
# RIMAROCC

RISK MANAGEMENT FOR ROADS IN A CHANGING CLIMATE

# Illustrative case study

## section/network scale on A2/A58
## 's Hertogenbosch - Eindhoven - Tilburg
## The Netherlands

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# illustrative case study for section/network scale on A2/A58 's Hertogenbosch - Eindhoven – Tilburg the Netherlands

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# Executive summary

The RIMAROCC method is developed to fit different geographical scales including structure, section, network and territorial scales. This case study aimed to be on the territorial scale. The territory used in the case study is relatively small but the case study is still interesting because of specific contextual site factors. The territorial aspect of this case study mainly relies on the analysis of the consequences of land management decisions on the road network operation. However, due to problems with getting an appropriate case on the territorial scale, the case study ended to be more on a section/network scale. Lessons of this case study are relevant for all study scales.

It has to be noted that all information in this case study report is based on three interviews with six experts from Rijkswaterstaat. For the further elaboration of the case study many assumptions have been made by the authors that have not been validated by these experts. The output of this case study therefore is only an illustration of the RIMAROCC method. Contents and conclusions in the different steps should not be used for the real case study subject.

The case study considers risk assessment and risk management for the roads A2 and A58 linking ‘s Hertogenbosch, Eindhoven and Tilburg in the Netherlands. In this case study, two climate factors were studied: high temperatures and extreme precipitation intensity. Even though the case study was based on a lot of assumptions it proved to be a good illustration of the framework.

Most important learning points are:

- The RIMAROCC framework allows for a structured approach, and at the same time it provides enough flexibility. Following the RIMAROCC steps leads to a well-founded strategy for dealing with climate change.
- Gathering all necessary information for analysis is difficult due to a large spread over the organisation or even non-existence. Step 1 that deals with gathering and structuring of all information is seemed very important and takes a lot of effort.
- Many information is available as expert knowledge. Intense contact with these experts throughout use of the RIMAROCC framework will certainly contribute to good results.
- A cause-effect scheme provides valuable insights into the roads, because climate, site and contextual risks are related to each other in a graph in which also the unwanted events and consequences are visible.

# Foreword

"ERA-NET ROAD – Coordination and Implementation of Road Research in Europe" was a Coordination Action funded by the 6th Framework Programme of the EC. The partners in ERA-NET ROAD (ENR) were United Kingdom, Finland, Netherlands, Sweden, Germany, Norway, Switzerland, Austria, Poland, Slovenia and Denmark (www.road-era.net). Within the framework of ENR this joint research project was initiated.

This report is part of the RIMAROCC project with the objective to develop a common ERA-NET ROAD method for risk analysis and risk management with regard to climate change for Europe. The project is led by a Project Management Group with representatives from all partners SGI, Bo Lind (co-ordinator); EGIS, Michel Ray; Deltares, Thomas Bles; NGI, Frode Sandersen. Additional funding to the RIMAROCC project has been provided by all participating partners. We would like to thank KNMI, Météo France and SMHI for their input on climate change and critical climate factors.

The Project Steering Group from the ERA-NET Board, Åsa Lindgren (Project Manager), SRA, Sweden; Alberto Compte and Eva Ruiz-Ayucar CEDEX, Spain and Geoff Richards and Dean Kerwick-Chrisp, HA, UK, have in a constructive way contributed to the project together with other persons from the ERA-NET organisations and other co-workers - they are all gratefully acknowledged.

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# Introduction

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## *Case study circumstances*

During many considerations with Rijkswaterstaat (Dutch Road Authority) we jointly realized that it was very difficult to find an appropriate case for a study on territorial scale. Together with Rijkswaterstaat we therefore decided to do a case study on a smaller scale, while trying to stick to the level of detail of a territorial scale. Also we decided to limit the number of climate factors to be addressed during the case study, and to make assumptions when no appropriate data/knowledge are available (on a short or uncomplicated way). The main purpose of the case study therefore was to show the way RIMAROCC can be used, rather than providing a report for Rijkswaterstaat to be used within their asset management.

It has to be noted that all information in this case study report is based on three interviews with six experts from Rijkswaterstaat. They provided a lot of input for steps 1 and 2 of the RIMAROCC framework. From step 3 onward all elaborations are based on assumptions by the authors which have not been verified by the experts of Rijkswaterstaat. The output of this case study therefore is only an illustration of the RIMAROCC method. Contents and conclusions in the different steps should not be used for the real case study subject.

## *The case*

Together with experts of Rijkswaterstaat we chose the highways A2 and A58 in the province of Noord-Brabant, because of two reasons: a recent study by Alterra (de Groot et al. 2009) shows that the probability of an extreme rainfall event is relatively high at certain spots along both routes, and the two highways differ in importance for the regional economy. According to the national road authority, the A2 is more important than the A58.

In this case study, we focus on the climate factors of high temperatures and extreme precipitation intensity. However, other climate factors should be studied as well, in order to get a total overview of climate change risks for both roads. For instance in 1995 the A2 flooded due to a breach in the levees of a river close to the road (figure 1).


**Figure 1 Flooding of highway A2 near 's Hertogenbosch in 1995**

## *Approach of this case study*

The RIMAROCC method prescribes which steps to follow and provides the user with suggestions on how to carry out those steps. However, the method is flexible in choosing a working method for each step. In this case study, interviews are used to collect the relevant road data. First, four employees of the national authority (DVS) were interviewed. They provided input on the physical consequences of a future change in the studied climate factors and on the way Rijkswaterstaat manages the state of existing road networks. Next, we interviewed three experts from the regional authority (Rijkswaterstaat directie Noord-Brabant) to get specific information for the two roads in this case study. These interviews provided enough information to get started. Afterwards the authors of this report used their own assumptions for further elaboration. This proved to be a good working method, because the illustration of the RIMAROCC method is the main purpose of this case instead of providing a well studied and ready to use report for Rijkswaterstaat.

The RIMAROCC Framework consists of seven steps, which are described subsequently in the sections below, i.e. one section for each step in the risk assessment. The terminology is used in accordance with the terminology use in the RIMAROCC framework.

# Step 1 : Context analysis

## *Step 1.1 : Establish general context*

The highways A2 and A58 are owned by the ministry of transport, public works and water management. The regional road authority (Rijkswaterstaat directie Noord-Brabant) is responsible for the maintainance, management and construction of all highways in the province of Noord-Brabant.

Rijkswaterstaat distinguishes two types of road reconstruction: regular reconstruction and reactive reconstruction. Regular reconstruction is planned based on a yearly check-up of the road. Among other things, the slope and the roughness of the top layer is measured and stored in a database. Based on this information, a reconstructions program is set-up. In contrast to regular reconstruction, reactive reconstruction occurs in response to an unexpected situation, for example due to flooding of a road section. When this happens, the road authority immediately closes off lanes. At the highway A2, digital displays are used for signalling. Next, the road section will be reconstructed to avoid the same event in the future.

## *Step 1.2 : Establish specific context for particular scale of analysis*

The highways A2 and A58 in the province of Noord-Brabant are the topic of this case study. According to the national road authority, the A2 is more important than the A58.


**Figure 2 Case study location. The highways A2 and A58 are marked.**

### *Step 1.3: Establish risk criteria and indicators*

The Rimarocc approach suggests ranking the hazard, exposure, vulnerability and consequences into 4 categories. Some of the categorization will be site- and level dependent, while other categorization may be universal. Below, the suggested criteria for categorization, relevant for the A2-A58 are shown.

The used vulnerability criteria are based on the output of step 2 in which site and context factors are identified. It was found to be very useful to make these factors explicit and use them as vulnerability criteria.

### *Hazard criteria*

| **Criteria to assess the hazard** | **Low** | **medium** | **high** | **Very high** |
|---|---|---|---|---|
| H1 Frequency of key climate conditions / past extreme events | < 1/50 year | < 1/10 year | < 1/5 year | > 1/5 year |

### *Vulnerability criteria*

| **Vulnerability to heavy precipitation** | | | | | |
|---|---|---|---|---|---|
| **codes** | **Criteria to assess exposure** | **low (1)** | **medium (2)** | **high (3)** | **critical (4)** |
| V1-1 | exposure duration | Not used as vulnerability criterion, because of possible double counting with consequences (C3) | | | |
| V1-2 | exposed area | Not used, as vulnerability criterion because of double counting with consequences (C4) | | | |
| V1-3 | traffic intensity | Not used as vulnerability criterion, because of possible double counting with consequences (C3) | | | |
| V1-4 | Design standards | Used design standards have an age of less than 5 years | 5 – 25 years | > 25 years | Unknown standards |
| V1-5 | maintenance frequency | excellent | Pro-active | Re-active | Not sufficient |
| V1-6 | number of lanes | Single | double | three | >three |
| V1-7 | shoulder height | lower than road | 0 – 5 cm | 0-2 m | sunken road |
| V1-8 | road gradient | >2,5% | 1-2,5% | 0-1% | horizontal |
| V1-9 | pavement type | porous asphalt | normal asphalt | concrete | no pavement |
| V1-10 | capacity of drainage system | High | | | Low |

| Vulnerability to high temperatures | | | | | |
|---|---|---|---|---|---|
| **code** | **Criteria to assess exposure** | **low (1)** | **medium (2)** | **high (3)** | **critical (4)** |
| V2-1 | exposure duration | Not used as vulnerability criterion, because of possible double counting with consequences (C3) | | | |
| V2-2 | exposed area | Not used, as vulnerability criterion because of double counting with consequences (C4) | | | |
| V2-3 | maintenance frequency | excellent | Pro-active | Re-active | Not sufficient |
| V2-4 | Berms | no berm | Only side-berm | Middle berm | |
| V2-5 | traffic type | only cars | | | heavy trucks |
| V2-6 | shoulder vegetation | fire insensitive | | | fire sensitive |
| V2-7 | pavement type | porous asphalt | normal asphalt | concrete | no pavement |

## ***Sensitivity** criteria*

| **Sensitivity indicators** | **Risk level** | | | |
|---|---|---|---|---|
| | **low (1)** | **medium (2)** | **high (3)** | **critical (4)** |
| S1 Speed of occurrence / forecast time | > 3 days accurate predictions possible | ½ to 3 days accurate predictions possible | < 12 hours accurate predictions possible | < 5 hours accurate predictions possible |
| S2 Amount and type of information to road users | Matrix boards available | Good radio coverage | No road information | No road information |
| S3 Amount of knowledge of a hazard with related consequences | Detailed insight in occurrence of hazard | Rough insight in occurrence of hazard | Only insight in trends | No idea |

## *Consequence criteria*

To fill in the risk criteria table, the ideas of the national road authority are followed, as collected through the interviews. Rijkswaterstaat is currently developing a system in order to continually check the state of maintenance of the highways and network. This system is based on RAMS(SHEEP), a list of standard criteria in order to rank the different roads and structures. These criteria are more or less in line with the criteria imposed by RIMAROCC, as can be seen in the list below (on the right are the proposed RIMAROCC criteria):

- **R**eliability -
- **A**vailability - unavailability
- **M**aintainability - ± direct costs
- **S**afety - loss of safety
- **S**ecurity - not applicable
- **H**ealth -
- **E**nvironment - impact on the environment
- **E**conomics - direct and indirect costs
- **P**olitics - loss of confidence / image / prestige / political consequences

Nuisance categories which are used by Rijkswaterstaat are also used in RIMAROCC as indicators of criterion C3 (unavailability of the road). The nuisance categories can be derived from the two tables below the consequence indicators.

| Consequences indicators | Risk level (indicators) | | | |
|---|---|---|---|---|
| | **low (1)** | **medium (2)** | **high (3)** | **critical (4)** |
| C1 Loss of safety on the road | Small injuries | Heavy injuries | death | > 5 death |
| C2 Direct costs; costs for reconstruction | < 2 M€ | 2 – 10 M€ | 10 – 30 M€ | > 30 M€ |
| C3 Unavailability of the road | Nuisance category D/E | Nuisance category C | Nuisance category B | Nuisance category A |
| C4 Indirect costs | Negative effects for corridor | Negative effects for own network | Negative effects on own territory | Negative effects outside own territory |
| C5 Loss of confidence / image / prestige / political consequences | complaints | Local consequences | National consequences | Position of minister at stake |
| C6 Impact on the environment | Release of toxic substances | Shoulder ecology disturbed for more than 1 year | Total loss of shoulder ecology | Impact on ecology outside shoulder |

| Nuisance class | Description | Characteristics |
|---|---|---|
| Class 0 | No nuisance | |
| Class 1 | Little nuisance | No traffic jam: delay of seconds / minutes |
| Class 2 | Limited nuisance | Less than 10 minutes delay (traffic jam or detour) |
| Class 3 | Big Nuisance | 10 - 30 minutes delay (traffic jam or detour) |
| Class 4 | Very big nuisance | Over 30 minutes delay (traffic jam or detour) |

| Nuisance class | Number of hindered vehicles | | | | |
|---|---|---|---|---|---|
| | **<1000** | **<10.000** | **<100.000** | **<1million** | **>1million** |
| Class 0 | - | - | - | - | - |
| Class 1 | E | E | D | C | B |
| Class 2 | D | D | C | C | B |
| Class 3 | C | C | B | A | A |
| Class 4 | C | B | B | A | A |

# Step 2: Risk identification

## *Step 2.1 : Identify risk sources*

### Climate risk factors

**Precipitation**

Extreme rainfall (more than 36 mm/uur) in summer is an important climate risk for road owners. According to the IPCC (2007), the probability of intense rainfall will increase in the future, especially in summer. Climate change scenarios from the Royal Netherlands Meteorological Institute (KNMI) show that the daily precipitation sum that is exceeded 1 in 10 years in summer is expected to increase with 5 to 27% until 2050 (Van den Hurk, 2006). The average precipitation amount in winter is expected to increase with 4 to 14% until 2050 (Van den Hurk, 2006). The number of days with more than 15 mm of precipitation increases in all scenarios. Whether this results in an increase in local flooding of roads depends on the actual rainfall intensity and the drainage capacity of the road. How the intensity will increase is not known.

Figure 3 shows the potential increase of local flooding over the next 50 years, according to the W-scenario (FutureWater/klimaatatlas). These maps combine the current average daily rainfall maps with information on the local characteristics such as elevation, groundwater level, infiltration capacity. The resolution is 250 by 250 meter, and road characteristics are not taken into account. It gives an idea about the possible increase in local flooding, and a differentiating between areas. In the province of Noord-Brabant we see an increase of about 20 mm in the cities of Eindhoven, Tilburg and Den Bosch. However, it is difficult to see whether the highways A2 and A58 are affected.

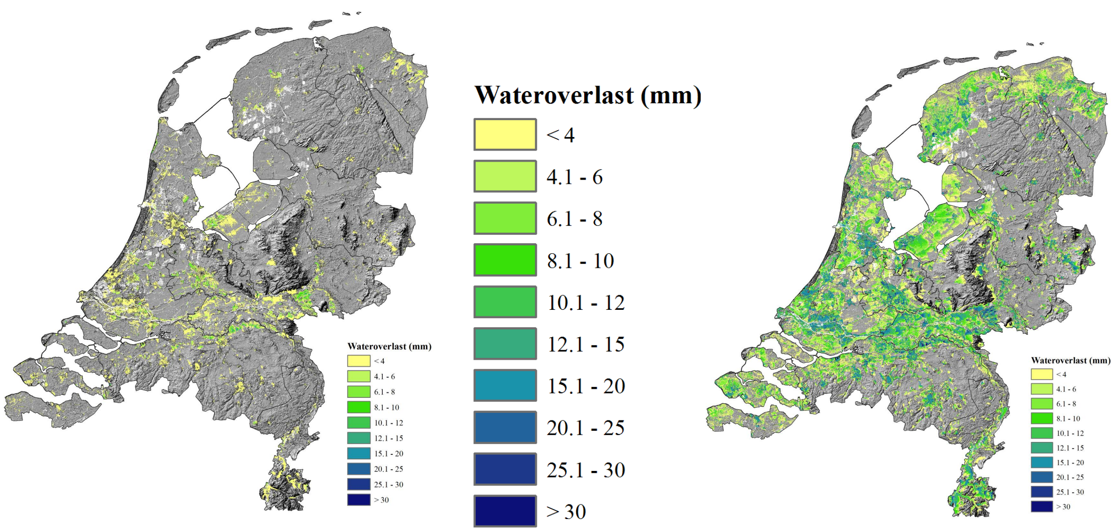



**Figure 3 potential increase of local flooding over the next 50 years (FutureWater/Klimaatatlas)**

### Temperature

The average summer temperature is expected to increase with 0.9 to 2.8 °C (Van den Hurk, 2006). Over the last 30 years, the temperature exceeded 30 degrees Celcius only about 5 days per year.

## Site factors

An overview of the cause-effect chain for both precipitation and temperature is given in figures 4 and 5. The site factors that are of importance are coloured orange. These figures are the results of an interview with technical experts at Rijkswaterstaat.

From the interviews it appeared that the selected highways do not suffer from local flooding in the current climate. However, over the next 40 years, the daily precipitation sum that is exceeded 1 in 10 years in summer is expected to increase with 5 to 27%. The respondents acknowledge that local flooding may occur on their roads in the future, but they do have high confidence in the drainage capacity. The identified effects that are relevant for the case are decrease of surface roughness, short circuit of Dynamic Traffic Management (DTM) and increased runoff of contaminated sediments.

The average summer temperature is expected to increase with 0.9 to 2.8 °C. As for temperature-related risks, the respondents of the interviews only expect problems with lift bridges, but these are not present along the highways A2 and A58 within the province of Noord-Brabant. As the top layer of these highways is made of porous asphalt (ZOAB), the respondents do not expect problems with rutting due to high temperatures. In theory, when tracks become too deep (>18 mm), the road will be reconstructed. This is part of the regular reconstruction program. However, before the tracks reach an unacceptable depth, the top layer will be replaced because of other factors such as aging. High temperatures accompanied by a drought period could increase the possibility of shoulder fires.

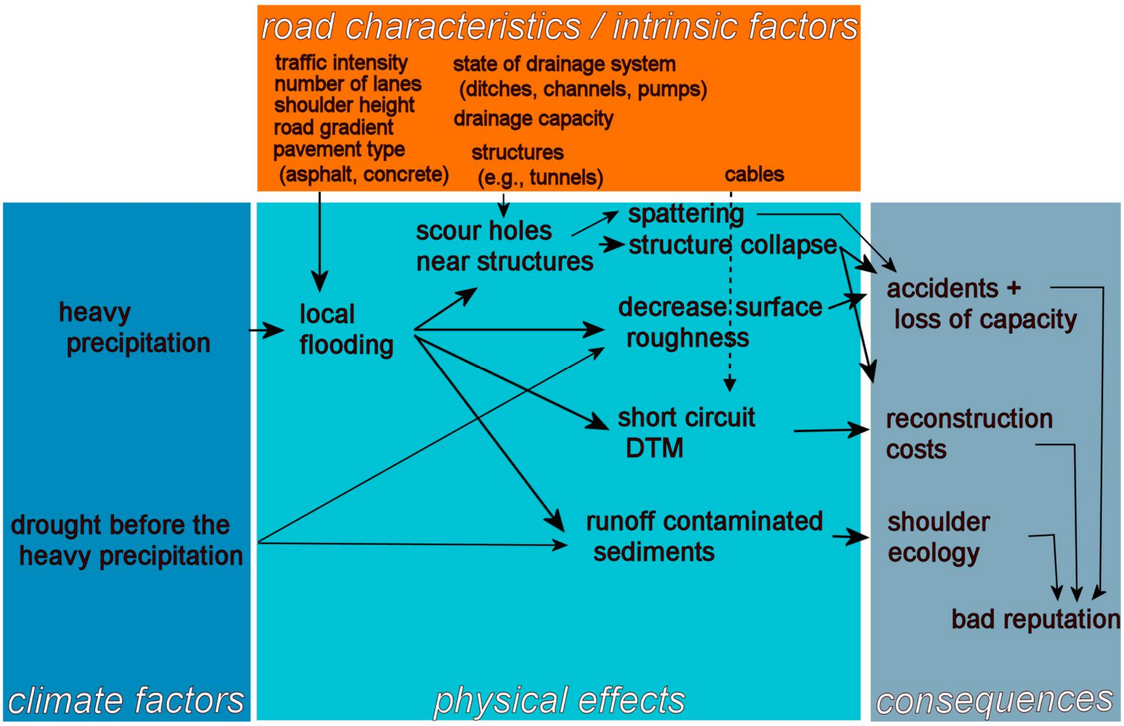



**Figure 4 Cause-effect scheme for precipitation**

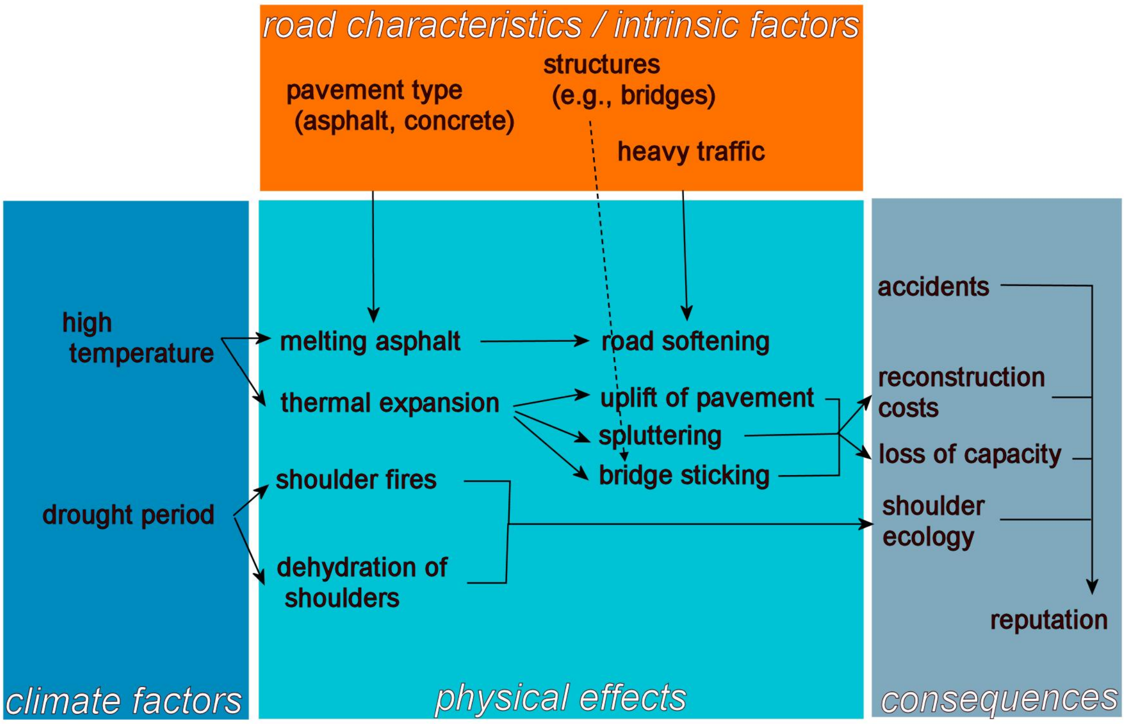



**Figure 5 Cause-effect scheme for temperature**

## *Step 2.2: Identify vulnerabilities*

## *Heavy precipitation*

From the list of road characteristics in figure 3, the following are considered relevant for local flooding of the highways A2 and A58:

- Height of road sides/shoulders
- Presence of noise barriers
- Presence, state and capacity of drainage system (surface water)

The height of the road sides are required to be lower than the bottom of the surface layer. However, it is to be expected that the height of the road side slowly increases due to grasses and other habitat serving as a sand and dirt catch. Unfortunately, the respondents indicate that this aspect is not part of the yearly check-up. This means that the actual state of the road sides remains unknown.

Noise barriers are common near cities and villages. As these barriers reduce the width of the road sides, as such reducing the natural drainage capacity, ditches are constructed which are connected to the sewer system. For a detailed study, the capacity of these ditches should be investigated. However, this case study is limited to an indication of where noise barriers are present.

For locations without noise barriers, bridges or tunnels, water is collected in the surface water system. The water level in these ditches and channels is managed by waterboards (regional water authority). Local flooding risk thus also depends on how the water levels along the roads are managed. For example, a long rainfall period preceding a high-intensity event may reduce the drainage capacity for roads, because the surface water levels will be high leaving less room for storage.

The top layer material is not a relevant factor for the case study. All highways in the Netherlands have a top layer made of porous asphalt (in Dutch: ZOAB). This material has a high infiltration capacity compared to normal asphalt or concrete. Furthermore, the top layer material is not a distinguishing road characteristic, because the top layers of the A2 and A58 are constructed with porous asphalt over the full stretch. Therefore, it is expected that local flooding/decrease of surface roughness is mainly determined by the drainage capacity (sewer system, ditches, channels, etc.).

The superelevation (in Dutch: dwarsverkanting) of the road is a relevant factor, but is not studied in this case study. When roads are constructed, the superelevation is standardized to 2.5% to prevent local flooding/decrease of surface roughness. This superelevation is subject to changes, because of road subsidence. Although the superelevation is measured every year, we consider it too detailed information for the scale of this case study.

Figure 6 shows the location of relevant road characteristics that determine the vulnerability to local flooding. The circles indicate sunken roads (in Dutch: verdiepte ligging), and the rectangles show the location of noise barriers. During the interview with the local authority it was expected that the drainage capacity was according to the norms and no real weak spots were available, except the sections with noise barriers and the sunken roads sections. Therefore, the A2 is more vulnerable to increase of heavy precipitation than the A58, since the latter one does not have these sections.


**Figure 6 Topographical map of the A2, showing location of noise barriers (rectangles) and sunken roads (circles)**

**Figure 7 Impression of road sides of highway A58 between the cities of Eindhoven and Tilburg**

## High temperatures

Road characteristics that influence the vulnerability to high temperatures are: the surface layer, heavy traffic, shoulder ecology and structures such as bridges (see also figure 4). As the surface layer is porous asphalt everywhere, the surface layer is not expected to melt. In fact, the traffic may even cool down the surface layer, as it makes the air move which prevents heat to accumulate. If the surface layer cannot melt, the heavy traffic is not a problem either. Lift bridges are also not present in the case study area. The only possible vulnerability is that the shoulders and road sides are fire sensitive. If the road sides are inhabited by important species, shoulders fires could destroy the biodiversity.

## Step 2.3: Identify possible consequences

The consequences are listed in figures 4 and 5, as well as in the table with consequence criteria.

# Step 3: Risk analysis

## *Step 3.1: Establish risk chronology and scenarios*

In general the following risks have been identified:

1. Shoulder fires due to drought period in combination with high temperatures
2. Decrease surface roughness due to heavy precipitation
3. Decrease surface roughness due to heavy precipitation, drought period
4. Runoff sediments due to heavy precipitation after drought period
5. Short circuit DTM due to heavy precipitation

With help of the vulnerability criteria the following specific risks along both roads are identified:

1. Shoulder fires due to drought period in combination with high temperatures
    a. on A2
    b. on A58
2. Decrease surface roughness due to heavy precipitation
    a. on A2 with sunken road sections
    b. on A2 with noise barriers on both sided
    c. on A2 at connecting roads (more than two lanes)
    d. on A2 at other sections
    e. on A58 at connecting roads (more than two lanes)
    f. on A58 at other sections
3. Decrease surface roughness due to heavy precipitation, drought period
    a. on A2 with sunken road sections
    b. on A2 with noise barriers on both sided
    c. on A2 at connecting roads (more than two lanes)
    d. on A2 at other sections
    e. on A58 at connecting roads (more than two lanes)
    f. on A58 at other sections
4. Runoff sediments due to heavy precipitation after drought period
    a. on A2
    b. on A58
5. Short circuit DTM due to heavy precipitation
    a. on A2

## Step 3.2 : Determine impact of risk

All identified risks are scored on the consequence criteria indicators from step 1.3. The vulnerability criteria that are related to the consequences are kept in mind during scoring. All scores are assumptions by the authors and are not validated by Rijkswaterstaat.

| Risk description | consequence | | | | | |
|---|---|---|---|---|---|---|
| | C1 | C2 | C3 | C4 | C5 | C6 |
| 1a | 1 | 2 | 4 | 3 | 2 | 2 |
| 1b | 1 | 2 | 3 | 2 | 2 | 2 |
| 2a | 3 | 2 | 4 | 2 | 2 | 1 |
| 2b | 3 | 2 | 4 | 2 | 2 | 1 |
| 2c | 3 | 1 | 3 | 1 | 1 | 1 |
| 2d | 3 | 1 | 3 | 1 | 1 | 1 |
| 2e | 3 | 1 | 3 | 1 | 1 | 1 |
| 2f | 3 | 1 | 3 | 1 | 1 | 1 |
| 3a | 4 | 2 | 4 | 2 | 2 | 1 |
| 3b | 4 | 2 | 4 | 2 | 2 | 1 |
| 3c | 4 | 1 | 3 | 1 | 1 | 1 |
| 3d | 4 | 1 | 3 | 1 | 1 | 1 |
| 3e | 4 | 1 | 3 | 1 | 1 | 1 |
| 3f | 4 | 1 | 3 | 1 | 1 | 1 |
| 4a | 1 | 2 | 1 | 1 | 1 | 3 |
| 4b | 1 | 2 | 1 | 1 | 1 | 3 |
| 5 | 2 | 1 | 2 | 1 | 1 | 1 |

## Step 3.3: Evaluate occurrences

For the evaluation of occurences  the following strategy is followed:

- determine probability of current climate event
- determine probability of future climate event
- determine probability of occurence of identified risk given the climate event occuring by making use of scoring the vulnerability criteria
- Translate the probability to a scale according to the hazard criteria table from step 1.3

The used probabilities are roughly estimated by the authors and not validated with climate and road experts.

## *Probability of current climate event*

All roads are engineered for a standard precipitation event that can occur once in 10 years. This is used as the probability for current climate events with regard to precipitation. It is assumed that the frequency of a standard precipitation event following a drought period is twice as low. The probability of high temperatures in combination with drought is assumed once every four years.

## *Probability of future climate event*

Heavy precipitation is expected to increase with approximately 30% in the coming 50 years. Drought periods in combination with high temperatures are assumed to increase with 100%.

## *Probability of identified risk given the climate event*

The probability of an identified risk is a function of the probability of the climate event and the vulnerability of the road. The vulnerability criteria give an indication of the probability of an identified risk given that the climate event is occurring. For the risks 2 and 3 the vulnerability criteria for precipitation are used. First the criteria are mutual weighed. Subsequently all identified risks are scored on the criteria. A combination of weights and scores gives insight in the vulnerability of each specific section that is considered. This list is standardized and it is assumed that the most vulnerable section has a probability of a certain occurrence given the climate event occurring.

In the table below one can see the mutual weights of the different vulnerability criteria for heavy precipitation induced decrease of surface roughness. A score of 3 means that the criterion is indicated as absolute more importance than the other criterion. A score of 0 is the other way around. A score of 1 and 2 lies in between.

The used design standards seem most relevant, followed by the maintenance frequency and the capacity of the drainage system.

| | V1-4 | V1-5 | V1-6 | V1-7 | V1-8 | V1-9 | V1-10 | total | standardized |
|---|---|---|---|---|---|---|---|---|---|
| **V1-4 Design standards** | | 2 | 3 | 3 | 3 | 3 | 3 | 17 | 0,27 |
| **V1-5 maintenance frequency** | 1 | | 3 | 2 | 2 | 2 | 2 | 12 | 0,19 |
| **V1-6 number of lanes** | 0 | 0 | | 1 | 1 | 0 | 0 | 2 | 0,03 |
| **V1-7 shoulder height** | 0 | 1 | 2 | | 1,5 | 1 | 1 | 7 | 0,10 |
| **V1-8 road gradient** | 0 | 1 | 2 | 1,5 | | 1 | 1 | 7 | 0,10 |
| **V1-9 pavement type** | 0 | 1 | 3 | 2 | 2 | | 1 | 9 | 0,14 |
| **V1-10 capacity of drainage system** | 0 | 1 | 3 | 2 | 2 | 2 | | 10 | 0,16 |

The risks dealing with a decrease of surface roughness due to heavy precipitation are scored on the vulnerability criteria. By multiplication of weights and scores a vulnerability score is gathered that is standardized and translated to a maximum score of 80%.

| Risk description | Vulnerability criteria precipitation | | | | | | | vulnerability score | standardized score | maximum vulnerability of 80% |
|---|---|---|---|---|---|---|---|---|---|---|
| | V1-4 | V1-5 | V1-6 | V1-7 | V1-8 | V1-9 | V1-10 | | | |
| **2a** | 2 | 1 | 2 | 4 | 1 | 1 | 2 | 1,77 | 0,95 | 0,76 |
| **2b** | 2 | 2 | 2 | 3 | 1 | 1 | 2 | 1,86 | 1,00 | 0,80 |
| **2c** | 2 | 2 | 3 | 2 | 1 | 1 | 2 | 1,79 | 0,96 | 0,77 |
| **2d** | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 1,75 | 0,94 | 0,76 |
| **2e** | 2 | 2 | 3 | 2 | 1 | 1 | 2 | 1,79 | 0,96 | 0,77 |
| **2f** | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 1,75 | 0,94 | 0,76 |
| **3a** | 2 | 1 | 2 | 4 | 1 | 1 | 2 | 1,77 | 0,95 | 0,76 |
| **3b** | 2 | 2 | 2 | 3 | 1 | 1 | 2 | 1,86 | 1,00 | 0,80 |
| **3c** | 2 | 2 | 3 | 2 | 1 | 1 | 2 | 1,79 | 0,96 | 0,77 |
| **3d** | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 1,75 | 0,94 | 0,76 |
| **3e** | 2 | 2 | 3 | 2 | 1 | 1 | 2 | 1,79 | 0,96 | 0,77 |
| **3f** | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 1,75 | 0,94 | 0,76 |

The same exercision is performed for risk 1 (shoulder fires due to drought period)

| | V2-4 | V2-5 | V2-6 | total | standardized |
|---|---|---|---|---|---|
| **V2-4** | | 2 | 1 | 3 | 0,33 |
| **V2-5** | 1 | | 0 | 1 | 0,11 |
| **V2-6** | 2 | 3 | | 5 | 0,56 |

| Risk description | Vulnerability - high temperatures | | | vulnerability score | standardized score | maximum vulnerability of 10% |
|---|---|---|---|---|---|---|
| | E2-4 | E2-5 | E2-6 | | | |
| 1a | 3 | 4 | 2 | 2,56 | 0,85 | 0,09 |
| 1b | 3 | 3 | 3 | 3,00 | 1,00 | 0,10 |

### *Probability scale*

All information is summarized in the table below.

| Risk description | Threat | | | | | |
|---|---|---|---|---|---|---|
| | p(described climate event occuring) | p(event occuring \| climate event occuring) | p(risk scenario) | | p(risk scenario in future) | |
| 1a | 0,25 | 0,09 | 0,021 | 2 | 0,043 | 2 |
| 1b | 0,25 | 0,10 | 0,025 | 2 | 0,050 | 2 |
| 2a | 0,1 | 0,76 | 0,076 | 2 | 0,099 | 2 |
| 2b | 0,1 | 0,80 | 0,080 | 2 | 0,104 | 3 |
| 2c | 0,1 | 0,77 | 0,077 | 2 | 0,100 | 3 |
| 2d | 0,1 | 0,76 | 0,076 | 2 | 0,098 | 2 |
| 2e | 0,1 | 0,77 | 0,077 | 2 | 0,100 | 3 |
| 2f | 0,1 | 0,76 | 0,076 | 2 | 0,098 | 2 |
| 3a | 0,05 | 0,76 | 0,038 | 2 | 0,050 | 2 |
| 3b | 0,05 | 0,80 | 0,040 | 2 | 0,052 | 2 |
| 3c | 0,05 | 0,77 | 0,038 | 2 | 0,050 | 2 |
| 3d | 0,05 | 0,76 | 0,038 | 2 | 0,049 | 2 |
| 3e | 0,05 | 0,77 | 0,038 | 2 | 0,050 | 2 |
| 3f | 0,05 | 0,76 | 0,038 | 2 | 0,049 | 2 |
| 4a | 0,05 | 1 | 0,050 | 2 | 0,065 | 2 |
| 4b | 0,05 | 1 | 0,050 | 2 | 0,065 | 2 |
| 5 | 0,1 | 0,05 | 0,005 | 1 | 0,007 | 1 |

# Step 4 : Risk evaluation

The risk evaluation is based on assumptions from the authors in order to illustrate the RIMAROCC method and should be read accordingly.

## *Step 4.1: Risk prioritization*

In this step the identified risks are prioritized in order to get insight in those risks that need proper attention. At first, the consequence criteria are mutually weighted as can be seen in the table below. This shows that safety is the most important criterion, followed by indirect costs and availability. According to this table, the criterion environment is considered relatively the least important. The standardized weights add up to 1.

| | c1 | c2 | c3 | c4 | c5 | c6 | total | standardized |
|---|---|---|---|---|---|---|---|---|
| **c1 safety** | | 3 | 2 | 2 | 3 | 3 | 13 | 0,29 |
| **c2 direct costs** | 0 | | 1 | 0 | 1 | 2 | 4 | 0,09 |
| **c3 availability** | 1 | 2 | | 1 | 2 | 3 | 9 | 0,20 |
| **c4 indirect costs** | 1 | 3 | 2 | | 2 | 3 | 11 | 0,24 |
| **c5 prestige** | 0 | 2 | 1 | 1 | | 3 | 7 | 0,16 |
| **c6 environment** | 0 | 1 | 0 | 0 | 0 | | 1 | 0,02 |

Subsequently all scores for threat and consequences from previous steps can be multiplied. In the table below one can see how risks are expected to increase over time. The scoring on sensitivity criteria is later used.

| Risk description | Threat | | Consequence | | | | | | | Risk | | Sensitivity | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | current | future | C1 | C2 | C3 | C4 | C5 | C6 | weighted average | current | future | S1 | S2 | S3 |
| 1a | 2 | 2 | 1 | 2 | 4 | 3 | 2 | 2 | 2,4 | 4,7 | 4,7 | 4 | 1 | 2 |
| 1b | 2 | 2 | 1 | 2 | 3 | 2 | 2 | 2 | 1,9 | 3,8 | 3,8 | 4 | 2 | 2 |
| 2a | 2 | 2 | 3 | 2 | 4 | 2 | 2 | 1 | 2,7 | 5,3 | 5,3 | 2 | 1 | 2 |
| 2b | 2 | 3 | 3 | 2 | 4 | 2 | 2 | 1 | 2,7 | 5,3 | 8,0 | 2 | 1 | 2 |
| 2c | 2 | 3 | 3 | 1 | 3 | 1 | 1 | 1 | 2,0 | 4,0 | 5,9 | 2 | 1 | 2 |
| 2d | 2 | 2 | 3 | 1 | 3 | 1 | 1 | 1 | 2,0 | 4,0 | 4,0 | 2 | 1 | 2 |
| 2e | 2 | 3 | 3 | 1 | 3 | 1 | 1 | 1 | 2,0 | 4,0 | 5,9 | 2 | 2 | 2 |
| 2f | 2 | 2 | 3 | 1 | 3 | 1 | 1 | 1 | 2,0 | 4,0 | 4,0 | 2 | 2 | 2 |
| 3a | 2 | 2 | 4 | 2 | 4 | 2 | 2 | 1 | 3,0 | 5,9 | 5,9 | 2 | 1 | 2 |
| 3b | 2 | 2 | 4 | 2 | 4 | 2 | 2 | 1 | 3,0 | 5,9 | 5,9 | 2 | 1 | 2 |
| 3c | 2 | 2 | 4 | 1 | 3 | 1 | 1 | 1 | 2,3 | 4,5 | 4,5 | 2 | 1 | 2 |
| 3d | 2 | 2 | 4 | 1 | 3 | 1 | 1 | 1 | 2,3 | 4,5 | 4,5 | 2 | 1 | 2 |
| 3e | 2 | 2 | 4 | 1 | 3 | 1 | 1 | 1 | 2,3 | 4,5 | 4,5 | 2 | 2 | 2 |
| 3f | 2 | 2 | 4 | 1 | 3 | 1 | 1 | 1 | 2,3 | 4,5 | 4,5 | 2 | 2 | 2 |
| 4a | 2 | 2 | 1 | 2 | 1 | 1 | 1 | 3 | 1,1 | 2,3 | 2,3 | 1 | | 4 |
| 4b | 2 | 2 | 1 | 2 | 1 | 1 | 1 | 3 | 1,1 | 2,3 | 2,3 | 1 | | 4 |
| 5 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 1,5 | 1,5 | 1,5 | 4 | | 3 |

With a colour scheme insight is obtained into the magnitude of the risks. A risk higher than 6,25 (probability of 2,5 times consequence of 2,5) is indicates as a high risk. Also a score of consequences of 4 is indicated as a high risk.

The following risks need proper attention, based on this prioritization:

- 2b — decrease of surface roughness at A2 on places with noise barriers
- 3a/3b/2a — decrease of surface roughness at A2 on places with noise barriers of sunken roads (after a drought period)
- 1a — shoulder fires due to a drought period and high temperatures on the A2
- 2/3 — decrease of surface roughness at other locations at A2 and A58 (after a drought period)

## *Step 4.2: Compare climate risk to other kinds of risk*

In this case study the risks are not compared to other kinds of risk.

## *Step 4.3: Determine which risks are acceptable*

Based on the standards, the risks 2b, 2c and 2e are not acceptable since the probability of occurrence is higher than the probability used in the standards. All risks are scored on the sensitivity criteria from step 1.3. Based on this scoring it is thought that the risk for shoulder fires (1a) is not acceptable since it is impossible to predict the occurrence of the event in combination with high consequences for availability of the road. The risk for runoff of sediments due to heavy precipitation after a drought period causing environmental problems is not identified as a high risk in step 4.1. Still, from evaluation of the sensitivity criteria it can be seen that no knowledge is available about this risk. The risk is acceptable, but gaining more knowledge about the risk can maybe change this.

Summarized, the following risks are identified as unacceptable risks:

- 2b decrease of surface roughness at A2 on places with noise barriers due to heavy precipitation
- 2c/2e decrease of surface roughness at A2 and A58 at intersections due to heavy precipitation
- 1a risk of shoulder fires

# Step 5: Risk treatment

This step is performed briefly and should normally be elaborated in close cooperation with the road authorities, in for instance a seminar (in an electronic boardroom).

## *Step 5.1 : Identify options*

Possible measures (no complete list) for the risk of decrease of surface roughness are:

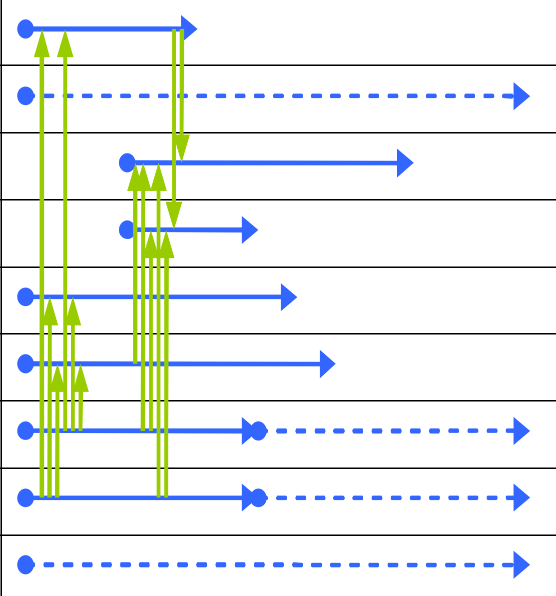
1. Do minimum / Wait and see
   - I. Do nothing
   - II. Research and monitoring of increase of dry periods due to climate change
2. Increasing resistance
   - III. Increase of drainage capacity (ditches, channels, pumps)
   - IV. Higher road gradient
3. Monitoring in combination with preventive measures
   - V. Shoulder height and if necessary lowering of the shoulder height
   - VI. State of drainage system and if necessary reconstruction of the system (dredging of ditches etc.)
4. Reduction of consequences
   - VII. Promotion or obligation of courses for driving on slippery roads or
   - VIII. Development of an early warning system for heavy precipitation in order to provide more information to the road user on matrix borders (lowering of speed/diversion)
5. Research
   - IX. Topographical research for getting more knowledge on vulnerable spots along the road (for instance with use of SWAMP)

Possible measures (no complete list) for the risk of shoulder fires are:

1. Do minimum / Wait and see
   - I. Do nothing
   - II. Research and monitoring of increase of dry periods due to climate change
2. Increasing resistance
   - III. More cutting of grass
   - IV. Planting of less fire sensible vegetation
3. Reduction of consequences
   - V. Promotion of being careful with fire
   - VI. Improvement of alternative routes
4. Development of contingency plans
   - VII. Standby of fire brigade in dry periods

## Step 5.2 : Appraise options

Within the scope of this case study there is not enough knowledge on the amount of climate change in relation to the effectiveness of the identified measures from step 5.1. For the purpose of illustration it is still tried to show how tipping points can be used in order to gain insight in an appropriate strategy. The strategy analysis sheet below is based on very rough assumptions of the authors and should not be used for the real case.

| Measure | The increase of heavy precipitation with a timescale according to climate scenarios | Consequence criteria | | | | | | Estimated costs |
|---|---|---|---|---|---|---|---|---|
| | | C1 | C2 | C3 | C4 | C5 | C6 | |
| I |  | -- | - | -- | -- | -- | 0 | ++ |
| II | | - | - | -- | - | 0 | 0 | + |
| III | | ++ | - | ++ | ++ | 0 | 0 | -- |
| IV | | + | - | + | + | 0 | 0 | - |
| V | | 0 | - | 0 | + | 0 | 0 | + |
| VI | | + | - | ++ | + | 0 | 0 | 0 |
| VII | | + | - | - | - | ++ | 0 | + |
| VIII | | + | - | - | + | + | 0 | - |
| IX | | - | - | -- | - | + | 0 | + |

The strategy analysis sheet provides insight into the effectiveness and flexibility of the identified measures. Also, one can see the effects the consequences. With this information one could choose the following strategy:

1. Start monitoring of the state of the drainage system and reconstruct if necessary (very flexible, keeping all options open, while good effects on consequences and reasonable costs)
2. Stimulate of obligate courses for driving on slippery roads (idem)
3. Identify vulnerable spots and do investment for an increase of drainage capacity on these specific spots

A same analysis could be performed for the risk of shoulder fires.

## Step 5.3: Negotiation with funding agencies

This step is not performed in the case study.

## Step 5.4: Elaborate action plan

This step is not performed in the case study.

# Step 6: Implementation of action plans

This is a step that should be performed by the road authority itself and cannot be done within this case study.

### *Step 6.1: Develop action plan at each level of responsibility*

### *Step 6.2: Implement adaptation action plan*

# Step 7: Monitoring, re-planning and capitalisation

This is a step that should be performed by the road authority itself and cannot be done within this case study.

### *Step 7.1: Regular monitoring and review*

### *Step 7.2: Re-plan in case of new data or delay in implementation*

### *Step 7.3: Capitalization of return of experience on both climatic events and progress of implementation*

# Conclusions

The RIMAROCC framework provides steps that were of good use for this case study. The method allows for a structured approach, and at the same time it provides enough flexibility. It can be used on different levels of scale. This case study aimed to be on the territorial level, but became more relevant on a section or network level. Even though the case study was based on a lot of assumptions it proved to be a good illustration of the framework.

The most important learning point of performing the case study is that information about the road(network) is very much spread among the road authority or even not existent. We expected that road owners know the state of their roads in detail. However, we found that this knowledge is either spread throughout the organization, or not present at all. For example, it is not explicitly known how and when road sections are designed. Because the road owner is not interested in this type of information, they do not store it in a database. As for the drainage capacity, we were told that nobody knows the actual state (except for the inspector maybe). As for traffic intensity we were told to visit a different department. This shows that a few interviews is not sufficient to collect the relevant information. In fact, to collect data on slope, roughness and state of the top layer, which is measured every year, it may be more efficient to contact the organization that stores this data.
This kind of problems is dealt with in step 1 of the framework, which therefore proved to be of major importance. Within the limitations of this case study it was not possible to elaborate more on this subject. However, for a 'real' study it is important to realize that a good elaboration of steps 1.1 and 1.2 is a precondition and will take a lot of effort.

Because of this spread of information and large amount of people that are related to such a study, it is also very important to keep everybody informed and to use the knowledge that is available in peoples heads. If the RIMAROCC framework is going to be used in real projects, effort should be applied in keeping contacts warm with these experts. This also takes a lot of effort but it is expected that the information and knowledge that is gathered with these contacts very much balances this effort. The use of facilities like an electronic board room can minimize the effort.

It is also learned that the cause-effect scheme that was prepared in step 2.1 provides valuable insights into the roads, because climate, site and contextual risks are related to each other in a graph in which also the unwanted events and consequences are visible. This can be used as a summary of the steps 2.1, 2.2 and 2.3.

Finally, one can see that iterative use of the steps is necessary, since the factors that are the output of step 1.3 need input from step 2 and vice versa.

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