or extreme weather impact.
- The Guide to Assessing Criticality in Transportation Planning is a short report that describes common challenges associated with assessing criticality, options for defining criticality and identifying scope, and the process of applying criteria and ranking assets.
- The CMIP Climate Data Processing Tool is a spreadsheet tool that processes raw climate model outputs from the World Climate Research Programme's Coupled Model Intercomparison Project (CMIP) CMIP3 and CMIP5 databases into relevant statistics for transportation planners, including changes in the frequency of very hot days and extreme precipitation events that may affect transportation infrastructure and services by the middle and end of the century.[8]
- The Vulnerability Assessment Scoring Tool (VAST) is a spreadsheet tool that guides users through conducting a quantitative, indicator-based vulnerability screening. It is intended for agencies assessing how components of their transportation system may be vulnerable to climate stressors.
- The Transportation Engineering Approaches to Climate Resiliency (TEACR) study provides detailed information to a range of engineering disciplines on integrating climate considerations into transportation project development. The project includes a Synthesis Report, the Adaptation Decision-Making Assessment Process tool, and case studies covering the topics of coastal and riverine hydraulics, pavement and soils, and economic analysis.

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[5] Risk Management for Roads in a Changing Climate: A Guidebook to the RIMAROCC Method (2010). Available at http://www.cedr.eu/download/other_public_files/research_programme/eranet_road/call_2008_climate_change/rimarocc/01_Rimarocc-Guidebook.pdf

[6] During the course of this project, FHWA released the Third Edition of the Framework. The Third Edition contains additional information on obtaining climate data, integrating results into decision-making, and results from FHWA pilot projects. The overall approach suggested in the Framework did not change, nor did the associated tools described in this section.

[7] The tools are available for download at: https://www.fhwa.dot.gov/environment/sustainability/resilience/tools/

[8] FHWA updated the CMIP Climate Data Processing Tool in 2020 to use the CMIP5 LOCA downscaled dataset. This report references the previous version of the tool, since that was the most recent version at the time of analysis. The updated tool and User's Guide are available at: https://www.fhwa.dot.gov/engineering/hydraulics/software/cmip_processing_tool_version2.cfm

- Hydraulic Engineering Circular (HEC) 17: Highways in the River Environment and HEC 25: Highways in the Coastal Environment, Volume 2 are resources on incorporating extreme weather, risk, and resilience into the design of highways in coastal and riverine environments.[9]

7.3 Key Similarities and Differences

Overall, ROADAPT and the FHWA Framework share many similarities; however, they do differ in a number of small yet important ways. Table 1 summarizes the key elements of ROADAPT and the FHWA Framework and tools and highlights the major similarities and differences between the two.

The two frameworks follow a similar overall approach of identifying potential vulnerabilities of transportation systems or assets and identifying adaptation strategies. Both define vulnerability as a function of exposure, sensitivity, and adaptive capacity. However, adaptive capacity is not stressed in the ROADAPT methodology; the ROADAPT Part C guidelines state that this is because adaptive capacity depends on factors related to the road owner/operator (e.g., budget, level of training, workforce size) and is likely to be constant across a road owner/operator's assets and across different threats. In contrast, the FHWA approach defines adaptive capacity as the ability of the transportation system or asset to adapt, and includes indicators such as detour route or system redundancy, which could vary across a road owner/operator's assets.

A key difference between the two approaches is how they address risk. Risk considers the likelihood of an impact as well as the severity or consequence of the impact. While the FHWA Framework discusses risk and recommends that agencies consider the likelihood and consequence of climate impacts, risk is not a central component of how the Framework presents vulnerability assessments. On the other hand, risk is a key aspect of the ROADAPT methodology. For example, the ROADAPT Quickscan method leads participants through identifying relevant threats and consequences of those threats, as well as the likelihood of these threats occurring. This process leads to a list of the greatest risks to the transportation system, which can then be spatially analyzed with the ROADAPT Vulnerability Assessment method.

Specific steps of the two methodologies are also comparable. For example, the following components are included in both tools:

- Identify how assets are likely to be affected by climate threats: Table of Threats in ROADAPT Part B and the FHWA Sensitivity Matrix tool.
- Describe methodologies for a stakeholder-based, qualitative vulnerability assessment: ROADAPT Quickscan methodology and FHWA Framework narrative on a qualitative approach based on institutional knowledge.
- Provide tools for a data-driven vulnerability assessment: ROADAPT Part C and the FHWA VAST tool.
- Provide information about developing adaptation strategies based on known vulnerabilities: ROADAPT Part E and database of adaptation measures, and FHWA Framework narrative on

[9] FHWA updated HEC-25 in 2020, and the latest version is available at: https://www.fhwa.dot.gov/engineering/hydraulics/pubs/hif19059.pdf

incorporating the results of the vulnerability assessment into decision-making, including identifying and prioritizing adaptation strategies.

Table 1: Comparison of key elements of ROADAPT and FHWA Tools

Topic	ROADAPT Framework	FHWA Vulnerability Framework
Summary	Provides methodologies and tools to develop tailored and consistent climate data and information, a preliminary and fast "Quickscan" for estimating the climate-related risks for roads, a vulnerability assessment, a socioeconomic impact analysis, and an action plan for adaptation.	Provides an overview of key steps in assessing vulnerability to extreme weather, and uses in-practice examples to show a variety of ways to approach the vulnerability assessment. Accompanied by tools for assessing criticality, conducting a sensitivity analysis, processing downscaled climate data, and scoring a vulnerability assessment. Provides information on incorporating results of vulnerability assessment into decision-making.
Intended audience	National road authorities; broad range of professionals including road engineers, asset managers, climate adaptation professionals, and project managers.	State departments of transportation (DOTs), metropolitan planning organizations (MPOs), and other agencies involved in planning, building, maintaining, or operating transportation infrastructure.
Definition of vulnerability	Adopts a risk-based approach by looking at how and where climate change will affect roads, the likelihood of these impacts, what the consequences of these impacts are, and what should be done to mitigate risks and when. Defines risk as a function of threat, vulnerability and consequence. Defines vulnerability as a function of sensitivity, exposure and adaptive capacity (however, adaptive capacity is assumed to be constant across an asset owner's assets, so it is not included in the tool).	Defines vulnerability as a function of a transportation system's exposure, sensitivity, and adaptive capacity. A vulnerability assessment may also incorporate risk, which considers the severity or consequence of an impact with the probability that an asset will experience a particular impact.
Sensitivity analysis	There is no specific sensitivity analysis but determining which types of assets are sensitive follows from the Table of Threats in the ROADAPT Quickscan appendix.	The Sensitivity Matrix is a spreadsheet tool that documents the sensitivity of roads, bridges, airports, ports, pipelines, and rail to 11 climate impacts. For each asset type, it lists undesirable events that could take place as a consequence of a certain climate stressor.
Stakeholder approach	The ROADAPT Quickscan helps determine the (generic) biggest risks in the area under consideration. It involves a series of workshops where stakeholders determine relevant weather-related hazards and threatened assets, and prioritize the relevant threats.	Framework describes in a general way a qualitative, stakeholder approach based on institutional knowledge.
Assessing vulnerabilities	The ROADAPT Vulnerability Assessment aims to determine the most vulnerable locations for each undesirable event using a GIS-based	The FHWA VAST tool aims to determine the most vulnerable assets for one or more climate aspects (stressors) or undesirable events. It is a spreadsheet-

Topic	ROADAPT Framework	FHWA Vulnerability Framework
	approach. Spatial data is needed as an input, and the output is a series of maps.	based tool that requires as an input information regarding the exposure, sensitivity, and adaptive capacity of each asset to be analysed.

8 Pilot Projects

The partner agencies each selected a transportation project that is vulnerable to the impacts of extreme weather events to apply the resilience tools. Rijkswaterstaat chose the InnovA58 project; WSDOT and FHWA choose the SR 167 Completion Project in Washington State. In addition to being vulnerable to extreme weather, both pilot projects are located on highly congested, major freight corridors. This section describes each project, including the ways in which each is affected by extreme weather.

8.1 InnovA58, the Netherlands

The A58 highway in the southern part of the Netherlands currently has two lanes in each direction. The highway experiences congestion due to significant international freight traffic and commuting between satellite cities within the Netherlands. This congestion has led to frequent accidents and traffic jams at junctions along the highway. To address these issues, Rijkswaterstaat is planning to add a lane in each direction on two heavily congested segments: a 28 kilometer (17.4 mile) segment between Tilburg and Eindhoven and a 7 kilometer (4.3 mile) segment south of Breda (see Figure 11). Dubbed InnovA58, this project will be a “living lab” that tests and implements innovations such as smart mobility, climate resilience, public involvement, and waste reduction and reuse. Due to regulations on environmental impacts of road projects, especially nitrogen emissions impacting nature, this project has been delayed. As of January 2023, construction is expected to start in 2028. An innovation area, a test location for sustainable road construction along the A58 near the city of Eindhoven, has been realized.[10]

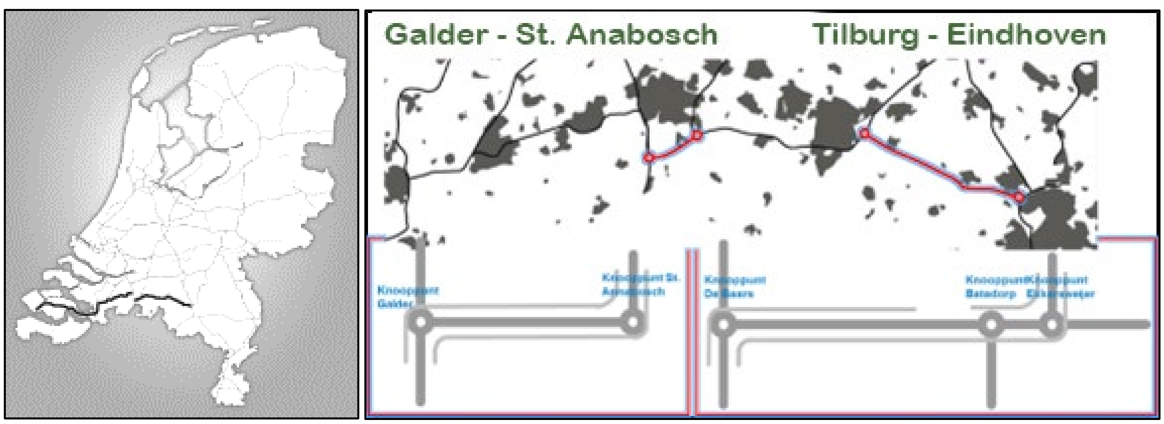

Figure 11: Location of A58 highway within the Netherlands (left) and location of the InnovA58 project (right). The InnovA58 project involves widening the highway between the Galder and St. Annabosch interchanges and between the De Baars and Ekkersweijer interchanges (Source: Rijkswaterstaat).

Twenty-six percent of the Netherlands is below sea level and 60 percent of the country is vulnerable to flooding from the sea, rivers, and canals. The Netherlands has been taking action to prevent flooding for hundreds of years. Following a disastrous flood in 1953, the Netherlands funded and constructed the Delta Works, a network of storm surge barriers, dikes, dunes, and sand nourishment projects. Today, flood risk protection is strongly regulated in the Netherlands on a national level, as described in the Delta Program.[11] The Netherlands’ national flood risk management policy aims to ensure that by no later

[10] Rijkswaterstaat 2022. Innovatiestrook A58 Kloosters officieel geopend (Innovation strip A58 officially opened). https://www.rijkswaterstaat.nl/nieuws/archief/2022/07/innovatiestrook-a58-kloosters-officieel-geopend

[11] Delta Programme 2019. Continuing the work on the delta: adapting the Netherlands to climate change in time. https://english.deltacommissaris.nl/documents/publications/2018/09/18/dp2019-en-printversie

than 2050, the probability of fatality due to flooding will be reduced to 1 in 100,000 per year (.001%) or less for every resident living behind the dikes. In response to expected increased flood risks in the future, Rijkswaterstaat is raising levees, adding natural protective features, and expanding floodplains to allow for more water storage.

For road projects in the Netherlands generally no calculations are made regarding protection from river or coastal floods, as the flood protection standards have been set in the Delta Program. Due to the high level of protection provided by the flood defenses, roads are typically not designed with flooding in mind (since the likelihood of failure of the flood defenses is unlikely). Road authorities rely on Rijkswaterstaat and regional water boards for flood protection and for addressing sea level rise. For more information about the Netherlands approach to coastal flood defense, see the Appendix.

The likelihood of pluvial flooding is much higher than the likelihood of flooding from failure of flood defenses in the Netherlands. Pluvial flooding, also called surface water flooding or urban flash flooding, occurs when heavy rainfall saturates drainage systems and the excess water cannot be absorbed. The flat topography of the Netherlands makes it more vulnerable to this type of flooding. Pluvial flooding can cause standing water on the roadway, blocking traffic and impacting safety if drivers lose traction on wet surfaces or attempt to drive through the floodwaters that are too deep for their vehicles to navigate. As such, highway designs in the Netherlands are required to comply with the following standards to prevent pluvial flooding:

Situation along the road	Normative shower to design for
Sufficient water retention space next to road, no danger for water on road shoulder. Runoff can infiltrate the road shoulder.	1 / 10 years
Insufficient space for water retention next to road; surface runoff accumulates in median; or when danger for erosion of shoulder or road embankment/slope. To accommodate the water, gutters or sump pits will be installed along the road, or there will be a bridge or viaduct.	1 / 50 years
No space for water retention next to road (e.g. tunnels, sections of the road below groundwater level).	1 / 250 years

Guidelines for water discharge from roads, including design rain curves, have been changed to meet KNMI climate scenarios[12] and new insights into extreme precipitation for the Netherlands. In 2023 KNMI will publish new climate scenarios, and based on that adjustments may be necessary; however no major changes to the climate scenarios are expected.

Unlike much of the Netherlands, the InnovA58 project is located above sea level and is not in a floodplain. However, the project area experiences heavy downpours that are increasing in intensity and frequency, resulting in localized flooding and the need for enhanced stormwater management. The two project segments cross 11 streams, and a number of the bridges along the highway are too small to handle increased stream flow (fluvial flooding). In addition, given the flat topography of the area, heavy downpours can cause flooding in locations not near streams if drainage is insufficient (i.e., pluvial or

[12] http://www.climatescenarios.nl/. KNMI will develop new climate scenarios in 2021, following the new scenarios from the International Panel on Climate Change (IPCC).

overland flooding). As a result, Rijkswaterstaat decided to look at projected climate and rainfall levels when designing the roadway expansion project.

Figure 12: Bridge over a stream along the A58 between Tilburg and Eindhoven. This is one of 11 stream crossings in the InnovA58 project (Source: FHWA).

Rijkswaterstaat has selected a contractor for the design of InnovA58. The request for quotations (RFQ) to select the contractor included a section with requirements for the contractor related to climate resilience. That section requires the selected contractor to develop robust and flexible climate adaptation measures for InnovA58 and develop recommendations on how they can be integrated into the project. The RFQ also requires the contractor to use climate scenarios developed by the Royal Dutch Meteorological Institute (KNMI), Rijkswaterstaat climate guidance, and a dynamic adaptation pathways approach (see Section 9.1). It also requires cost-benefit analysis of adaptation measures and analysis of their potential impact on other issues, such as noise and ecological impact. Finally, the RFQ requires that climate resilience of the road and the surrounding area be considered in conjunction with each other. As of January 2023, specific climate adaptation measures were not yet available due to the delay of the project.

8.2 SR 167 Completion Project, Washington State

The SR 167 Completion Project in Washington State will extend the highway to connect with Interstate 5 (I-5) and State Route 509, completing a critical missing link in the regional transportation network (see Figure 13). The project involves 10 kilometers (6.2 miles) of new construction and five new interchanges. This highway has been planned since the late 1950s, but the final segment of the highway has been on hold since the 1970s. Completing this highway will benefit the movement of freight (particularly to and from the Port of Tacoma), while reducing congestion on local roads and improving safety. Design for the project began in 2017, and WSDOT has completed construction of the initial phase of the project. Construction on the next phase will occur from 2021 to 2026, and the final phase will be constructed from 2024 to 2028.

Figure 13: Location of the future SR 167 extension (Source: WSDOT).

Figure 14: The SR 167 freeway ends before I-5 and the Port of Tacoma, channeling heavy freight and passenger traffic onto congested local roads. The SR 167 Completion Project will complete the limited access freeway to the Port of Tacoma (Source: FHWA).

Figure 15: Aerial view of the SR 167 project area, with Mt Rainier in the background and the Port of Tacoma in the foreground (Source: WSDOT).

The project traverses a floodplain of a minor tidal creek (Hylebos Creek) and is within the floodplain of a major river (Puyallup River). In the future, the area is expected to be impacted by hydrologic changes in streams, wetlands, and highway runoff due to increased frequency of high intensity rainfall events, as well as higher creek flood levels during high tides due to sea level rise.

Figure 16: Highly degraded segment of Hylebos Creek in linear ditch along I-5 (Source: WSDOT).

As part of the SR 167 Completion Project, WSDOT developed a riparian restoration program (RRP) to convey stormwater, including stormwater generated by the project and flood flows originating upstream, through the project area. Hylebos Creek is the primary stream that passes through the project area. The creek and small tributaries that drain into it within the project area have been highly modified by past agricultural and urban development. In many places, the creek flow is conveyed in a straightened channel akin to a ditch by the side of the road (see Figure 16) rather than in a natural meandering channel connected to a floodplain as it was prior to intensive development.

The RRP will realign several kilometers of stream channels and create a sustainable natural corridor that reconnects Hylebos Creek and its tributaries to floodplains and adjacent wetlands, increases flood flow conveyance, and reduces flooding of the existing highway and local road network (see Figure 17). Additionally, the RRP design will inherently reduce the potential for streambank erosion induced by

Figure 17: Planned stream realignment under the riparian restoration program. White dotted line shows existing stream location (note straight lines and right angles) while solid blue shows proposed location (note more natural meanders). (Source: WSDOT).

stormwater runoff, including runoff from the new highway, such that conventional stormwater flow control measures are unnecessary. The RRP has substantially greater flow and storage capacity than a traditional closed conveyance and detention basin system to manage stormwater runoff, such as the system shown in Figure 18.[13] The RRP will also improve habitat for a wide range of aquatic and terrestrial species.

The RRP, and other efforts to improve the resilience of the SR 167 Completion Project, builds off of lessons learned from WSDOT's two previous FHWA-funded pilot projects to identify the vulnerabilities of transportation infrastructure. In 2011, WSDOT facilitated workshops across the state, during which participants used asset maps, climate scenarios, and their local knowledge to assess vulnerability.[14] WSDOT synthesized the results from each workshop by producing a series of maps for each region showing the vulnerability ratings for road segments, airports, ferries, and rail lines.

Figure 18: Conventional stormwater detention ponds under the I-5/SR 16 interchange. Due to the topography, shown on the inset, the detention pond is not located in an area with shallow groundwater and the topography provides the hydraulic head to evacuate the pond prior to a subsequent precipitation event. (Source: WSDOT).

[13] Herrera Environmental Consultants, Inc. Discussion Paper: Applicability of the SR 167 Completion Project Riparian Restoration Program as an Adaptation Strategy for Climate Resilience. March 2017. Prepared for WSP Parsons Brinckerhoff and Washington State Department of Transportation.

[14] FHWA Climate Change Vulnerability Assessment Pilot Project: WSDOT https://www.fhwa.dot.gov/environment/sustainability/resilience/case_studies/washington_state/index.cfm

In a pilot project from 2013 to 2015, WSDOT examined adaptation options in the Skagit River Basin, a highly vulnerable area of the state that was the focus of a major flood study by the U.S. Army Corps of Engineers (USACE).[15] The pilot project offered an opportunity to actively engage with the flood study and search for compatible long-term solutions that create a more resilient transportation system throughout the Basin. WSDOT worked with the USACE and the Skagit County Public Works Department to identify vulnerabilities and opportunities for flood risk reduction.

[15] FHWA Climate Resilience Pilot Project: WSDOT https://www.fhwa.dot.gov/environment/sustainability/resilience/pilots/2013-2015_pilots/washington/index.cfm

9 Application and Evaluation of the Resilience Tools

Rijkswaterstaat and WSDOT implemented ROADAPT and the FHWA tools on their projects in different ways. The following section describes their approaches to applying these tools, as well as additional climate resilience strategies that they implemented in the pilot projects. This section also discusses benefits and challenges of using each of the tools and recommendations for improving their use in the future.

9.1 Rijkswaterstaat Process

Rijkswaterstaat and Deltares, an independent institute for applied research, tested two of the FHWA tools on the InnovA58 project and compared them with elements of the ROADAPT Framework, which were also applied to the project. They compared the FHWA Sensitivity Matrix with the Table of Threats in ROADAPT Part B, and compared FHWA's VAST with the ROADAPT Part C Vulnerability Assessment (VA) methodology. Rijkswaterstaat also developed an adaptation strategy for the project and incorporated climate considerations into their contracting documents.

FHWA Sensitivity Matrix vs. ROADAPT Quickscan Table of Threats

The FHWA Sensitivity Matrix and the ROADAPT Quickscan Table of Threats are both checklists that project teams can use to determine what hazards are likely to affect transportation infrastructure. The Table of Threats is a starting point for users to see the range of possible threats that could impact the transportation system. It can be used to identify which threats are most relevant to a project area. The table covers 12 main threats and 40 sub-threats. For each threat (e.g., flooding of road surface), the table lists:

- Sub-threats (e.g., pluvial flooding caused when the precipitation intensity exceeds the capacity of natural and engineered drainage systems, flooding due to snow melt, flooding due to sea level rise and storm surge).
- Climate variables that would increase the possibility of the threat happening (e.g., extreme rainfall).
- Intrinsic factors that contribute to the vulnerability of the infrastructure to the threat (e.g., road surface elevation, cross slope, or the presence of a drainage system).
- Contextual site factors that contribute to vulnerability (e.g., coastal areas, slope, presence of river systems, vegetation cover).
- Impact of the threat in terms of the duration of when the threat occurs until when normal operations are resumed, as well as the warning time horizon (the time between the realization that the threat might happen and the threat occurring).

Whereas the Table of Threats is a static resource, the Sensitivity Matrix is an interactive spreadsheet tool that allows users to filter by asset type or climate impact of interest (e.g., to see how extreme precipitation affects roads and bridges).

Overall, Rijkswaterstaat and Deltares found that the two tables produced similar results on which climate threats are likely to impact infrastructure. The project team recommends first considering the possible hazards for a project, and using either resource as a checklist. They also recommend confirming the results with local experts who have a good understanding of relevant assets and how extreme weather impacts them.

Another difference between the two tools is that the Sensitivity Matrix provides more background information and links to information on the internet, while the ROADAPT threats table includes less background or supplemental information.

ROADAPT Quickscan

The Table of Threats is part of the broader ROADAPT Quickscan methodology. Quickscan relies on workshops with stakeholders to identify which undesirable events pose the greatest risk to transportation infrastructure. The A58 project team held several workshops using the Quickscan methodology to determine the risks to A58 and its surrounding area resulting from extreme weather now and in the future, and to identify which measures can be taken to counter these risks. Stakeholders at the workshops included staff from Rijkswaterstaat – including the InnovA58 project team and asset managers – and representatives from local municipalities and water authorities.

As part of the Quickscan workshops, the team developed a matrix of current risks based on rankings of consequence and likelihood. The consequences for threats to the road were determined for each relevant threat based on the following criteria and weighting:

Consequences for the road	weight
Safety	22%
Availability / reliability	19%
Environmental impact	17%
Effects for surrounding road network	13%
Direct costs	12%
Effects on maintenance	10%
Reputation of road agency	7%

Consequences for the area	weight
Impact on ecology	25%
Impact on health/disruption to local residents	25%
Economic impact	15%
Repair costs	13%
Effects on maintenance	13%
Political considerations	8%

Then, participants scored the likelihood of each threat on a scale of 1 to 4, using the following scale:

Score	Likelihood of event
1	Very seldom: less than once every 250 years
2	Seldom: once every 50 to 250 years
3	Sometimes: once every 10 to 50 years
4	Often: more often than once every 10 years

Deltares then translated current risks into future risks by adjusting the likelihood of the different impacts using a higher and a lower climate impact scenario (see Figure 19).[16] For instance, for surface runoff (pluvial) flooding, roads in the Netherlands are designed to the 1 in 10 year rainfall, which is 36 millimeters (1.4 inches). Climate scenarios for the Netherlands project that in 2050, the 36 millimeter rainfall event will occur on average every five years under the higher climate impact scenario and every

[16] The KNMI ’14 Climate Scenarios (http://www.climatescenarios.nl/) translate research on global climate change to the Netherlands. Rather than using different emissions scenarios, the climate scenarios provide information on the climate impacts likely to be experienced in the Netherlands based on a moderate and warm scenario of global temperature rise, and a high and low scenario for changes in circulation patterns.

10 years under the lower scenario. As such, Deltares shifted the likelihood by a factor of two for the */upper bound.

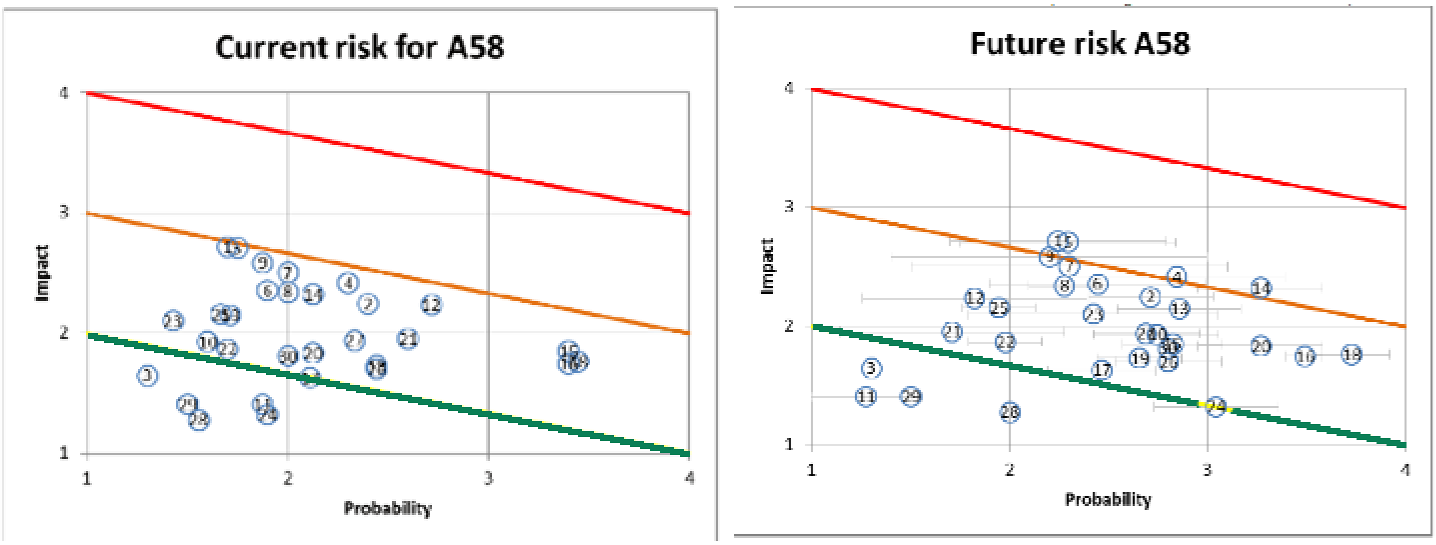

Figure 19: Risk matrix plotting the different estimates of likelihoods (probability) and consequences (impact) of the undesirable events for the road (numbering in accordance with bullets below). The left and right ends of the range bars in the future risk chart indicate likelihood under lower and higher climate impact scenarios, respectively. (Source: Deltares).

Based on this determination of consequence (impact) and likelihood (probability), workshop participants identified the highest risks for InnovA58. The highest risks, in rank order, were as follows (identification numbers following each threat correspond to the numbers in the charts above):

- Flooding of road at creek crossings (1);
- Flooding of road as a result of heavy rainfall (surface runoff, increase in groundwater level, puddle forming) (also called pluvial flooding) (2);
- Erosion of embankments/foundations due to inadequate capacity of waterway structures (e.g. drainage culverts and bridges) (4);
- Erosion/loss of bearing capacity in the highway sub-base due to prolonged water alongside the road (5);
- Landslide/road subsidence of embankment in periods of extreme precipitation (6);
- Loss of driving safety due to restricted visibility during snow or showers, including spray (16);
- Driver safety due to water on roads (hydroplaning when water film is thicker than 3 millimeters) (18); and
- Flooding of underpasses (31)

Using a similar process, workshop participants also determined the greatest risks for the environment surrounding A58. These include:

- Flooding in stream valleys following periods of prolonged precipitation;
- Flooding in urban areas due to intense precipitation;
- Fall in groundwater levels leading to a change in the ecology and/or agricultural earnings; and
- Increase in groundwater levels leading to flooding in villages/towns/cities.

Workshop participants also began to identify potential adaptation measures given these risks. The adaptation measures were further refined in a later stage of the ROADAPT process.

The ROADAPT Quickscan approach can also be applied in a less extensive way than was done with the InnovA58 project. An example of this type of approach is described in the CEDR report *Quickscan of the A24 Portugal*.[17] A less extensive form of the ROADAPT approach was also applied in the Netherlands for the strategic environmental assessment phase of the A20 expansion between Rotterdam and Gouda. Two workshops with stakeholders led to the development of a shortlist of eight opportunities for climate change adaptation along this motorway.

The FHWA Framework describes strategies for a qualitative, stakeholder-based approach, but does not provide as structured a method as Quickscan; Rijkswaterstaat did not pursue the FHWA stakeholder-based approach as part of this project.

FHWA VAST vs. ROADAPT Vulnerability Assessment (VA)

The Rijkswaterstaat/Deltares team compared the FHWA VAST tool with the ROADAPT VA methodology for identifying assets and locations vulnerable to climate impacts. Since the ROADAPT VA methodology does not include adaptive capacity, the project team gave adaptive capacity a weighting of zero in VAST. After this adjustment, the results from the two tools were very similar – the locations identified as most vulnerable in ROADAPT VA were also identified as most vulnerable in VAST. While the tools produced similar results, each tool presents the results differently. The output of ROADAPT VA is a series of maps showing the most vulnerable locations for each undesirable event, while the output of VAST is a spreadsheet with vulnerability scores from which a user could create graphs and tables (see Figure 20). Both tools rely on indicators to develop the vulnerability scores. The Rijkswaterstaat/Deltares team used the following indicators for surface runoff (pluvial) flooding vulnerability:

- Ground elevation, soil type, and groundwater level
- Site visit assessment
- Elevation difference between the road and the surrounding area
- Road drainage system capacity

[17] ROADAPT Consortium. "Quickscan - A24 Portugal." March 2014. http://www.cedr.eu/download/other_public_files/research_programme/call_2012/climate_change/roadapt/ROADAPT_case_study_A24_Portugal_Quickscan_report.pdf

ID	Name	Vulnerability Score (from low of 1 to high of 4)
6	A58 parking area (Kriekampen)	2.5
3	A58 segment near Ulvenhout	2.2
7a	A58 Exit / access ramp near Moergestel	2.1
1	A58 near Galderse meren	1.9
8	A58 habitat crossing near Leij	1.6

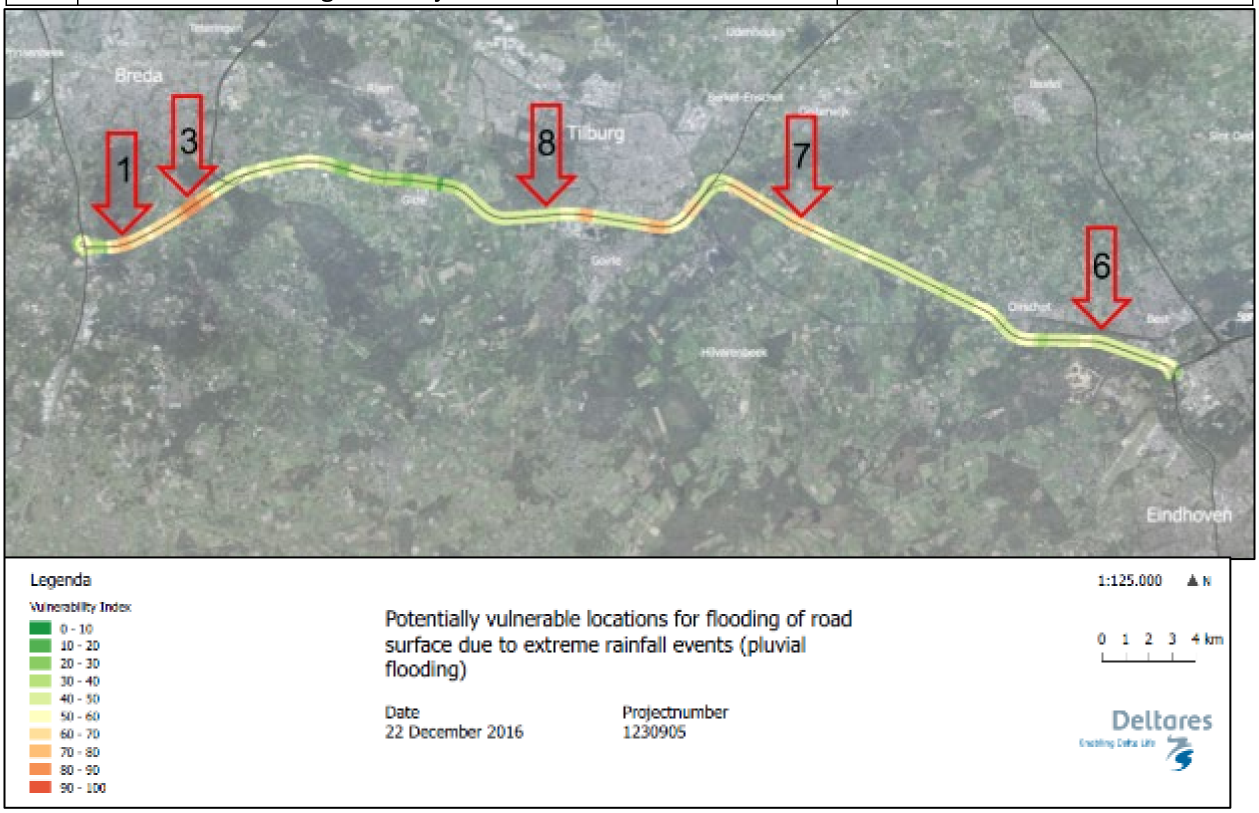

Figure 20: Detailed vulnerability assessment of assets using ROADAPT VA and FHWA VAST. This output is for vulnerable locations for road flooding due to surface runoff (pluvial flooding). Top: FHWA VAST output lists the most vulnerable segments on a scale of 1 to 4. Bottom: Output from GIS-based ROADAPT VA. Green indicates relatively low vulnerability while orange indicates relatively high vulnerability. Arrows indicate areas of highest vulnerability and contain identification numbers which match to the ID numbers in the VAST table above (Source: Deltares).

The Rijkswaterstaat/Deltares team found that ROADAPT VA and VAST each had some advantages and disadvantages. Since ROADAPT VA follows a GIS-based approach, it requires spatial data to input into the tool and someone with GIS skills to conduct the analysis. Because it is based on GIS, ROADAPT VA displays the results in a visual way that can be easily understood at a high-level by decision makers. In contrast, VAST does not require specialized skills to use and the tool guides users through the steps in the process. However, the tool requires data on exposure, sensitivity, and adaptive capacity for each asset. Collecting this data can be time-consuming and/or require special expertise if the data is not already in a useable format (e.g., in an asset management system). Therefore, if the data is not already available the project team recommends using VAST for a small number of selected assets instead of trying to use it for all assets in a project area.

The Rijkswaterstaat/Deltares team noted that an advantage of VAST is that the indicators for exposure, sensitivity, and adaptive capacity can be weighted and that the weightings can be adjusted, allowing users to quickly see the sensitivity of the results to different weightings. However, it is more difficult to understand the process that leads to the end result and to explain the results to decision-makers who may not have a background in this topic area. For both tools, the team recommends checking the results using expert opinion and taking into account the quality and limitations of the input data.

Engineering Tools

As part of the pilot project, Rijkswaterstaat reviewed the FHWA *Transportation Engineering Approaches to Climate Resiliency (TEACR)* study. They found the study to be useful and are sharing it within the agency. Rijkswaterstaat also referred to FHWA's *HEC 17: Highways in the River Environment* and *HEC 25, Volume 2: Highways in the Coastal Environment* as part of their pilot project. They found that HEC-17 and HEC-25 contain information of interest to the Netherlands, and shared the information with experts on topics such as bridges and culverts and nature-based solutions. In the Netherlands, the approach to taking into account climate change when designing new and replacing old bridges is still under development. There is an awareness that climate change may impact several aspects of bridge design, including geotechnical parameters, hydraulic loads and thermal requirements.

Using Results to Inform Project Decisions

Rijkswaterstaat and Deltares developed adaptation strategies for the greatest risks identified in the ROADAPT Vulnerability Assessment. These risks fall into the following categories:

- Stream valleys: inundation, erosion of slopes as a result of engineering structures' limited capacity, and erosion/ loss of carrying capacity as result of water alongside the road.
- Driving safety: Limited visibility (splash & spray).
- Flooding due to heavy rainfall (pluvial flooding).

First, the team identified potential adaptation strategies to address these risks. The strategies were then combined using a "dynamic adaptation pathways" approach (also referred to as "adaptive management") consisting of adaptation strategies that can be selected and combined at various points in the future. Figure 21 shows an example of adaptation pathways for increased pluvial flood risk to A58 to illustrate the concept. The circles show decision points where it would be possible to switch from one strategy to another when the original strategy stops being effective. The pathway diagram aligns with climate variables (e.g., amount of precipitation in two hours), and climate impact scenarios can be matched up with the climate variables to show when the strategies would stop working under different scenarios.

For example, in Figure 21 business as usual practices (3.5 cm of porous asphalt, represented by the grey line) are adequate for up to about 52 millimeters (2 inches) of rainfall in two hours; this amount of precipitation is projected to occur by 2032 under a high climate impacts scenario (W_H upper) or by 2050 under a low climate impacts scenario (G_L centre).[18] While porous asphalt is used as a noise control measure in the Netherlands, it also can accommodate more stormwater than traditional pavement, and reduces splash and spray during rainstorms. Increasing the thickness of the porous

[18] Hodges, Tina. Resilient and Sustainable Transport – Dutch Style: An interim report on bilateral cooperation between FHWA and Rijkswaterstaat. FHWA, 2017. https://www.fhwa.dot.gov/environment/sustainability/resilience/publications/dutch_style/index.cfm

asphalt (for example, to 7 cm [purple line], 10 cm [green line], or 18 cm [light blue line]) provides a greater volume of storage to accommodate the more intense rainfall expected in the future. Similarly, using gutters instead of manholes (also known as drainage sumps) to manage stormwater is expected to be adequate for approximately 64 millimeters (2.5 inches) of precipitation in two hours; this amount of rainfall is expected to occur around 2070 in the high emissions scenario.

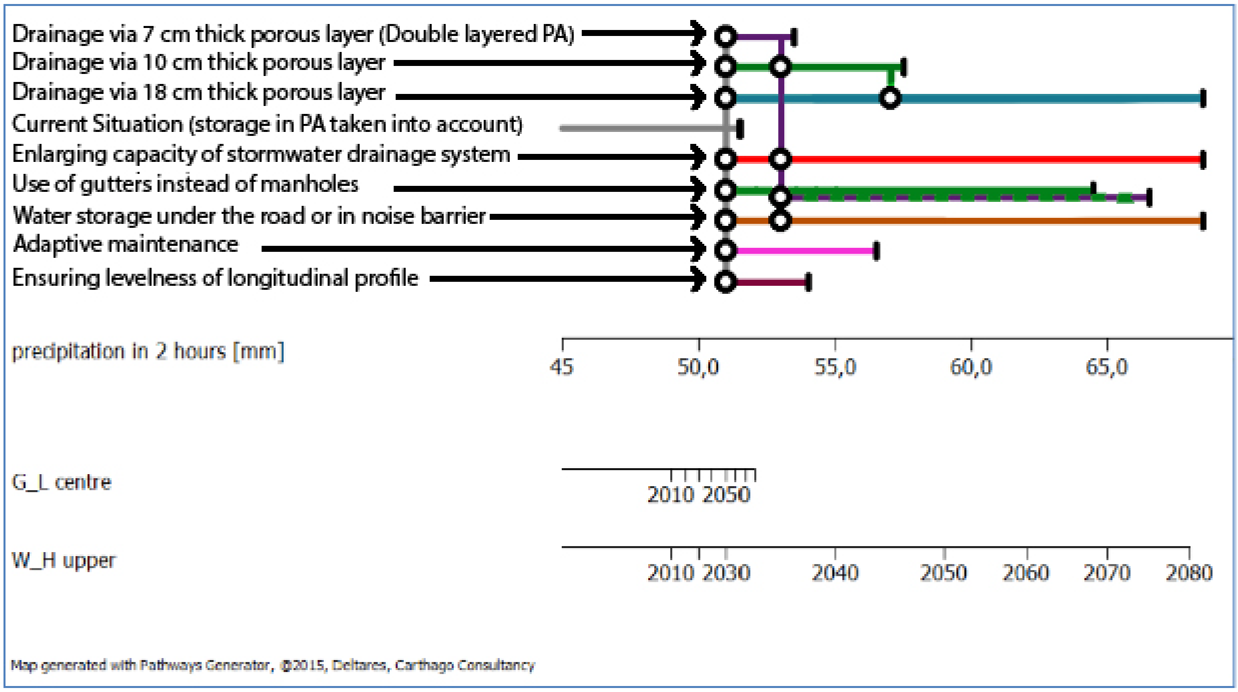

Figure 21: Diagram showing potential adaptation pathways for increased pluvial flood risk to A58. In the figure PA refers to porous asphalt and manholes refer to drainage sumps. (Source: Deltares).

9.2 WSDOT Process

Comparison of Quickscan to FHWA Framework

In its earlier FHWA-funded pilot project, WSDOT used a qualitative, stakeholder-based approach to assess the vulnerability of its transportation network. As part of that project, conducted in 2011, WSDOT held a series of workshops with over 200 staff, including maintenance staff; regional office staff; and state ferry, aviation, and rail system managers. Using asset maps and climate scenarios that the project team gathered ahead of time, as well as their own knowledge of the infrastructure, participants discussed vulnerabilities and what would happen to the transportation assets if climate-related conditions worsened. WSDOT synthesized the results from each workshop by producing a series of maps for each region showing the vulnerability ratings for road segments, airports, ferries, and rail lines.

As part of the 2016-2018 project, WSDOT compared the stakeholder-based approach it used for its 2011 pilot project with the process laid out in ROADAPT Quickscan. While WSDOT did not go through the full Quickscan process or conduct any additional workshops, the agency's review of their previous work allowed them to determine that ROADAPT Quickscan generally followed the procedures used in the statewide vulnerability assessment in terms of the type of data compiled in advance of the workshops and the stakeholder input collected during the workshops. WSDOT anticipates that both the Quickscan approach and the methodology in the FHWA Framework would identify similar broad concerns for the

SR 167 project area related to riverine flooding, high intensity precipitation and local flooding, and inundation due to sea level rise.

WSDOT's 2011 statewide vulnerability assessment using the FHWA Framework found that some of the highway segments in the SR 167 project corridor are vulnerable to climate change impacts. The segment of I-5 where the new SR 167 interchange will be located has a high vulnerability rating (see Figure 24). In several recent flood events (1990, 1996, 2003, 2009, and 2015), the right most southbound lane of this segment of I-5 was inundated when Hylebos Creek floodwaters rose to overtop the road shoulder (Figure 22). WSDOT rated this issue in the high vulnerability category because they consider this highway segment very critical, and flooding in this location causes temporary operational failures. The SR 167 Completion Project's riparian restoration program will reduce I-5 flood vulnerability by providing floodplain storage for Hylebos Creek and isolating the creek from developed areas.

Figure 22: Flooding of Hylebos Creek around I-5 near the 70 Street over crossing (Fife Curve) in 2009 (Source: WSDOT).

The non-freeway section of the current SR 167 (also called River Road) runs parallel to the Puyallup River. In its 2011 vulnerability assessment, WSDOT rated this segment as having moderate vulnerability (shown in orange in Figure 23). This road is protected from flooding by a levee that it is built upon. WSDOT's 2011 report notes that while the river has not overtopped the levees in this area, this came close to happening during a flood event in 2009. In addition, the riverbed is aggrading (rising) because of sediment washing down from the mountains, primarily from Mount Rainier, an active volcano. This decreases the capacity of the river channel to convey flood flows, and is gradually increasing the vulnerability of River Road to overtopping flood events. Rising temperatures are accelerating melting of the glaciers in the watershed, exposing more unconsolidated sediments, which could exacerbate the existing problem. Rising sea levels will also send the tidal influences and storm surges farther upstream in the river and affect this roadway section.

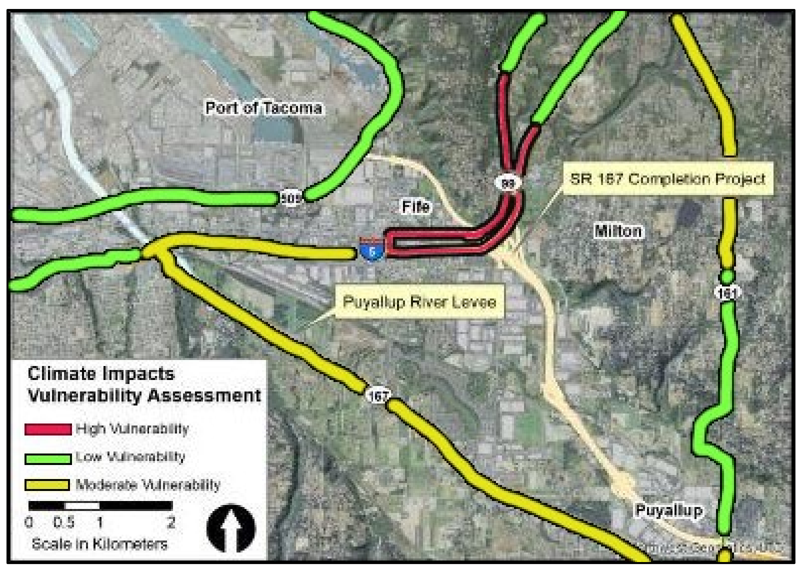

Figure 23: Vulnerability assessment of the highway segments in the vicinity of the SR 167 Completion Project, based on WSDOT's 2011 vulnerability assessment (Source: WSDOT).

Flood Control Measures

In 2001 the Federal Emergency Management Agency (FEMA) began an update of the Flood Insurance Study for Pierce County. The analysis found the Puyallup River levees inadequate to be accredited primarily because the river was aggrading. In 2007 FEMA published Draft Preliminary Flood Insurance Rate Maps showing that flooding would occur without levees. The current maps, published in March 2017, have a note indicating that the levees do not comply with the NFIP regulations and will be updated in the future. Pierce County, the City of Tacoma, the Port of Tacoma and the City of Fife petitioned FEMA to not adopt the new maps as they were working on a solution for the levees. The USACE prepared a draft Puyallup River Basin Flood Risk Management Study and General Investigation to identify flood issues and measures to address flood risk management.[19]

Although the USACE decided to terminate the General Investigation in April 2018, Pierce County and other local partners are likely to eventually recommend improvements to the levees (including set back levees that allow the river to access historical floodplain areas), which would lead to the levees being recertified. Given the ongoing activity in this area, WSDOT's flood mitigation focus for the SR 167 Completion Project is on Hylebos Creek rather than the Puyallup River.

Future actions to reduce flood risks in the lower Puyallup River could be similar to levee setback projects that Pierce and King Counties recently completed on the White River, which feeds into the Puyallup River just upstream of the SR 167 project corridor. The levee setback projects allow more floodplain storage, reducing flooding of nearby communities and delaying the timing of flood flows from the White River entering into the Puyallup River. Several other levee setbacks in the Puyallup River system are also planned or have been implemented by other local entities.

King County recently completed a large levee setback (County Line Project) on the White River. The project removed 4,500 linear feet of existing levee and reconnected the river to 121 acres of off-channel

Figure 24: Delegation members walk along the new White River levee, which King County shifted out further from the river to allow for flood storage and habitat restoration. (Source: WSDOT).

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[19] US Army Corps of Engineers Seattle District and Pierce County Public Works and Utilities. Puyallup River Basin Pierce County, Washington Flood Risk Management General Investigation. March 2016. https://www.nws.usace.army.mil/Portals/27/docs/civilworks/projects/puyallup/Puyallup%20River%20Basin%20GI-Draft%20FR-EIS-Main-Report-18MAR2016.pdf

aquatic habitat. The 6,000 linear feet of new setback levee is protected by 5,780-foot wood bio-revetment (see Figure 24). The FHWA and Rijkswaterstaat delegation toured this levee setback project during the Washington State site visit in October 2018 (see Section 10.1). In addition to the flood protection benefits, the project provides substantial habitat restoration benefits. WSDOT contributed funding to the King County levee setback project to mitigate downstream impacts on the Puyallup River.

Climate Data Tools

WSDOT used FHWA's CMIP Climate Data Processing Tool to process downscaled temperature and rainfall projections for the region (see Figure 25). They found the tool useful, although the daily resolution does not address high intensity precipitation on the highway that may lead to aquaplaning hazards. WSDOT would consider using the tool again, especially for stormwater planning when detention is required.

FHWA VAST vs. ROADAPT Vulnerability Assessment (VA)

WSDOT used the ROADAPT VA methodology to assess the vulnerability of the SR 167 project area.[20] WSDOT used the list of climate impacts in ROADAPT VA as a checklist to ensure that they were considering the full range of potential climate impacts that are likely to impact the project area. In addition to the primary impacts of sea level rise and higher intensity rainfall that had been identified previously, through use of the checklist WSDOT noted that increased groundwater levels, saltwater intrusion, and increased tidal flux could affect the SR 167 Completion Project corridor and should be considered in project design.

Precipitation Measure	**Baseline (1950 - 1999)**		**2000-2049**			**2050-2099**		
	Observed Value	*Modeled Value*	*Projected Value*	*Change from Baseline*	*% Change*	*Projected Value*	*Change from Baseline*	*% Change*
Average Total Annual Precipitation (inches)	43.8	42.4	44.0	1.2	3%	45.1	2.3	5%
"Very Heavy" 24-hr Precipitation Amount (defined as 95th percentile precipitation) (inches)	0.6	0.5	0.7	0.0	3%	0.7	0.0	3%
"Extremely Heavy" 24-hr Precipitation Amount (defined as 99th percentile precipitation) (inches)	1.1	0.9	1.2	0.1	6%	1.2	0.1	9%
Average number of Baseline "Very Heavy" Precipitation Events per Year (0.6 inches in 24 hrs.) (number of occurrences)	12.2	15.9	14.4	2.2	18%	16.0	3.7	31%
Average number of Baseline "Extremely Heavy" Precipitation Events per Year (1.1 inches in 24 hrs.) (number of occurrences)	2.4	3.2	3.7	1.3	53%	4.5	2.1	85%

[20] The initial analysis was done before the alignment of the road was finalized, so WSDOT looked at the regional transportation system as a whole rather than the specific road footprint. Since this initial application, WSDOT has finalized the planned road alignment and refined the analysis.

Largest 3-day Precipitation Event - Winter (inches)	2.7	2.3	3.0	0.3	9%	3.1	0.4	14%
Largest 3-day Precipitation Event - Spring (inches)	1.7	1.4	1.8	0.1	5%	1.9	0.2	9%
Largest 3-day Precipitation Event – Summer (inches)	1.1	0.9	1.1	-0.1	-8%	1.0	-0.1	-13%
Largest 3-day Precipitation Event - Fall (inches)	2.3	1.9	2.4	0.1	4%	2.6	0.3	13%

Figure 25: Projected Changes in Precipitation Conditions for SR 167 Area using FHWA CMIP Climate Data Processing Tool and the RCP 8.5 emissions scenario. (Source: WSDOT).

WSDOT attempted to use the VAST tool, but did not have detailed asset data for the SR 167 Completion Project as it is still in the design phase. WSDOT planned to use I-5 as a surrogate to test the application. However, although WSDOT had a very detailed inventory of the highway, the information was not georeferenced. Although the inventory could be entered into the VAST spreadsheet, the spatial information regarding hazards could not be assigned to each asset and incorporated into the spreadsheet in an automated method.

Incorporating Climate Data into Hydraulic Analysis

WSDOT reviewed and utilized relevant guidance from FHWA's *HEC 25, Vol. 2: Highways in the Coastal Environment: Assessing Extreme Events* and *HEC 17: Highways in the River Environment: Extreme Events, Risk and Resilience*. WSDOT noted that while HEC-25 addresses coastal impacts and HEC-17 addresses riverine impacts, neither addresses the impact of sea level rise on tidal rivers and streams, a key consideration for the SR 167 corridor.[21] However, WSDOT found relevant guidance in HEC-17 on designing for non-stationarity processes, including the importance of design life and service life. WSDOT found relevant information in HEC-25 on coastal weir-flow damage and measures to address roadway overtopping.[22]

[21] FHWA updated HEC-25 in 2020 and the updated version includes content on this topic.

[22] Herrera Environmental Consultants, Inc. Discussion Paper: Applicability of the SR 167 Completion Project Riparian Restoration Program as an Adaptation Strategy for Climate Resilience. March 2017. Prepared for WSP Parsons Brinckerhoff and Washington State Department of Transportation.

WSDOT pursued an analysis similar to the process described in HEC-17 to analyze the impact of climate change on the SR 167 project corridor and the Riparian Restoration Program (RRP). WSDOT had developed the conceptual design for the RRP in 2008, before the agency had begun incorporating climate change impacts considerations into project designs. Beginning in 2016, WSDOT and a consultant evaluated whether the RRP may reduce the vulnerability of I-5 and the future SR 167 highway. In particular, they looked at the potential impacts of hydrologic changes and sea level rise in the project area, and how the RRP strategy could help address these impacts.

Figure 26: The Surprise Lake tributary to Hylebos Creek at the location of the future RRP. (Source: Volpe Center).

WSDOT's analysis is described below. Based on this analysis, WSDOT found that the RRP approach is a far more practical means of accommodating sea level rise and increased precipitation on SR 167 than designing and operating infrastructure to hold increased volumes of water within the riparian buffer. Given the high groundwater table and flat terrain in the project area, traditional engineering approaches such as infiltration or runoff detention ponds would have limited effectiveness in addressing flows from future high-intensity rainfall events. In contrast, the RRP approach can make use of high groundwater as an advantage to nurture wetland establishment. In addition, the riparian wetlands to be created and enhanced in floodplain areas along Hylebos Creek will be able to naturally transition from freshwater wetlands to estuarine wetlands as sea level rises, without compromising hydrologic and hydraulic function.

To analyze the impact of sea level rise on Hylebos Creek flood profiles, WSDOT modified its existing hydraulic model of Hylebos Creek by increasing the downstream boundary conditions to simulate sea level rise. In 2016, WSDOT ran four sets of simulations based on the University of Washington Climate Impacts Group sea level rise forecast data from 2009. The scenarios were for 6, 13, 22, and 50 inches (0.15, 0.33, 0.56, and 1.27 meters) of sea level rise.[23] All of the scenarios used the 1 percent annual chance streamflow from heavy precipitation. Since it is unlikely that the 1 percent annual chance streamflow would occur simultaneously with the 1 percent annual chance high tide from storm surge, WSDOT used daily high tide (Mean Higher Water (MHW)) rather than an extreme high tide in these simulations. The analysis assumed the SR 167 Completion Project would include measures identified in the RRP, including replacing the SR 99 bridge, replacing the 12th Street culvert with a bridge, replacing

[23] Mote et al. Future Climate in the Pacific Northwest. Chapter 1 in The Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate. Climate Impacts Group, University of Washington, 2009.

the I-5 bridge with a larger (120-foot wide) open span bridge, and removing fill in the floodplain between I-5 and 12th Street.

As shown in Figure 27, sea level rise results in higher flood elevations downstream of the 12th Street culvert, though even under the highest sea level rise scenario evaluated (50 inches), the bridges and culverts downstream of 12th Street have sufficient elevation to pass the 100-year flood flow. Upstream of 12th Street, including at the new I-5/SR 167 interchange, this analysis indicated that sea level rise will not have an impact.

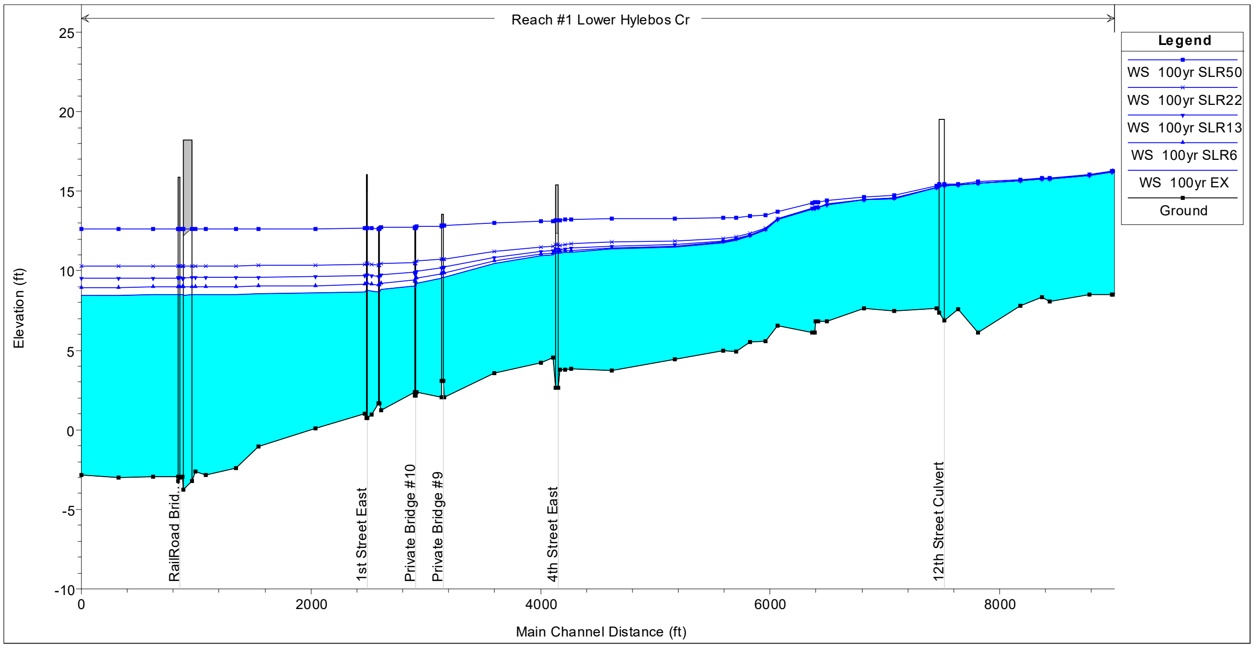

Figure 27: Hylebos Creek Flood Profiles. WS 100 yr SLR50 stands for water surface elevation for the 100-year flood flow with 50 inches of sea level rise added to the downstream boundary condition. The elevations and locations of the culverts and bridges are indicated by the skinny, vertical rectangles. (Source: WSDOT)

In 2018, WSDOT's SR 167 consultant project team evaluated the impact of sea level rise on the SR 167 project area using two-dimensional hydraulic modeling. For this analysis, WSDOT used the probabilistic sea level rise projections provided by the Washington Sea Grant Washington Coastal Hazards Resilience Project.[24] The probabilistic sea level rise values for the Washington coast allow users to select which value to use based on their risk tolerance. For instance, users with very low risk tolerance can select the five percent exceedance probability, meaning that there is only a five percent chance that value will be exceeded.

WSDOT used the 50 percent exceedance probability (in other words, the median value) of 2.2 feet (0.67 meters) of sea level rise in Commencement Bay (into which Hylebos Creek flows) for the year 2100 under the business-as-usual high emissions scenario (RCP 8.5). WSDOT did not adjust streamflow for future changes in precipitation because Washington State University researchers found that the extremes of the measured range of precipitation exceeded the modeled range under the RCP 6.0

[24] Washington Sea Grant. Washington Coastal Hazards Resilience Project. http://www.wacoastalnetwork.com/washington-coastal-resilience-project.html

emission scenario.[25] The future conditions hydrologic model considered full buildout of the watershed in accordance with the current zoning and a more extensive SR 167 Completion Project. This was a very conservative assumption, as communities are buying up natural areas to preserve as open space and it is unlikely that all space would be developed due to presence of steep slopes, wetlands, or other constraints.

WSDOT used two hydraulic models, RiverFlow2D and SRH2D, to analyze the impact of year 2100 sea level rise of 2.2 feet, plus a 2-year high tide event of 2.2 ft., plus a 2-year streamflow event from heavy precipitation. WSDOT chose the combination of a 2-year high tide event and a 2-year streamflow event because expert judgement suggested this would approximate a 1 percent exceedance event for high water level due to a combination of sea level and creek flow (it would be relatively rare for an extreme high tide event to coincide with an extreme creek flood event).

The results of this modeling indicated that for all but the 8th Street crossing, the existing conditions 100-year peak water surface elevation due to creek flooding alone (with an existing mean higher high water tailwater condition) is greater than the peak flood level in lower Hylebos Creek that could occur under the climate change scenario evaluated. This is because the RRP improvements are not yet implemented or incorporated into the existing conditions model. The future conditions model considers both climate change and the hydrological changes resulting from the RRP and SR 167 Completion Project.

WSDOT is aware of the Delft3D model in use in the Netherlands but did not feel that model is applicable to the SR 167 Completion Project because Hylebos Creek is tidally influenced by freshwater flow, and stormwater infrastructure is more accurately modeled by simpler hydraulic models built with that purpose in mind.

WSDOT's modeling results show that the Hylebos RRP is expected to lower peak creek flooding levels and reduce flow velocities throughout the project area. Importantly, the RRP will reduce peak flood elevations by approximately two feet (0.6 meters) on the upstream side of I-5, greatly reducing the threat of creek flooding overtopping the southbound lanes of I-5. The RRP design approach will also redirect Hylebos Creek floodwaters away from I-5 and SR 167 and onto what is currently agricultural land but that WSDOT will convert into wetlands, meandering stream channels, and floodplain storage.

Other Tools

WSDOT also used other elements of ROADAPT and the FHWA tools as part of the SR 167 Completion project. It used ROADAPT Part E, the list of adaptation strategies, to identify potential strategies for the SR 167 Completion project. This comprehensive list of potential vulnerabilities and how to mitigate them allowed WSDOT to consider some new factors, which it plans to incorporate in project design. For example, the WSDOT's analysis found that the area may be transitioning from a riverine to a tidal environment, so WSDOT may consider engineering strategies from ROADAPT Part E to address this as part of project design.

[25] Demissie, Y., 2015. Development and Update of Rainfall and Runoff Intensity-Duration- Frequency Curves for Washington State Counties in Response to Observed and Anticipated Extreme Rainfall and Snow Events. Washington State University, Pullman, WA.

9.3 Benefits and Challenges of Applying the Resilience Tools

Rijkswaterstaat and WSDOT identified benefits and challenges of each of the tools. Ultimately, which tool or combination of tools an agency chooses will likely depend on the purpose of their analysis as well as the data they have available.

ROADAPT

Quickscan (ROADAPT Part B)

A challenging aspect of the Quickscan methodology is that it requires stakeholders to participate in multiple days of workshops. Rijkswaterstaat found it difficult to get the right people in the room to participate, particularly the asset managers who had many other responsibilities. WSDOT thought that the comprehensive list of possible hazards in ROADAPT was a tool that workshop organizers could use to determine which staff and experts should be invited to the workshops.

One benefit of Quickscan is that it is a structured process and includes agendas for the workshops, so workshop organizers do not need to start from scratch in figuring out what they will cover at the workshops.

Vulnerability Assessment (ROADAPT Part C)

The GIS-based approach to conducting a vulnerability assessment laid out in ROADAPT VA has both advantages and disadvantages. Both WSDOT and Rijkswaterstaat liked the visual, spatial format of the results, especially when showing them to decision-makers or discussing them at a high-level. However, to be able to use this method an agency needs both spatial data and staff with GIS expertise. Rijkswaterstaat found that it could be difficult to obtain the data in the correct format for GIS.

Selection of Adaptation Strategies (ROADAPT Part E)

WSDOT found ROADAPT Part E, the selection of adaptation strategies, one of the most helpful sections of the ROADAPT methodology. This section includes a long catalog of potential climate impacts, how they could impact transportation infrastructure, and potential strategies to mitigate the impacts. Going through this resource helped WSDOT identify additional climate impacts and potential adaptation strategies that they had not previously considered in detail.

FHWA Tools

VAST Tool

One advantage of the VAST tool is that no specialized expertise is needed to use the tool (unlike ROADAPT VA, which requires GIS skills). In addition, VAST allows users to adjust the weightings for the different indicators to understand the sensitivity of the results; this flexibility also allows agencies to prioritize the factors that are most important to them. A challenge with VAST is that a lot of data needs to be collected as an input to the model, which could take considerable time to collect. Both WSDOT and Rijkswaterstaat thought that the VAST tool would be difficult to use for many locations or assets unless the agency already had a detailed database of georeferenced asset data. However, in the U.S. many state departments of transportation are moving towards GIS-based asset management systems, so VAST may have potential in these states in the future.

CMIP Tool

WSDOT found FHWA's tools for downscaling CMIP data useful and plans to use them again, particularly for stormwater planning. However, the CMIP tool is not relevant for Rijkswaterstaat because it draws from a data set covering only the continental U.S. In addition, KNMI, the Dutch meteorological office, has detailed climate data specific to the Netherlands (see Figure 28), which are generally used as input for Rijkswaterstaat projects.[26] This data is also used to change design guidelines if necessary. The Dutch KNMI climate scenarios will be updated in the fall of 2023.

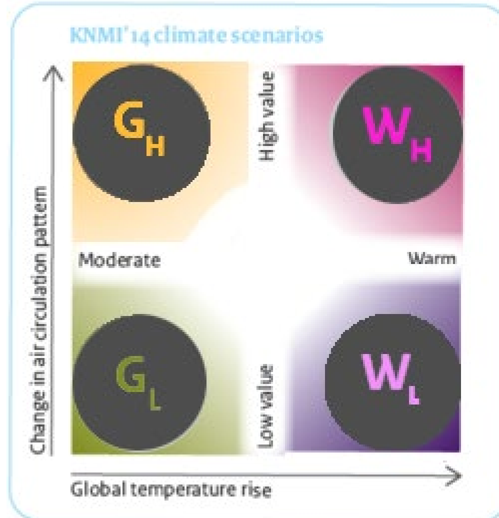

Figure 28: Climate impact scenarios from the Dutch meteorological office, KNMI, provide information on the climate impacts likely to be experienced in the Netherlands based on a moderate and warm scenario of global temperature rise, and a high and low scenario for changes in circulation patterns.

Rijkswaterstaat has sponsored CEDR research leading to the development of climate data related tools that may be of use in a U.S. context. These tools, which are available on the CEDR.eu website, include:

- ROADAPT climate data requirements of National Road Authorities for the current and future climate[27]
- Clipdar ("Design guideline for a transnational database of downscaled climate projection data for road impact models")[28]
- WATCH "Climate and climate change: protocol for use and generation of statistics on rainfall extremes"[29]

9.4 Impact of Using the Tools

Using ROADAPT and FHWA's Vulnerability Assessment Framework and tools helped Rijkswaterstaat and WSDOT more systematically consider vulnerability and risk in project design and planning. Both approaches contain tools that can be used as a checklist to identify potential climate impacts. ROADAPT also contains a list of potential adaptation strategies. Having a checklist can help agencies ensure that they are considering the range of potential extreme weather impacts that they are likely to face, as well as potential adaptation options. These lists can be used as a starting point, saving agencies time and

[26] KNMI Climate Scenarios. 2014. http://www.climatescenarios.nl/

[27] ROADAPT Consortium. Climate data requirements of National Road Authorities for the current and future climate. 2015. http://www.cedr.eu/download/other_public_files/research_programme/call_2012/climate_change/roadapt/ROADAPT_Part_A2_-_Climate_data_requirements_of_national_road_authorities.pdf

[28] Conference of European Directors of Road (CEDR). Call 2012 Climate Change. http://www.cedr.eu/strategic-plan-tasks/research/cedr-call-2012/call-2012-climate-change-road-owners-adapting-climate-change/

[29] Conference of European Directors of Road (CEDR). WATCH. Climate and climate change: protocol for use and generation of statistics on rainfall extremes. 2018. http://www.cedr.eu/download/other_public_files/research_programme/call_2015/climate_change/watch/WATCH-Climate-and-climate-change_Protocol-for-use-and-generation-of-statistics-on-rainfall-extremes.pdf

money that would otherwise be required to collect this information from scratch and seek out experts to obtain the information.

The analyses conducted using the resilience tools are feeding into the design process for both highway projects. Rijkswaterstaat's contract with the design firm for InnovA58 requires the contractor to use the climate analysis conducted under this project. The hydrologic and hydraulic analysis WSDOT conducted as part of this project will be used as inputs into the design of bridges and culverts for the SR 167 Completion Project.

The tools can also be used to help communicate results to decision-makers. In particular, the map-based results of ROADAPT VA can help communicate at a high level what potential vulnerabilities are and where they are likely to occur. Also, if the same tools are used across projects and across agencies, the results may be more comparable and more transparent than if different methods were used for each project.

As a result of this tools comparison project, FHWA and Rijkswaterstaat have made or are considering improvements to their tools. FHWA updated its Vulnerability Assessment Framework with information learned from ROADAPT and the collaborative tools testing process. Through the collaborative testing of the tools, FHWA identified multiple aspects of Dutch climate resilience approaches that were helpful and not already included in the FHWA Framework. FHWA then included these best practices from the Netherlands in the update of the FHWA Framework, issued in early 2018. Aspects of Dutch approaches included in the FHWA Framework Third Edition include:

- Discussion of ROADAPT's approach of analyzing threats to the surrounding environment as well as to the road itself. This helps planners and road operators understand how climate impacts will affect access roads and the communities that the road serves.[30]
- Citing ROADAPT's approach as an example of how a stakeholder-based vulnerability assessment can be combined well with an indicator-based assessment. The ROADAPT framework starts with the stakeholder-based Quickscan process to identify the primary climate risks and damage mechanisms. The next step in ROADAPT is an indicator-based approach that ranks the vulnerability of specific assets relative to one another.[31]
- Including the InnovA58 ROADAPT VA analysis as an example of an indicator-based approach similar to VAST, but with geographic output.[32]
- Including descriptions of the ROADAPT guidelines in the FHWA Framework with direct hyperlinks to them.[33]
- Highlighting the Rijkswaterstaat risk assessment approach for InnovA58 as an example of criteria and weighting for consequences and likelihood.[34]
- Using the results of a vulnerability assessment in contracting, as Rijkswaterstaat did for the design contract for InnovA58.[35]

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[30] FHWA, Vulnerability Assessment and Adaptation Framework, 3rd Edition, 2018. p35. https://www.fhwa.dot.gov/environment/sustainability/resilience/adaptation_framework/climate_adaptation.pdf
[31] Ibid. Page 36.
[32] Ibid. Page 38.
[33] Ibid. Pages 39, 47, and 53.
[34] Ibid. Pages 44-45.
[35] Ibid. Page 58.

These improvements to the Framework will help future projects in the United States. Similarly, when ROADAPT is updated, Rijkswaterstaat wants to incorporate some elements that are possible in the FHWA tools but not currently in ROADAPT. For example, VAST allows users to adjust the weightings for different indicators and get a sense of how the results would change; this flexibility also allows agencies to prioritize the factors that are most important to them. There is interest in making this adjustment of weightings possible in the ROADAPT VA tool. There is also interest in incorporating adaptive capacity indicators into ROADAPT VA.

9.5 Recommendations

Through using the tools on their pilot projects, both Rijkswaterstaat and WSDOT identified recommended improvements for the tools as well as situations where it makes sense to use each tool. Overall, the agencies obtained similar results from both tools. For example, the Rijkswaterstaat/Deltares team found that both the ROADAPT Table of Threats and the FHWA Sensitivity Matrix have a similar purpose and led to similar results for identifying assets that are sensitive to extreme weather. ROADAPT VA and VAST also led to similar results.

Rijkswaterstaat and WSDOT identified the following recommendations for using and improving the tools:

ROADAPT Recommendations

- Agencies should use ROADAPT VA to understand the spatial distribution of vulnerable locations within a region or a corridor and to present information to decision-makers in an easy to interpret, graphical way.
- ROADAPT VA could be improved by adding variable weighting to the vulnerability factors, which would allow users to easily manipulate the various vulnerability factors without having to change underlying data coding in the GIS environment.
- To align the results of ROADAPT VA with VAST, factors for adaptive capacity could be added to ROADAPT. As a result of the tools comparison, the ROADAPT tool developers were inspired to further develop the ROADAPT VA tool to make that possible.

FHWA Tools Recommendations

- VAST may be a good choice for agencies that have data on their assets compiled, such as through an asset management system, in a way that can be easily imported into VAST. VAST requires detailed data on the selected assets, which can be difficult to compile for a large number of assets, if not already available. Alternatively, agencies can use VAST to understand the vulnerability of a small number of selected assets.
- VAST could be improved with a more user-friendly interface and input mechanism that guides the user through the process.
- Rijkswaterstaat has sponsored CEDR research leading to climate related tools that may be of use for the US situation, all available on the CEDR.eu website. These tools could be relevant to compare against the CMIP tool or to incorporate into the CMIP tool if it is updated. The CEDR tools include:

- ROADAPT Climate data requirements of National Road Authorities for the current and future climate[36]
- Clipdar ("Design guideline for a transnational database of downscaled climate projection data for road impact models")[37]
- WATCH "Climate and climate change: protocol for use and generation of statistics on rainfall extremes"[38]

Recommendations for Both Tools

- Given the similarities between the tools, agencies should use whichever tool or combination of tools they feel most comfortable with or have the data to support. As one example of how the tools could be combined, ROADPT VA could be used to determine the most vulnerable locations, which could then be inputted into the VAST tool to further prioritize.
- For both VAST and ROADAPT, it is important to verify the results with stakeholders who are familiar with the assets, such as maintenance staff or asset managers. These individuals would be able to indicate whether the results match up with what they are seeing in the real world. They also may identify additional areas or assets of concern that were not identified through using the tools.
- Entering data into VAST or ROADAPT VA can be a time-consuming process. Developers of the ROADAPT VA tool are planning to automate the process of entering data, and VAST could be improved in this way as well.

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[36] ROADAPT Consortium. Climate data requirements of National Road Authorities for the current and future climate. 2015. http://www.cedr.eu/download/other_public_files/research_programme/call_2012/climate_change/roadapt/ROADAPT_Part_A2_-_Climate_data_requirements_of_national_road_authorities.pdf

[37] Conference of European Directors of Road (CEDR). Call 2012 Climate Change. http://www.cedr.eu/strategic-plan-tasks/research/cedr-call-2012/call-2012-climate-change-road-owners-adapting-climate-change/

[38] Conference of European Directors of Road (CEDR). WATCH. Climate and climate change: protocol for use and generation of statistics on rainfall extremes. 2018. http://www.cedr.eu/download/other_public_files/research_programme/call_2015/climate_change/watch/WATCH-Climate-and-climate-change_Protocol-for-use-and-generation-of-statistics-on-rainfall-extremes.pdf

10 Related Collaboration

An integral part of the collaboration between FHWA, Rijkswaterstaat, and WSDOT was in-person and virtual sharing of information. Through site visits to the Netherlands and Washington State, and quarterly webinars, the agencies were able to exchange information on the pilot projects and tools comparison, as well as explore other topics related to climate resilience. Moving forward, both Rijkswaterstaat and FHWA are refining their approaches to climate resilience, and incorporating many of the lessons learned from the collaboration.

10.1 Site visits

Netherlands, April 2017

The project team participated in a site visit to the Netherlands in April 2017. The site visit allowed participants from WSDOT and FHWA to visit the InnovA58 project site, meet the team involved with the project, and get a better understanding of how the resilience tools were applied. The site visit also allowed participants to learn more about a variety of topics related to transportation infrastructure resilience in the Netherlands, including:

- Climate projections and risks in the Netherlands;
- Dutch approach to coastal flood control;
- Including climate resilience requirements in contracting documents;
- Approaches to public engagement ("social design");
- Smart mobility;
- Building With Nature/nature-based resilience strategies;
- Emergency preparedness;
- Sustainability-check self-assessment tool; and
- Porous asphalt.

For more information about the site visit, see *Resilient and Sustainable Transport - Dutch Style: An interim report on bilateral cooperation between FHWA and Rijkswaterstaat.*[39]

Netherlands, June 2018

A different delegation from WSDOT and FHWA visited the Netherlands in 2018. This site visit focused on pavements and hydraulics. The delegation participated in a workshop on taking into account climate change on a project on the A20. The site visit also included presentations and discussion on:

- Porous pavement, pavement drainage, and incorporating climate into pavement design;
- Designing resilient water crossings, and co-benefits for fish passage;
- Road-weather operations and future precipitation projections;
- Asset management;
- Sustainability and resilience policy; and
- Nature-based adaptation strategies.

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[39] Hodges, Tina. Resilient and Sustainable Transport – Dutch Style: An interim report on bilateral cooperation between FHWA and Rijkswaterstaat. FHWA, 2017. https://www.fhwa.dot.gov/environment/sustainability/resilience/publications/dutch_style/index.cfm

Resilience Innovations Summit and Exchange (RISE) –Denver, Colorado, October 2018

The RISE conference had the goal of sharing emerging and state-of-the-practice information about how to include resilience practices in transportation system performance activities. In two conference sessions, FHWA, Rijkswaterstaat, and Deltares delegates gave presentations on resilience strategies and the topics covered as part of this collaboration. Both sessions were facilitated by FHWA and generated interest from conference participants.

The sessions were:

- *Frameworks for Resilience Strategies: Part A*
  This session covered national, state and community-level resilience frameworks, and the role of technologies in enhancing resilience. The presentations included:
    - FHWA's Resilience Framework: Highlights from State and MPO Pilots, Rebecca Lupes, FHWA
    - ARC's Resiliency Framework, David D'Onofrio, Atlanta Regional Commission
    - Climate Safe Infrastructure in Communities, Cris Liban, Los Angeles Metro
- *Frameworks for Resilience Strategies: Part B, Dutch Experience with Resilience*
  This session covered risk assessments and stress tests, lessons learned during implementing projects in the Netherlands and other parts of the world, and developing action plans for an uncertain future. The presentations included:
    - The Dutch Approach: Policy, Implementation, Challenges, Examples, Kees van Muiswinkel, Rijkswaterstaat, the Netherlands
    - Stress Testing the Dutch National Highway system for Climate and Extreme Weather Effects, Thomas Bles, Deltares, the Netherlands.
    - Applying Risk Assessment Methods in the Netherlands, Paraguay and Albania, Mike Woning, Deltares, the Netherlands.
    - FHWA-Rijkswaterstaat Cooperation on Resilient Transportation, Robert Kafalenos, FHWA

Washington State, October 2018

In October 2018 the project team, including a delegation from the Netherlands, participated in a site visit to Tacoma, Washington to view the SR 167 Completion Project location and continue to explore approaches to climate resilience being employed in Washington State and the U.S. The project team toured the location of the future SR 167 Completion Project near Tacoma, and viewed the creeks in their existing condition as well as where they have been restored. The project team also visited a Port of Tacoma wetland and stream habitat restoration area (Upper Clear Creek) that resembles what the RRP may look like in the future (see Figure 30), toured a levee setback project that incorporates flood control and habitat restoration, and viewed innovations along I-90 that promote habitat connectivity and wildlife passage (see Figure 29).

Figure 29: The project team visited a habitat crossing under construction on Interstate 90 near Snoqualmie, Washington. (Source: Volpe Center).

Figure 30: Left - Project team tours the Port of Tacoma's Clear Creek wetland and stream habitat restoration site in Tacoma. (Source: WSDOT). Right - The Clear Creek restoration is similar to what is intended for the Hylebos RRP. Previous development had channeled Clear Creek into a straight line running parallel to the rail tracks in this area. The Port of Tacoma restored the creek in this area to a meandering flow with floodplain, wetlands, and native plantings, yielding impressive habitat improvements. The delegation observed salmon jumping and heard multiple species of birds and frogs. (Source: FHWA).

The site visit also included presentations and discussion on the following topics:

- SR 167 and RRP project updates and use of climate projections in the project;
- Climate and sea level rise projections for Washington State;
- City of Tacoma sustainability and resiliency efforts;
- Wetlands restoration and wetlands mitigation banks;
- Emergency response;
- Hazard mitigation planning and coastal hazards management; and
- Rijkswaterstaat approaches to climate resilience and stress-testing the Dutch highway network.

Washington DC, October 2018

The Rijkswaterstaat delegation visited the FHWA offices in Washington, DC on October 15-16, 2018, after the visit to WSDOT. The delegation met the FHWA the sustainability team, and FHWA presented about the following topics:

- Update on FHWA and Rijkswaterstaat sustainability and resilience efforts;
- Incorporating resilience into asset management plans;
- Dealing with uncertainty in climate projections and incorporating climate projections into design of bridges and culverts;
- Update on initiatives involving natural and nature-based features for flood risk mitigation;
- Sustainable pavements; and
- Alternative fuel corridors.

10.2 Webinars

As part of the collaboration, participants identified topics of interest (generally related to climate resilience) that they wished to explore in more detail through information sharing webinars. These webinars typically included presenters from Rijkswaterstaat and FHWA (and sometimes WSDOT or another agency), who would talk about their agency's approach to the topic. Attendees included those working on the tools comparison project as well as others from the agency or partner agencies who were working on or had expertise in the topic area. The webinars covered the following topics:

- Stormwater management (December 2016)
- Precipitation projections and climate change (June 2017)
- Porous asphalt and noise reduction (September 2017)
- Habitat crossings (September 2017)
- Green infrastructure and nature-based resilience solutions (January 2018)
- Precipitation projections and project design, in support of a National Cooperative Highway Research Program (NCHRP) project (May 2018)[40]
- Integrating resilience in asset management and performance measurement (December 2018)

[40] NCHRP 15-61, Applying Climate Change Information to Hydrologic and Hydraulic Design of Transportation Infrastructure. http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4046

11 Conclusion and Next Steps

Throughout the collaboration, FHWA, Rijkswaterstaat, NCDOT, and WSDOT shared information on agency-wide resilience strategies, compared climate resilience tools, and delved into case studies of specific projects that incorporated nature-based solutions. Moving forward, both Rijkswaterstaat and FHWA are refining their approaches to resilience and incorporating many of the lessons learned from the collaboration.

A key benefit of this collaboration has been information sharing. Despite differences in geology and hydrology between the pilot projects, and differences in policy and approaches for design standards in the two countries, the agencies were able to learn from each other on approaches for integrating climate change into project design.

Partners shared their experiences and successes with vulnerability assessment tools and nature-based and other resilience strategies, and identified common challenges. Topics covered a mix of policy, climate science, and practical applications, and participants represented a range of disciplines (including policy, planning, engineering, hydrology, and more). Viewing common challenges in different contexts sparked ideas and improved analyses.

As a result of this information sharing, partners can build off and learn from what others have done, saving time and resources. Participants noted that information sharing was particularly beneficial around the following topics:

- Practices for improving resilience (e.g., the use of sand for beach nourishment)
- Approaches for optimizing where to make resilience investments
- Learning from tools that are being developed
- Integrating resilience into asset management
- Assessing vulnerability and considering a range of vulnerabilities in planning and project development
- Policy and funding allocation for resilience
- Sharing communication and outreach materials

In addition, the ROADAPT tools and the FHWA Framework and associated tools have been or are being updated based on findings from the tools comparison portion of the collaboration. As a result, the tools will be improved for other agencies that use them in the future.

Over the last two years of the collaboration, work on climate resilience has ramped up at all of the partner agencies. Agencies are moving from assessing vulnerabilities and planning for climate change resilience to incorporating resilience into working procedures and implementing projects that enhance resilience. There are numerous opportunities for continued information sharing as agencies move into this implementation phase. For example, in 2021 the Conference of European Directors of Roads (CEDR) began a research program on climate change resilience with the goal to undertake research on integrating climate change into decision-making processes and implementing existing research into practice.

This importance of implementing resilience strategies is underscored by the extreme weather faced by partner agencies during the course of this collaboration, including severe riverine flooding in the

Netherlands, wildfires and landslides in Washington State, and storm damage in North Carolina. These and other impacts are expected to become more frequent and severe as climate change intensifies, highlighting the need for large, rapid investments in resilience.

At the same time, there is significant new funding and policy direction for resilience in the Bipartisan Infrastructure Law in the U.S. and the European Green Deal. WSDOT, NCDOT, and Rijkswaterstaat also have State and agencywide policies that promote resilience. Implementation of climate resilience projects, including those that incorporate nature-based strategies, is ramping up, and the partner agencies will continue to draw on information shared during this collaboration as they implement these policies and projects.

Appendix: Planning and Environmental Topics in the Netherlands

Throughout the collaboration, the agencies identified topic areas where the approaches in the U.S. and the Netherlands for environmental regulation and planning differed. This following sections describe how the Netherlands and Rijkswaterstaat address several of these topics: coastal flood defenses, bridge design standards, and nature compensation.

Approach to Coastal Flooding and Flood Defenses

Sixty percent of the Netherlands is prone to coastal or riverine flooding, which determines the way the government manages water. In areas prone to flooding from the sea, rivers, or canals, fixed water levels are maintained by pumping water out when water levels are high and letting it in when water levels are low. Road surfaces are generally at least 0.5 meter above groundwater level to prevent frost damage. Roads are generally not designed to be flooded, as the flood defenses will typically prevent this.

Flood risk protection is strongly regulated in the Netherlands on a national level, as described in the Delta Program.[41] The Delta Program states that flood risk management policy is aimed at ensuring that by no later than 2050, the probability of fatality due to flooding will be reduced to 1 in 100,000 per year (.001%) or less for every resident living behind the dikes, as proposed in the Delta Decision on Flood Risk Management. Additional protection is needed in areas with potentially large groups of victims, potential for major economic damage, or vulnerable infrastructure of national significance. For that reason, new flood protection standards are in place for the dikes, dunes, and dams. The risks are reduced even further by adaptations in spatial planning and disaster control systems.

This means that for road projects in the Netherlands, generally no calculations are made regarding flood protection or standards, as the flood protection standards have been set in the Delta Program. Primary flood defenses along rivers and the sea are managed and maintained by Rijkswaterstaat.

In the parts of the Netherlands below sea level, secondary flood defenses are managed by 21 regional water boards (water authorities) that work on water safety, water quality, and water quantity. They work together in an organization called Dutch Water Authorities, which consists of these 21 regional water authorities and their association, the 'Unie van Waterschappen'.[42]

Road authorities (in the Netherlands these are municipalities, provinces, water boards and Rijkswaterstaat) rely on Rijkswaterstaat (primary flood defenses) and the water boards (secondary flood defenses) for flood protection and for addressing sea level rise. Due to the high level of protection provided by the flood defenses, roads are typically not designed with flooding in mind (since the likelihood of failure of the flood defenses is low). In some cases, like the Afsluitdijk[43], roads are built on flood defenses or dikes. As the road is built on the flood defense itself, designing for resilience to flooding is not an issue in itself.

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[41] Delta Programme 2019. Continuing the work on the delta: adapting the Netherlands to climate change in time. https://english.deltacommissaris.nl/documents/publications/2018/09/18/dp2019-en-printversie

[42] Dutch Water Authorities. https://dutchwaterauthorities.com/

[43] "The Afsluitdijk." Rijkswaterstaat. https://www.rijkswaterstaat.nl/english/water-systems/protection-against-water/dykes/the-afsluitdijk-project/index.aspx

Bridge Design Standards

For bridge design standards, the Netherlands uses *Eurocodes* and the national technical document Richtlijnen Ontwerpen Kunstwerken (ROK, which means 'guidelines for design of bridges, flyovers and viaducts'). ROK includes guidelines on country specific factors such as traffic load. There are two main standards for bridges in the Netherlands: one for new bridges and one for existing bridges.

Eurocodes and ROK are applied through a database with technical risks for designing and building bridges. Rijkswaterstaat gives the requirements and the accepted risk level for a bridge (rather than designing the bridge itself), and lets the contractor provide the solution that they think is best, as long as it complies with the Eurocodes and ROK. A risk level is set from the beginning of the project, and the contractor has to show that the design complies with that risk level. This approach aims to leave as much as possible to the market and allow for innovative solutions. The contractor is responsible for the quality of the bridge and uses quality controls to ensure that the bridge is built the way it was designed. Rijkswaterstaat also controls (assesses) certain parts of the process, especially critical phases of the construction process. One challenge with the Dutch approach is finding the right balance between the number of guidelines and requirements and the desire for flexibility and allowing for market forces. There need to be sufficient guidelines for the bridge to have the required function, and to incorporate knowledge and experience from previous projects.

Climate change is another uncertain factor that may have to be taken into account when designing new bridges. At a European level, Eurocodes can be a suitable instrument for addressing climate resilience in different infrastructure sectors. Eurocodes are a set of European standards for the structural design of buildings and civil engineering works, produced by the European Committee for Standardization (CEN) to be used in the European Union (EU). The European Commission has asked CEN to prepare a proposal for how to incorporate climate change and extreme weather events in the Eurocodes.

A section of the EU document titled *Adapting infrastructure to climate change*[44] is about EU policy mainstreaming. This section states: "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 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."

Nature Compensation

In the Netherlands, if adverse effects of road projects on protected nature values cannot be prevented (e.g., by means of an alternative planned route) or limited (through mitigating measures such as habitat crossings), nature must be compensated by replacing the nature value that was lost as a result of the project. The *Structuurschema Groene Ruimte* (Green Space Structure Scheme, or SGR) of 1993 lays out

[44] Eurpoean Commission. Commission Staff Working Document: Adapting infrastructure to climate change. 2013. https://ec.europa.eu/clima/sites/clima/files/adaptation/what/docs/swd_2013_137_en.pdf

this policy. The compensation does not necessarily have to be performed by Rijkswaterstaat itself. However, as the initiator of road projects Rijkswaterstaat is responsible for ensuring that these measures are implemented.

The compensation policy includes the “no, unless” principle, which prescribes that no development may take place in protected areas, unless there is a need for it. This means that a deliberation must be made between the usefulness and necessity of the activity in question (e.g., the construction of a road) and the damage to nature that it will cause. The outcome of this consideration determines whether or not an activity may continue.

Nature compensation can involve improving the existing habitats of plant and animal species that suffer damage from the project, or of the development of new habitats. The acquisition (if necessary), landscaping, and long-term management of the designated land is also part of the compensation. In many cases the land and management of these nature compensation areas are transferred to nature conservation organizations.

Rijkswaterstaat has over ten years of experience with nature compensation in accordance with the SGR. Since 2000, the Netherlands - and with it Rijkswaterstaat - has been confronted with the effects of the European Habitats and Birds Directives. These guidelines are incorporated in the Netherlands in the (New) Nature Conservation Act and the Flora and Fauna Act. The rules for determining whether work should take place in areas designated under these directives are now much stricter. Under these rules nature compensation must also occur if the impacts cannot be prevented or mitigated. Compensatory measures, such as the creation of ponds for amphibians, can also be a condition for an exemption under the Flora and Fauna Act.

As of February 2019, no final plans have been made in the InnovA58 project for nature compensation. The current highway is a barrier for small rivers crossings. The reconstruction plans for the InnovA58 project offer opportunities to improve the connections with an eye towards nature, recreation, and scenery. In a recent study, Rijkswaterstaat identified potential improvements of stream passages of the A58. Desired improvements mainly concern the streams Beerze, Reusel, Leij and Mark, which connect large nature and recreational areas on both sides of the A58. The InnovA58 project will include measures to preserve the current functioning of the passages. Possible improvements of the passages will require extra financing from external parties, such as water boards or provincial governments. The option to improve the passages would include a large area of nature compensation (60,000 square meters) along the banks of one of the small rivers of and a wider crossing underneath the highway.