

# International Practices on Climate Adaptation in Transportation

Findings from a virtual review



Source: New Zealand Transport Agency

## Synthesis Report — January 2015

Prepared for:  
**Federal Highway Administration**  
**Office of Natural Environment**  
**Washington, D.C.**



U.S. Department of Transportation  
**Federal Highway Administration**

## **Notice**

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for the contents or use thereof.

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the objective of this report.

---

**REPORT DOCUMENTATION PAGE***Form Approved*  
*OMB No. 0704-0188*

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE January 2015	3. REPORT TYPE AND DATES COVERED Final Report	
4. TITLE AND SUBTITLE International Practices on Climate Adaptation in Transportation: Findings from a Virtual Review			5a. FUNDING NUMBERS	
6. AUTHOR(S) Gina Filosa and Alexandra Oster			5b. CONTRACT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Department of Transportation John A. Volpe National Transportation Systems Center 55 Broadway Cambridge, MA 02142-1093			8. PERFORMING ORGANIZATION REPORT NUMBER DOT-VNTSC-FHWA-15-01	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) US Department of Transportation Federal Highway Administration Office of Natural Environment 1200 New Jersey Avenue, SE Washington, DC 20590			10. SPONSORING/MONITORING AGENCY REPORT NUMBER FHWA-HEP-15-012	
11. SUPPLEMENTARY NOTES FHWA Project Leads: Tina Hodges and Rob Kafalenos				
12a. DISTRIBUTION/AVAILABILITY STATEMENT This document is available to the public on the FHWA website at <a href="http://www.fhwa.dot.gov/environment/climate_change/adaptation/publications_and_tools/">http://www.fhwa.dot.gov/environment/climate_change/adaptation/publications_and_tools/</a>			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) The Federal Highway Administration (FHWA) conducted an international review to study how international transportation agencies are addressing issues related to adapting highway infrastructure to the impacts of climate change. The review involved transportation agencies from Australia, Canada, Denmark, Korea, New Zealand, the Netherlands, Norway, and the United Kingdom. The review elicited information on adaptation issues associated with all aspects of the transportation project delivery process. This synthesis report highlights the state of the practice of how transportation agencies are addressing climate adaptation through the following: adaptation frameworks/strategies; climate change risk assessments; selecting adaptation measures and strategies; long range planning and land use; changes in design standards; maintenance and operations; asset management; and research. The information collected during the review and presented here is relevant to transportation planners, asset managers, design engineers, and policy-makers.				
14. SUBJECT TERMS Climate Change, Adaptation			15. NUMBER OF PAGES 37	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT Unlimited	

## Acknowledgments

The U.S. Department of Transportation Federal Highway Administration (FHWA) in partnership with the Volpe National Transportation Systems Center (Volpe Center) prepared this synthesis report. The Volpe Center project team included Gina Filosa and Alexandra Oster of the Transportation Policy and Planning Technical Center.

The Volpe project team wishes to thank Tina Hodges and Rob Kafalenos, the FHWA project leads, for their guidance and support in conducting the virtual review and developing the report. The team also thanks the Volpe Center's Carson Poe for his time and expertise in reviewing this document.

Lastly, the team also thanks representatives of the following international transportation agencies who graciously shared their time, knowledge, and valuable insights (please see Appendix C for a full list of agency representatives that were interviewed):

- VicRoads, Victoria, Australia
- New Zealand Transport Agency, New Zealand
- Vejdirektoratet (Danish Road Directorate), Denmark
- Rijkswaterstaat (Ministry of Infrastructure and the Environment), Netherlands
- Korea Expressway Corporation (KEC), Republic of Korea
- Department for Transport, United Kingdom
- Highways Agency, United Kingdom
- Statens vegvesen (Public Roads Administration), Norway
- Transport Canada, Canada

This report could not have been developed without the input from experts at these agencies.

## Contents

List of Figures .....	v
List of Tables .....	v
Executive Summary .....	i
1. Introduction .....	1
2. Adaptation Strategy.....	3
3. Climate Change Vulnerability and Risk Assessment .....	8
4. Long Range Transportation Planning and Land Use .....	12
5. Integration of Climate Change into Design Practices.....	15
6. Maintenance and Operations.....	21
7. Asset Management.....	23
8. Research.....	25
9. Conclusions .....	28
Appendix A: Discussion Topics .....	29
Appendix B: Agency Snapshots .....	30
Appendix C: Interview Participants .....	33
Appendix D: Bibliography .....	35

## List of Figures

Figure 1: Description of Delta Scenarios .....	5
Figure 2: Highways Agency Adaptation Framework Model.....	7
Figure 3: Collecting Well and Connecting Pipe .....	17
Figure 4: Length of Collecting Dish .....	17
Figure 5: Retrofit of In-Service Bridges .....	18
Figure 6: Causeway Upgrade Project Construction. Top Image: Existing Causeway Configuration in 2013. Bottom Image: Final Causeway Configuration by 2017.....	20
Figure 7: XGEO Web Tool.....	22

**List of Tables**

Table 1: Change in Precipitation Pattern ..... 16

Table 2: Design Rainfall Generation Frequency (years)..... 17

## Executive Summary

Global climate change poses serious challenges to the transportation community. Climate change effects, such as changes to long-term annual average temperatures and precipitation patterns, increased frequency and intensity of storm events and heat waves, and rising sea levels, have direct implications on the planning, design, construction, operations and maintenance of transportation systems. In recent years, many transportation agencies in the United States have begun to assess the risks that their transportation systems and operations face and the vulnerabilities that they have due to climate change impacts. However, even the most proactive agencies are in the early stages of developing and implementing adaptation strategies and are keen to learn from the experiences of peers, including those internationally.

The Federal Highway Administration (FHWA) conducted a virtual international review to study how transportation agencies worldwide are working to adapt highway infrastructure to the impacts of climate change. The review team spoke with staff from the following agencies on adaptation issues associated with all aspects of the transportation project delivery process, including policy development, planning, design, construction, operations, and maintenance:

- VicRoads, Victoria, Australia
- New Zealand Transport Agency, New Zealand
- Vejdirektoratet (Danish Road Directorate), Denmark
- Rijkswaterstaat (Ministry of Infrastructure and the Environment), Netherlands
- Korea Expressway Corporation (KEC), Republic of Korea
- Department for Transport, United Kingdom
- Highways Agency, United Kingdom
- Statens vegvesen (Public Roads Administration), Norway
- Transport Canada, Canada

While there is considerable confidence in climate model estimates for future climate change, the exact timing and magnitude of climate change effects as well as their precise impacts on roadway infrastructure and logistics is uncertain. The uncertainty is related to unknown future emissions levels; climate models limitations, and a lack of information on the degree of effectiveness of adaptation strategies. Nevertheless, transportation agencies still must make decisions about and investments in their road networks.

### Key Findings and Observations

This synthesis report highlights proactive actions that international transportation agencies are taking to address uncertainties connected to climate change and to manage the associated risks. The report highlights the following state of the practice:

- *Adaptation frameworks/strategies:* An adaptation framework or strategy is a foundation for an organization to implement adaptive actions. It provides a sound basis for decision-making when confronted with climate uncertainties. Several of the countries - included in the review – namely Canada, Denmark, the Netherlands, New Zealand, Norway, and the United Kingdom have developed climate adaptation strategies and policies at the national level. Although the levels of

detail in these documents vary, common elements typically found include a brief description of climate change predictions, an assessment of associated risks and/or vulnerabilities, and identification of a process of how to address and respond to the risks and vulnerabilities. These national strategies have in turn influenced the climate adaptation strategies their transportation agencies have developed.

- *Climate change risk assessments:* Several of the transportation agencies that participated in the review are employing systematic methods to address some of the inherent uncertainties and to manage the associated risk. The purpose of a climate change risk and/or vulnerability assessment is to determine how climate change may impact an agency's transportation assets and prioritize measures to maximize impact and minimize costs. The Danish Road Directorate follows the Blue Spot method – a four level analysis to identify roadway locations where the likelihood of floods is high and the consequence of flooding is significant. Similarly, the ROADAPT research project, a joint research effort supported by a number of European countries, developed a preliminary risk assessment method that can identify vulnerable locations in the transportation network, understand the probabilities and consequences that climate change events could have on these locations, and provide options for adaptation actions.
- *Changes being implemented in long range planning and land use processes:* Incorporating climate change impacts and climate data into long range transportation planning and land use decisions can play a significant role in both mitigating and adapting to climate change. The United Kingdom requires that applicants seeking approval for Nationally Significant Infrastructure Projects must take climate change effects into consideration when planning the facility's location, design, construction, and operation. Similarly, the New Zealand Government provides best practice information and guidance to local authorities on integrating climate change considerations, including sea level rise, into land-use planning and decision-making processes. The Guidance Manual includes specific recommendations for the degree of sea level rise to consider.
- *Integrating climate change into design standards:* Several international transportation agencies have begun to integrate climate projections into design criteria and specifications for transportation infrastructure projects. Examples include the Danish Road Directorate's new drainage standards, the Korea Expressway Corporation's bridge design countermeasures, which include requirements for new bridges to be designed for a 200-year return period (instead of a 100-year return period) and have a minimum freeboard of 2 meters. The agency is also adapting in-service bridges at low elevation by either reconstructing them or raising their heights by 1 to 3 meters. The Norwegian Public Roads Administration also recently updated its planning, design and construction manuals to integrate adaptation measures.
- *Maintenance and operations:* Climate change impacts will likely necessitate changes in the ways transportation agencies operate and maintain their systems and facilities. Some of the agencies participating in the review are making minor changes to maintenance and operation activities, though most indicated that they are not at the point where climate change impacts have directly translated to changes in their maintenance practices. Examples of changes that agencies are making include: increased field inspection of drainage systems; providing traveler information to address weather-related safety; installing traffic safety and warning measures; and improving emergency plans.
- *Asset management practices:* Climate change impacts will likely alter transportation asset



management investment cycles. Several of the transportation agencies included in the review are actively integrating climate change considerations into their asset management plans. Examples include the Korea Expressway Corporation's new preventative slope management strategy, which is designed to prioritize slopes for preventative maintenance and reduce the amount of money spent on emergency relief, and the New Zealand Transport Agency's *Coastal Effects Assessment Guideline*, which outlines a simple, consistent, and comprehensive process for asset managers to determine short- and long-term risks to state highway assets in the coastal environment.

- *Research:* Many of the transportation agencies included in the review are participating in collaborative research initiatives that address critical information and data needs related to climate change adaptation. These collaborative research efforts include two research programs from the European Road Association that focus on climate change adaptation. The first effort, *Road Owners Getting to Grips with Climate Change*, was designed to provide European road authorities with the knowledge and tools necessary to "get to grips" with climate change and its impacts on all elements of road management by adapting design rules, updating and improving data collection, and developing risk management methods. The second program focused on providing owners with adaptation technologies and the models and tools to support decisionmaking concerning adaptation measures for road infrastructure.

# I. Introduction

## I.1 Background and Purpose

Global climate change poses serious challenges to the transportation community. Climate change effects, such as changes to long-term annual average temperatures and precipitation patterns, increased frequency and intensity of storm events and heat waves, and rising sea levels, have direct implications on the planning, design, construction, operations, and maintenance of transportation systems. Climate change adaptation is the practice of implementing actions to avoid, withstand, or take advantage of current and projected climate changes and impacts. Adapting transportation infrastructure to anticipated climate change impacts is critical to avoiding or at least minimizing potential damage, disruption in service, and safety concerns.

In recent years, many transportation agencies in the United States have begun to assess the risks that their transportation systems and operations face and the vulnerabilities that they have due to climate change impacts. However, even the most proactive agencies are in the early stages of developing and implementing adaptation strategies and are keen to learn from the experiences of peers, including those internationally.

The Federal Highway Administration (FHWA) conducted a virtual international review to study how international transportation agencies are addressing issues related to the adaptation of highway infrastructure to the impacts of climate change, and to identify innovative and best practices that could be implemented in the United States to help advance the development and implementation of adaptation strategies. The review involved nine agencies that were chosen based on their leadership in the climate adaptation field. Agencies that participated in the review were:

- VicRoads, Victoria, Australia
- New Zealand Transport Agency, New Zealand
- Vejdirektoratet (Danish Road Directorate), Denmark
- Rijkswaterstaat (Ministry of Infrastructure and the Environment), Netherlands
- Korea Expressway Corporation (KEC), Republic of Korea
- Department for Transport, United Kingdom
- Highways Agency, United Kingdom
- Statens vegvesen (Public Roads Administration), Norway
- Transport Canada, Canada

The adaptation efforts for transportation infrastructure underway in these countries are diverse in scope and application, reflecting a broad array of geographic, environmental, and societal conditions much like those found across the United States.

The scope of the review corresponds with the wide-ranging and multidisciplinary implications of climate change on transportation infrastructure. The review elicited information on adaptation issues associated

with all aspects of the roadway transportation project delivery process, including policy development, planning, design, construction, operations, and maintenance. The compiled information presented here is relevant to transportation planners, asset managers, design engineers, and policy-makers.

## **I.2 Methodology**

The review team included staff from FHWA's Offices of Natural Environment; Asset Management, Pavements, and Construction; Bridges and Structures; and International Programs; and staff from the Volpe National Transportation Systems Center. The review team determined which agencies to include in the review using information from three primary sources: reports on prior related scanning studies; published literature; and knowledge from experts in the field. Once the agencies were selected, the review team reached out to an initial point of contact at each agency to identify appropriate point of contact(s) who could participate in one, 1.5-hour web-based meeting. The review team provided each interviewee with a list of discussion topics about which FHWA was interested in learning more (see Appendix A).

The review team then conducted web-based meetings with each of the nine agencies. See Appendix C for a list of interview participants. The format of the meetings allowed for discussion over the phone with concurrent sharing of presentations and documents online. The review team conducted the interviews between May and September 2014. Finally, the review team reviewed research reports and official agency documents that the peer agencies provided in supplement to the information discussed during the interviews (see Appendix D).

## 2. Adaptation Strategy

An adaptation strategy or framework is a foundation for an organization to implement adaptive actions. It provides a sound basis for decision-making when confronted with climate uncertainties. Several of the countries included in the review have developed climate adaptation strategies and policies at the national level. These national strategies have in turn influenced the climate adaptation strategies their transportation agencies have developed.

The following section highlights the adaptation strategies and frameworks for the agencies included in the review who have established formal frameworks. Although the levels of detail in these documents vary, common elements typically found include a brief description of climate change predictions, an assessment of associated risks and/or vulnerabilities, and identification of a process of how to address and respond to the risks and vulnerabilities.

### **Canada's Federal Climate Change Adaptation Framework**

Environment Canada developed a Federal Adaptation Policy Framework that guides the Government's domestic adaptation actions. This Framework sets out a vision, objectives, roles of the federal government, and criteria for identifying adaptation priorities. The Framework identifies three key themes to the Federal Government's role in climate change adaptation:

- Generating and sharing knowledge and building adaptive capacity to respond
- Integrating adaptation into federal policy and planning
- Using convening power to facilitate collaboration among stakeholders and sectors

Building upon the Federal Framework, Transport Canada developed its first Climate Adaptation Action Plan in 2013. The Adaptation Plan is the department's first step in addressing and identifying gaps, risks, and opportunities related to adaptation, and sets the stage for future action. The plan includes an action plan that outlines goals and objectives that align with the Federal Framework, and identifies specific actions that the department will take to achieve those goals.

### **Denmark: Strategy for Adapting to Climate Change**

In 2012, the government of Denmark developed an *Action Plan for a Climate-Proof Denmark*, which identified a series of initiatives that different government entities, including the Ministry of Transport and the DRD, are conducting or have planned to ensure that the country will become more resilient to climate change. Building off the overarching guidance and commitments in this plan, the DRD published its *Strategy for Adapting to Climate Change* in 2013. The aim of this document is to ensure DRD takes actions to address climate change in the most economically responsible and efficient manner. DRD's climate strategy is focused on road flooding, which is the agency's central challenge associated with climate change impacts. The DRD's climate strategy involves a three-pronged approach to addressing increased rainfall and water on roads: "we manage, we improve and we prevent." DRD carries out this approach as follows:

1. *Manage flooding when it occurs.* When flooding occurs, the DRD will close affected roadways, provide information to warn motorists, and work to clear up incidents quickly.
2. *Make improvement to roads.* After a road flooding, DRD will analyze the event and conduct a cost-benefit analysis to identify a financially viable improvement. As part of this work, the DRD is developing a database of climate events in order to understand climate impacts at a national level. The DRD has defined climate events as a "complete or partial closure of a national road, or

part of that road, for the duration of more than one hour, as a result of water on the road surface.” Additionally, DRD is committed to cooperating with relevant authorities to better coordinate activities and ensure they capitalize on opportunities to reduce risk.

3. *Prevent wherever it is possible.* The DRD has determined that it is not necessary or economically feasible to prevent all climate events on the road network. In order to prioritize actions, the DRD conducts Blue Spot Analysis to screens for particularly vulnerable areas (see Chapter 3 for more information on the Blue Spot Analysis). The agency is also proactive about considering climate change in the planning and construction phases in order to climate-proof – make more resilient to climate change - new infrastructure.

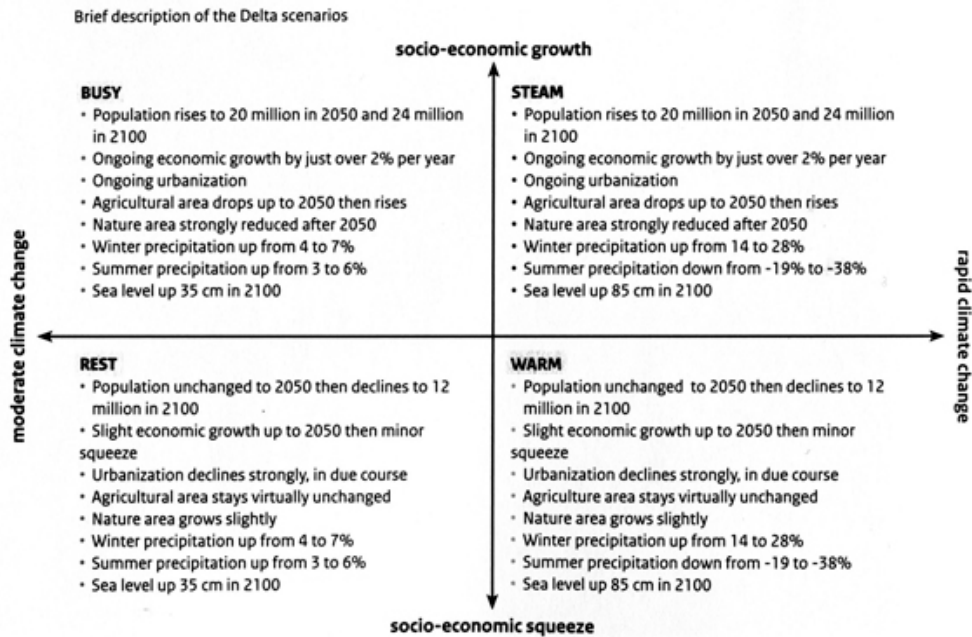
DRD is now developing an action plan to carry out its climate change strategy. The action plan will describe climate adaptation actions more fully and assign responsibility for implementation of these actions.

### **The Netherlands Delta Programme**

The Netherlands is a low-lying country that is vulnerable to flooding. The country’s Delta Act, which took effect in 2012, requires a Delta Programme, which involves the development of yearly plans to protect the country from high water and ensure a sufficient supply of freshwater. Since the Delta Programme is designed to address future impacts, many of which are uncertain, Delta Scenarios were developed to help manage the uncertainty. The four scenarios (see Figure 1) take the relationship between socio-economic trends and climate change into account. The initial Delta Scenarios, which were developed in 2012, were based on the climate scenarios of the Royal Netherlands Meteorological Institute (KNMI). In 2014, the KNMI incorporated the latest insights into its scenarios. The changes were so slight that it was not necessary to adjust the Delta Scenarios as they still corresponded to the range of plausible future changes.

**Figure 1: Description of Delta Scenarios**

Source: Delta Programme



The annual Delta Programme identifies measures and projects to adapt physical systems, such as dykes and pumps, as well as spatial planning strategies (i.e. prohibiting construction in some locations, raising structures in others, etc.) to proactively manage flooding. Delta Programme 2015 outlines final proposals for addressing water safety and fresh water supply in the country. A key measure in the 2015 Programme is a new approach to water-safety standards. The new standards are based on a risk-based approach, in which the risk of flooding and the possible consequences are taken together to determine the safety standard level (the current approach only looks at a flood water level being exceeded). The 2054 Programme outlines three types of measures that will be implemented to manage flood risk:

- Layer 1: preventive measures to limit the probability of a flood;
- Layer 2: spatial organization of an area to limit consequences of a flood and, in specific cases, to contribute directly to the desired level of safety;
- Layer 3: disaster management to limit the consequences of a flood in terms of casualties.

The government aims to have the new water-safety standards embedded in law by 2017. The goal is to have all flood defense systems meet the new standards by 2050. The Netherlands has a Climate Agenda (2013) addressing both mitigation and adaptation aspects and plans to adopt a national adaptation policy, which will be broader than infrastructure alone, by 2017.

**New Zealand: State Highway Resilience Programme Business Case**

New Zealand’s 2010 National Infrastructure Plan outlined New Zealand’s priorities for infrastructure and highlighted future investments for all major sectors, including transportation. This plan also acknowledged the need to consider climate change adaptation as part of the planning and development process for new infrastructure projects. In the subsequent 2011 National Infrastructure Plan, infrastructure resilience emerged as a guiding principle, driven in part by two major earthquakes in the country’s Canterbury region. In the 2011 plan, the New Zealand Government set a new vision for infrastructure, committing to create resilient infrastructure that is coordinated and contributes to

economic growth and increased quality of life. According to the plan, “the concept of resilience is wider than natural disasters, and covers the capacity of public, private and civic sectors to withstand disruption, absorb disturbance, act effectively in a crisis, adapt to changing conditions, including climate change, and grow over time” (p. 14). Thus, in this plan, climate change adaptation is a way to achieve resilience.

In response to the National Infrastructure Plan and several significant highway emergency events, the New Zealand Transport Agency recently released a *State Highway Resilience Programme Business Case*. This business case establishes the rationale for investment in a program of works to ensure the Agency has the capacity to withstand, absorb, adapt to, and recover from disturbance and change conditions and to grow over time as required to meet demands. The Business Case is focused on understanding risks, such as those posed by sea level rise, and concentrating efforts on where the risk to the state highway network is greatest. By 2017, the Transport Agency aims to have a national infrastructure network investment and management approach to resilience, which will be incorporated into the 2018-2021 three-year National Land Transport Plan (New Zealand Transport Agency, 2014).

#### **Norway: National Climate Change Adaptation Strategy**

In 2013, the Norwegian Parliament issued a national strategy for climate change adaptation, which established a common framework for climate change adaptation across sectors and administrative levels (Meld. St 33, 2013). The strategy emphasizes building scientific knowledge on which to base policy decisions and strengthening that knowledge through collaboration across sectors and levels of government. As a precautionary approach, the strategy recommends that assessments of the impacts of climate change should be based on figures from the high end of the range of national climate projections. The national strategy provided the Norwegian Public Roads Administration with the political framework to advance its climate adaptation work.

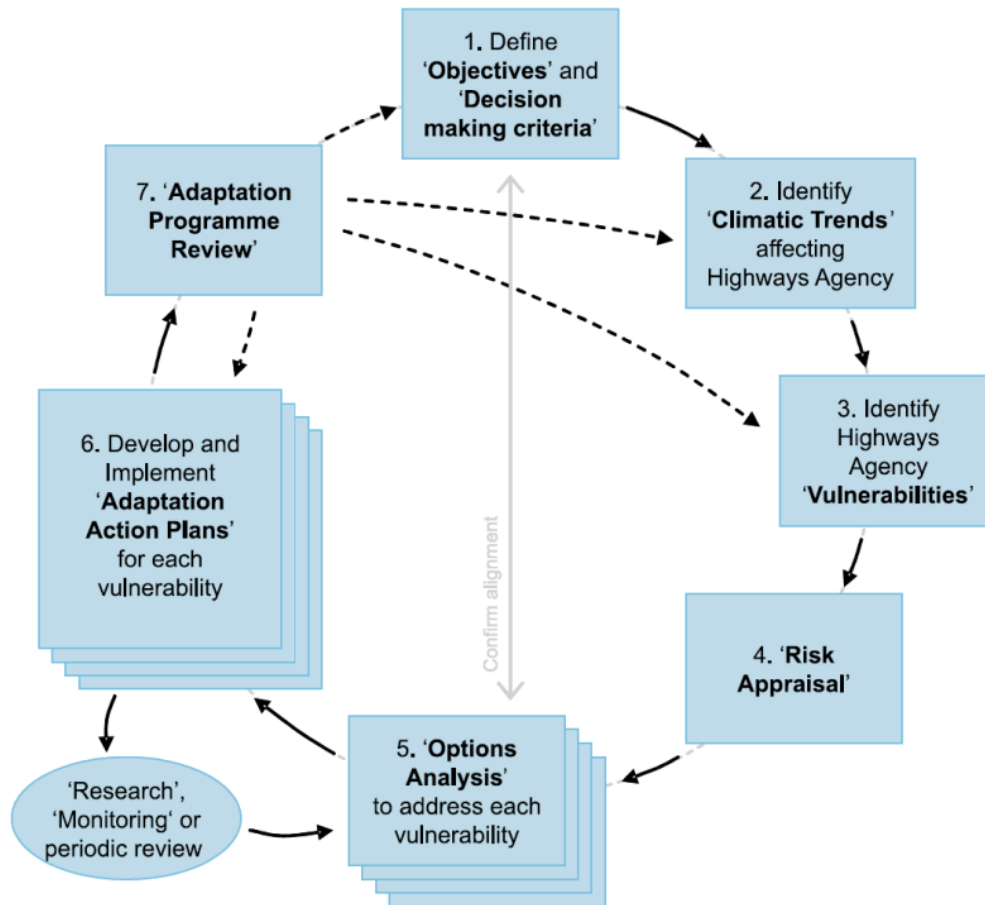
#### **United Kingdom: Highways Agency Climate Change Adaptation Strategy and Framework**

The Climate Change Act of 2008 was the first major policy action that raised the profile of adaptation work in the UK. The Government charged major infrastructure owners, including transport companies, with assessing the risks to their assets and the operation of their assets to the projected changes in climate. Infrastructure owners were required to submit climate change risk assessment information to the Department of Environment, Food, and Rural Affairs. As an Executive Agency of a Government Department, the Highways Agency was not required to report; however, it voluntarily agreed to report information.

The Highways Agency published its *Climate Change Adaptation Strategy and Framework* in 2009. The Framework lays out a strategic model to assessing and understanding the risks posed to the strategic network. The model (see Figure 2) provides a platform for decision makers to examine their individual business areas, including standards, specifications, maintenance, and the development and operation of the Highways Agency network. It provides a process for identifying agency activities that are expected to be impacted by climate change (defined as “vulnerabilities”), assessing associated risks and opportunities, and determining the most appropriate actions to address and manage these risks.

**Figure 2: Highways Agency Adaptation Framework Model**

Source: UK Highways Agency



Using the Adaptation Framework Model, the Highways Agency identified over 80 corporate activities that may be affected by climate change. After conducting a preliminary appraisal of the risks associated with these activities, the Highways Agency discovered that over 60 percent of the activities will likely be substantially impacted by climate change and are thus time-critical. The Highways Agency prioritized vulnerabilities based on a variety of criteria, including the extent and severity of the disruption a climate-change event could cause. The Highways Agency then used this list of priorities to go through an options analysis to determine the preferred option for dealing with the risks associated with each of the vulnerabilities. Next, the agency moved forward with the development and implementation of “Adaptation Action Plans” that outline the specific actions that need to be taken, who is responsible for the actions, and the timeframe for carrying them out.



### 3. Climate Change Vulnerability and Risk Assessment

While there is considerable confidence in climate model estimates for future climate change, the exact timing and magnitude of climate change effects as well as their precise impacts on roadway infrastructure and logistics is uncertain. The uncertainty is related to unknown future emissions levels; climate models limitations, and a lack of information on the degree of effectiveness of adaptation strategies.

Several of the transportation agencies that participated in the review are employing systematic methods to address some of the inherent uncertainties and to manage the associated risk. The purpose of a climate change risk and/or vulnerability assessment is to determine how climate change may impact an agency's transportation assets and prioritize measures to maximize impact and minimize costs. Risk assessments often rely on both quantitative data and a qualitative analysis based on local knowledge of vulnerabilities. The following section highlights the climate change risk assessment methods that transportation agencies involved in the review are employing.

#### Denmark's Blue Spot Project

The DRD's *Strategy for Adapting to Climate Change* notes that it is neither necessary nor economically feasible to prevent climate-related events across the entire national road network. Instead, the Directorate applies the Blue Spot method to identify the locations on the national road network that are most vulnerable to flooding and to determine whether improvements to those road sections are economically viable. The Blue Spot analysis is a central activity that supports the agency's goal of achieving the highest degree of climate adaptation with available allocated resources.

A Blue Spot is an identified stretch of roadway where the likelihood of flooding is high (determined by perception return patterns) and the consequence of flooding (quantified by socioeconomic factors, such as safety, traffic management systems, and traffic intensity.) is significant. The Blue Spot method uses a geographic information system (GIS)-model , comprised of three levels:

- Level 1 provides a screening of all terrain depressions which are computed based on a hydrologically adapted digital terrain model.
- Level 2 produces a risk map by incorporating the amount of rainfall needed to fill a given depression alongside the integration of the imperviousness of the catchment area.
- Level 3 couples terrain characteristics with drainage system specifications in order to determine depths and retention time of a flooding scenario. An important aspect of Level 3 is the incorporation of climate factors, in terms of changing precipitation pattern, to enable model outcomes from the present time and from the year 2050 and 2100. With this information the model is able to identify Blue Spots in 2100 which may not exist under present day conditions.

The DRD uses the information from the Blue Spot analysis to inform funding decisions in terms of prioritizing locations to address, as well as to inform adaptation actions for a specific location.

Nationwide the agency has identified 14 Blue Spots under present day scenarios, and an additional 35 Blue Spots have been identified for 2050 and beyond. The DRD compares the identified Blue Spots against each other to determine where funding and adaptive measures should be targeted first and most effectively. For individual locations, the agency also uses the Blue Spot analysis to conduct a cost-benefit analysis to determine what should be done to address risk and consequence.

Both the Swedish Transportation Agency and the Dutch Ministry of Infrastructure and the Environment have adopted the Blue Spot method to identify areas vulnerable to flooding. The results of the Dutch's analysis on the Dutch highway network was followed by an investigation of the risks of flooding and further identification of critical assets. The results of this assessment were used to provide information to the public in the case of major floods and to investigate the implications for evacuations and risk management.

### **Roads for Today, Adapted for Tomorrow (ROADAPT)**

The ROADAPT project was a joint research effort supported by the Netherlands, Germany, Denmark, and Norway. The primary objective of ROADAPT was to develop a preliminary risk assessment method that can identify vulnerable locations in the transportation network, understand the probabilities and consequences that climate change events could have on these locations, and provide options for adaptation actions. The outcome of ROADAPT was guidelines on:

- A. The use of climate change projections
- B. The application of a QuickScan on climate change risks for roads
- C. How to perform a detailed vulnerability assessment
- D. How to perform a socioeconomic impact assessment
- E. How to select an adaptation strategy

The ROADAPT guidelines are available to download on the [Conference for European Directors of Roads website](#).

Below is a description of guidelines B, C, and E.

#### *Application of QuickScan*

QuickScan is a climate change risk assessment method that provides preliminary estimates of the major risks associated with weather conditions in the current climate and in future climate projections. QuickScan does not use extensive quantitative analyses; rather, it is a semi-quantitative approach that relies on stakeholder participation in a series of workshops to determine, consecutively:

1. Consequences,
2. Top risks and locations, and
3. An action plan for adaptation.

Workshop participants include experts in the fields of transportation, economics, roadway engineering, and communications, as well as climate change specialists, engineers for specific threats, and road asset owners. In a first workshop, participants establish a prioritized list of climate change impacts (i.e. threats), climate parameters, and vulnerability factors. In a second workshop, participants identify locations with high risk profiles and map them according to risk. In a third and final workshop, participants develop an action plan that outlines a prioritized list of strategies to address the threats. The action plan incorporates details as to the life span of the road segments, and whether the action is for adaptation versus regular maintenance.

By engaging stakeholders in the process, the QuickScan method increases awareness about climate change impacts, starts team building among key players, and creates a mutual understanding of future actions.

### *Vulnerability Assessment*

The ROADAPT vulnerability assessment outlines a three-step process for each threat identified in the previous risk assessment. Step one identifies factors that are a prerequisite for the threat to occur and factors that affect the level of vulnerability. In step two, the vulnerability factors are assigned a vulnerability score and incorporated into geographic information system (GIS) layers. In step three, the vulnerability factors are indexed and mapped to identify areas of varying degrees of vulnerability for a particular threat.

### *Selecting Adaptation Strategies*

The ROADAPT Guideline for Selecting Adaptation Strategies includes guidance on identifying and selecting appropriate adaptation strategies to address and minimize risk associated with climate change impacts. The guideline outlines an 11-step approach that road owners can use to generate a set of policies or best strategies across a network. The 11 steps in the method are:

1. Identify the road owners' needs.
2. Identify the damage mechanisms, design models, and climate parameters.
3. Assess the resilience of the asset in the current situation.
4. Assess the resilience of the asset in the future situation.
5. Identify adaptation measures using the ROADAPT adaptation measures database.
6. Establish adaptation policies.
7. Assess consequences of measures using the ROADAPT adaptation measures database.
8. Select adaptation strategies.
9. Identify stakeholders to be involved.
10. Identify knowledge gaps in climate change projections, technologies and essential data.
11. Develop technology roadmaps for upcoming adaptation technologies.

The ROADAPT Guideline for Selecting Adaptation Strategies includes a database of over 500 adaptation measures for geotechnical and drainage assets, pavements, and traffic management. The measures cover a range of categories including planning, construction, legislation, maintenance and management, traffic management, capacity building, monitoring, and research. The measures fall within five stages: pro-action, prevention, preparation, response, and recovery.

## Highlights from National and Agency Level Assessments

### **UK Department for Transport (DfT), Transport Resilience Review**

In 2014, the DfT commissioned an independent review of the transport network's ability to cope with extreme weather. The review examined the primary challenges that prolonged adverse and extreme weather presents to the transport industry and how the challenges are currently being addressed. The [plan](#) assessed impacts to each transport mode, including the strategic and local road network, the national rail infrastructure network, and airports and ports of economic and strategic importance, as well as issues common across modes. Based on the evidence gathered, the review team developed 63 recommendations for actions to improve the resilience of the UK's transport network, many of which are short-term actions that can be taken immediately.

### **Climate Change Risks to Australia's Coasts: A First Pass National Assessment and Climate Change Risks to Coastal Buildings and Infrastructure- A Supplement to the First Pass National Assessment**

In late 2009 the Australian Government released the first national assessment of climate change risks to Australia's coastal assets. The report provided an analysis of the location and number of residential properties that are at risk of inundation from rising sea levels and erosion as a consequence of climate change. The supplemental report provides additional data on the exposure of commercial buildings, light industrial buildings, and transport systems (road, rail, tramways) in Australia's coastal areas. The assessment focuses on impacts and risks at the end of the century and provides a plausible worst case scenario to assess risk. The results of the assessment are intended to inform dialogue on a national approach to manage risk in the future.

### **Infrastructure and Climate Change Risk Assessment for Victoria**

The Victorian Government commissioned a study to examine the likely impacts of climate change on Victoria's infrastructure, including water, power, telecommunications, transport and buildings, identify the categories of infrastructure most at risk, and identify opportunities for adaptation (CSIRO, 2007). The report describes a worst-case scenario for low and high climate change projections for the years 2030 and 2070. For each infrastructure category, the report outlines the likely impact of climate change on infrastructure services (the infrastructure itself and its functions), social amenity (including health and public response), governance and the costs of maintenance, repair, and replacement. The report also considers several adaptation responses, including change in design standards, materials selection, planning, and maintenance regimes.

### **Adapting to a changing climate: Norway's vulnerability and the need to adapt to the impacts of climate change**

From 2008-2010, the Norwegian government conducted a study to identify the impacts of and vulnerabilities towards climate change on Norway's natural environmental and society, and to identify measures to reduce vulnerabilities and increase resilience. The [report](#), which was published in 2010, found that while Norway has high adaptive capacity in many areas, the lack of maintenance and repair in key infrastructures and fragmentation in the natural environment increases vulnerability towards climate change. The study recommends three overarching principles for climate change adaptation:

- A comprehensive approach to adaptation that assesses the effects of greenhouse gas emissions, pollution, and the natural environment should always be taken when adaptive measures are planned.
- Management of the natural environment must have an ecosystem-based approach.
- Adaptation must be integrated into regular planning processes.

## Highlights from National and Agency Level Assessments (continued)

### New Zealand's National Land Transport Programme

In 2008-2009 the New Zealand Transport Agency completed *Research Report 378* (Gardiner, et al. 2008, 2009), a two-stage project that identified and assessed the impacts that climate change may have on New Zealand's land transport network. The report provides recommendations, including adaptation options, to address identified information gaps and risks. The Stage Two report deals with regional effects of climate extremes on the networks, and considers how these vary by region, when and where these risks emerge and which parts of the land transport networks are most at risk. Existing data from infrastructure providers was used to assess the current vulnerability of networks to extreme weather. Extrapolation was used to predict future effects based on modelling of climate extremes for 10-, 50- and 100-year projections using a mid-range (A1B) scenario. Regional impacts were determined from GIS maps by overlaying climate change predictions with transport infrastructure. Priority adaptation responses are discussed for each national profile in the context of design, operation, research and policy issues, and related emerging climate change research.

The New Zealand Transport Agency aims to have a national infrastructure network investment and management approach to resilience in place by 2017 to include in the 2018-2021 three year National Land Transport Plan (New Zealand Transport Agency, 2014). To achieve this resilience approach goal, over the next three years the Transport Agency will complete a risk assessment to determine where funding is required and feasible for adaptation works via the National Land Transport Plan. This assessment will identify priority corridors and critical points and associated risk treatment work that meet funding criteria. The Agency intends to allocate budget in the 2018-2021 National Land Transport Plan to carry out the works identified.

## 4. Long Range Transportation Planning and Land Use

Incorporating climate change impacts and climate data into long range transportation planning and land use decisions can play a significant role in both mitigating and adapting to climate change. Even though transportation and land use decision-making often occur at the local and/or regional level, the examples featured below, illustrate how different countries have been able to integrate climate change considerations into national and state policies and procedures to inform and guide transportation and land use planning processes.

### United Kingdom National Road and Rail Networks National Policy Statement

The UK passed its Planning Act 2008 to improve and accelerate the process for developing major infrastructure projects, deemed Nationally Significant Infrastructure Projects, including as roads, ports, energy facilities, and large-scale hazardous waste infrastructure. The Act tasked the Government with creating National Policy Statements for different types of national infrastructure development projects (transport, energy, water, wastewater, and waste) to provide guidance on how to assess and mitigate the impacts of large-scale projects. To date, nine National Policy Statements have been released regarding Energy, Ports, Waste Water, and Hazardous Waste. The statements lay out the Government's objectives for the development of nationally significant infrastructure, and outlines information on how the policy takes into account mitigation of and adaptation to climate change.

The Department of Transport issued a Draft National Road and Rail Networks National Policy Statement in December 2013 and the final version of the policy will be completed soon. This policy stipulates that applicants seeking approval for Nationally Significant Infrastructure Projects must take climate change effects into consideration when planning the facility's location, design, construction, and operation. More specifically, the policy requires that for transport infrastructure that has safety critical elements, the applicant should apply the high emissions scenario (high impact, low likelihood) to those elements critical to the safe operation of the infrastructure (Section 4.35).

### New Zealand Guidance for Local Governments

There are locations along the New Zealand's state highway network that have been identified as being vulnerable to sea level rise. The New Zealand Ministry for the Environment's *Coastal Hazards and Climate Change: A Guidance Manual for Local Government in New Zealand* provides best practice information and guidance to local authorities on integrating climate change considerations, including sea level rise, into land-use planning and decision-making processes. The Guidance Manual includes specific recommendations for the degree of sea level rise to consider. For planning and decision timeframes out to the 2090s, the Guidance Manual recommends:

1. a base value sea-level rise of 0.5 m relative to the 1980–1999 average be used, along with
2. an assessment of potential consequences from a range of possible higher sea-level rise values. At the very least, all assessments should consider the consequences of a mean sea-level rise of at least 0.8 m relative to the 1980–1999 average.

For longer planning and decision timeframes, the Guidance Manual recommends an additional allowance for sea-level rise of 10 mm per year beyond 2100 (New Zealand Ministry for the Environment, 2008). The Ministry for Environmental has recently commenced a review and update of this guidance manual.

See Chapter 5 for more information on how the New Zealand Transport Agency integrates this sea level rise planning recommendation as part of transportation project design.

### **Victorian Civil and Administrative Tribunal**

In the State of Victoria, Australia, land use planning and development appeals go through the Civil and Administrative Tribunal (Victorian Civil and Administrative Tribunal, 2014). Historically, this tribunal has not factored in climate change in terms of permitting decisions related to development in coastal areas. However, in recent years, as climate change has emerged as a pressing issue especially pertaining to planning and environmental decision-making, the Tribunal has begun to take into account climate change impacts in reviewing development applications. In numerous decisions, the Tribunal has rejected development applications or refused planning permits due to the potential risk and damage that would be caused by flooding, rising sea levels, and storm surge associated with climate change (University of Melbourne, 2010a). In other instances, the Tribunal has only allowed development to move forward if certain conditions are met related to mitigating the impact of climate change (University of Melbourne, 2010b). While the Tribunal's decision-making authority only applies to the State of Victoria, it has sparked a change within Australia in terms of how climate change factors into State and local land use and development. Additionally, permitting decisions pertaining to VicRoads planning and development, as well as local and private transportation suppliers, could potentially be impacted by this move toward more fully tackling climate change impacts.

## 5. Integration of Climate Change into Design Practices

Engineering design standards govern many aspects of a transportation system – from roadway geometrics and bridges and structures to erosion, sediment control, and hydraulics. Design standards are based on the amount of risk that an infrastructure owner is willing to accept for that infrastructure to physically be damaged or fail or to fail to provide a certain level of function/service. Transportation engineers have traditionally relied on historical records of climate, especially extreme weather events, when designing highway systems to meet these design standards. Most transportation infrastructure is built to last for 50 years or longer. Confronted with climate change, past conditions may not be reliable indicators of future conditions, thus potentially bringing into question whether the magnitudes of extreme weather events based on historical records truly represent the amount of acceptable risk or, in other words, meet the design standards that have been set at the time of design. This suggests that climate projections/trends should inform or be incorporated into the design process to allow for adjustment of the magnitude of the flows to meet the design standard over the actual service life of the infrastructure, particularly in cases where the remaining service life is long and climate trends are projected to change.

Some transportation engineers in the U.S. have been reluctant to modify designs to promote resilience to future environmental conditions due to uncertainties in climate projections, as well as a lack of usable climate data at the scale (i.e. local and regional level) needed to base engineering and design requirements. Despite facing similar challenges, several international transportation agencies have begun to integrate climate projections into design criteria and specifications for transportation infrastructure projects. The following sections highlight best practice examples from the agencies included in the review.

### **Canada's Public Infrastructure Engineering Vulnerability Committee (PIEVC) Engineering Protocol**

Since 2005, Engineers Canada has been leading a project in Canada in partnership with Natural Resources Canada to complete a national engineering vulnerability assessment of existing and planned public infrastructure to the impacts of climate change. One outcome of the project is a formalized assessment procedure or tool, known as the [PIEVC Engineering Protocol](#). The Protocol is a five step process to analyze the engineering vulnerability of an individual infrastructure to current and future climate parameters, such as extreme heat or rainfall. It includes an estimate of the severity of climate impacts on the components of the infrastructure (i.e. deterioration, damage or destruction) to enable the identification of higher risk components and the nature of the threat from the climate change impact. This information can be used to make informed engineering judgments on what components require adaptation as well as how to adapt them. The Protocol has been applied in 24 case studies of infrastructure located across Canada (Engineers Canada, 2013).

### **Danish Road Directorate Drainage Standards**

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

The DRD recognizes that integrating climate considerations into the design and construction of a project is less expensive than having to adapt a project at a later stage. As such, the agency continuously analyzes and updates road regulations to account for the changes in climate. In addition, for a



considerable time now, the agency has made a standard practice of planning new roads away from locations that have a high risk of flooding or by creating structures with higher barriers.

Current design standards require that infrastructure be built to withstand a 25-year return period for precipitation. Under current conditions, a 25-year return period corresponds to 58 mm of rain. Analysis by the Danish Meteorological Institute predicts that in 2100, a 25-year event will equal 74 mm of rain. At present, this amounts to a 100-year event (see Table 1).

**Table 1: Change in Precipitation Pattern**

Source: Danish Meteorological Institute

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

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

**Korea Expressway Corporation**

Climate change impacts on the Korean Peninsula are expected to entail more frequent heavy rain and typhoon events, stronger winds, greater flooding, heavier snowfall, and higher average temperatures (Korean Meteorological Administration, 2013). The KEC is taking steps to improve its design criteria to protect transportation infrastructure against these anticipated changes.

- *Strengthened Design Rainfall Generation Frequency:* In 2000, KEC required culverts and drainage pipes to be built to accommodate a 25-year precipitation event. Beginning in 2006, the KEC now requires that in mountainous areas these drainage facilities be built to accommodate a 100-year event (see Table 2).

**Table 2: Design Rainfall Generation Frequency (years)**

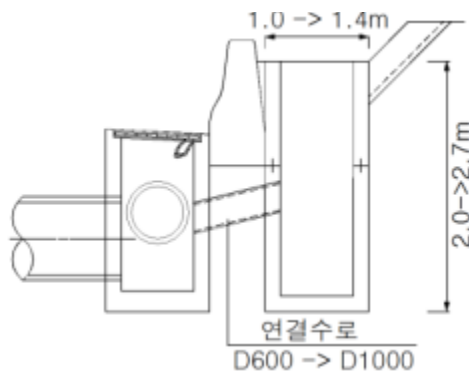
Source: Korea Expressway Corporation

Drainage Type	~2000	2000-2002	2003-2005 (flatland)	2006 (mountain area)
Culvert and Drain pipe	25	25	25-50	100
Frontage road and adjacent area drainage (V-shaped, U-shaped, ridge)	5	10	10	20
Surface and slope drainage (dyke, head race)	3-5	5	10	20

- *Increased safety factor for slope stability:* Safety factors for slope stability describe the structural capacity of a system on a slope. In order to improve and strengthen slope stability, KEC has increased the required design factor of safety from 1.1 to 1.2.
- *Improved function of drainage facilities:* The KEC has made improvements to its design criteria to improve the ability of drainage facilities to collect water. These improvements included requiring a higher superelevation of curved sections (increased from 0 to 6 percent); increasing the width of the collecting well (from 1.0m to 1.4m) and the diameter of the collecting ditch (from 600 millimeters (mm) to 1,000 mm); and increasing the length of collecting ditches (from 2.4 m to 3.5 m) (see Figure 3 and Figure 4).

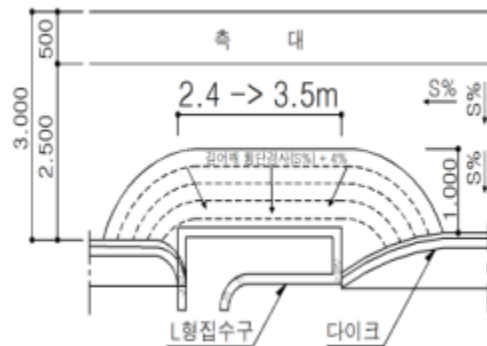
**Figure 3: Collecting Well and Connecting Pipe**

Source: KEC



**Figure 4: Length of Collecting Dish**

Source: KEC



- *Increased concrete strength:* In order to protect structures from salt damage caused by an increased use in de-icing materials, the KEC increased the concrete protection of concrete used on small-sized bridges. The concrete strength was increased from 24 megapascals (MPa) to over 30 MPa. This increased strength also helps to protect the structures against frost damage.
- *Employed bridge design countermeasures:* Flooding has major impacts on bridges, including overflow and inundation, scour of foundations, debris accumulation on bridge piers, and deterioration and failures. To address an anticipated increase in flooding intensity and frequency, the Ministry of Land, Infrastructure and Transport and KEC are employing new hydraulic design requirements for new bridges. Starting in early 2000s, KEC required new bridges to be designed for a 200-year return period. The agency also increased the minimum freeboard from 1 to 2 meters. KEC has also increased bridge opening sizes and flow capacity by raising required span lengths. Where possible, KEC has begun locating bridge piers and

foundations outside of main channels. The agency is also taking steps to adapt in-service bridges at low elevation, regardless of their size, by either reconstructing them or raising their heights by 1 to 3 meters (see Figure 5). Concrete piers and abutments are now reinforced with more steel to ensure that the raised bridges meet the requirements for stiffness and strength.

**Figure 5: Retrofit of In-Service Bridges**

Source: Korea Expressway Corporation



### Norwegian Public Roads Administration

In recent years, the Norwegian Public Roads Administration reviewed existing manuals that defined agency requirements for planning, design, operation, maintenance and management of the road network to determine necessary changes to account for climate change impacts. Examples of adaptation measures integrated into the planning, design and construction manuals include:

- Guidelines require 200-year flood level as design level for road elevation. Sea level rise and increasing storm surge levels must also be taken into account (Manual N100, Road and Street Design).
- It is strongly recommended to plan for drainage solutions that cover a larger area and includes alternative flood ways, retention ponds, and protective ditches on slopes and cuts.
- A climate factor (greater than 1 but not of fixed value) has been introduced as a safety factor, in the procedure for calculating the necessary capacity of culverts and drainage pipes. The formula used to calculate the necessary drainage capacity (Q) is  $Q = C \times i \times A \times K_f$ , where

C = runoff factor

i = design rainfall intensity (l/s x ha)

A = runoff area (hectare)

$K_f$  = climate factor

The standard formula to calculate drainage includes a number of uncertainties, including uncertainties in rainfall frequency curves and in determining the runoff factor, all of which are enhanced by climate change. Introducing a climate factor helps to address the additional uncertainty when calculating drainage capacity.

- The design requirement for bridges, including design of erosion protection and free height over water, is the 200-year flood water levels and flood loads. It is also recommended to perform a risk analysis with respect to 1000-year flood conditions in order to avoid catastrophic

consequences, such as loss of life or loss of the entire structure.

- Climate change aspects have been included in the model used for comparing landslide risk for roads and prioritizing protections measures. In addition, three new guidelines have been published that reflect climate change risks: for protections against rock fall, for managing snow avalanches, and for “wet” landslides, i.e. slush avalanches and debris flow.

### **UK Department for Transport**

The UK Department for Transport’s Highway Agency is moving away from relying solely on historical weather for design considerations and is beginning to integrate climate change considerations into its design standards. For example, the Highway Agency has adopted the Enrobé à Module Élevé Class 2 (EME2) pavement standard where appropriate. EME2, which is based on French practice, has a higher cost but it is more resilient to high loads under higher temperatures.

The Highway Agency also addressed climate change impacts in recent revisions to highway drainage standards in its *Design Manual for Roads and Bridges* (HD 33 and HD 45). The design manual includes the following guidance regarding detailed design of pavement drainage:

*Allowance for climate change:* The rainfall intensities used to calculate the design storms must include an allowance for the effects of climate change. Where rainfall data exclude such an allowance, a sensitivity test on the design of the drainage system must be carried out by increasing rainfall intensities of the design storm by 20 percent.

As part of the next iteration of drainage standards, the agency is considering an allowance for a 30 percent increase in rainfall intensities of the design storm. This demonstrates the agency’s commitment to ensuring that its infrastructure is able to withstand the changing climate over its expected lifetime.

### **New Zealand Transport Agency**

As previously highlighted, the New Zealand Ministry for the Environment recommends specific sea level rise values that agencies should consider as part of the planning process. The New Zealand Transport Agency incorporated this sea level rise planning recommendation as part of the design for the SH16 Causeway Upgrade Project. The Causeway is a key part of the Western Ring Route – one of the country’s

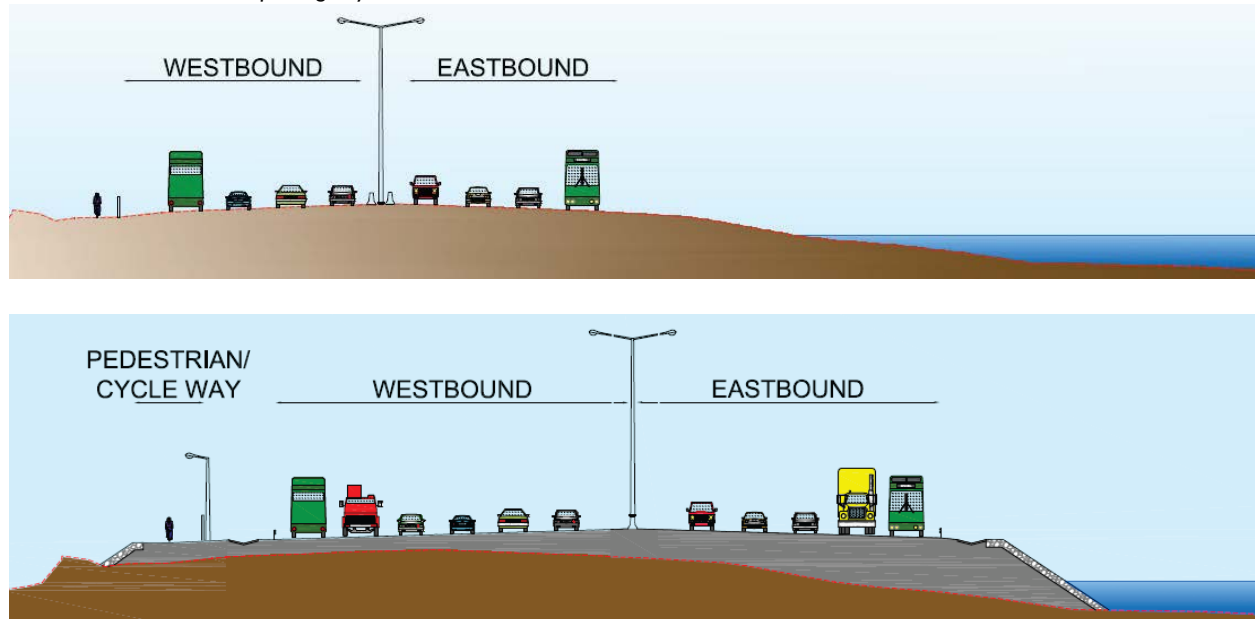
### **Project Case Study: High Speed Two (HS2)**

HS2 is the UK Government’s proposal for a new, high speed north-south railway that will connect London to Leeds and beyond. As part of the environmental impact assessment for the project, the project sponsor conducted a high level climate change risk and resilience assessment to identify the potential risks of climate change on the proposed project. The assessment considered climate-related hazards such as extreme hot and cold weather, heavy rain, high winds, and storms posed to the infrastructure and assets associated with the proposed project. The assessment identified two high risk areas: (1) flood of track work, cuttings and tunnels, and (2) overheating in tunnels. To mitigate these risks, the project design incorporated resilience design measures. To address the potential risk of flooding, all operational infrastructure and assets are protected by a one meter freeboard above the 1 in 1,000 year (0.1 percent) annual probability of flooding. The one meter freeboard provides increased protection to allow for flood risk modeling uncertainty. In addition, the railway drainage will be designed to accommodate storms up to the 1 in 100 year (1 percent) annual probability of flooding, including an increase of 30 percent for climate change allowance (Department for Transport, 2013).

seven roads of national significance. As part of the project the Causeway is being raised to reduce flooding during extreme tidal conditions (see Figure 6).

**Figure 6: Causeway Upgrade Project Construction. Top Image: Existing Causeway Configuration in 2013. Bottom Image: Final Causeway Configuration by 2017.**

Source: New Zealand Transport Agency



The New Zealand Transport Agency's Bridge Manual (3<sup>rd</sup> Edition) also requires consideration of climate change impacts in the design of bridges and culverts. Specifically, the manual states:

*Design for climate change effects:* Where it is practical and economic for a bridge or culvert structure to be retrofitted at a later date to accommodate increased flood flows arising from the effects of climate change, the structure need not initially be designed to accommodate increased flood flows arising from the effects of climate change. Where future retrofitting is not practical or does not reflect value for money, future climate change impacts shall be taken into account in the design.

Finally, the New Zealand Transport Agency's state highway environmental plan (2008) includes an objective to manage increased hazards of climate change impacts on state highway infrastructure. The plan states that "in factoring in climate change adaptation into design, consider the following:

- the intended design life of the infrastructure and whether climate change impacts may manifest within the intended design life; and
- whether future-proofing the design is required so later retro-fit is feasible and cost-effective.

## 6. Maintenance and Operations

Climate change impacts will likely necessitate changes in the ways transportation agencies operate and maintain their systems and facilities. Some of the agencies participating in the review are making minor changes to maintenance and operation activities, though most indicated that they are not at the point where climate change impacts have directly translated to changes in their maintenance practices. However, nearly all interviewees believed that such changes – conducting more frequent maintenance of pavement, for example – would likely occur.

The following is a summary of the changes to maintenance and operation activities that the countries included in the review have already made as a result of changes in climate.

### **Increased field inspection of drainage systems**

Several agencies, including the DRD, UK Highways Agency, and New Zealand Transport Agency, noted an increased emphasis on the need to inspect and improve drainage systems to ensure that they are being maintained properly and meet the appropriate levels of service. The need for increased field inspection and maintenance of drainage systems is particularly important for areas that are potentially vulnerable to flooding. It is vital for such systems to run at optimal levels to mitigate any flooding that may be associated with increased precipitation levels or higher intensity precipitation events.

### **Provision of traveler information to address weather-related safety**

Several agencies have expanded efforts to provide travelers with better information in order to minimize weather-related traffic incidents. The DRD for example operates and maintains a road-user information center that, through collaboration with the Danish Meteorological Institute, provides information about flooding through its traffic information services, including its website and mobile telephone applications. The agency also coordinates with Danmarks Radio, the country's national broadcasting corporation to provide information on road mobility problems, including those caused by flooding. Similarly, the KEC has increased efforts to provide traveler information. In 2010, Korea's Meteorological Administration launched Weavigation, which provides drivers with weather forecast information at their current location, destination, and for the route to the destination. The information is sent directly to drivers' navigation systems, social network services, and variable message signs. Weather data such as precipitation, temperature, humidity, road surface temperature, and wind speed and direction is collected and updated every minute from roadside weather sensors. In addition, current weather, weather forecast, severe weather alerts, and interactive radar images are also sent to drivers. Drivers can refer to the service when they choose and change their own paths; however the information is not fully integrated into automatic route guidance.

### **Installation of Traffic Safety and Warning Measures**

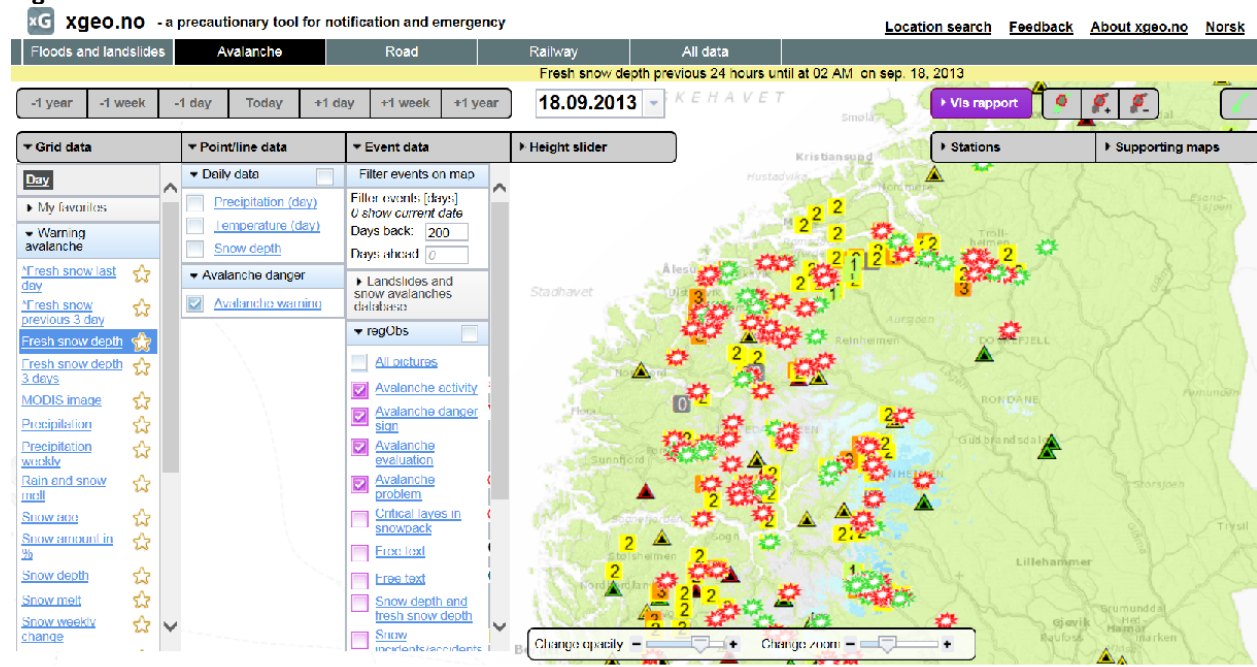
The KEC has enhanced traffic safety measures to adapt to changes in climate conditions. In recent years, Korea has experienced an increase in the occurrence of severe, localized winds and an increase in the intensity of typhoons. To minimize safety impacts to motorists, the KEC has implemented speed limit restrictions or full closures on long-span bridges under strong wind conditions (i.e. when 10-minute average wind speed measured using anemometers on the bridge is above 25 m/s, the bridges are closed to traffic). The agency has also installed mesh wind screens on smaller-scale bridges in order to reduce the velocity of crosswinds. Road management agencies in Korea are also monitoring vulnerable slopes for avalanches and land/mudslides in real time through closed caption televisions or sensors installed on the slopes. These warning systems automatically notify the appropriate experts at the responsible agencies via mobile phone.

## Improved Emergency Plans

The Norwegian Public Roads Administration developed a system for “stepwise preparedness” for readiness against avalanches, floods, and other natural hazards. The agency uses the system to outline recommended preparedness levels during challenging weather situations. Specific tasks and responsibilities are outlined for the four preparedness levels: green, yellow, orange, and red.

The Public Roads Agency, in collaboration with the Norwegian National Rail Administration, Norwegian Water Resources and Energy Directorate, and the Meteorological Institute, developed a web portal tool – [www.xgeo.no](http://www.xgeo.no) – to assist with preparedness, monitoring, and forecasting of floods, landslides, and avalanches. XGEO is a map centric tool for visualizing temporal and spatial data from various data sources. The tool shows historical daily maps of the snow conditions, interpolated weather observations and numerical predictions (which are based on European atmospheric models), gridded water balance, and climate means and anomalies. It also includes data from real-time weather point observations from 300 weather stations as well as webcams. The tool also provides access to real-time observations of avalanches, including observations from professional avalanche observers, public observers, and observers from the rail and road authorities (see Figure 7)(specific information about each avalanche or flood incident through a separate registration system). The weather and climate data is overlaid on administrative data, such as rail and road infrastructure.

Figure 7: XGEO Web Tool



Map depicting avalanche activity for the past 200 days in a subarea of Norway.

The Norwegian Public Roads Administration has also developed an improved template for emergency plans for natural hazards, which it is integrating into all operation contracts. The plan includes more elaborate use of weather data and map-based information concerning flood and landslides for the specific area of road that the contractor is responsible for maintaining. By providing more detailed information the agency hopes to encourage proactive management, such as prioritizing culverts to clean in advance of anticipated heavy rain, in order to mitigate issues.

## 7. Asset Management

Transportation asset management is a strategic and systematic approach to effectively managing transportation infrastructure through its life cycle. It focuses on business and engineering practices for resource allocation and utilization, with the objective of better decisionmaking based upon quality information and well-defined objectives.

Climate change impacts will likely affect transportation asset management investment cycles. The following section highlights examples on how transportation agencies are actively integrating climate change considerations into their asset management plans.

### **Korea Expressway Corporation Risk-Based Slope Management**

The KEC manages approximately 8,400 slopes (cut-slopes higher than 5 meters) across its roadway network. Each year the country experiences casualties and property damage due to slope failures and debris flow caused by typhoons and heavy rain events. The KEC inspects approximately three percent of these slopes annually through its general inspection process, programming funding for slope maintenance activities based on the results of the inspection and evaluation. However, the agency has found that in extreme weather events related to climate change, damages have occurred on non-targeted slopes. As a result the agency has had to invest funding in emergency relief to restore these damaged slopes rather than perform maintenance activities on the programmed slopes. Since the agency does not have the capacity and financial resources to inspect all slopes simultaneously, it has focused on early detection and preventive maintenance to reduce risk and damage caused by slope failures.

In 2011, the KEC instituted a new preventive slope management strategy in order to reduce the amount of money spent on emergency relief. As part of this strategy, the KEC now performs basic and in-depth surveys and prioritizes investments in a five-year cycle. In order to prioritize slopes for preventative maintenance, the agency conducts a debris flow risk assessment process. The debris flow risk assessment process involves four steps:

- Risk assessment scope definitions – identify the risk location and risk area
- Hazard analysis – identify risks based on the hydrologic and geologic character of the region and the damage range
- Consequence analysis – analyze the facilities affected and vulnerabilities
- Risk assessment – conduct both a qualitative and quantitative evaluation based on hazard and consequence

The risk assessment results in a score from 0–30 and a corresponding risk grade of S, A, B, C, D, and E that is based on the likelihood of damage occurring during different rainfall frequency events. A risk grade of “S,” for example, is defined as damage that may occur in a 2–5 year rainfall event; whereas a risk of grade of “D” is defined as damage that may occur in a 1,000-year rainfall event. The risk assessment helps to inform design considerations for risk mitigation and asset management decisions. The KEC is also developing an accountable, reliable database of the effectiveness of preventative slope management activities to help ensure the quality of preventive investment decisions.

### **New Zealand’s Coastal Effects Assessment Guideline**

The New Zealand Transport Agency manages its state highway infrastructure in accordance with the



State Highway Asset Management Plan (NZTA, 2014), which requires assets to be regularly checked for dependability to ensure they perform as required. The Asset Management Plan also discusses risk to the networks and its impact on customer service and transport efficiency including long term issues such as climate change effects.

To assist staff with assessing infrastructures' existing and future dependability, the Transport Agency developed a draft Coastal Effects Assessment Guideline, outlining a simple and consistent process for asset managers to determine short- and long-term risks to state highway assets in the coastal environment. The Guide provides a systematic way to collect information on risks to assets and the surrounding coastal environment, both short- (up to 10 years) and long-term (50–100 years), and considers these across a section of the network, rather than at individual locations. By taking a comprehensive approach to assess and record coastal environmental risks management,4 approaches can be adapted to differing scenarios and consider wider issues than just the structural integrity of an asset (Grieg, et al 2014).The Guide also emphasizes making decisions on what work to prioritize based on the magnitude of the risk, and provides documentation to support a business case for the actions identified, which is required for all Agency projects to be approved and funded. The Transport Agency is currently testing the Guide in determine its usefulness in real-world settings before refining and finalizing it.

The New Zealand Transport Agency is also working with regional councils who have taken an active role in looking at regional risk issues and consequences. Joint approaches that are inclusive of major stakeholders are aimed at improving overall resilience of regional networks focused on an understanding of past and recent events and looking forward at climate change effects.

## 8. Research

Many of the transportation agencies included in the review are participating in collaborative research initiatives that address critical information and data needs related to climate change adaptation. The following section showcases these research initiatives.

### ERA-NET Road

Since 2006, the European Road Administrations have shared their road research priorities and budgets to organize transnational research programs that cover a range of topics. In 2008, the Conference for European Directors of Roads (CEDR) initiated ERA-NET ROAD, its first cross-border funded research program. The National Road Administrations in the following 11 countries funded the program: Austria, Denmark, Finland, Germany, Ireland, The Netherlands, Norway, Poland, Spain, Sweden, and the UK. The goal of the research program, titled “Road Owners Getting to Grips with Climate Change,” was to provide European road authorities with the knowledge and tools necessary to “get to grips” with climate change and its effects on all elements of road management by adapting design rules, updating and improving data collection, and developing risk management methods. The 2008 program funded four research projects (see below). Information about each of the four projects, including a summary of results and implementation strategies, is available in the *Final Report of ERA-NET ROAD Programme “Road Owners Getting to Grips with Climate Change”*:

- IRWIN - Improved local winter index to assess maintenance needs and adaptation costs in climate change scenarios: The main objective of IRWIN is to develop an improved local road winter index, which is sufficiently detailed and comprehensive so that road authorities and owners can use it to assess the implications of future scenarios and climate change implications, and perform reliable cost/benefit analyses. The project collected ten years of observations from 50 road weather stations in Sweden and 49 stations in Finland. Maintenance actions from the regions of interest were available as well, and were used in the final winter index calculations. The resulting IRWIN observational database provides a better understanding of local weather variations and a clearer representation of weather and climate of the road network.
- P2R2C2 - Pavement Performance & Remediation Requirements following Climate Change: The P2R2C2 project investigated the likely impacts of climate change in Europe, from the Alps and northwards, on the moisture/ice conditions in the pavement and the subgrade, and the consequential pavement material behavior and pavement response to traffic over a 100-year timescale. The project found that the life cycle of the pavement is much less than the time span over which climate change will have a statistically dependable influence on pavement performance. At present, road designers only need to change their practice for the pavements with the longest life or for the lower layers that may not be touched during future rehabilitation and reconstruction. The appropriate responses to these changes in pavement performance will be achievable, in most cases, by routine material formulations that can be employed at the next reconstruction/rehabilitation event. However, some responses will require engineers to develop new design criteria regarding temperature and return period of storm flows (regionally specific) and to pay more attention to drainage systems, particularly to make them self-cleaning and easily inspectible. In addition, actions to improve future pavement performance will likely include stabilization of unsealed pavements, overlaying by bound layers or operational management solutions based on continuously monitored condition,
- RIMAROCC - Risk Management for Roads in a Changing Climate: The RIMAROCC method is a risk management-based framework or decision support for road owners dealing with climate

change. The project developed the RIMAROCC framework to facilitate the production of a Risk Management Study by or for a road authority. The method can be used to mitigate threats, reduce vulnerabilities and minimize the consequences of an event. The RIMAROCC Framework consists of seven steps each with a number of sub-steps:

1. Context Analysis
  2. Risk Identification
  3. Risk Analysis
  4. Risk Evaluation
  5. Risk mitigation
  6. Implementation of an Action Plan
  7. Monitoring, Review & Capitalization
- SWAMP - Storm Water prevention—Methods to predict damage from water stream in and near road pavements in lowland area: The SWAMP project addresses the critical issue of finding the parts of the road network that are most vulnerable to flooding, using GIS as a basis. The project developed the Blue Spot concept: a chain of procedures that can be used by road owners, operators or consultants to systematically analyze, adapt and protect the road network with respect to flooding (see Chapter 3 for more details on applying the Blue Spot concept). The project also identified the crucial issues to consider when creating national or even regional guidelines for inspections and maintenance of Blue Spots.

### **CEDR Research Program**

In 2012, CEDR (European Road Directors organization) initiated a second call that built upon the first ERANET call for a research program on climate change. The second call focused on providing owners with adaptation technologies and the models and tools to support decisionmaking concerning adaptation measures for road infrastructure. The climate change research program was funded by Denmark, Germany, Norway, and the Netherlands. The program call resulted in two projects, which are currently underway:

- ROADAPT: Roads for Today, Adapted for Tomorrow: The ROADAPT project, which was highlighted in previous chapters, provides integrated, more detailed, and hands-on methods and tools to be used within the RIMAROCC framework in a transnational setting (see Chapter 3 for more details on the ROADAPT project).
- ClipDaR: Design guideline for a transnational database of downscaled *Climate Projection Data* for *Road* impact models: The project will focus on the review, analysis, and assessment of existing regional Climate Change projections regarding transnational highway networks needs.

### **Infrastructure Slopes – Sustainable Management and Resilience Assessment**

The UK Highways Agency is partnering with academic institutions, infrastructure owners, and engineering companies on the Infrastructure Slopes – Sustainable Management and Resilience Assessment (iSMART) project. The purpose of the project is to create a visualized model of transient water movement in infrastructure slopes under a range of current and future environmental scenarios based on a fundamental understanding of earthwork material and system behavior (Engineering and Physical Sciences Research Council, 2014). The results of the study will provide decision-makers with a better understanding of the interactions between earthwork, vegetation, and climate, which is needed

in order to develop robust guidance on which maintenance approaches should be adopted and how they should be applied.

### **Transport Canada's Northern Transportation Adaptation Initiative**

Transport Canada's Northern Transportation Adaptation Initiative is designed to improve understanding of climate impacts and facilitate better and more integrated transportation planning and adaptation measures. As part of the Initiative, Transport Canada provides funding support to territorial governments and non-profit organizations to conduct research and development activities related to the design, development, and adoption of innovative technologies and best practices. This work will help make existing and future northern transportation infrastructure and operations more resilient and adaptable to climate change. To support the delivery of the research and development activities, two networks for experts from government, academia, and the private sector were established: the Permafrost Network and the Network of Expertise on Transportation in Arctic Waters.

## 9. Conclusions

The activities of the international transportation agencies included in this review offer valuable insights into how transportation agencies globally are beginning to adapt infrastructure to anticipated climate change impacts. While the geographic, environmental, and societal conditions of the agencies in the review may differ in some ways to those of transportation agencies in the United States, they face many of the same challenges. For all agencies, the cost of adapting the transportation network to climate change is much greater than the funding currently available for adaptation. Additionally, each agency faces similar uncertainties in terms of climate models, unknown future carbon emission levels, and the timing and extent of anticipated impacts. However, the transportation agencies included in the review are taking proactive actions to address the inherent uncertainties and manage the associated risks.

Many of the agencies have established formal strategic frameworks for addressing climate change adaptation and have identified processes to address and respond to these risks. The most proactive agencies have comprehensively examined the risks and vulnerabilities of the transportation network to climate change impacts and are employing systematic methods to identify and prioritize measures to maximize their effectiveness while minimizing costs.

Several agencies have also begun to employ specific adaptation measures, particularly in terms of integrating climate change considerations into the planning and design of projects. Those agencies that are modifying design practices acknowledge that in some cases it is more economically responsible to climate proof infrastructure during the construction phase than to adapt in the future during the operational phase. Changes to the planning and design of projects are primarily associated with drainage systems, bridges, and culverts. Some of the agencies included in the review referenced using passive adaptation options that use the natural environment to protect transportation infrastructure, such as through protecting wetlands, barrier islands, or other natural features. However, while the transportation agencies recognize that climate change impacts will have implications on maintenance and operations, few are making changes in maintenance practices at this point in time.

## Appendix A: Discussion Topics

1. **Evolution of Policy:** Overview of how your agency has reached where it is today with respect to climate adaptation planning or action. What laws, regulations, or policies guide or influence your work on climate change? How has climate change influenced the allocation of funds in your agency?
2. **Climate Data:** Where do your climate projections come from and how do you translate this information into a level of detail that is usable by transportation engineers and planners? For which variables do you have useful projections and which not?
3. **Uncertainty:** How do you deal with the multiple layers of uncertainty inherent in adapting to climate change (uncertainties regarding emissions levels, climate sensitivity, timing and extent of impacts, effectiveness of adaptation strategies, future demographic and economic conditions, etc.)? In the United States, we have found that engineers are sometimes reluctant to change the design process because of uncertainties in climate projections, a lack of usable data at the scale they need, and the fact that assets are already engineered to withstand extreme events. How have you dealt with this?
4. **Integration of Climate Data into Design:** Please provide examples of how you have integrated climate projections into design criteria and specifications of specific transportation infrastructure projects.
5. **Costs and Benefits:** Have you analyzed the costs and benefits of particular adaptation options at the project level and can you provide examples? Please describe any tools you have used for this process.
6. **Ecosystem Services:** What opportunities have you found to build in adaptation options that use the natural environment to protect the transportation facility, such as through protecting wetlands, barrier islands, or other natural features?
7. **Long Range Transportation Planning and Land Use:** How have you incorporated climate data into long range transportation planning and land use decisions?
8. **Operations and Maintenance:** Are you maintaining your transportation systems differently due to changes in climate or do you plan to do so in the future?
9. **Asset Management:** If you have an asset management system, are climate change impacts considered with regard to asset management investment cycles and if so, how?
10. **Research, Training, and Communication:** Are you funding or conducting any research or training on improving the resilience of transportation to climate change? If so, please describe. Is there recognition among the public, senior officials, and staff of the need for climate adaptation? How do you communicate with internal and external stakeholders regarding climate adaptation?

## Appendix B: Agency Snapshots

### **VicRoads, Victoria, Australia**

*Agency Overview:* VicRoads is an agency under the Department of Transport, Planning and Local Infrastructure within the State Government of Victoria. VicRoads plans, develops, and manages over 22,000 kilometers (km) of roads (including freeways, highways, major arterials), approximately 3,200 bridges, and more than 4,500 other structures. The roads, which amount to approximately 20 percent of those in Victoria, carry 80 percent of the State's traffic.

*Projected Climate Impacts for Victoria:* Victoria is a coastal state with diverse environmental regions, including wet, temperate climates and semi-arid plains. The anticipated climate change impacts in Victoria are: higher temperature; increase in the number and intensity of hot days (over 95°); decrease in average number of frost days; decrease in annual average rainfall by 4% by 2030; an increase risk of drought, and increase in heavy rainfall intensity in the summer and fall (Victorian Government Department of Sustainability and Environment, 2008). Under most scenarios, projected sea level rise by 2030 for Victoria is approximately 0.2 meters (m). By 2100, projected sea level rise ranges from 0.8 m and 1.4 m. (Sinclair Knight Merz, 2012).

### **New Zealand Transport Agency, New Zealand**

*Agency Overview:* The New Zealand Transport Agency manages nearly 11,000 km of highways in New Zealand. The Agency's state highways carry 50 percent of traffic vehicle miles and 75 percent of heavy traffic vehicle miles traveled, and provide vital connections to much of New Zealand's 83,000 km of local roadways. NZTA also runs the Roads of National Significance Programme, which focuses on reducing congestion, improving safety, and spurring economic growth through the implementation of seven major

infrastructure projects within or adjacent to New Zealand's five major population centers.

*Projected Climate Impacts for New Zealand:* New Zealand anticipate the following changes as a result of climate change: higher temperatures; rising sea levels; more frequent extreme weather events such as droughts and floods; a change in rainfall patterns; an increase in the intensity of severe storms; and, an increase in storm surge levels (New Zealand Ministry for the Environment).

### **Vejdirektoratet (Danish Road Directorate), Denmark**

*Agency Overview:* The Danish Road Directorate (DRD) oversees approximately 3,800 km of highway and main state roads. These roads account for approximately 5 percent of the total road network in Denmark in length, but control 50 percent of the total traffic.

*Projected Climate Impacts for Denmark:* The DRD bases its future projections on climate scenario A1B from the Intergovernmental Panel on Climate Change (IPCC). The Danish government recently released guidance that all government levels use this scenario to make climate projections. The A1B model is corrected for local effects using models from the Danish Metrological Institute. One of the primary anticipated changes from climate change in Denmark is increased rainfall. The A1B scenario predicts that annual rainfall will increase 11 percent by 2050 and 22 percent by 2100. Also, the number of days with precipitation greater than 20mm is projected to increase to more than 4 days by 2030, 5 days by 2015, and 7 days by 2100.

### **Rijkswaterstaat (Transportation and Water Infrastructure Agency), Netherlands**

*Agency Overview:* Rijkswaterstaat is part of the Dutch Ministry of Infrastructure and the Environment. It is responsible for the design,

construction, management, and maintenance of the main infrastructure facilities in the Netherlands. In this, Rijkswaterstaat aims at a good balance between economy, environment and quality of life. Rijkswaterstaat responsibilities include the main road network, the main waterway network, and the main water systems. The main road network includes 3,046 km of motorways, 1,428 km of access and connecting roads, 2,749 viaducts, 22 tunnels, and 743 bridges.

*Projected Climate Impacts for The Netherlands:*

The Netherlands anticipates more storms and heavier rainfall due to global climate change. The country also projects sea level rise between 20 centimeters (cm) and 85 cm by 2100.

**Korea Expressway Corporation (KEC), Korea**

*Agency Overview:* KEC, one of Korea's major government-invested corporations, is a competent authority for national expressway system in Korea. KEC currently manages 3,790km of expressway network.

*Projected Climate Impacts for Korea:* Based on Korean Meteorological Administration's reports on climate change, climate change will have a variety of impacts on the Korean Peninsula, including an increase in temperature, a reduction of winter period, an increase in extreme typhoons, heavier snowfall, and an increase in heavy rainfall. Annual precipitation days are projected to decrease, whereas the annual number of heavy rain days and the amount of rainfall is projected to increase.

**Department for Transport and Highways Agency, United Kingdom (UK)**

*Agency Overview:* The UK Department for Transport is a ministerial department, supported by 21 agencies and public bodies that include all modes of transportation. The Department is responsible for providing policy, guidance, and funding to English local authorities to help them run and maintain their road networks, improve passenger and

freight travel, and develop new major transport schemes. The agency also sets the strategic direction for the rail industry and the ports and establishes national aviation policy. The Highways Agency, which is under the Department for Transport, is responsible for the trunk roads and major strategic routes in England. These roads represent less than 3 percent of the country's total roadways, but carry the vast majority of traffic (a third of all traffic and two thirds of all UK freight).

*Projected Climate Impacts of the UK:* The UK's Met Office produces probabilistic climate change projections for the country. The most recent information, the UK Climate Projections (UKCP09), predicts increased temperatures for all areas of the UK, an increase in the number of days with high temperatures, a reduction in the number of frost days, an increase in the amount of winter rainfall, and a decrease in summer precipitation. Sea level rise is projected to be between 12 and 76 cm for the period 1990–2095. Sea level rise coupled with more frequent storm surges may increase flood risk (United Kingdom Highways Agency, 2009).

**Statens vegvesen (Public Roads Administration), Norway**

*Agency Overview:* The Norwegian Public Roads Administration plans, builds, operates, and maintains national and county roads in Norway. The road network includes 10,446km of national roads and 44,333km of county roads.

*Projected Climate Impacts for Norway:* Projections for Norway show that the climate can be expected to change considerably: mean temperature will increase; sea level could rise between 500-100cm; and storm surges will increase correspondingly. The average annual precipitation in Norway is expected to increase, and more days with heavy precipitation and higher average amounts of precipitation are also expected during all seasons (Norwegian Ministry of the Environment, 2010).



## **Transport Canada, Canada**

*Agency Overview:* Transport Canada has jurisdiction over aviation and marine transportation, major railways, and interprovincial and international bridges and tunnels. Canadian provinces and territories have jurisdiction over intraprovincial transportation, including roads and bridges.

*Projected Climate Impacts for Canada:* Canada has experienced increases in temperatures and annual precipitation. The frequency and severity of extreme weather events, such as heat waves, droughts, and floods, will increase as a result of climate change. The country also anticipates reduced Arctic ice cover and loss of permafrost. Climate change-related risks to coastal areas in Canada include coastal inundation, increased storm-surge flooding, and shoreline erosion (Government of Canada, 2014).

## Appendix C: Interview Participants

### VicRoads, Victoria, Australia

**Simon Renton**

Team Leader, Climate Change and Adaptation

### New Zealand Transport Agency, New Zealand

**Rob Hannaby**

Environment and Urban Design Manager  
Highways and Network Operations

**Vanessa Browne**

Principal Environmental Specialist  
Highways and Network Operations

### Danish Road Directorate, Denmark

**Christian Axelsen**

Department of Research and Development

**Marianne Grauert**

Specialist Coordinator, Climate and  
Environment

### Rijkswaterstaat, Ministry of Infrastructure and the Environment, Netherlands

**Onno Tool**

Senior Advisor  
Rijkswaterstaat

**Thomas Bles**

Project Coordinator ROADAPT  
Deltares

**Kees van Muiswinkel**

Senior Advisor, Climate and Infrastructure  
Rijkswaterstaat

**Arjan Venmans**

Senior researcher, transportation  
infrastructure  
Deltares

**Per Danielsson**

Swedish Geotechnical Institute, SGI

### Korea Expressway Corporation, Republic of Korea

**Dr. Sung-min Michael Cho**

Head (Director)  
Strategy & Policy Research Division

**Dr. Seongkwan Mark Lee**

Senior Researcher  
Strategy & Policy Research Division

**Dr. Heungbae Gil**

Research Director  
Structures Research Division

**Hosik Yoo**

Senior Manager  
SMART Highway R&D Division

### Department for Transport, United Kingdom

**Dean Kerwick-Chrisp**

Sustainability, Equality and Diversity  
Highways Agency

**Miles Gidlow**

Transport Resilience Review  
Department for Transport

**Public Roads Administration, Norway**

**Gordana Petkovic**

Climate and Transport, Program Manager  
Public Roads Administration

**Tore Humstad**

Data Collection and Processing  
Public Roads Administration

**Transport Canada, Canada**

**Elizabeth Smalley**

Sustainable Transportation and  
Adaptation Team  
Transport Canada

**Kathy Palko**

Policy Advisor  
Environmental Policy  
Transport Canada

**Jenna Craig**

Sustainable Transportation and  
Adaptation Team  
Transport Canada

**Janice Festa**

Manager, Northern Transportation  
Adaptation Initiative  
Innovation Policy Team  
Transport Canada

## Appendix D: Bibliography

- Adesiyn, A; S. Phillips; L. Phillips; B. Verhaeghe; and B. Wlaschin. March 2011. *Final Report of ERA-NET ROAD Programme "Road Owners Getting to Grips with Climate Change*. ERA-NET. Available at [www.eranetroad.org/index.php?option=com\\_docman&task=doc\\_download&gid=278&Itemid=53](http://www.eranetroad.org/index.php?option=com_docman&task=doc_download&gid=278&Itemid=53)
- Australia Government. 2013. *Climate Change Risks to Coastal Buildings and Infrastructure. A Supplement to the First Pass National Assessment*. Available at [www.climatechange.gov.au/sites/climatechange/files/documents/03\\_2013/risks-coastal-buildings.pdf](http://www.climatechange.gov.au/sites/climatechange/files/documents/03_2013/risks-coastal-buildings.pdf)
- Australia Government. 2009. Department of Climate Change. *Climate Change Risks to Australia's Coast: A First Pass National Assessment*. Available at [www.mfe.govt.nz/publications/climate/coastal-hazards-climate-change-guidance-manual/coastal-hazards-climate-change-guidance-manual.pdf](http://www.mfe.govt.nz/publications/climate/coastal-hazards-climate-change-guidance-manual/coastal-hazards-climate-change-guidance-manual.pdf)
- Barfod, E, et al. 2013. "The Expert tool XGEO and its applications in the Norwegian Avalanche Forecasting Service". *International Snow Science Workshop Grenoble – Chamonix Mont-Blanc*.
- Conference of European Directors of Roads. 2015. *ROADAPT Guidelines*. Available at [www.cedr.fr/home/index.php?id=wwwcedreuresearchcall2012&dlpath=CEDR%20Call%202012%20Climate%20Change%20ROADAPT&cHash=93605ec7f8059c198d817901559ee5c5](http://www.cedr.fr/home/index.php?id=wwwcedreuresearchcall2012&dlpath=CEDR%20Call%202012%20Climate%20Change%20ROADAPT&cHash=93605ec7f8059c198d817901559ee5c5)
- Commonwealth Scientific and Industrial Research Organisation (CSIRO). 2007. *Infrastructure and Climate Change Risk Assessment. Report to the Victorian Government*.
- Danish Road Directorate. October 2013. *Strategy for Adapting to Climate Change*. Available at [http://en.klimatilpasning.dk/media/808853/klimatilpasningsstrategi\\_eng\\_web.pdf](http://en.klimatilpasning.dk/media/808853/klimatilpasningsstrategi_eng_web.pdf)
- Danish Road Institute. 2010. *The Blue Spot Method: Development of a Screening Method to Assess Flood Risk on Highways*. Report 183-2010.
- Denmark Government. 2012. *How to manage cloudburst and rain water. Action Plan for a climate-proof Denmark*. Available at [http://en.klimatilpasning.dk/media/590075/action\\_plan.pdf](http://en.klimatilpasning.dk/media/590075/action_plan.pdf)
- Department for Transport. July 2014. *Transport Resilience Review: A review of the resilience of the transport network to extreme weather events*. Available at: [www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/335115/transport-resilience-review-web.pdf](http://www.gov.uk/government/uploads/system/uploads/attachment_data/file/335115/transport-resilience-review-web.pdf)
- Department for Transport. November 2013. *H2S Phase One Environmental Statement Volume 5: Technical Appendices. Resilience to impacts from climate conditions (CL-003-000)*. Available at [www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/259614/Volume5\\_Climate\\_Change\\_Resilience\\_Report\\_CL-003\\_000.pdf](http://www.gov.uk/government/uploads/system/uploads/attachment_data/file/259614/Volume5_Climate_Change_Resilience_Report_CL-003_000.pdf)
- Department for Transport. July 2014. *Transport Resilience Review: A review of the resilience of the transport network to extreme weather events*. Available at [www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/335115/transport-resilience-review-web.pdf](http://www.gov.uk/government/uploads/system/uploads/attachment_data/file/335115/transport-resilience-review-web.pdf)

- Department for Transport. December 2013. *Draft National Policy Statement for National Networks*. Available at [www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/263720/consultation-document-draft-national-policy-statement.pdf](http://www.gov.uk/government/uploads/system/uploads/attachment_data/file/263720/consultation-document-draft-national-policy-statement.pdf)
- Engineers Canada. February 2013. *Infrastructure Climate Risk Assessment Backgrounder*. Available at [http://www.pievc.ca/e/PIEVC\\_Backgrounder\\_February\\_2013.pdf](http://www.pievc.ca/e/PIEVC_Backgrounder_February_2013.pdf)
- Engineering and Physical Sciences Research Council. *Infrastructure Slopes – Sustainable Management And Resilience Assessment (iSMART)*. [www.ismartproject.org/home.html](http://www.ismartproject.org/home.html)
- Gardiner, L. et al. 2008. Climate change effects on the land transport network volume one: literature review and gap analysis. *NZ Transport Agency Research Report 378*. New Zealand Transport Authority. Available at [www.nzta.govt.nz/resources/research/reports/378/docs/378-v1.pdf](http://www.nzta.govt.nz/resources/research/reports/378/docs/378-v1.pdf)
- Gardiner, L. et al. 2009. Climate change effects on the land transport network volume two: approach to risk management. *NZ Transport Agency Research Report 378*. New Zealand Transport Authority. Available at [www.nzta.govt.nz/resources/research/reports/378/docs/378-v2.pdf](http://www.nzta.govt.nz/resources/research/reports/378/docs/378-v2.pdf)
- Government of Canada. 2014. *Canada's Sixth National Report on Climate Change*. Available at [http://www.ec.gc.ca/cc/0BA54AAB-6E8E-4D48-B42C-DCBB09B27D10/6458\\_EC\\_ID1180-MainBook\\_high\\_min%20FINAL-s.pdf](http://www.ec.gc.ca/cc/0BA54AAB-6E8E-4D48-B42C-DCBB09B27D10/6458_EC_ID1180-MainBook_high_min%20FINAL-s.pdf)
- Greig, D.; J. James.; and P. Hunter. *Adaptive Infrastructure Management for Coastal Highways: both a physical and a planning exercise*.
- Intergovernmental Panel on Climate Change. 2014. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Volume II: Regional Aspects: Asia*. Available at [http://ipcc-wg2.gov/AR5/images/uploads/WGIIAR5-Chap24\\_FGDall.pdf](http://ipcc-wg2.gov/AR5/images/uploads/WGIIAR5-Chap24_FGDall.pdf)
- Netherlands Government. 2014. *Delta Program 2015. Working on the delta: The decisions to keep the Netherlands safe and livable*. Available at [http://www.deltacommissaris.nl/english/Images/Delta%20Programme%202015%20English\\_tcm310-358177.pdf](http://www.deltacommissaris.nl/english/Images/Delta%20Programme%202015%20English_tcm310-358177.pdf)
- New Zealand Government. 2011. *National Infrastructure Plan 2011*. Available at [www.infrastructure.govt.nz/plan/2011/nip-jul11.pdf](http://www.infrastructure.govt.nz/plan/2011/nip-jul11.pdf)
- New Zealand Government. 2010. *National Infrastructure Plan 2010*. Available at [www.infrastructure.govt.nz/plan/mar2010/nip-mar10.pdf](http://www.infrastructure.govt.nz/plan/mar2010/nip-mar10.pdf)
- New Zealand Ministry for the Environment. July 2008. *Coastal Hazards and Climate Change: A Guidance Manual for Local Government in New Zealand*. 2<sup>nd</sup> Edition. Available at [www.mfe.govt.nz/publications/climate/coastal-hazards-climate-change-guidance-manual/coastal-hazards-climate-change-guidance-manual.pdf](http://www.mfe.govt.nz/publications/climate/coastal-hazards-climate-change-guidance-manual/coastal-hazards-climate-change-guidance-manual.pdf)

- New Zealand Transport Agency. 2014. *Transport Solutions for a Thriving New Zealand*. Available at [www.nzta.govt.nz/resources/statement-of-intent/docs/SOI-2014-18-Transport-Solutions.pdf](http://www.nzta.govt.nz/resources/statement-of-intent/docs/SOI-2014-18-Transport-Solutions.pdf)
- New Zealand Transport Agency. *Bridge Manual (SP/M/022)*. Third Edition. Available at [www.nzta.govt.nz/resources/bridge-manual/bridge-manual.html](http://www.nzta.govt.nz/resources/bridge-manual/bridge-manual.html).
- New Zealand Transport Agency. October 2011. *State Highway Asset Management Plan 2012-2015*. Available at <http://nzta.govt.nz/resources/state-highway-asset-management-plan/docs/state-highway-asset-mgmt-plan-2012-2015.pdf>.
- New Zealand Transport Agency. June 2008. *State Highway Environment Plan: Improving environmental sustainability and public health in New Zealand*. Available at [www.nzta.govt.nz/resources/environmental-plan/docs/environmental-plan.pdf](http://www.nzta.govt.nz/resources/environmental-plan/docs/environmental-plan.pdf)
- Norwegian Ministry of the Environment. 2010. *Adapting to a changing climate*. Available at [www.regjeringen.no/pages/36782608/PDFS/NOU201020100010000EN\\_PDFS.pdf](http://www.regjeringen.no/pages/36782608/PDFS/NOU201020100010000EN_PDFS.pdf).
- Rijkswaterstaat. 2012. *Flood Risk and Water Management in the Netherlands: A 2012 Update*.
- Sinclair Knight Merz. May 2012. *Coastal climate change vulnerability and adaptation*. Great Ocean Road Coast Committee. Available at [www.gorcc.com.au/file/file/media/2012/SKM%20VW05093%20Project%20Report%20final%20low%20res.pdf](http://www.gorcc.com.au/file/file/media/2012/SKM%20VW05093%20Project%20Report%20final%20low%20res.pdf).
- United Kingdom Department for Transport. July 2014. *A review of the resilience of the transport network to extreme weather events*. Available at [www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/335115/transport-resilience-review-web.pdf](http://www.gov.uk/government/uploads/system/uploads/attachment_data/file/335115/transport-resilience-review-web.pdf)
- United Kingdom Highways Agency. November 2009. *Climate Change Adaptation Strategy and Framework*. Available at [http://assets.highways.gov.uk/about-us/climate-change/CCAF\\_Strategy\\_and\\_Vol\\_1\\_Rev\\_B\\_Nov.pdf](http://assets.highways.gov.uk/about-us/climate-change/CCAF_Strategy_and_Vol_1_Rev_B_Nov.pdf)
- United Kingdom Highways Agency. Design Manual for Roads and Bridges. Volume 4, Section 3, Part 3 (HD33/06): Surface and Sub-Surface Drainage Systems for Highways. Available at [www.dft.gov.uk/ha/standards/dmrb/vol4/section2/hd3306.pdf](http://www.dft.gov.uk/ha/standards/dmrb/vol4/section2/hd3306.pdf)
- United Kingdom Parliament. Planning Act 2008. Available at [www.legislation.gov.uk/ukpga/2008/29/pdfs/ukpga\\_20080029\\_en.pdf](http://www.legislation.gov.uk/ukpga/2008/29/pdfs/ukpga_20080029_en.pdf)
- University of Melbourne. 2010a. *Australian Climate Change Litigation: Taip v East Gippsland Shire Council*. Available at [www.law.unimelb.edu.au/creel/research/climate-change&caseID=447](http://www.law.unimelb.edu.au/creel/research/climate-change&caseID=447).
- University of Melbourne. 2010b. *Australian Climate Change Litigation: Suburban Blue Print Pty Ltd v Hobsons Bay City Council*. Available at [www.law.unimelb.edu.au/creel/research/climate-change&caseID=475](http://www.law.unimelb.edu.au/creel/research/climate-change&caseID=475).

Victorian Civil and Administrative Tribunal. 2014. *Planning and Environment*. Available at [www.vcat.vic.gov.au/disputes/planning-and-environment](http://www.vcat.vic.gov.au/disputes/planning-and-environment).

Victorian Government Department of Sustainability and Environment. June 2008. *Climate Change in Victoria: 2008 Summary*. Available at [www.climatechange.vic.gov.au/\\_data/assets/pdf\\_file/0020/73172/DSEstatesummaryWEB.pdf](http://www.climatechange.vic.gov.au/_data/assets/pdf_file/0020/73172/DSEstatesummaryWEB.pdf)

VicRoads. September 2010. *Sustainability and Climate Change Strategy: 2010-2015*. Available at [www.vicroads.vic.gov.au/~media/files/documents/planning%20and%20projects/sustainabilityandclimatechangestrategy20102015.ashx](http://www.vicroads.vic.gov.au/~media/files/documents/planning%20and%20projects/sustainabilityandclimatechangestrategy20102015.ashx)

U.S. Department of Transportation  
John A. Volpe National Transportation Systems Center  
55 Broadway  
Cambridge, MA 02142-1093

(617) 494-2000  
[www.volpe.dot.gov](http://www.volpe.dot.gov)



U.S. Department of Transportation  
John A. Volpe National Transportation Systems Center

**Volpe**