Proceedings of 7th Transport Research Arena TRA 2018, April 16-19, 2018, Vienna, Austria

Development of a Climate Adaptation Strategy for the InnovA58 highway in the Netherlands

Myrthe Leijstra[a], Kees van Muiswinkel[a], Wim Leendertse[a,c]*, Thomas Bles[b]

[a] *Rijkswaterstaat, P.O. Box 2232,3500 GE Utrecht,the Netherlands*
[b] *Deltares, P.O. Box 177,2600 MG Delft, the Netherlands*
[c] *University of Groningen, Faculty of Spatial Sciences, P.O. Box 800, 9700 AV Groningen, the Netherlands*

Abstract

Due to climate change, more frequent and extreme weather events will lead to extreme heat, drought and precipitation. This may affect the functionality of (federal) highways and therefore pose a risk for safety and traffic flow. As the asset manager of the main road system in The Netherlands, Rijkswaterstaat has to ensure that road networks continue their operational functions, both now and in the future. Therefore adaptation strategies are needed to develop and maintain climate resilient infrastructure, integrated in the environment. To develop such a strategy, the ROADAPT methodology - developed in response to the 'CEDR call 2012: Road owners adapting to climate change' – and Dynamic Adaptation Policy Pathways were tested on a planned Dutch highway project, InnovA58. This paper elaborates on this test and derives lessons for broader application. By this paper the authors wish to contribute to the discussion about creating climate resilient road infrastructure as integral part of their environment.

Keywords: climate change, infrastructure, resilience, area-oriented approach, ROADAPT

* Corresponding author. *Tel.:* +31 6 51572847, *E-mail address:* wim.leendertse@rws.nl or wlleend@yahoo.com

1. Introduction

The notion of climate change has become one of the world's most dominant issues. Scientific research shows that the global surface temperature by the end of the 21st century is likely to exceed 1,5°C relative to the 1850 to 1900 period for most scenarios, which may have severe consequences for potentially all human and natural systems (IPCC, 2013). These consequences, extreme weather events in particular, pose a safety and mobility risk to transportation infrastructure across the globe (Jaroszweski et al., 2010; Schulz et al., 2017; Axelsen et al., 2016). Since global and local economies strongly depend on reliable and safe infrastructure, disruptions of the system can lead to major personal and economic losses (Picketts et al., 2016). Taking possible consequences of future climate change in consideration is therefore important when planning and designing transportation infrastructure, all the more because of the typical long life spans of infrastructure as well as the significant costs related to the loss of safety and accessibility (Picketts et al., 2016; Koetse and Rietveld, 2009).

The impact of climate change on roads is mainly associated with extreme weather events related to temperature and precipitation, like heat, drought and intense rainfall. Also changes in hydrogeological conditions, like the rise of sea levels and ground water levels, may affect road infrastructure (Rattanachot et al., 2015). In the Netherlands these effects already accumulate, for example: bridges have failed to close due to extreme heat which caused steal to deform, embankments have collapsed due to heavy rain and roads have experienced splash and spray due to pluvial flooding. These effects reduce safety and affect the level of service offered to users (Bles et al, 2016). However "institutionalization of adaptation and resilience in the planning processes are rather complex and compete with other goals" (Schulz et al., 2017, p.195). Since roads are traditionally being designed from a technical and rational (mobility) approach, which is based on current design standards and assumes predictability of the future, changing climate and changing demands for road infrastructure ask for different approaches and integration of the road in its environment. Hence, the central issue in this paper is: how to design climate resilient and adaptive road infrastructure as an integral part of its environment?

There appears to be a gap in knowledge of how to use the concepts of resilience and adaptive planning in the actual design of road infrastructure. Several tools have been developed to assess the vulnerability of roads and possible measures to increase resilience, albeit there are not many examples of actual application of such tools in Europe. In fact, none of these tools have been used by Rijkswaterstaat and knowledge for turning theory and tools into practice is lacking. To test and improve climate resilience tools, concrete cases are required and the InnovA58 in the Netherlands provides such a case. The aim of this project is, among others, to increase the robustness and resilience of the A58 highway and its surrounding environment for the effects of climate change, and to derive lessons for broader application in the main Dutch highways network. In this, the challenge is to use risk and vulnerability assessment tools in such a way that the most cost effective approach is chosen, taking both short and long term into account.

The paper will present main findings of how the concepts of resilience and adaptive planning are applied on InnovA58. The paper first elaborates on the concepts of resilience, adaptive planning and area-oriented planning approaches, and why these concepts are necessary for the development of climate resilient roads. Subsequently, the ROADAPT methodology and the Dynamic Adaptation Policy Pathways, which were applied to InnovA58, will be explained, after which the results of the InnovA58 case are being discussed. The paper concludes with a discussion of the results and recommendations to develop an adaptive area-oriented planning process in order to achieve climate resilience for both the road infrastructure and the surrounding environment.

2. Resilient and climate adaptive roads as integral part of their environment

The concept of resilience has first been used by (ecological) scientists to denote the ability of predictable systems to absorb and resist external shocks without losing functionality (Holling, 1973; Davoudi, 2012). This fits current road design, which is sectoral, linear- and technical oriented. It assumes that projects can have predefined outcomes. However, according to Heeres et al. (2012) this caused road planners to neglect the interaction between road infrastructure and other spatial functions. Furthermore, climate change causes uncertainty in spatial planning, which is inherent to the fact that planning occurs in a complex and adaptable system (e.g. a city), and issues are locally specific, hard to define and context related (De Roo and Porter, 2007). Moreover, Bles et al. (2016) argue that uncertainties also exist in changing demands for road infrastructure, originating in socio economic developments and changing technologies. Therefore Davoudi advocates incorporating uncertainty and nonlinearity within the concept of resilience for the field of spatial planning, rather than merely focusing on linearity and predictability (Davoudi, 2012; Davoudi et al., 2013). In this way, resilience provides "an understanding as the system adapts and changes" in an uncertain and unpredictable environment (Davoudi et al., 2013, p. 310). Davoudi mentions four characteristics that are specific for (socio-ecological) resilience: persistence, adaptability, transformability and preparedness (Davoudi, 2012; Davoudi et al., 2013). First of all, *persistence*, also called robustness, refers to the ability of a system to withstand a given level of stress. It is an important part of managing climate-related risks, to increase the strength of for example the utilities and infrastructure (Davoudi et al. 2013). Secondly, *adaptability* is about making adjustments within a system to make it less vulnerable, through flexibility and the ability to adapt to change. Flexibility in a system refers to connectedness of networks and cooperation between stakeholders, which can lead to adaptability of the system and therefore contribute to resilience (Davoudi et al., 2013). The third characteristic is *transformability*, which means that a system can transform (suddenly or gradual) to a new system, when the existing system collapses (Davoudi, 2012; Davoudi et al., 2013). Finally, *preparedness*, which refers to the influence of human action and intervention on the environment. An important characteristic of social systems is the capacity of humans to predict and plan on future scenarios, by anticipating 'surprises' and learning from previous events (see also Holling, 2001).

As mentioned above, adaptation to climate change refers to making adjustments within the system to make it less vulnerable and more resilient. Adaptability of roads is necessary (Oswald & McNeil, 2013) to manage the possible consequences of future climate conditions and should be proactive in nature (Axelsen et al., 2016). Haasnoot et al. (2013, p.485) therefore propose the method of 'Dynamic Adaptation Policy Pathways' as an analytical approach for pro-actively plotting potential measures, based on alternative external developments over time. Adaptability of roads includes the possible development of new infrastructure or components, as well as maintenance, refurbishment and the use of traffic management systems which can deal with the effects of climate change and should provide the opportunity to adapt to new situations in the future when new knowledge about climate change is available (Rattanachot et al., 2015).

In the Netherlands climate adaptation is particularly concerned with the impact of extreme drought, heat, precipitation and floods. The Delta Programme[1] describes these as the 'four threats' of climate change, which need specific attention (Deltaprogramma, 2014). The impact of these threats is context dependent, hence, when it comes to adapting to climate change, localized solutions are required (Schulz et al., 2017). When it comes to infrastructure, attention should be paid to the fact that most parts of road networks cross multiple borders managed by multiple authorities and levels of government (Axelsen et al., 2016). In the Netherlands this is for example true for the local water boards that manage the regional water systems, in which roads are located. This makes the water boards, amongst other regional stakeholders like municipalities and provinces, important partners in identifying possible measures to increase resilience of the roads, especially because possible measures that contribute to the resilience of roads have to be found elsewhere in the surrounding environment. For example, one can think of the development of upstream water retention that can store water in the case of extreme precipitation. This reduces the chance of inundation of the road infrastructure, thereby increasing its climate resilience, and in the same time making the whole area more flood-proof. Axelsen et al. (2016, p.55)

[1] The Delta Programme is a national programme and involves collaboration between the national government, provincial authorities, municipal authorities and water boards. The objective of the Delta Programme is to protect the Netherlands and its future generations from high water and ensure a sufficient supply of freshwater. website: http://english.deltacommissaris.nl/

therefore stress that: "managing the future increase in water requires an interdisciplinary and inter-organizational approach" and adapting to climate change thus requires regionally tailored approaches to appropriately address specific needs (Deltaprogramma, 2014; IPCC, 2013). To create a regionally tailored approach, Heeres et al. (2012) argue that 'area-oriented' approaches, rather than a 'line' approaches, provide an opportunity to create better and more sustainable infrastructure development. With area-oriented approaches, innovative and effective combinations between road infrastructure and other spatial policy sectors, like recreation, water, nature, housing and agriculture, including climate adaptation measures in the area not directly related to the road, can be made (Heeres et al., 2012). For example, larger culverts underneath roads can lead to better drainage of water in the case of extreme precipitation, yet it can also be beneficial for local nature, as it can serve as an underpass for wild life. Moreover, by involving other stakeholders in the process to increase resilience, knowledge can be shared that leads to better solutions for uncertain developments in climate change.

In short, the road infrastructure system needs persistence, adaptability, transformability and preparedness to be able to cope with the impact of new and uncertain climate situations in the future. For this, an area-oriented approach is crucial, since climate change has an effect on the roads in relation to the surrounding environment and vice versa. Moreover, this approach offers the possibility of smart combinations of measures by combining other challenges in the surrounding environment with the climate adaptation challenge of the road infrastructure.

3. Research method

To develop climate adaptation strategies for the Dutch highway network, InnovA58 (see Figure 1), part of the A58 highway, situated in the provinces of Zeeland and Noord-Brabant in The Netherlands, was used as a case. InnovA58, situated between the cities of Eindhoven and Breda, consists of both an extension of the existing A58 highway (with extra driving lanes) over 50 km in length as well as major maintenance and refurbishment. Furthermore, InnovA58 is part of a broader regional program focused on integration of urban, natural, recreational and environmental challenges which offered the opportunity to imply an area-oriented approach.

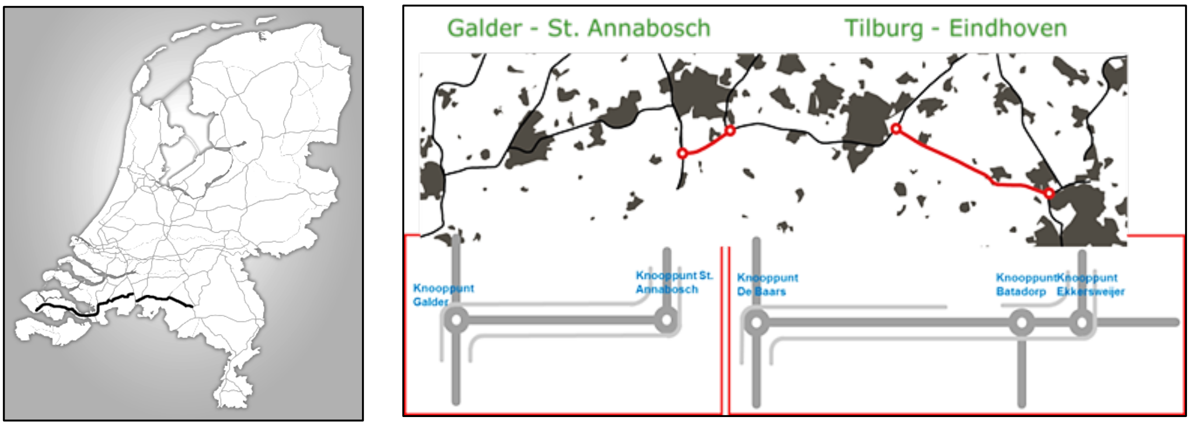

Figure 1. The A58 highway and InnovA58

To assess the risks, vulnerability and possible measures, a process was designed to develop an adaptation strategy for InnovA58 and the surrounding environment from September 2016 to February 2017. Attention was payed to the surrounding environment, since possible measures that contribute to the resilience of the road can be found in the surrounding environment. However, increased resilience in one place may lead to decreased resilience elsewhere. For example; if the road discharges pluvial water at a higher rate into the regional water system, there is a possibility that a local water board is not able process the excess water from the road. Therefore, the involvement of local stakeholders and experts was of high priority in this process. Additionally, the sense of urgency of the local water boards in the project area is high, since they have already experienced what damage extreme weather can cause, when in the spring of 2016 greenhouses and farmland were destroyed due to extreme precipitation, hail storms and flooding.

After the scope was determined, a stepwise process was designed to develop an adaptation strategy. The process consisted of three steps according to the ROADAPT methodology and a fourth step using he Dynamic Adaptation Policy Pathways. In the first step, climate threats, key risks and potential measures were scanned, through two joint workshops, with experts and asset managers from Rijkswaterstaat, Deltares and local stakeholders, like municipalities, water boards and provinces. In the second step, the key risks were mapped to determine the places where the key risks can occur on the road. The output of the first two steps were then analysed on costs, benefits and effectiveness. Finally, an adaptation strategy was developed with the Dynamic Adaptation Policy Pathways. In Table 1 the above described steps of the study are summarized.

Table 1. InnovA58 climate adaptation approach

Process steps	Actions taken
Quick Scan	Two workshops: – To determine climate threats for the A58 infrastructure and surrounding environment – To determine key risks and potential measures
Vulnerability Assessment	GIS-methodology for mapping distinctive vulnerabilities in the road network
Socio-economic Impact Assessment	Two methods: – Cost Effectiveness Analysis – Cost Benefit Analysis
Adaptation Strategy	Dynamic Adaptation Policy Pathways to determine an adaptation strategy

4. ROADAPT and Dynamic Adaptation Policy Pathways

4.1. ROADAPT- methodology

The ROADAPT-project was part of CEDR Call 2012 ‘Road Owners Adapting to Climate Change’. The output of this project were integrated guidelines (see CEDR, 2015) containing different parts as shown in Figure 2. As mentioned above, only the guidelines for the quickscan, the GIS aided vulnerability assessment and the socio-economic impact analysis were used in the study of InnovA58.

The quickscan guidelines provide a method to identify the major risks that can be associated with weather conditions both in the current and in the future climate. The identification of top risks allows a road authority to focus on specific areas in their network or specific threats. The output of the quickscan is generated by bringing all available knowledge, information and experiences of stakeholders together in workshops.

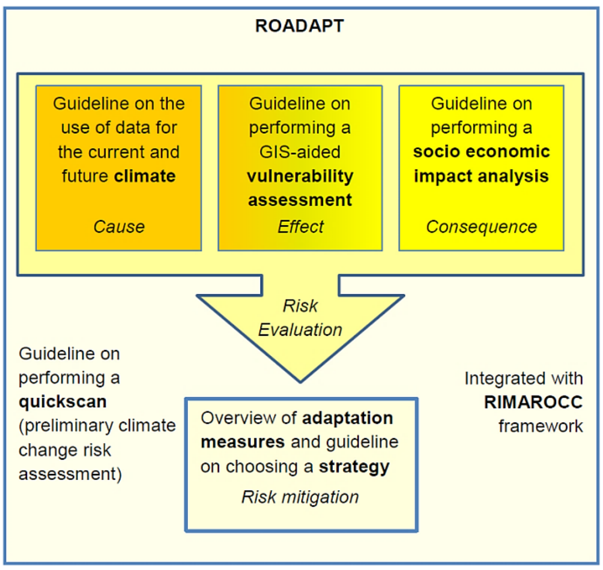

Figure 2. The ROADAPT-guidelines

Vulnerability of the road is assessed in a GIS-environment using geographically distributed vulnerability factors describing the infrastructure and the area surrounding the road. The output is a GIS-layer with areas with prerequisites for the analyzed risk and vulnerability scores. The guidelines for Socio-Economic Impact Assessment direct users on estimating social costs and losses from climate related treats using travel time as the key indicator for assessing impacts. The impacts can be evaluated on a network level using users travel times, on a surrounding area level, using wider local impacts on travel times affected by the network disruption and on the level of the economic system as a whole, looking at corridor, regional and national economic activities that may be affected.

4.2. Dynamic Adaptation Policy Pathways

For formulating the adaptation strategy for InnovA58, Dynamic Adaptation Policy Pathways have been used to visualize potential measures over time. In a Dynamic Adaptation Policy Pathway, the effectiveness of a measure is plotted against the normative climate parameter, for example, a precipitation intensity. Different time scales corresponding to different climate scenarios may then be linked to this. By means of the overview thus created, different paths become visible that may be taken in order to be ready for future climate change. An adaptation path or strategy is a combination of one or more measures in time. A central concept when using these pathways are the adaptation tipping points (Kwadijk et al., 2010), which are “the conditions under which an action no longer meets the clearly specified objectives” (Haasnoot et al., 2013, p.487). When a tipping point for a certain measure is reached, additional actions are needed to achieve the initial objectives (Kwadijk et al., 2010). In this way, combinations of measures provide alternative routes to a desired state in the future (Haasnoot et al., 2013). An example is shown in Figure 3. Central in the figure is the possible change of a climate parameter on the horizontal axis. In this case, this is the amount of precipitation in mm in 2 hours. The associated time scales are shown underneath for two climate scenarios. In this case, these are the scenarios GL centre and WH upper of KNMI (2014). This shows that in one scenario the changes run much faster than in the other scenario. A list of measures is shown on the top left. These measures have been identified as effective, yet one measure is more effective than the other. The associated horizontal lines show for which amount of the climate parameter the measures will be effective. For example, the construction of gutters, is effective up to 57 mm of precipitation in 2 hours and porous asphalt 5 cm thick ‘only’ up to 51 mm of precipitation in 2 hours. The vertical lines that run from and to a circle indicate how one may switch from one measure to the other. One may for example, change from 5 to 7 to 10 cm thick porous asphalt. Sometimes measures can also be carried out simultaneously and are effective together. In those cases, this is shown by means of a dotted line. In the example this relates to the combination of 7 cm thick porous asphalt and the installing of gutters.

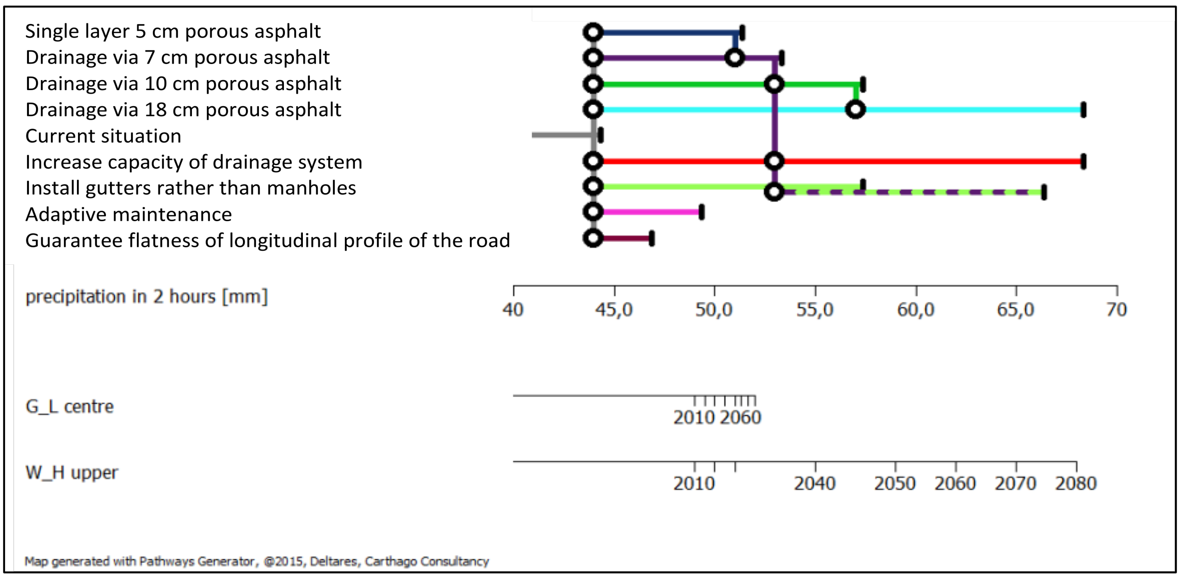

Figure 3. An example of adaptation paths (associated with pluvial flooding)

5. Results of the case InnovA58

5.1. Results from the ROADAPT and Dynamic Adaptation Pathways methodologies

In the Quickscan-workshops, experts from Rijkswaterstaat, Deltares and local stakeholders identified unwanted events of current and future weather that pose the greatest risks for the A58 and its surrounding environment. The risk matrices in Figure 4 show the risks that have been identified for InnovA58. Each number represents a different extreme weather related risk. For the risk assessment, a semi quantitative approach was adopted. This means that both likelihood and impact have been scored using classes 1 to 4. The classes themselves were determined in the workshops. The higher the number for probability, the higher the likelihood; the higher the impact class, the higher the consequences. Due to climate change the probability of these risks change in the future. It can be seen that in general the probability of the risks increase, however, under high uncertainty, which is illustrated with horizontal whiskers (see the horizontal lines attached to the risks in the 'future risk' matrix). After risk evaluation with the stakeholders five key risk were identified (see Table 2) including possible measures for which an adaptation strategy.

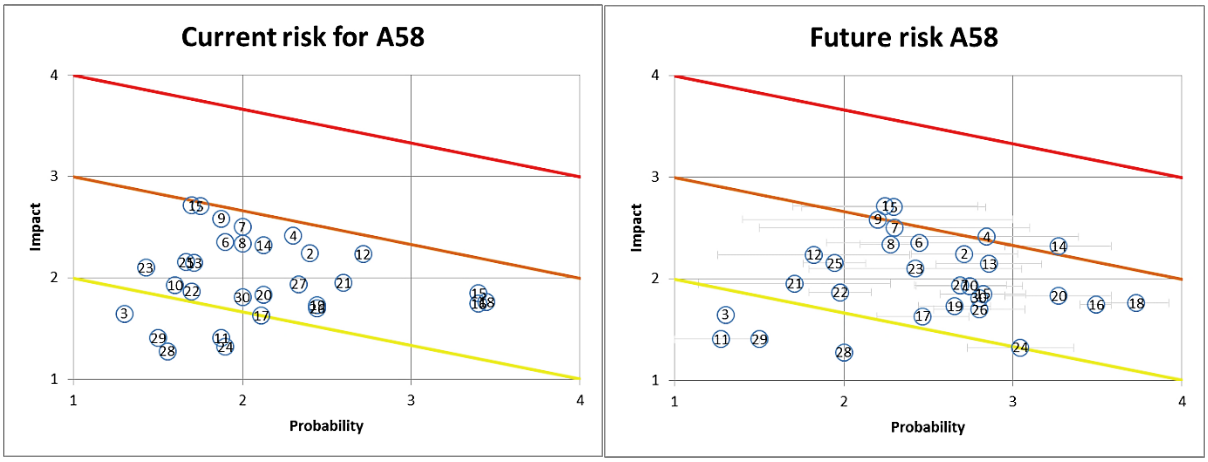

Figure 4. Risk matrices for InnovA58 as generated in the Quickscan (the tilted lines show the magnitude of risk. The more in the upper right corner of the matrix, the higher the risk. In order to emphasize that risks with low probability and high consequences also pose a high risk, the lines are not diagonal but are tilted).

Table 2. Identified key risks and possible measures

Key risks	***Possible measures (examples)***
Flooding of infrastructure as a result of inundation	• Enlarge capacity of the existing bridges (wider/higher) • Improving water storage of rainwater drainage of the road (slower discharge into the streams) • Laying the road higher • Adjusting road design so that road may flood plus diversions • Realizing upstream water storage ('room for the ditches/streams', other vegetation, slower afflux to the stream) • Pumping water from the one side to the other side of the road when there's high water
Flooding of infrastructure due to extreme precipitation	• Increase capacity of rainwater drainage system • Use gutters rather than gullies • Guarantee flatness of longitudinal profile of the road • Build water storage under or next to the road • Dimension/ design intersections for intense precipitation • Use of 'pluvial flooding culverts'
Erosion of embankments	• Improving erosion protection
Loss of safety due to splash and spray	• Better-draining asphalt (thicker) or vertical/central drains under the asphalt • Lowering the emergency lane • Better management and maintenance of the verges and rainwater drainage • Adaptive lighting/ notification on the road
Flooding of streams and urban areas due to extreme precipitation	• 'Pumps' longitudinally to road, from wet to dry places • Store water and add it again during drought ('wadis') • Infiltration of pump water into aquifers • Make sure rainwater does not drain into urban drainage system

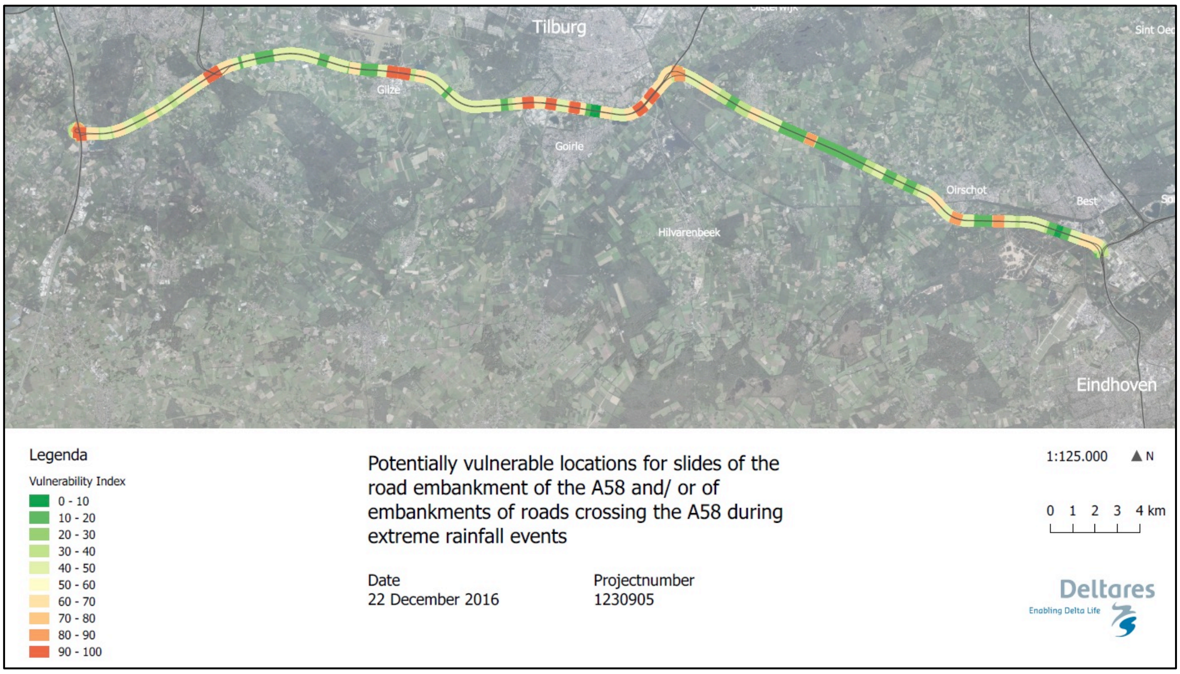

Figure 5. Vulnerability map of potential vulnerable locations for subsidence of road embankments

After having identified the key risks with the quickscan, the ROADAPT Vulnerability Assessment was carried out to analyze the vulnerability of InnovA58 for related current- and future weather circumstances in more detail. The vulnerability assessment resulted in several vulnerability maps, presenting the most vulnerable locations of the project. An example is given in Figure 5. This provided the starting point for more detailed location specific analysis, to examine whether a key risk constitutes an unacceptable risk for the road and the environment, and whether or not measures can and should be taken.

Subsequently, the ROADAPT Socio-economic Impact Assessment provided an analysis whether specific climate change related measures could be potentially viable. This analysis has been made by assessing the economic impact of congestion (related to the loss of travel time) due to climate related events and the chances of occurrence of these events. Furthermore, the benefits of measures have been scored using a multi criteria approach (relevance/effectiveness, flexibility, robustness, maintenance and lifecycle costs and secondary benefits). Last, a cost effectiveness analysis and a cost benefit analysis of the potential measures were made. Based on the information of the previous three steps an adaptation strategy was developed for the five key climate change related risks for InnovA58. To examine when certain measures are needed, the potential measures have been plotted as Dynamic Adaptation Policy Pathways, in line with the example given in Figure 3.

6. Discussion and conclusion

Extensive literature has been written on the concepts of resilience and adaptive planning approaches to foster for climate resilient infrastructure. They often stress the need for regionally tailored approaches to foster for resilience and climate adaptive environments. However, literature on how to use the concepts of resilience, adaptive planning and area oriented approaches in the actual design of road infrastructure is scarce, and since the infrastructure network in the Netherlands is at the limits of its capacity, the current resilience of the system is low. One disturbance can disrupt the functionality of the system. Extreme weather increases the risk of disturbances in the road infrastructure and therefore poses a risk for safety and mobility.

The ROADAPT method provides a clear structure of generating risks, opportunities, consequences and possible measures. In addition, the Dynamic Adaptation Policy Pathways provide insight into which measures can be logically combined into an adaptation strategy. However, the methodologies are highly dependent on the input of involved experts. Local knowledge is essential, since local stakeholders often have location specific knowledge that can lead to realistic and better solutions. Looking at the environment holistically, rather than merely focusing on the road, is important to increase climate resilience, since knowledge about local water systems, ecology and urban planning is crucial to match possible measures for the road to measures that are beneficial for the environment and vice versa. This is illustrated by the example of the 'Stream Valley Report' that was created on the request of local stakeholders during the plan development phase of the InnovA58. This report assessed measures to improve the underpasses under the A58 and it takes several topics into account, such as nature, recreation, cultural history, urban planning and landscape. Measures proposed in the Stream Valley Report appeared to be beneficial for the climate resilience of the A58 and measures proposed for climate resilience may contribute to ecological development. For the A58 project '*matching solutions*' with other goals provided opportunities to achieve multiple goals.

However, in the process it proved difficult to integrate information from stakeholders of the area surrounding the road with information of the road itself. The ROADAPT methodology has primarily been designed specifically for roads, being line- and object oriented, rather than area-oriented. The methods are also technical in character and focus mainly on the functionality of the road. This made it more difficult to make an integral assessment of the climate resilience of the road as an integral part of the surrounding environment. Since climate adaptation is pre-eminently area specific (at least for risks with a cause or consequences outside the boundaries of the road, such as flooding), a process that incorporates an area-oriented approach, involving relevant stakeholders in each process step, is absolutely needed.

Such an area-oriented process should also be adaptive in itself since future climate conditions and the effectiveness of measures is uncertain. But how to develop such an adaptive process? Especially in relation to the current practice of road design, which is technical depending on predefined outcomes for a long life span. The Dynamic Adaptation Policy Pathways may help to address these issues, since the pathways plot potential measures against normative climate parameters. This may help authorities and engineers to assess which measures are needed and when they are needed to achieve climate resilient roads and environments, whilst still being able to make adjustments in the future.

The ROADAPT methodology aims to increase the *robustness* of the A58, through the vulnerability assessment and the development of potential physical measures. The adaptation pathways provide a means to design a road with measures that increase resilience, whilst still being able to adjust to future circumstances. This fosters the *adaptability* and *transformability* of the road and the surrounding environment. 'Matching solutions' with other goals for the A58 provided a further chance to increase the adaptability of the infrastructure. Both methods partially contribute to the *preparedness* of the road and the environment, because the methods are based on future scenarios and the pathways leave room to deal with future surprises. However, the social learning capacity is not addressed, which is a vital element to be able to move towards more desirables states of the road and environment, by learning from previous events.

Finally, attention should be paid to the differences in the perception of urgency between the different involved stakeholders when applying an area oriented approach. Climate resilience for road infrastructure is a new issue for Rijkswaterstaat, whereas several stakeholders in the InnovA58 project area have already experienced the effects of extreme weather on the environment. They have a great sense of urgency for the matter, which is beneficial for collaboration between stakeholders. However, within the Rijkswaterstaat organization the lack of urgency and knowledge makes it difficult to translate resilience and adaptive planning into practice.

We conclude this article by stating that ROADAPT provides an effective methodology to assess the climate change vulnerability and potential measures for road infrastructure and that Dynamic Adaptation Policy Pathways provide a method to increase adaptive design of road infrastructure. An area-oriented approach is needed, since climate resilience requires regionally tailored solutions.

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