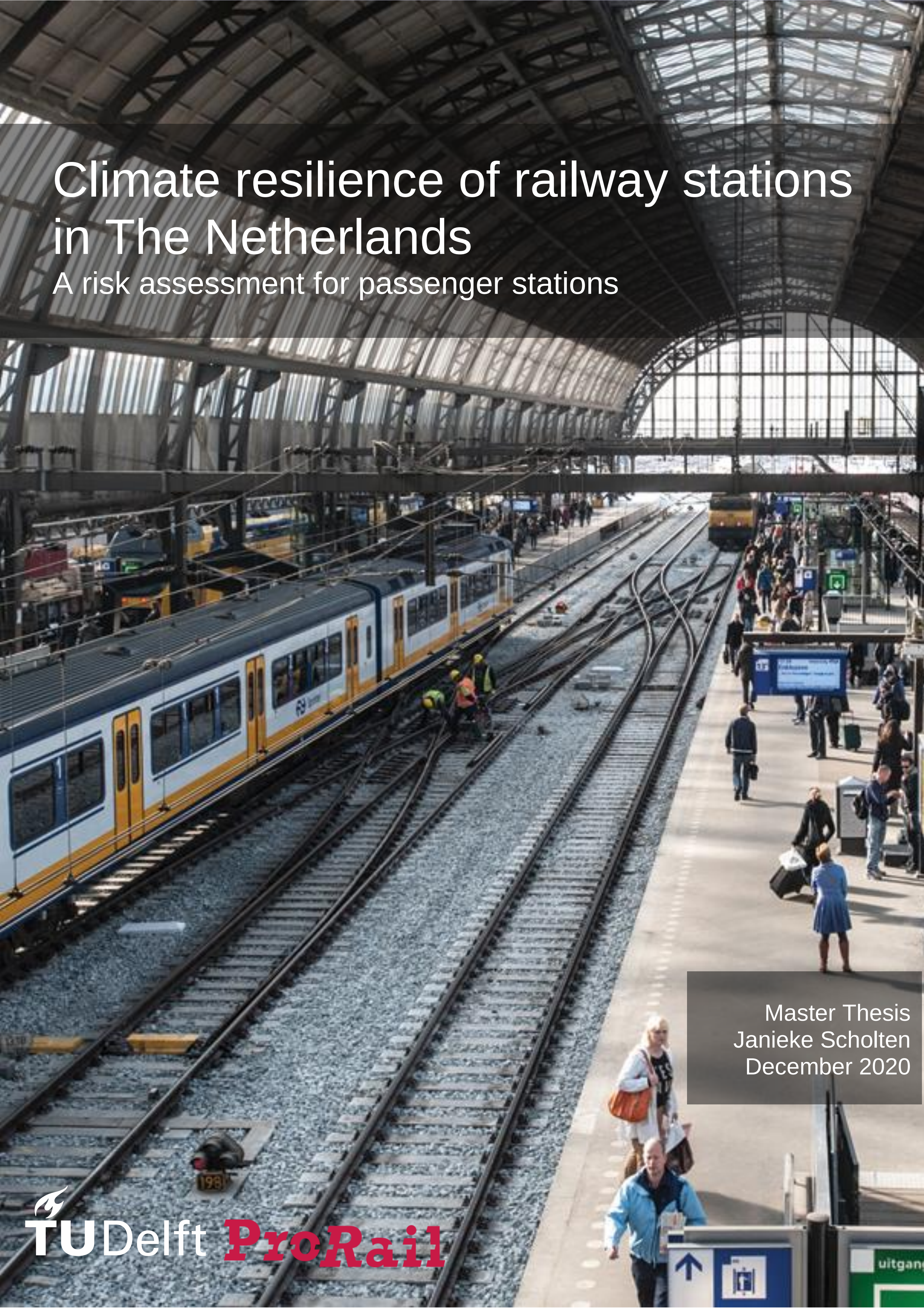

Climate resilience of railway stations in The Netherlands

A risk assessment for passenger stations

Master Thesis
Janieke Scholten
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The cover of this report shows a photo created by Jos van Zetten

Climate resilience of railway stations in The Netherlands

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By

Janieke Scholten

in partial fulfilment of the requirements for the degree of

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in Civil Engineering

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Abstract

As climate change takes hold, extreme weather events increasingly pressure the performance of the railway infrastructure. A first insight has been obtained into the impacts of climate change for the train system and the railway network, but there are almost no studies on the impact of our changing climate on railway stations. This study therefore aims to provide insight into the risks of climate change-induced hazards for railway stations in The Netherlands and the associated effects on the functionality of the station for passengers. Scenarios of climate change show that the Netherlands will experience increasingly intense rainfall, dryer, hotter summers and warmer, wetter winters. This poses a number of risks to the operation, reliability, availability and safety of train stations in a country with the busiest and densest rail network of the European Union. In this study, a method was created to study the risks of climate extremes for train stations on the basis of thirteen identified threats, and risk matrices were developed to support ProRail in defining their attitude towards climate risks. Results show that Dutch railway stations are vulnerable to climate change and demonstrate that there are many aspects of climate change at stations that require attention. The most important nodes in the station network, and stations that have a relatively high number of boarding and disembarking passengers per day, are at a higher risk than the national average. The results of this study show that this could have implications for a relatively high number of travellers in terms of their safety and contentment, and it could have socio-economic consequences for both ProRail and NS, as well as for the accessibility of The Netherlands. The local applicability of the risk assessment methodology was tested in five case studies on stations with very different characteristics, sizes and locations. The case studies have demonstrated that many of the identified risks appear to be relevant and appropriate on a local scale as well, but that risk is situation-specific. Furthermore, the case studies provide strategic long-term quantitative insights on adaptation strategies for all stations in the Netherlands, projecting the cases onto comparative situations.

Summary

The rail network of The Netherlands is the busiest and densest network of the European Union and plays an essential role in the accessibility of The Netherlands and in driving population agglomeration and urban growth at regional and national scales (European Commission, 2016; Wang et al, 2009). The Dutch railway sector faces several major challenges, one of which is anticipating on the effects of climate change. Globally, weather records are broken every year. Regionally, extreme weather events are disturbing railway operations more and more frequently with an associated effect on safety, reliability, availability and functionality of rail as a transport mode (Quinn et al, 2017). Furthermore, studies show that (extreme) weather influences travel behaviour, timing, travel modes and travel routes, and affects passenger flows in public transport (Kuhnimhof et al., 2010; Sumalee et al., 2011).

ProRail's awareness level of potential climate risks for stations can currently be characterized as somewhere between pathological and reactive: little is yet being invested in improving adaptative capacity and ProRail generally responds to events after they have happened. This indicates a level of random- or reactiveness in the implementation of measures rather than an organized approach as part of a strategy on climate resilience. The large degree of uncertainty and inconsistency in decision-making and climate research, in combination with the increased risk of a higher frequency of extreme climate-related events beyond the present coping range, result in increasing deficiencies in the climate resilience of the railway sector. Both academic publishing and climate experts from ProRail have obtained an initial insight into the risks for the (Dutch) railway network to the consequences of climate change. The risk of climate change for railway *stations* however, has not yet been addressed. **This research project therefore aims to provide insight into the risks of climate change-induced hazards for railway stations in The Netherlands and the associated effects on the functionality of the station for passengers.** This study was done in cooperation with, and with data made available by ProRail.

This study focuses on the climate risks for rainfall-, heat- and drought extremes for a passenger station using the W_H-scenario of the KNMI (2014). The risks for stations were assessed in terms of probability of exposure and the damage sensitivity, on the basis of thirteen identified threats. Damage sensitivity was evaluated for five different categories; ProRail's reputation, the experience of customers, technical functionality, society, and the safety of travellers, station visitors or employees. Furthermore, the potential chain effect in the station network were assessed. The probability of exposure was determined with use of ProRail's climate stress test for the railway network, and by analysing additional available data from the national climate effect atlas, ProRail, NS, Arcadis and Deltares. ProRail's risk attitude towards climate risks for stations was established with use of three risk matrices for extreme rainfall, heat and drought hazards. This is essential for determining appropriate response strategies and for prioritising certain risks over others. The local applicability of the risk assessment methodology was tested in five case studies on stations with very different characteristics, sizes and locations. In addition to this, a heat risk assessment was made with use of a questionnaire on a traveller's heat perception.

Results show that out of 401 Dutch railway stations, there are only 6 stations with zero associated climate threats and over 60 stations with 5, 6 or 7 associated threats, with a national median of 3 threats per station. The most important transport nodes in the Dutch network and the “mega” stations with over 25,000 boarding and disembarking travellers per day have a median of 4 threats per station, meaning that these stations are at a higher risk than national average. The consequences of these threats can vary from damage to structures, inaccessibility of the rail network, negative effects on the safety and wellbeing of travellers, failures of electrical and/or telecom systems, or negative effects on customer satisfaction and the reputation of ProRail. Furthermore, extreme weather events could lead to a different use of the train and public transportation system and to different behaviour, causing

overcrowding or congestion, increasing dwell times and causing delays. These findings suggest a degree of vulnerability of the current system and demonstrate that there are many aspects of climate change at stations that require attention.

The questionnaire showed that more than half of travellers felt fairly (38%), very (18%) or terribly hot (3%) on the station on hot summer or tropical days, and on average, the opportunities to cool down or find shelter, water or ventilation were rated insufficient. The case studies have demonstrated that many of the identified threats appear to be relevant and appropriate on a local scale as well, but that risk is situation-specific since other threats than those initially identified could be applicable. This confirms the understanding that stations are or could be vulnerable to climate change, but also emphasizes the importance of further research into the specific local risks and vulnerability to climate extremes.

A variety of feasible solutions are available for strengthening resilience to extreme weather. For extreme rainfall, especially water retention and storage measures are very relevant for stations and it would be beneficial to design the vital infrastructure in such a way that it can withstand a period of flooding and continue to function. To strengthen resilience to heat, increasing shade is the most effective strategy, for example through installing green waiting shelters or sun protection canvasses. For drought, it would be most efficient to start monitoring the movements of buildings and platform structures in critical areas. Extended dwell times or delays as a result of weather extremities can be minimized by improving the station layout, so that clustering of boarding passengers due to the lack of facilities to protect travellers from (extreme) wind, rain, or heat conditions, can be prevented. A final selection of measures for any station is location- and problem dependent and ought to be based on a risk assessment of the specific station.

To minimize the effects of climate change on the functionality of railway stations, it could be beneficial for ProRail to become more proactive in increasing the resilience of railway stations to climate change. Climate adaptation is to become a higher concern and improvements to increase resilience should be introduced and evaluated more systematically. It is recognized that it is challenging, if not impossible, to fully capture the diversity between the stations and the climate risks these stations have to cope with. Standardization of the methods of determining the risks is therefore beneficial, as it reduces confusion and increases simplification, optimization and coordination. This does not imply that standardization is not a process of evolution: research initiatives on climate risks for stations should be constantly updated based on new climate scenarios, threats and the expected change in mobility (behaviour) in the future. To decrease vulnerability and provide focus for adaptation, it is valuable to develop a climate adaptation strategy with clear goals and ambitions from now until 2050, in line with the national climate policy on spatial adaptation (Deltacommissie, 2018). This strategy should follow from the study and quantification of risks at individual stations, which can be assessed with use of the risk matrices developed in this study. When assessing the need for measures to strengthen climate resilience, it is important to discuss different stakeholder’s responsibilities, interests, and intended contributions. Responsible person(s) or actor(s) need to be appointed for implementation and maintenance of the adaptive measures.

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Glossary

Extreme weather event

An event that is rare at a particular place and time of year. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense. When a pattern of extreme weather persists for some time, such as a season, it may be classed as an extreme climate event, especially if it yields an average or total that is itself extreme (e.g., drought or heavy rainfall over a season) (IPCC, 2014: Annex II: Glossary)

Hazard

The potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources (IPCC, 2014: Annex II: Glossary).

Sensitivity

The degree to which a system is affected, adversely by climate variability or change (IPCC, 2007, p. 881).

Exposure

The presence of people, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected (IPCC, 2014: Annex II: Glossary).

Risk

The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. In this study, risk is represented as probability of exposure to hazardous events multiplied by the damage sensitivity if these events occur (IPCC, 2014: Annex II: Glossary).

Vulnerability

The degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity and its adaptive capacity (IPCC, 2007, p. 883).

Adaptive capacity

The ability of a system to adjust to climate change and to minimise the risk associated with a given hazard (IPCC, 2014: Annex II: Glossary).

Resilience

The capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation (IPCC, 2014: Annex II: Glossary)

Coping range

The range of climate stimuli that a system can absorb without significant negative impacts (IPCC TAR, 2001, p.370)

Coping capacity
The ability of people, institutions, organizations, and systems, using available skills, values, beliefs, resources, and opportunities, to address, manage, and overcome adverse conditions in the short to medium term. (IPCC, 2014: Annex II: Glossary)

Risk attitude
The chosen response to uncertainty that matters, influenced by perception (Hillson & Murray-Webster, 2006).

Risk aversion
Attitude whereby events with low probability of exposure yet large damage sensitivity are assigned a higher risk level than events with small damage sensitivity and high probability of exposure, even if the expected damage sensitivity × probability is the same' (Duijm, 2015)

Risk neutral
Attitude whereby low probability- high damage events are assigned an equal risk as high probability- low damage events, if the expected risk is the same (Duijm, 2015)

Risk seeking
Attitude whereby events with low probability of exposure yet high damage sensitivity are assigned a lower risk level than events with small damage sensitivity and high probability of exposure, even if the expected damage sensitivity × probability is the same (Duijm, 2015)

Loss aversion
The tendency to prefer avoiding losses to acquiring equivalent gains (Kahneman & Tversky, 2013).

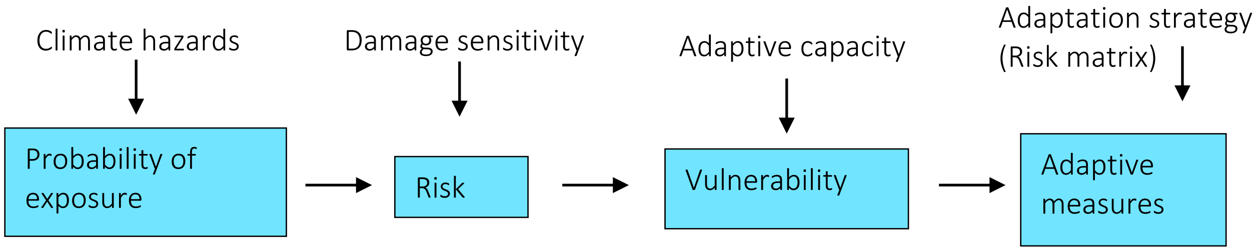


Figure 1: Relation between different terminologies within the risk assessment framework of this study

1. Introduction

The rail network of The Netherlands is the busiest and densest network of the European Union (European Commission, 2016). On average, 1.3 million train journeys are made every day on the Dutch railways, which comprises a total of over 2.2 million train rides and a total of 219 million train kilometres per year in 2018 (ProRail, 2018a). Studies show that the performance of the Dutch railway is in line with or better than European standards (Ministerie IenM, 2008). The rail network plays an essential role in the accessibility of The Netherlands and has important implications for nurturing development and driving population agglomeration and urban growth at regional and national scales (Wang et al, 2009). Additionally, if well managed, the rail can be a reliable and environmentally sound transport mode, which could give it the unique opportunity to stimulate the shift from road to rail, utilizing new technology. Railways can thus increase their role in reducing greenhouse gas emissions to stimulate economic development and improve national resilience to climate change (Quinn et al, 2017).

ProRail, with the Ministry of Infrastructure and Water Management as its main shareholder, is responsible for the Dutch rail network in the field of construction, maintenance, management and safety. To help shape the major sustainability tasks that the Netherlands face and to be able to continue connecting the country by rail in the future, ProRail faces several major challenges. The demand for passenger and freight transport by train is for instance predicted to grow rapidly until 2040 (ProRail, 2019a). In dealing with this, ProRail faces the tasks of facilitating mobility growth and product development of carriers, maintaining the current performance level at a more intensive use of the infrastructure, whilst also realizing its other ambitions for the future to further increase its durability and reliability. These tasks must be completed with the same financial resources, an increased average age of the infrastructure and at a higher price level for materials and labour (ProRail, 2019a). Another challenge for ProRail is ensuring that the rail remains one of the most sustainable forms of transport, for example by reducing its footprint, connecting nature reserves and “greening” its energy consumption. An important part of this is anticipating on the effects of climate change.

Globally, weather records are broken almost every year. Regionally, extreme weather events are disturbing railway operations more and more frequently with an associated effect on safety, reliability, availability and functionality (Quinn et al, 2017). Furthermore, studies show that (extreme) weather influences travel behaviour, timing, travel modes and travel routes, and affects passenger flows in public transport (Maze et al., 2006; Kuhnimhof et al., 2010; Sumalee et al., 2011). The adaptation to previously observed changes in climate, as well as mitigation of future climate change, are very important in this regard (Palin et al., 2013). This study focuses on adaptation-relevant science. A detailed comprehension of climate change-induced risks and impact is crucial in addressing relevant preventative measures for associated hazards (Lu et al. 2012).

The Dutch government has set up several programs and strategies to map and mitigate risks induced by climate change. The Delta Plan for Spatial Adaptation (Deltaplan Ruimtelijke Adaptatie) is a part of this. This plan describes how municipalities, water boards, provinces and the central government wish to accelerate and intensify the process of spatial adaptation. Climate-proof and water-robust design must become a natural part of these spatial (re)-developments. The first ambition of the Delta Plan is "to identify vulnerabilities", for which extra attention has been devoted to vulnerable and vital functions such as the railway network, to counteract the social and economic damage that the potential failure of these functions may entail. By the end of 2020, these functions must have clearly identified their vulnerabilities to climate change, and climate proof thinking- and acting must be anchored in their policy. This is in accordance with the government’s ambition to make national vital and vulnerable functions more resistant to floods and other climate-related effects by the end of 2050 (Ministerie IenW

& Ministerie EZK, 2019). In line with this ambition, the Ministry of Infrastructure & Water Management has asked ProRail to map the vulnerability of their assets to all hazards associated with climate change, now and in the future. To properly map this vulnerability and to create productive coping strategies for the railway system under climate change, risk assessment is a key step in climate change adaptation (Baker et al, 2010).

In the field of climate change, the terms “risk” and “vulnerability” are defined very differently throughout literature (O’Brien et al., 2004; Thompson et al., 2005; Field et al., 2012; Ionescu et al., 2009). In this study the definitions of the IPCC (2014) have been used, in which risk is described as the product of the probability of occurrence of a hazardous event or trend, and the impact if such events or trends were to occur. Vulnerability is defined as “the propensity or predisposition to be adversely affected” (p.5). It describes the degree to which a system is susceptible to, and unable to cope with, the adverse effects of climate change. This relates vulnerability to a certain risk and the (lack of) adaptive capacity of a system to cope with such a risk. Adaptive capacity is the ability of a system to adjust to climate change and to cope with the consequences of potential (future) damages (IPCC, 2014).

Besides Dutch policy, the importance of addressing climate change and devoting effort to adapt to its negative effects is apparent in both global policies and academic publishing. The Commission of the European Community and the UN Environmental Program stress that countries must boost climate adaptation efforts (COM, 2019; UNEP, 2019). The transport sector is repeatedly mentioned by both organizations as a sector that is likely to experience adverse effects as a result of climate change. Several studies have tried to reveal these effects on the transport sector to various degrees on national scale, for example in the US, Mexico, the UK, Sweden and the Netherlands (Neumann et al., 2015; Espinet, Schweikert, van den Heever, & Chinowsky, 2016; Ford et al., 2015; Swedish Commission on Climate and Vulnerability, 2007; Oslakovic, ter Maat, Hartmann, & Dewulff, 2012). A common conclusion is that the impacts of climate change on the transport sector are likely to be large, and that adaptation measures to reduce vulnerability could increase road infrastructure resilience to climate change. Similarly, research has been conducted to disclose the impacts of climate change for the specific case of the railway network, with a focus on incidents and extreme weather events. For example, in Canada, the governmental department Natural Resources Canada (2009) has studied the susceptibility of the rail infrastructure to extremes in temperature and concluded that the Canadian railway is more sensitive to extremely cold conditions than to severe heat. Baker et al. (2010) and Palin et al. (2013) assess a variety of possible temperature-related climate change impacts on the railway network of Great Britain. The main climate change related impacts included track buckling, severe pressure on railway drainage systems, and the general increased likelihood of disruption because of extreme weather events. A more recent study by Chinowsky et al., (2019) has examined the impacts of climate change on the operation of the rail network of the United States. They concluded that the US rail system is expected to face notable increases in delay due to increases in temperature and to face additional costs due to an increased intensity of precipitation events. Furthermore, they discuss the potential for adaptations to reduce impacts, and thereby stress the need for proactive approaches over reactive approaches.

The above studies all suggest that climate change already increases – and will further increase – the risk of weather-induced impacts on the railway network which will challenge the operation of the railways. Most studies are, however, analysed on a national level, which makes the results less applicable for railway managers in the Netherlands as climate change effects can differ substantially between geographic locations (IPCC, 2014). Furthermore, the above studies focus primarily on railway tracks, but little to none have considered the effect of climate change on railway stations, their functions and the surrounding network. Railway stations, however, are a crucial part of the rail infrastructure as they are the only link between the traveller and the trains, and the catchment area and the (public) transport network. If stations are perceived as unpleasant or unsafe, or the station is inaccessible because of extreme weather; all these functions are being compromised.

Both academic publishing and climate experts from ProRail have obtained an initial insight into the risks for the (Dutch) railway network to the consequences of climate change (ProRail, 2019b). The risk of climate change for railway stations however, has not yet been addressed.

> This research project therefore aims to provide insight into the risks of climate change-induced hazards for railway stations in The Netherlands and the associated effects on the functionality of the station for passengers.

This study is done in cooperation with, and with data made available by ProRail.

1.1. Research activities

In order to answer the main question, two sets of research questions are formulated. The first set of research questions are part of the risk assessment, and the second set of research questions are part of the case studies.

1. ***Risk assessment***

   1.1. What is ProRail’s current climate adaptation approach?
   1.2. What are the generic functions of the system railway station?
   1.3. What are projected future weather trends under the KNMI ’14 W_H-scenario and what effects could this have on the functionality of railway stations?
   1.4. How does change in one station influence other parts in the station network?
   1.5. What is the probability of exposure of Dutch railway stations to identified threats?
   1.6. What is ProRail’s attitude towards climate risks, and does this differ for different climate hazards?
   1.7. How do travellers perceive heat at stations, and what are the main factors that influence this perception?

2. ***Case studies***

   2.1. Which stations have a relatively high probability of exposure to climate risks?
   2.2. What are the local risks and vulnerabilities of the selected stations?
   2.3. What climate adaptation measures can be implemented for stations, and how can these be applied to specific cases?

1.2. Scope of the study

The terms “railway station” or “station” in this study refer to the place along a railway line where passenger trains regularly stop so that passengers can get on or off the train. Stations are important nodes in the railway network, connect the train to access and egress modes and are the gateways to cities and villages. They are therefore an essential part of the door-to-door journey of travellers. It is ProRail’s ambition to provide clean, reliable, accessible, sustainable and comfortable stations and to provide all (transfer) facilities that enable a comfortable journey. This includes all elements in the station complex that are necessary for the accommodation of movement, transfers, waiting, and leisure activities (e.g. shops, restaurants) for travellers between, before or after transport processes. The effect of climate change on stations is viewed from the perspective of *the functionality* of the station *for passengers*. All assets in the surrounding network of the station that ensure its functionality are included in this terminology, e.g. bicycle sheds, taxi stands, forecourts, waiting areas, connected passenger tunnels, information boards and the telecom connections and equipment cabinets that supply the power for these information boards. Rail freight related facilities are thus not included in this study when referring to railway stations or stations. The performance and functioning of trains are scaled under the functionality of the railway tracks and the associated technology and is thus beyond the scope of this study.

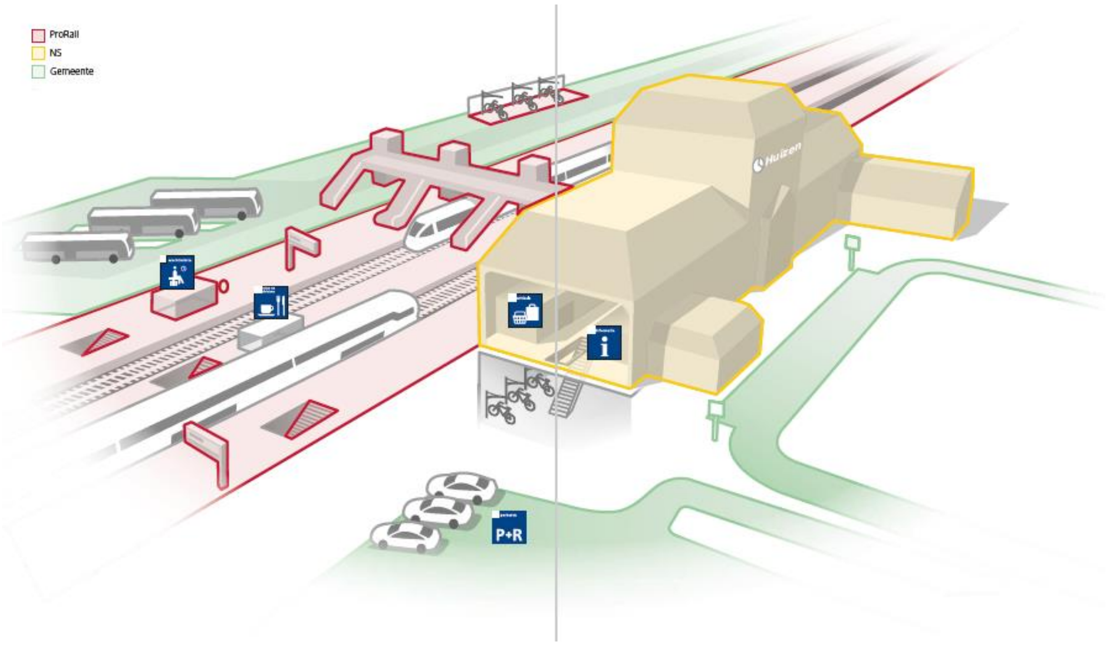


Figure 2: Sketch of all included elements of a train station (ProRail, 2018)

Furthermore, this study considers current risks and risks of climate change induced hazards associated with the W_H -climate scenario of the KNMI (2014) in 2050, to provide an insight into the scenario that usually shows the strongest changes. These hazards could cause disruptions to the train, the track, the station, elements in the surrounding area of the station, and other stations in the station network. Because the focus of this study is on the railway station, only the potential consequences of climate hazards on the station, its surrounding area, and stations in the (nearby) network are considered. The effects of climate hazards on the train or the track are not studied in detail.

The Deltaplan on Spatial Adaptation identifies four climate hazards that the Netherlands faces; floods, heavy rainfall, heat and drought (Ministerie IenM, 2014). ProRail has added winds to this list, as the disturbance at stations due to storms is increasing. According to the IPCC (2014), however, there is no indication of substantial changes in typical wind strengths or frequencies, as regional differences in wind speed make it difficult to draw meaningful conclusions based on single simulations. According to studies, the mean wind speed in a city can be surprisingly different from its rural counterpart for some atmospheric conditions, due to the higher roughness and random shapes, sizes and distributions of buildings in cities. (Droste, Steeneveld & Holtslag, 2018; Coceal & Belcher, 2005). Since wind cannot directly be attributed to climate change, but is more likely a result of urbanization, this study will not include wind as a climate hazard. Moreover, the Deltaplan on Spatial Adaptation stipulates that in the event of a flooding, the railways in principle do not need to contribute to any form of evacuation (Deltacommissie, 2018). Flooding because of a dike breach and the effects of wind or storms are thus beyond the scope of this study and this research will focus on the risks associated with heavy rainfall, heat and drought.

For extreme rainfall, heat and drought, detailed risks and vulnerability analyses will be provided of case study stations to illustrate the approach of a comprehensive risk analysis for specific stations. For extreme rainfall and heat, this study will demonstrate how this can be translated into the application of appropriate adaptation measures. A concrete design of adaptation strategies for drought related issues such as soil subsidence and / or foundation restoration is not part of this study.

1.3. Reader's guide

This thesis consists of 8 chapters. Chapter 2 provides context to the subject of the study, and chapter 3 introduces the theories and methods used in this research, for the risk assessment, the risk matrix, the case studies and the questionnaire. Chapter 4 provides an analysis on future weather trends and characteristics of a station. The results of the risk assessment, risk matrix development and the questionnaire are presented in Chapter 5. In chapter 6, the case studies are discussed. Chapter 7 reviews the research findings and chapter 8 discusses conclusions and consequent implications for ProRail's policy developers and researchers.

2. Context

2.1. The institutional context

The institutional context of the Dutch railway system is strongly influenced by the railway policy of the European Union (van de Velde, 2013). According to the European Commission, the management of railway infrastructure and the provision of train services must be split up for rail markets to function properly and fairly. The belief of the European Commission -- and the basis of its rail policy -- is therefore that open access to rail and tenders should be introduced. According to this view, complete unbundling of infrastructure management and train operation is the best way to give all potential carriers equal access to the infrastructure (Janssen, 2009). Consequently, during the end of the 20th century, the vertically integrated Dutch railway company NS (Nederlandse Spoorwegen N.V.) was separated into a train operations company (NS) and a rail infrastructure management company (ProRail). Both companies are still in state hands (van de Velde, 2013). ProRail divides the space on the track, arranges all train traffic and constructs new tracks. They also maintain existing tracks, points, signals and level crossings. NS is the passenger transport operator on the main rail routes. Besides NS, there are seven other regional passenger carriers that run on routes in the region and 20 freight carriers (Ministerie IenW, 2014). Regarding stations and tunnels on or connected to a station, there is a division in responsibilities between ProRail and NS. ProRail is the advisor in the design and development of new stations and forecourts and is responsible for the construction and maintenance of all stations and bicycle facilities (Ecorys, 2014). The commercial activities at the stations and the implementation of daily management are the responsibility of NS Stations, which is a separate part of NS. Local and regional governments own the forecourts and the land around the stations. In addition, real estate developers and housing associations are important actors involved in the realisation of the surrounding area of the station (Tudorica, 2014). The institutional relationship between government and market- and task organizations and the property division of station are shown in figure 3 and 4, respectively.

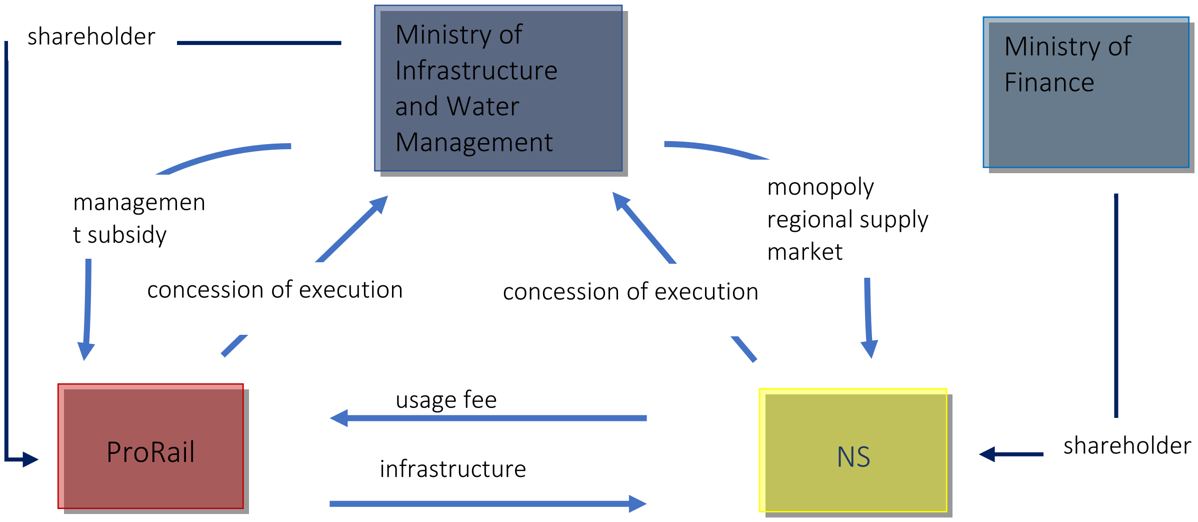


Figure 3: Institutional triangle between ProRail, NS, and the Ministry.

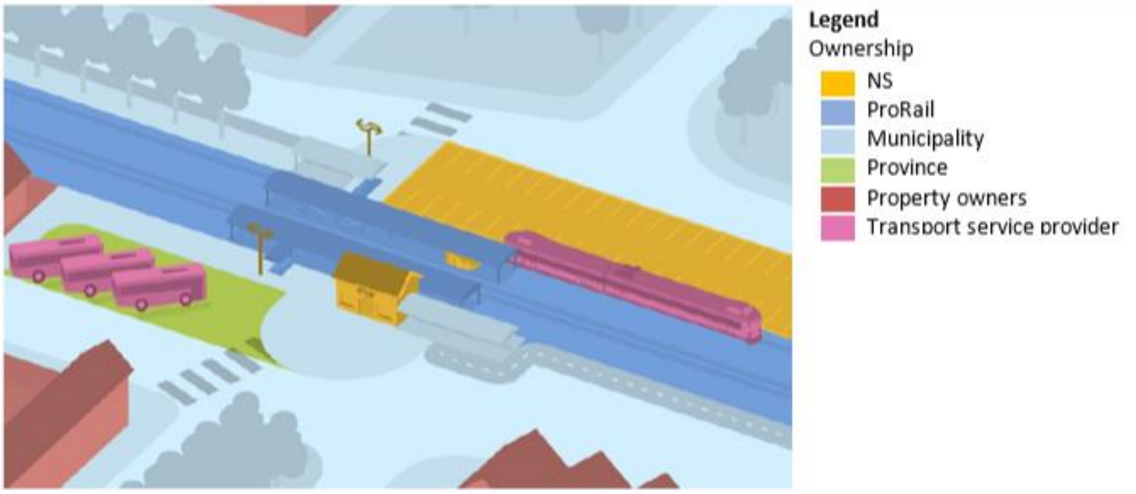


Figure 4. Representation of ownership distribution at stations (Tudorica, 2014).

2.2. ProRail’s climate adaptation strategy

The current degree of attention that ProRail pays to climate adaptation will be assessed throughout this study based on the Safety Culture Ladder (“Veiligheidsladder”) of the NEN (Nederlands Normalisatie Instituut) (NEN, n.d.). This ladder distinguishes five steps that could indicate the development phase in which ProRail finds itself in the field of climate risk awareness. The ladder begins at a pathological development stage and develops into a reactive, a calculating, a proactive and finally a progressive development stage.

“ProRail Connects, Improves and Increases sustainability” are the three main ambitions of ProRail as a company. The aim "increasing sustainability", as described in the management plan for 2021, is to increase the share of rail in total mobility, and to maintain and further develop the position of rail as one of the most sustainable modes of transport (ProRail, 2019d). One of the six means to achieve this, is “working on” the climate resilience of the assets. This is only a small part of the sustainability strategy and of ProRail’s ambitions in general: in the management document for 2021 which comprises 74 pages, six sentences are devoted to climate adaptation.

Part of ProRail’s climate adaptation strategy is the development of a climate stress test to map the vulnerabilities of the rail for 2050. Heat stress, flooding, lightning, storm, drought and subsidence are considered. The stress test initially mainly focused on the effects of climate change for the rail network, but recently, a number of threats were added to gain insight into the vulnerability of stations. The stress test is a good first step to formulate the risks to ProRail’s assets due to climate change, provided that it is adapted for stations, and that the test is used before the start of projects. Besides the stress test, ProRail has developed a climate adaptation guide (Handreiking Klimaatadaptatie). This guide is a step in the search process for a structural approach to make sure that climate impacts play a fully-fledged role in the development of ProRail's policy and projects. It mainly points out that the effects of climate change must be outlined using the national climate effect atlas and that, before starting with a project, potential measures and opportunities should be explored. No reference is made to ProRail's climate stress test, and no concrete examples of potential measures are given, nor are suggestions on how to explore the opportunities mentioned. In practice, the guide is not often used yet in projects.

Furthermore, there is currently no database in which all past projects or measures regarding climate adaptation are registered, or in which future projects can be registered. Additionally, possibly as a result of the aforementioned, there is no one within the Stations Department with a clear view of all station projects in which climate adaptive strategies have been considered. This suggest that the implementation of measures is partly random, and indicates a reactive, rather than a structured and proactive approach. This stresses the need for a clear vision on the risks of climate change-induced hazards for Dutch railway stations, in order to increase awareness and develop a strategy to minimize the negative effects of climate change.

3. Methods

3.1. Research setup

To study the risks of climate change induced hazards on the functionality of Dutch railway stations, it is important to first consider the characteristics of a railway station and to analyse the main services and functions that a station does or should provide. The main services of a station are summarized in “Het stationsconcept”, developed by ProRail, NS and Bureau Spoorbouwmeester (Bureau Spoorbouwmeester, ProRail, & NS (n.d.)), which was used to identify the functions provided at or around stations ***(4.1).*** To study how climate change might affect these station functions, the associated future weather trends of the W_H-scenario were reviewed to evaluate how the functions could be affected by climate extremes ***(5.1).*** The damage to the exposed station functions is labelled as “the damage sensitivity” of a station and is determined in terms of five categories; ProRail’s reputation, the experience of customers, technical functionality, society, and the safety of travellers, station visitors or employees. Every risk category is linked to one or more station functions. Next, the potential chain effect in the station network were assessed ***(5.2)***. Based on the assessment of the potential effects of weather extremities on the functionalities of railway stations, a selection of thirteen threats to the railway station was developed, divided over the specific hazards. The probability of exposure to these threats was assessed with use of ProRail’s climate stress test, and through analysing available data from the national climate effect atlas, ProRail, NS, Arcadis and Deltares through ArcGIS Pro 2.4. ***(5.3).*** This is elaborated on in section 3.2. Consequently, the probability of exposure for critical stations was assessed ***(5.4).***

To be able to determine an appropriate response to a certain level of risk exposure, it is important to develop an attitude towards risk. This must outline which combinations of probability of exposure and damage sensitivity within a risk category are accepted and which are not. Developing a risk attitude is also necessary to be able to determine (future) design requirements for station buildings. ProRail’s risk attitude towards climate risks for railway stations were defined with the use of a risk-matrix ***(5.5).*** This matrix was developed with use of two input variables; the probability of exposure and the damage sensitivity, and consequently by asking the management team of ProRail stations which combination of probability and damage they accept. This method is described in detail in section 3.3.

Furthermore, a questionnaire was conducted at multiple stations with different locations, materials and facilities, to ask station visitors about the degree of (dis)comfort they experience on hot summer days. This could verify whether travellers indeed experience discomfort from heat at stations, and provided an insight into the influence of location, facilities and materials on the traveller’s perception of heat ***(5.6).*** This insight enables an enhanced analysis into the vulnerability of the stations of the case studies (see next section) and can be used to verify the relevance of adaptation strategies found in the literature.

Lastly, five stations were selected that are at relatively high risk. For each of these station, in-depth risk and vulnerability analyses have been conducted, using the results from the questionnaire, local climate stress tests, and on-site research. This allows for a verification of the risks previously identified and from this finding, appropriate adaptation measures for railway stations under climate change can be studied. Figure 5 depicts a flow chart of the used methods.

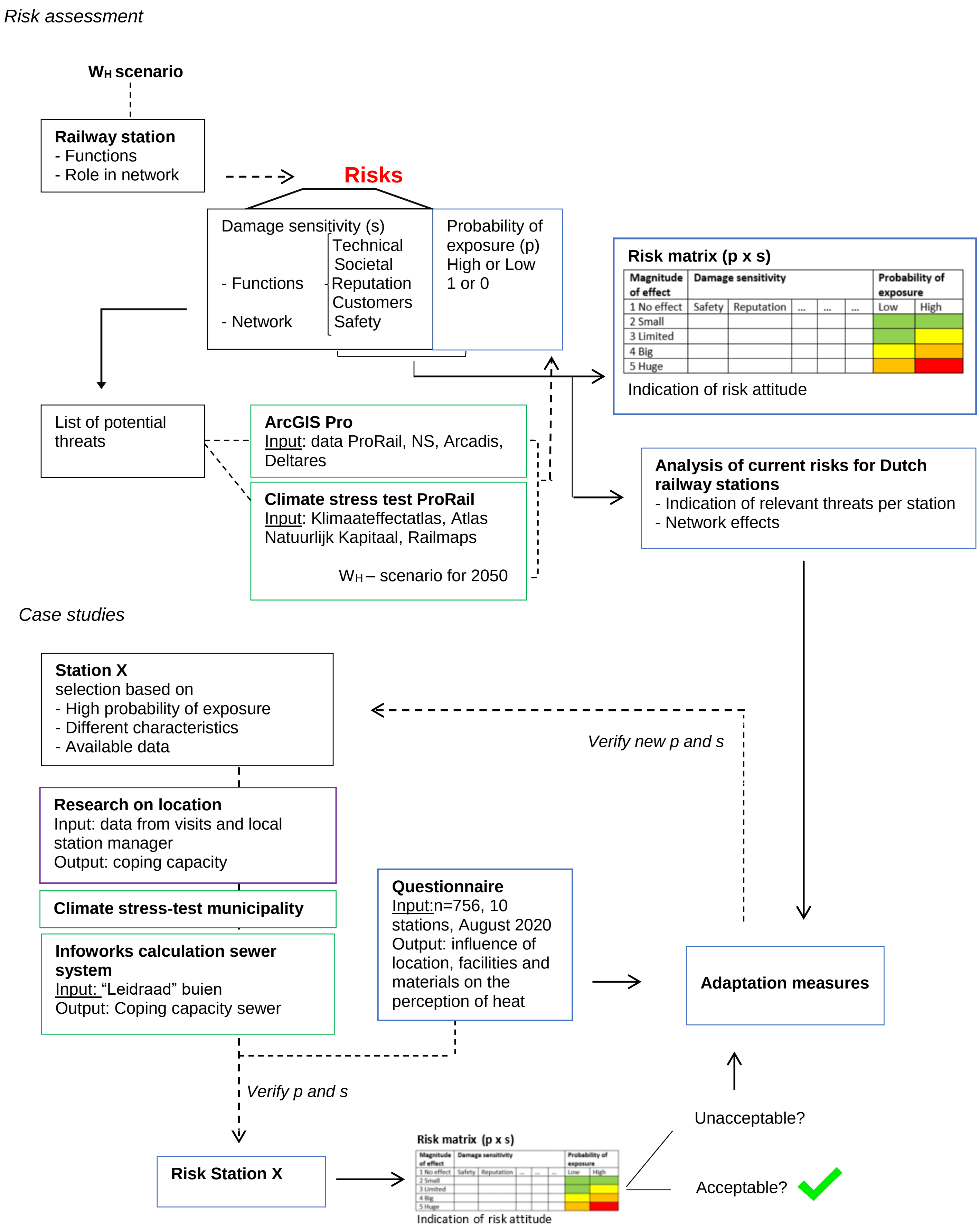


Figure 5: Flow chart of the used methods. The black rectangles are (input) data gathered through desk research, the green rectangles are analyses of probability of exposure with use of ArcGIS or Infoworks and the purple rectangle indicates research on location. The blue rectangles are results. Dotted arrows imply indirect effects or mean: "with use of". Solid arrows are a direct input for the box they point to or a direct result of the box that points to them.

3.2. Risk assessment

To manage risk and reduce sensitivity to loss, potential hazards or threats can be identified and evaluated by means of a risk assessment (Baker et al., 2010). In any risk assessment, risks are sorted according to their relative importance, which is often based on the combination of the estimated probability of occurrence of a hazard, and the estimated damage in case a hazard were to occur (Hallegatte, 2016), defined as the damage sensitivity (IPCC, 2014). Instead of the probability of *occurrence*, this study considered the probability of *exposure*, which is the likelihood of being in the state of having no protection from something harmful. Risk is then defined as the probability of exposure, given a certain probability of occurrence incorporated in the W_H-scenario, multiplied by the damage sensitivity. This definition of risk allows for comparisons between different railway stations because it inherently says something about the characteristics of a station, rather than the likelihood of occurrence of extreme events. This makes it more relevant when studying multiple comparable elements, rather than one single element.

3.2.1. Damage sensitivity

To study the damage sensitivity of railway stations to extreme weather, the potential effects of climate extremes on the functionality of railway stations were estimated based on academic literature and an inventory of risks related to extreme weather conditions in the past. Furthermore, the network effects were assessed, as a change in one station can influence other parts in the station network.

Damage sensitivity can translate into many corporate processes that could be affected. ProRail identifies the following categories that are important for its corporate success: core operational performance, society, costs, safety, reputation and customer satisfaction (ProRail, 2017). These “risk categories” are outlined below and were used throughout this study to evaluate the damage sensitivity on. The financial risk category was not taken into account as it is beyond the scope of this study to research the exact monetary values of climate change for railway stations. The damage sensitivity is influenced by the extent to which a station can provide (all or some of) its station functions. These functions, which will be elaborated on in section 4.1, were therefore used to give the descriptions of the risk categories below.

- *Technical functionality:* The access control of technical functions, including the provision of information to travellers. This is measured as the accessibility of technical rooms and the quality of the provision of information (F4)
- *Society:* Linking the catchment area to the transport network and the provision of public space. This is measured as the accessibility of the station premises to ensure accessibility of homes, schools and companies in the village or town of the station (F3, F5)
- *Customer satisfaction of station visitor:* The accommodating of travellers while waiting. This is being measured as the effect on comfort, cleanliness and/or entertainment at stations (F1,F2)
- *Reputation:* Sum of all the views and beliefs held about ProRail. This is measured by the degree of attention in the local or (inter)national press and the relationship with carriers and / or governments. (F1, F2, F3, F4, F5,)
- *Safety:* The ability to safely transfer within the rail system and to/from other forms of transport. This is measured as the degree of being protected from hazards, risk and injury. (F1, F4)

3.2.2. Probability of exposure

To be able to study the probability of exposure to climate extremes for railway stations, several concrete threats were defined. The selection of threats was based on the damage sensitivity analysis as described above, and on availability of data. The relevance of this selection was verified by specialists from ProRail and Arcadis. This resulted in an assessment of a total of thirteen threats for railway stations, which are described in section 5.3, for which the probability of exposure was analysed based on climate stress tests from ProRail, and on additional analyses with the use of ArcGIS Pro 2.4.

For the analyses of the effects of extreme rainfall, the national climate effect atlas (‘Klimaateffectatlas’) was used as a basis, along with maps from Atlas Natural Capital (‘Atlas Natuurlijk Kapitaal’) and sources from Deltares, Movares and Arcadis. For extreme rainfall, a storm event of 1:100 years was used, corresponding to a storm event of 70 mm in 2 hours in 2050. For this storm, the maximum water depth was calculated for a uniform sewer storage and drainage capacity of up to 20 mm / hour, assuming that the paved outdoor space in the built-up area is optimally connected. The maximum water depth that occurs was calculated for a uniform storm event of 2 hours, followed by 4 dry hours, with runoff only over land, discharge into the sewer or through soil infiltration (Climate Adaptation Services et al., 2017). It was assumed that - due to the short simulation time - the interaction with the surface water system is negligible. The surface water was assumed to have an unlimited storage capacity. The AHN2 elevation model was used, which is measured between 2007 and 2012 (Climate Adaptation Services et al., 2017). The analysis of this study therefore has little value for areas developed after 2012.

To study heat risks, the relative expected increase in the amount of summer (>25 ℃) or tropical (>30 ℃) days per region in 2050 was used, based on data from De Bilt. For drought, the projection of increasingly long and frequent dry periods under the W_H-scenario was used, in combination with maps of the expected soil subsidence due to low groundwater levels between 2016 and 2050. This map was developed by Deltares, TNO-GDN and WEnR for the national climate effect atlas (Climate Adaptation Services, 2017). It shows the total amount of soil subsidence (in cm) estimated in the Netherlands in the period 2016-2050, if no measures would be taken. This map assumes a constant climate and areas in which the total subsidence is very small (< 3 cm) are not shown.

All stations, properties or assets from ProRail or NS were projected over these base maps to show the probability of exposure to the identified climate threats. It was analysed to what extent the hazard applies to the whole of the Netherlands or to specific areas only, and to which stations it precisely applies. All threats include textual explanation of the data, the number of vulnerable stations or assets, and for most threats, a map layer was created in GIS. The analyses of all threats will provide an insight into the probability of exposure for all 401 railway stations, which can be found in section 5.3.

3.2.3. Vulnerability and adaptive capacity of a station

The vulnerability of a system is the degree to which it is susceptible to, and unable to cope with, the adverse effects of climate change. It is a function of the character, magnitude, and rate of climate change, the variation to which a system is exposed and its adaptive capacity (IPCC, 2014). Adaptive capacity is defined as the ability of a system to adjust to climate change and to cope with the consequences of potential (future) damages (IPCC, 2014). Reducing a system’s vulnerability could therefore be achieved by reducing risk or by increasing adaptive capacity.

In general, a system is vulnerable to all conditions that fall outside its coping range, which is defined as the range of climate stimuli that a system can absorb without significant negative impacts (IPCC TAR, 2001, p.370). To improve adaptive capacity, it is therefore important to develop an understanding of climate risks and the present coping range of the railway system. Secondly, efficient management is deemed as a particularly important variable that determines the adaptive capacity of a system (Lindgren, Jonsson & Carlsson-Kanyama, 2009; Engle, 2011). A key area to assess would therefore be the implementation of management approaches associated with vulnerability reduction or adaptive capacity improvements, such as the implementation of anticipatory, proactive and planned adaptation strategies for future climate change. Following from this, the adaptive capacity of Dutch stations was based on the following criteria:

1. Whether a systematic mapping of different types of climate threats has been carried out (e.g. in the municipality of the station), and whether this has been done based on a probable future scenario rather than past events. Such stress-tests are only a first step in increasing adaptive capacity; without taking measures that follow from this stress test, it will not lead to a higher adaptability.

2. Whether the coping range and the potential consequences of climate events for a station have been evaluated.

3. Whether clear and realistic ambitions have been defined for a station by the municipality, ProRail and/or NS, based on a climate adaptation strategy for now until 2050.

4. Whether, in the design of a station, climate change was considered in the early stages of the planning process.

5. Whether in the planning and design process of a station, the effects of potential conflicts have been assessed to avoid the implementation of counter-productive measures. For instance, an increase in the use of electrical cooling solutions that contribute to an increase in greenhouse gas emissions, would be counter-productive. In this process, the potential of creating synergies amongst climate adaptation goals should be studied and exploited.

These criteria were used to evaluate the adaptive capacity of the cases, by assessing the quality of the municipality's stress tests and their strategy to decrease vulnerability. Furthermore, the efficiency and proactivity in dealing with extreme weather events during the planning and design process was evaluated. For the assessment of the coping range of the station system and the damage sensitivity of a specific station, the station manager was consulted. His or her expertise can play a major role in determining the risks of a station, and therefore also in increasing or decreasing its adaptive capacity.

3.3. The risk matrix

A risk assessment matrix is a widely used tool to assess a variety of risks and to conduct a semi-quantitative risk assessment (Ni, Chen & Chen, 2010). In this matrix, two input variables were used; the probability of exposure and the damage sensitivity. The representation of the risk within the matrix is then in line with this study's definition of risk; if probability of exposure given a certain occurrence is p and the damage sensitivity is s, then risk is p x s (Markowski & Mannan, 2008). This means that if there are 'N' probability categories and 'M' damage sensitivity categories, one can discern N×M discrete risk categories. A Risk Priority Number, or RPN, which is often used in Failure Mode Effect Analyses, was assigned to every risk exposure category, depicting the level of risk that an organization is willing to accept (Sharma, Kumar & Kumar, 2005; Ayyub, 2014). The RPN's show a basic logarithmic scaling. A high RPN then means that a station is either more likely to be exposed to a hazard, or that in case of exposure, the damage will be more severe. The RPN's were also divided into different levels of "risk acceptance", determining whether the combination of probability of exposure and damage sensitivity is large enough to warrant spending money to avoid it. This study distinguished three levels of risk acceptance in ascending order of magnitude, marked by three different colours in the risk matrix. A green colour or zone stands for a low and acceptable risk level, yellow stands for a serious and undesirable risk level, and red means a high and unacceptable risk level. The risks that are put in the red zone are given the highest priority for risk avoiding measures. In this study, three risk matrices were created; one for extreme rainfall, one for heat, and one for drought. This allows ProRail to develop a different attitude towards the consequences of each hazards and, thereby, to prioritise adaptation strategies of one hazard over the other. Next sections will explain how different levels of probability of exposure and damage sensitivity will be defined within the matrix, and how these will bring forward ProRail's risk attitude.

3.3.1 Expression of damage sensitivity in the risk matrix

Damage sensitivity in this study was evaluated in terms of the five risk categories elaborated on in section 3.2.1. Then, in the risk matrix, the severity of damage was divided into different levels with different orders of magnitude for each category. There are different approaches towards the quantitative scaling of the risk category levels. In this matrix, a basic linear scaling was used where each category differs by an order of magnitude from the previous one (none to very minor, minor, limited, considerable, severe, very severe) (0,2,4,6,8,10). All levels were sorted according to their relative impacts in successive order, based on available KPIs laid down in a contract with NS or with the Ministry of IenW, on business continuity analyses, or on empirical and historical data regarding incidents of previous years (ProRail, & NS, 2020; ProRail, 2015; ProRail, 2018; ProRail 2019a;). To ensure their fit, all levels within the risk categories were discussed with specialists from ProRail and were then amended according to their suggestions.

3.3.2 Probability of exposure in the risk matrix

The probability of exposure within the risk matrix was categorized as either low (1) or high (1.5). All stations that have critical constructions (e.g. tunnels), that lack certain facilities or elements (e.g. water taps, shade, vegetation) and that are located in areas that are more likely to suffer from weather extremities (e.g. low-lying areas, areas on peat soils, or areas with a high increase in number of summer days) were assigned a high probability of exposure. Stations with opposite characteristics or that are located in areas less likely to suffer from weather extremities were assigned a low probability of exposure. A scaling of 1 and 1.5 were chosen over an equal scaling of both categories. Category scaling determines the amount of risk aversion (Duijm, 2015). A scaling of 1.5 rather than 2 or 3 leads to a smaller difference in RPN between low probability-high damage and high probability-low damage events, suggesting a more neutral risk attitude, which is better suited for ProRail's perception of risk.

3.3.3 Defining risk attitude

The RPN values in this study range from 0 (absolute lowest priority) to 15 (absolute highest priority). The lowest priority then refers to the best-case scenario, since there is zero risk, and the highest priority refers to the worst-case, or the highest possible risk. It is up to an organisation to assess and compare the expected damage sensitivities for the various risk categories, and to determine which RPN value is acceptable and which requires corrective action. In this study, the three member of the Management Team of ProRail Stations and the two climate adaptation experts within the stations' team, were asked to determine ProRail's risk attitude. To correlate the expected damage sensitivity levels for the various risk categories, they were asked to constantly compare two different possible consequences and ask themselves which consequence would be worse (e.g. an ***x*** amount of loss of accessibility or a ***y*** amount of damage to reputation). This comparison ensured an equal weight distribution for all corporate values in the same category, so that priorities could be set between reasonably incomparable harmful effects.

Consequently, they were asked to assign a colour (green, yellow or red) to all 6x2 cells, corresponding to a level of acceptance. Each respondent was asked to argue or justify their answers with use of a rubric, to be able to gain insight into any implicit indicators and factors that they had considered in the decision making. Additionally, all members were asked to argue whether they had differentiated between damage as a result of extreme rainfall, heat or drought, and if so, what was the reason for the difference in their prioritisation.

The rubric of table 1 was used by the team of ProRail Stations for explaining why they applied a rating, or a colour-code to a certain RPN value. The consistent use of this same format makes it possible to compare and discuss the choices of the respondents in an objective manner. These rubrics were therefore used as a basis in an interactive risk dialogue session with all respondents, in which all individual matrices were discussed and argued. This session resulted in one final, uniform risk matrix to assess climate change risks on Dutch railway stations on. The completed risk matrix is presented in section 5.5.

	Risk acceptance level		
Risk category	Green *Low, acceptable risk level* *Lowest priority*	Yellow *Serious, undesirable risk level*	Red *High, unacceptable risk level* *Highest priority*
Technical functionality			
Society			
Reputation			
Customer experience			
Safety			

Table 1: Analytic rubric for applying a colour-code to a certain risk.

3.4. Case studies

3.4.1. Locations

For this research, five stations throughout the Netherlands have been selected to be able to analyse the risks, vulnerabilities and adaptation strategies for climate change in detail for specific locations. Criteria for the selection were:

- Stations with a relatively large probability of exposure to climate change induced risks (extreme rainfall, heat or drought) (>4 threats)
- Equal spread over zones with different soil conditions and different increases in number of summer days (figure 6)
- Different spatial environments
- Different station classes - and therefore a different number of boarding and aligning passengers per day - and a different number of facilities between stations
- Different adaptive capacities at research location
- Availability of research and data at locations

Locations:
1. Amsterdam Amstel
Sensitive to a variety of threats related to extreme rainfall, heat and drought. 5 threats in total
2. Ede – Wageningen
An ongoing tender which makes it an interesting station in the study of ProRail's adaptive capacity, multiple threats related to extreme rainfall and drought, 6 threats in total
3. Boskoop
Sensitive to multiple threats related to heat and drought, located on the edge of the town in a green environment, and in an area sensitive to land subsidence, 5 threats in total
4. Breda – Prinsenbeek
Sensitive to multiple threats related to extreme rainfall and heat, located in an urbanised area and a large increase in summer days, 4 threats in total
5. Leeuwarden Camminghaburen
Sensitive to multiple threats related to extreme rainfall and heat, located in an urbanised area with a small increase in summer days, 5 threats in total

3.4.2. Approach

For all stations, the specific risks and vulnerabilities of the station to climate extremes were assessed based on local climate stress tests and details on the characteristics and location of the station obtained through station visits and a consult with the station manager. Amsterdam Amstel was studied in more detail, to illustrate the approach of a more comprehensive risk analysis for specific stations, and to provide an insight into the translation of risks into the application of appropriate adaptation measures. The case study of Amstel station therefore also included an analysis on the current coping range to flood hazards, which was assessed through information on past flooding events, and the retrievement of their corresponding storm event with duration and return period. With this information, it was determined which system caused the flooding, and composite storm events were projected onto the malfunctioning system to determine its coping range. For heat risks, the questionnaire on the traveller's perception of heat was used to gain a better understanding of the vulnerability of the station, and to help gain useful insights of potentially relevant adaptation strategies.

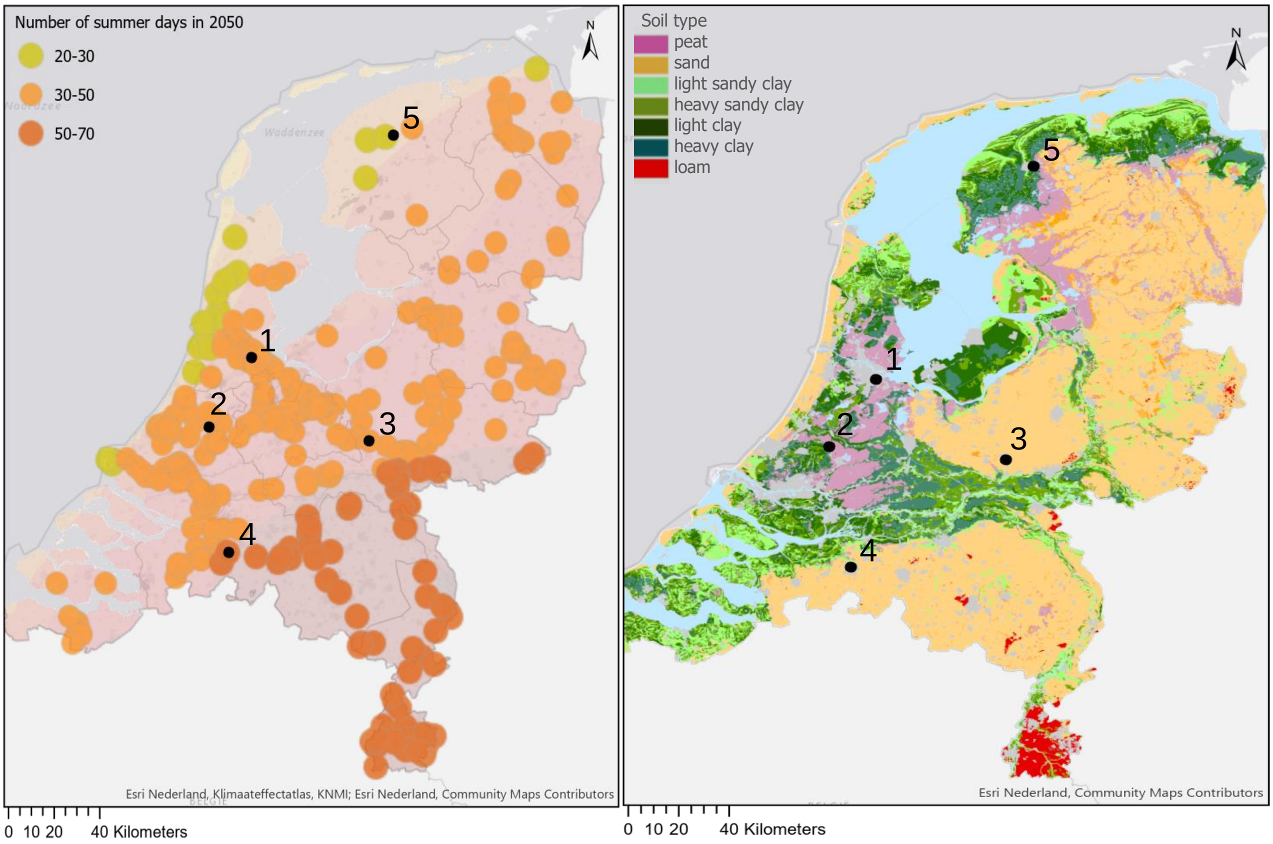


Figure 6: Left: Increase in number of summer days with the locations of this research included. Modified from ProRail & Arcadis, 2020. Right: Soil map of the Netherlands with the locations of this research included. Modified from Alterra, 2006. 1: Amsterdam Amstel. 2: Boskoop. 3: Ede-Wageningen. 4: Breda-Prinsenbeek. 5: Leeuwarden Camminghaburen

3.5. Questionnaire on the perception of heat on stations

A questionnaire amongst travellers was held on 10 different railway stations to ask how they experience heat on the station in relation to the liveability and their health.

Five hypotheses were tested:

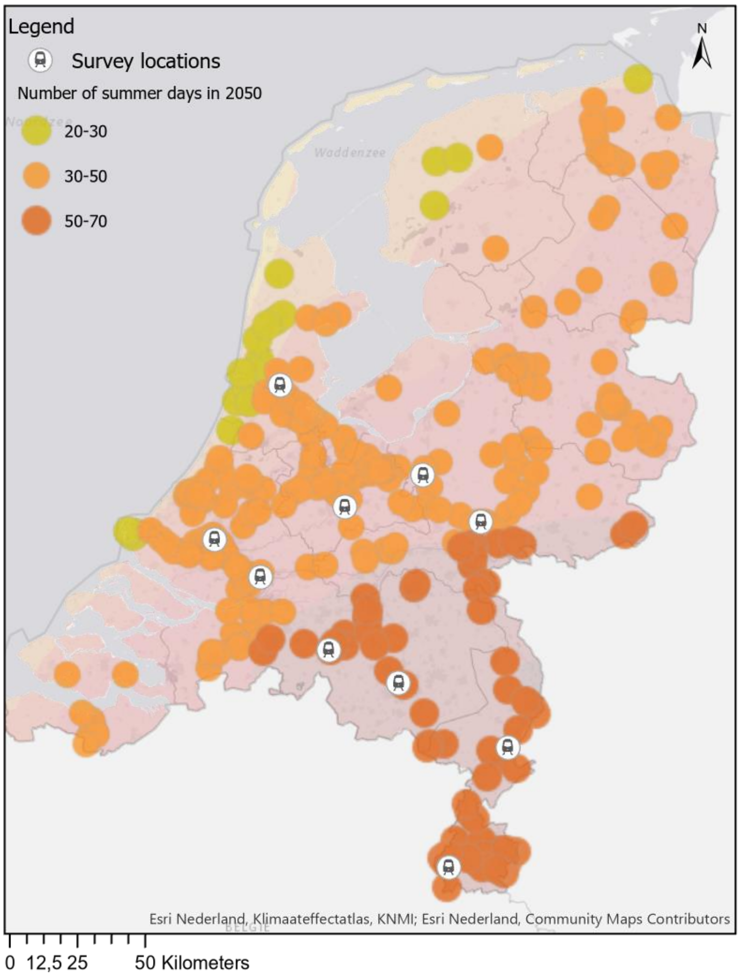
- Stations with water taps are perceived as being less hot
- Stations with planted vegetation are perceived as being less hot
- Stations with some form of shade are perceived as being less hot
- Ventilation has a positive influence on the perception of heat
- Larger stations with a higher number of facilities are perceived as being less hot. Large stations have more strict requirements for the degree of shelter, the number of comfort facilities and the number of green zones for larger stations.

The stations were selected based on their distribution over the country since the temperatures can differ substantially between the north and south, even more so in 2050 (KNMI, 2014). Furthermore, it was made sure that there is a difference in the (amount of) services provided, roof-types and used materials. The stations where the surveys were held are: Rotterdam, Arnhem, Tilburg, Zaandam, Houten, Barneveld centrum, Maastricht Randwijck, Swalmen, Eindhoven Strijp S and Dordrecht Stadspolders. The questionnaire for this survey (n=756) was developed based on a literature review, covering previous surveys held on the same topic

(Klok et al., 2019, Daanen et al., 2010). To ensure its fit to circumstances at stations, the questionnaire was discussed with staff from ProRail and NS and was then amended according to their suggestions. The final survey was administered by a research bureau and data collection occurred over a span of one month, on hot summer days (>27 °C) in August 2020. Due to the heat, the holiday period and the corona pandemic, the number of passengers at the stations was relatively low. The response ranged from n = 58 to n = 108, except for Maastricht Randwyck and Swalmen, where the response was *very* low (n=26, n=2, respectively). The questionnaires can be found in the appendices A and A1.

3.5.1 Statistical testing of the results

Two-sided Z-tests are used to test the validity of each of the hypotheses. This method is used to compare an observed proportion to a theoretical one, in which the critical area of a distribution is two-sided. It is used to test whether a sample is greater- or less than a certain range of values. A confidence level of 95 % was used (alpha =0.05) to test the results.



Esri Nederland, Klimaateffectatlas, KNMI; Esri Nederland, Community Maps Contributors

Figure 7: Geographical spread of survey locations.

4. Stations and future weather

In the first section of this chapter the characteristics and functions of a railway station are being analysed. The second section gives an insight into the current issue of weather-related hazards, the chosen climate scenario and its associated weather trends.

4.1. Characteristics of a Dutch railway station

There are 401 passenger stations in the Netherlands, all with great diversity in architecture, layout, size, use and relationship between the station and surroundings (ProRail, 2019c). These stations are divided into five classes, based on the number of boarding and disembarking passengers per day or on the available transfer space and availability of elevators and escalators (ProRail, 2019c);

1. Halte (Stop): Maximum 1,000 boarding and disembarking passengers per day and no elevators or escalators, or if the area of the available transfer space is less than 2000 m^2, of which less than 20% is roofed.
2. Basis (Base): Between 1,000 - 10,000 boarding and disembarking passengers, or if there are lifts and / or escalators.
3. Plus (Plus): Between 10,000 - 25,000 boarding and disembarking passengers.
4. Mega (Mega): Between 25,000 - 75,000 boarding and disembarking passengers.
5. Kathedraal (Cathedral): More than 75,000 boarding and disembarking passengers.

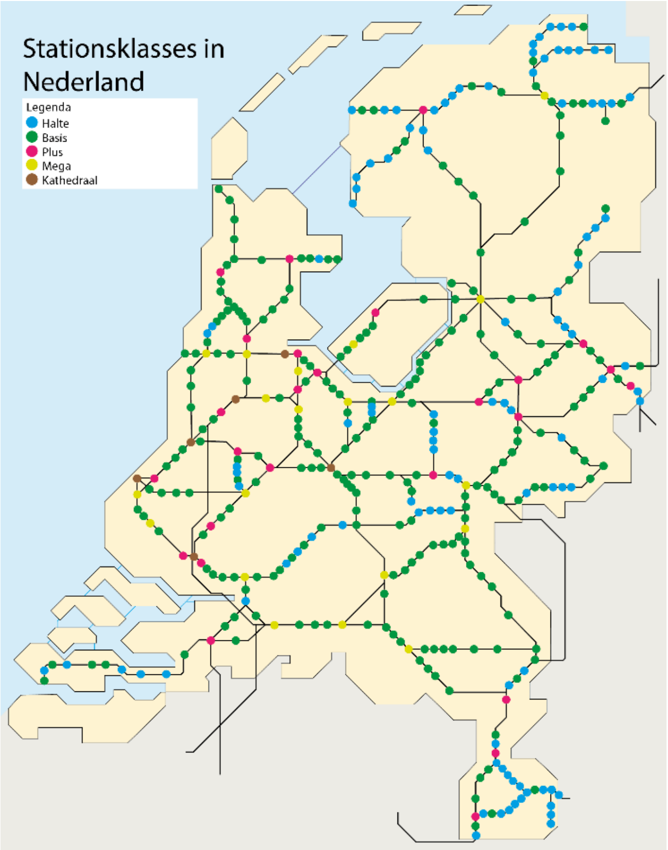


Figure 8: Station classes in the Netherlands (Damen, 2020).

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The higher the class, with “Halte” being the lowest and “Kathedraal” being the highest, the more facilities and type of facilities are available. This is reflected in the degree of shelter, the number of comfort facilities and the amount of green zones, as described in the Vision on stations equipment (ProRail, 2011). The facilities that always must be available at every station are; timetable information, ticket sales, seating objects, shelter, lighting, and waste facilities. All other types of facilities are optional and are dependent on the function, size and architect of the station (ProRail, 2011).

4.1.1 Functions and services at stations

When functioning properly, stations are the links that connect cities, villages, districts or regions to the travel network. They organize the transition between origin, destination and journey in a logical and coherent way: functional, spatial and with attention to the experience of travellers. Furthermore, stations are important transfer points for all public transport in the Netherlands as they connect the trains to intersecting rail lines and to various forms of access and egress modes such as the bus, taxi, tram and bicycle. In this way they form an essential part of the door-to-door journey and of the infrastructure chain. In addition, the station often functions as a corridor to get from one side of the track to the other or from one part of the city to the other. Stations can also be a destination in themselves, due to the concentration and nature of facilities in and around the station, which is often located at a central point in the city or town.

According to Bureau Spoorbouwmeester, each station ideally has four domains; the Surroundings-domain, the Welcoming-domain, the Travel-domain and the Staying-domain (Bureau Spoorbouwmeester, ProRail, & NS. (n.d.). These domains organize functions and facilities according to the needs of the users on their way to and through the station. They indicate which features and amenities belong where and where there is room for free interpretation. The domains are connected by the connecting zone. This zone is clearly recognizable, can be found at any station and provides a fast, safe transfer (see figure 9).

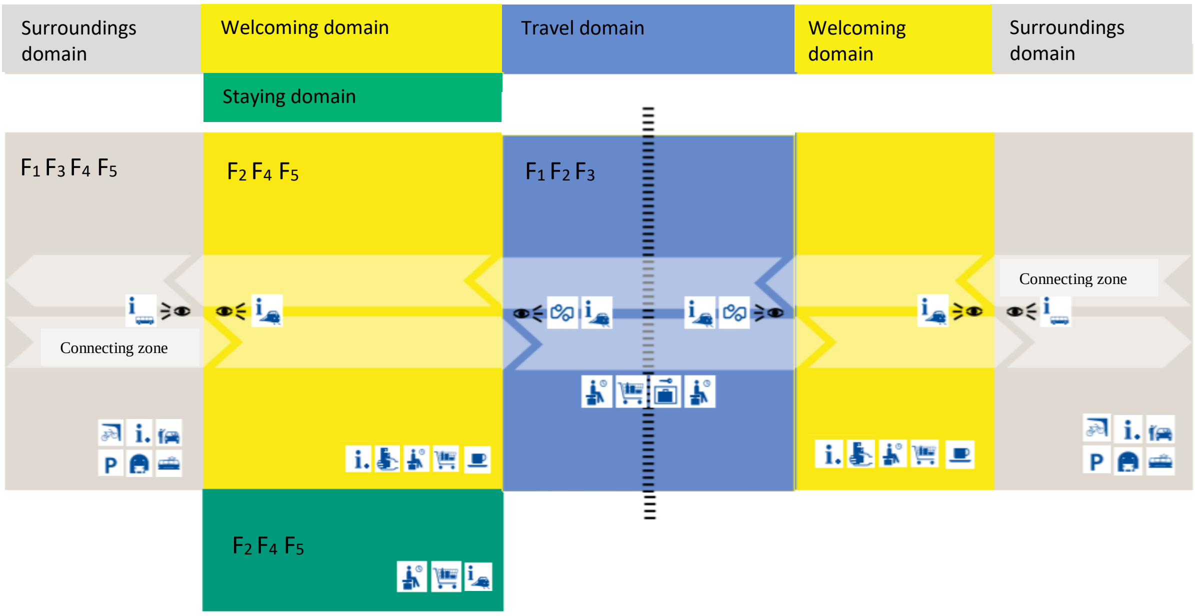

Figure 9: Station domains with their functions and facilities. Modified from Bureau Spoorbouwmeester, ProRail, & NS. (n.d.)

The role of the surroundings domain is to ensure that train passengers can safely enter the station when they arrive and that they can smoothly transfer to their bicycle, car and the connecting local and regional public transport when they leave. The role of the welcoming domain is to receive and welcome travellers, and to prepare travellers for their journey. The travel domain is about easy and efficient moving to and from the train. It serves both arriving and departing travellers. The staying domain, which is often absent at many small and medium-sized stations, forms a world of its own within the station. The purpose of this domain is offering the possibility to turn waiting time into valuable time. Visitors to the staying domain do not necessarily have to be travellers. The connecting zone provides a fast navigation and traffic flow between station entrance and train platforms. The zone is part of all domains and can also function as a walking route from one district to another (Bureau Spoorbouwmeester, ProRail, & NS. (n.d.). Furthermore, part of the technical rooms for the station system itself, for transport or for third parties are often located in stations, and the accessibility of the connecting zone ensures proper access control of these rooms. By assessing the roles and services within each domain, five functions at or around stations can be identified under regular circumstances:

Boarding, disembarking and transferring within the rail system or to and from other forms of transport (F_1)

Within the railway station premises, passengers transfer within the rail system and to and from other modes of transport by foot. To maintain these transfers, the railway stations must secure the safe access and standing of vehicles of all modes, support safe movement between transport services, and secure the presence of sufficient and competent staff.

The accommodating of travellers while waiting (accessibility of shops, waiting areas in a clean, comfortable environment) (F_2)

Travellers spend a lot of time waiting for their train, which is why it is important to design the station in such a way that it supports passengers waiting for their connections. According to van Hagen (2011), who has ranked the various needs of waiting travellers analogous to Maslow's pyramid-shaped hierarchy, the basic needs for travellers waiting for their train are safety and reliability of services. When this is realised, travellers expect a certain amount of physical comfort at the station, in the form of (sheltered) waiting and seating areas and food and refreshment facilities. Finally, the wish of having a pleasant experience must be fulfilled, which is influenced by visual aspects such as station architecture and design, choice of materials, offering shopping and leisure facilities, cleanliness, and music influence. All this can all help improve the quality of experience at stations and reduce the emotional waiting time of travellers (van Hagen, 2011).

Linking the catchment area to the transport network (accessibility of surrounding area of the station (homes, companies)) (F_3)

Railway stations are the links between a catchment area that comprises a certain transport demand and a transport network providing a transport supply. For the rail transport network, a station must localize public transport demand, which indirectly relates the size of the catchment area to the accessibility of the railway station premises (Zemp et al., 2011). For residents within the catchment area, the railway station must provide public transport supply whereby rail is the most important.

Access control of technical functions for the station function itself, for transport or for third parties, including the provision of information (F_4)

Technical rooms both for station and rail processes (cable tunnels, relay houses, etc.) are often located at stations or in or under station infrastructure. The accessibility and proper functioning of these rooms is essential to keep the trains running and to for example keep the lighting, ticketing, and (digital) provision of information on transport services of the station working. Accessibility and proper indoor climate conditions are essential performance indicators influencing the functioning of the technical rooms.

The provision of public space (F_5)

Railway stations usually provide public space, which may serve for multiple purposes. This function can therefore be divided into four subfunctions. Firstly, stations are attractive locations for commercial purposes. NS can generate a lot of additional revenues when operating a business and retail area ($F_{5,1}$) or when facilitating an advertising and promotion area ($F_{5,2}$) on the station premises. Secondly, the public space of the station premises may serve to simplify the meeting of users ($F_{5,3}$) through specific dedicated meeting point (used by both residents and passengers). Lastly, the public space of stations could serve as a disaster support hub ($F_{5,4}$), which are designated locations where people gather to coordinate efforts and to offer assistance to others (Dobie, Schneider, Kesgin & Lagiewski, 2018). For example, as a resource distribution point after a catastrophic event, a shelter for large groups of people in emergency situations, or a covid-19 vaccination hub). Furthermore, a train station often has back-up power supplies, emergency phonelines, and sometimes internet, which allows travellers to spread and gather information. To be able to be serve as a disaster support hub, it is important for ProRail and NS to develop a disaster plan to include how the station can assist the community in post-crisis recovery. Plans should be in place prior to a hazard and should include activities related to both the essential disaster response role that the station can provide, and the continuity of station processes (Bishop & Veil, 2013). For a station to be able to provide public space; freedom of access and use density, square footage, and degree of familiarity are essential performance indicators (Zemp et al., 2011).

4.2. Extreme weather trends and associated effects on the railway station

4.2.1. Current issue of weather-related hazards affecting Dutch railway stations

The largest part of the train services in the Netherlands is operated by NS. Every malfunction or disruption at stations is reported, assessed and registered at the service desk of NS Stations. The technician or mechanic in charge of solving the disruption is responsible for assigning a category to the malfunction (e.g. vandalism, pollution, misuse, or software problems). Yearly, a significant percentage of disruptions are categorized as “other”, as a result of which the number of risks per category may be underestimated. It was only from 2018 onwards, that weather conditions were added as a category, which could imply an observed trend in disruptions due to extreme weather conditions over the years.

Over the period 2010-2018 the total disruption costs at stations have increased significantly compared to the increase in the total station area: in 2018, the disruption costs were 22% higher than in 2017 and 39% higher than in 2012, while the total station area increased by 0.04% and 6%, respectively (see figure 10) (NS, 2018b). In total, 1230 disruptions were reported in 2018 that were caused by extreme weather (out of 52465 in total), which amounts to a significant part of the total disruption costs (NS, 2018b). 90% of this is attributed to leakage and additional damage to, for example, lifts, escalators and lighting. In 2019, 842 out of 49009 disruptions were related to extreme weather or weather conditions. The costs hereof are unknown.

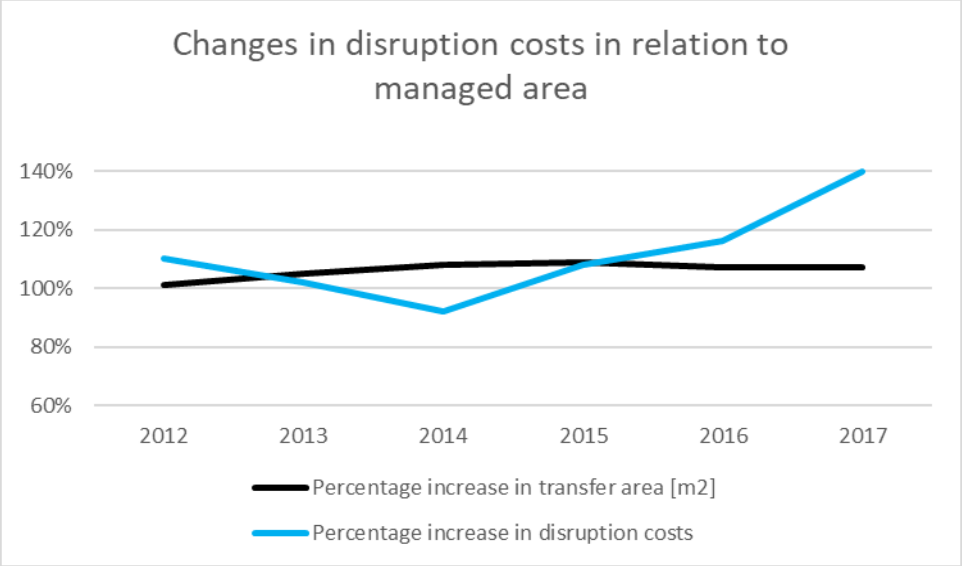

Figure 10: Changes in disruption costs in relation to the managed area

4.2.2. The W_H scenario and uncertainty

Climate change is accompanied by a degree of uncertainty as no one exactly knows what the future will look like. The practice of generating an outlook for future climate conditions has for this reason grown extensively over the past few decades. This is often done with the use of climate scenarios, which are projections based on simulated responses of the climate system under assumption of a forcing (IPCC, 2013b; Hawkins and Sutton, 2009). The KNMI has come up with four scenarios that enable users to include climate change in decision-making about the future, even if the future climate is uncertain (2014). These scenarios are a translation of the global research results and scenarios from the IPCC (2013) to the Dutch climate and local conditions. Together, the scenarios represent the vertices within which climate change is likely to occur. Each scenario gives a coherent picture of changes in twelve climate variables for 2050 and 2085, compared to the climate in the reference period 1981-2010. The KNMI'14 scenarios are the four combinations of two varying values for global temperature rise, "Moderate" (G) and "Warm" (W), and two possible changes to the air flow pattern, "Low value" (L) and “High value” (H).

For this study, the most extreme scenario (the W_H or Warm High Value - scenario) of the KNMI was chosen. This corresponds to the RCP 8.5 scenario of the IPCC (2013), and accounts for a 2 °C increase in temperature in 2050 with a large influence of modified airflow patterns. The most extreme scenario is being used because it will prepare the railway assets for climate change in the best way possible, which ensures that the system can last for multiple years to come.

4.2.3. Expected future weather trends under the W_H-scenario

A selection of the estimated weather trends associated with the hazards considered in this study under the W_H scenario of the KNMI for the year 2050, are listed below.

Extreme rainfall

- There will be 2.5-5.5% more precipitation per year in 2050;
- There will be 3-17% more precipitation in the winter period. This increases the risk of groundwater nuisance;
- The maximum 10-day precipitation amount in winter increases by 6-17% (from 89 mm);
- The intensity of heavy rainfall increases by 12-25%;

Heat

- The average temperature in 2050 will be between 1.0-2.3 °C higher than in 2020
- Temperature on the hottest day of the year will be 1.4-3.3 °C higher in 2050 than in 2020
- The number of summer days (> 25 °C) will increase from 20-30 in 2020 to 40-50 in 2050
- The number of tropical days (> 30 °C) will increase from 3-6 in 2020 to 12-15 in 2050
- The longest series of consecutive summer days will increase from 7-9 days in 2020 to 11-13 days in 2050
- The number of frost days (minimum < 0 °C) will decrease by half in 2050

Drought

- Summer rainfall deficits increase up to 25%
- Summer relative humidity decreases by about 1%
- Summer potential evaporation (Makkink) increases by about 3.5%
- Summer average highest precipitation deficit during the growing season highest increases by 4%

5. Results

In this chapter, the results of the risk assessment are presented. The first section of this chapter describes how extreme rainfall, heat and drought could affect the station's functionality. Next, the potential chain effect in the station network are assessed. In section three, the probability of exposure to several concrete threats is evaluated for all Dutch railway stations, and the fourth section describes the probability of exposure for critical stations. In the fifth section the risk matrices and risk attitude of ProRail's personnel are presented, and the sixth and last section shows the results of the questionnaire.

5.1. Damage sensitivity of the functionality of the station

5.1.1. Extreme rainfall

Increasingly extreme rainfall has consequences for the sewage and (rainwater) drainage systems, as they can no longer process the increasingly large amounts of water (CAS, KNMI, & Deltaprogramma, 2009). The excess water then remains on the streets as it cannot infiltrate into the soil due to the enormous increase in urbanized and built-up areas over the years. Several stations are at a lower level than their surrounding area which causes rainwater to flow from the surrounding streets and squares towards the station in the case of an (extreme) storm event. This could cause flooding at station squares, bicycle cellars, station tunnels and/or platform viaducts. This increases the risk of slipping hazards with associated effects on travellers' safety, as well as ProRail's and NS' reputation, potentially leading to damage claims. Furthermore, if these station tunnels or viaducts form the only access routes to the platforms, which they often are (ProRail & Arcadis, 2020), platforms could become inaccessible, making it (temporarily) impossible for travellers to board their train or to leave the platform (**F_1**). This reduces passenger transport, could lead to discontent amongst travellers and causes economic damage as travel time is valued as an economic commodity (Muneera, 2018). Increased traffic congestion also impacts business costs, productivity, and output levels (Weisbrod, Vary & Treyz, 2003). Moreover, the inaccessibility of a station affects the accessibility of the entire surrounding area since people have an increased difficulty in getting to work, education or trainings, and homes and companies could become (partially) inaccessible to emergency services (**F_3**) (ProRail, 2019b). Additionally, the operation of a business and retail area **($F_{5,1}$**), the operation of an advertising and promotion area (**$F_{5,2}$**), and the meeting of users (**$F_{5,3}$**) are compromised by the flooding of the station premises. This, in turn, leads to societal damage, discontent amongst retailers or advertisers, and economic damage for NS (Ministerie IenW, 2017).

Furthermore, extreme precipitation events could cause water to accumulate on the roofs of station buildings and the platform canopy, or it could lead to the overflow of gutters (Mentens, Raes & Hermy, 2006). When the drainage capacity of such structures is insufficient, water can uncontrollably find its way from the roofs towards the lowest places within the station premises. Depending on the station design, this could be towards the platform or rail, with the aforementioned consequences, but also towards the public "waiting" space or vulnerable objects such as shops or technical areas. This firstly influences the waiting function and its purpose of turning waiting time into valuable time (**F_2**), since the water could cause an accumulation of sand, mud or to other forms of pollution in the station premises. Secondly, it could lead to the inaccessibility of shops, food and refreshment facilities. This causes a physical shift of the waiting domain from flooded areas within the station towards non- flooded areas within or outside of the station, which could cause overcrowding, accidents and increased dwell times (ProRail, 2019b). Moreover, the flooding of vulnerable objects within the station (e.g. telecom, electricity), but also outside of the station (e.g. relay houses, substations or switching stations) compromises the station's technical functionality (**F_4**). This too, could cause overcrowding, accidents and increased dwell times, and poses an additional risk to the safety of travellers as the flooding of technical areas could cause electrocution through contact with the water, if equipment cabinets are located at floor level.

Lastly, climate change will lead to more precipitation in winter causing winter groundwater levels to rise (KNMI, 2014). Rising groundwater levels have often not been considered in the design of drainage systems or infrastructure (Ministerie BZK, 2011). This could also lead to flooding in cellars of technical rooms, and cause damage to cables and pipes (**F_4**) (ProRail, 2019b). Furthermore, rising groundwater levels lead to pressure differences in the soil, which are undesirable for underpasses such as tunnels as they can start to float on the groundwater (**F_1**), which would cause a lot of damage to tunnels and their surroundings (**F_3**, **F_5**). The effect of floating is greater with tunnels on sandy soil (ProRail & Arcadis, 2020).

5.1.2. Heat

The rise in average annual temperatures in the Netherlands does not pose any acute problems for the railway system (CAS et al., 2019; ProRail, 2019b). The problems occur during the temperature peaks, such as on summer (>25 ℃) or tropical (>30 ℃) days and during prolonged hot periods. Extreme temperatures and persistent heat affect the behaviour of people and causes health problems, such as headaches, fatigue, respiratory complaints or heart failure (GGD, 2019). The high temperatures and associated health problems are further enhanced by the urban heat island effect, which is the phenomenon that the temperature in an urban area is higher on average than in the surrounding rural area (Terpstra, Huizinga, Hurkmans, & Jacobs, 2019). A study commissioned by the province of Overijssel shows that this urban heat island effect occurs not only in large cities but also in small centres, and in public places where many people get together (Terpstra et al., 2019). The spatial environment of the station, e.g. density of buildings and paved surfaces near the station influences the intensity of the heat island effect.

Extreme temperatures on platforms will firstly compromise the waiting function (**F_2**), because it affects the wellbeing of travellers, creates a feeling of discontent, and compromises the purpose of the waiting function of turning waiting time into valuable time. This has an associated effect on ProRail's reputation and on customer satisfaction in general. Furthermore, extreme temperatures lead to a behavioural change, for example when a lack of opportunities to cool down leads to overcrowding in "cooler" areas, e.g. areas with shade, wind or water. This increases dwell times and could pose security risks at platforms (**F_1**). Furthermore, extreme heat, in the long-term, poses a risk to the operation of the business and retail area (**$F_{5,1}$**), the operation of the advertising and promotion area (**$F_{5,2}$**), and the simplification of the meeting of users (**$F_{5,3}$**) when the station is not prepared for future temperature extremities. Heat reduces the attractiveness of the station and travellers may start preferring other modes of transport over travelling by train.

In addition, extreme temperatures and severe heat waves in combination with periods of drought increase the chance of a power outage in the technical rooms because of overheated equipment (Behrens, Van Vliet, Nanninga, Walsh, & Rodrigues, 2017) (**F_4**). The malfunctioning of equipment cabinets poses risks to the safety of travellers and employees working at the station, as fire installations, critical information or communication systems, lighting or cameras could seize to work due to flooding, heat or drought. When (travel) information cannot be provided, the operational process and the punctuality of the trains is compromised since travellers cannot be informed or updated on the itinerary, leading to chaos at the station with possible consequences for ProRail's reputation.

5.1.3. Drought

Under the W_H scenario, the rainfall deficit in summer will increase significantly because the summers will be dryer and hotter (KNMI, 2014). This causes the groundwater levels to drop and accelerates land subsidence in peat areas (ITF, 2016; NCG, n.d). This is an irreversible process: the organic carbon in peat oxidises when the peat dries, so that more CO_2 is released into the atmosphere. Climate change will thus cause additional subsidence on top of the already expected subsidence (ITF, 2016). This could have negative consequences for station buildings, rails and platforms, because local subsidence or differential settlement can cause damage to constructions or underground infrastructure. The degree of damage then depends on the speed of movement, the presence, condition and materials of foundations and the degree of subsidence (Taranath, 2016). Furthermore, with persistent drought, the risk of forest and roadside fires increases (Littell et al., 2016)

Due to the relatively low weight of the rails, the tracks experience a different degree of subsidence than the platforms and the station building. Since it is easier to put the tracks back to their intended height, there is therefore a chance that the platforms subside while the track remains at its design level (ProRail & Arcadis, 2020). This poses a risk to the safety of travellers whilst boarding and disembarking to and from the rail system (ITF, 2016; ProRail, 2019b) (**F_1**). Furthermore, the risk of fire hazards or the risk that (parts of) the building could collapse as a result of the accelerated land subsidence could influence the accessibility of the station (**F_3, $F_{5,1}$, $F_{5,2}$, $F_{5,3}$**) This could lead to local or even national disruptions, safety issues, discontent among inhabitants and to societal and economic damage.
Lastly, drought risks and especially the risk of wildfires could compromise the access control of technical functions (**F_4**) because fires could cause disruptions or destruction of the technical rooms and the equipment cabinets located here.

In table 2 the station functions and the potential effects of extreme rainfall, heat and drought are summarized. It is worth mentioning that function $F_{5,3}$ (the meeting of users) can be both compromised and supported by climate hazards. Function $F_{5,4}$ (serve as a disaster support hub) only comes forward after a (climate) hazard and could positively influence society's ability to cope with different kinds of threats and disasters. What must be noted however, is that in case a climate hazard is extremely severe (e.g. a dike breach that floods the entire coastal area) and the station is located in a low-lying critical area prone to disasters (e.g. the coast), function $F_{5,3}$ and $F_{5,4}$ will also be compromised.

Function	**Hazards**		
	Extreme rainfall	Heat	Drought
F_1 (boarding, disembarking)	- Slippery platforms - Congestion - Inaccessibility of platforms and thereby rail network - Economic damage - Safety issues - Floating underpasses	- Effect on behaviour of travellers - Crowd forming in areas with shade: congestion - Affect wellbeing of travellers and attractiveness of station	- Subsidence of platforms while the rail remains at the same level, compromising safe boarding distance
F_2 (waiting)	- Inaccessibility of shops/waiting area - Shift of waiting domain to outside the station	- Feeling of discontent - Affect wellbeing, liveability and attractiveness of	

	- Affect cleanliness - Overcrowding	station	
F_3 (linking the catchment area)	- Inaccessibility of the train network: Residents cannot leave the area where their home is located - People have an increased difficulty to get to their daily tasks - Inaccessibility to emergency services - Societal and economic damage	- Affect attractiveness of station as public space in the long term	- Inaccessibility of the train network: Residents cannot leave the area where their home is located - People have an increased difficulty to get to their daily tasks - Inaccessibility to emergency services
F_4 (technical functions)	- Short circuit in the technical rooms - Risk of electrocution through contact with water in flooded tunnel.	- Overheated equipment rooms: defects in electricity/telecom - Safety issues	- Inaccessibility of equipment rooms - Destruction of equipment rooms
$F_{5,1}$, $F_{5,2}$, $F_{5,3}$ (retail, advertising, meeting of users)	- Inaccessibility of public space - Financial damage for NS - Economic/ Societal damage - Discontent amongst retailers	- Affect attractiveness of station as public space in the long term	
$F_{5,3}$ $F_{5,4}$ (meeting of users, disaster support hub)	Only come forward after a climate hazard: function $F_{5,4}$ is positively influenced by flooding, wild fires		

Table 2: Station functions and potential effects of extreme rainfall, heat and drought

5.2. ‘Snow ball’ effects within the station network

The growing mobility in the Netherlands puts pressure on the railway network (Ministerie IenW, 2019b). The fact that the rail network of The Netherlands is one of the busiest and densest networks in the world, also means that the Dutch network is particularly vulnerable to disturbances (European commission, 2016). One of the main vulnerabilities of the railway system, is that a disturbance in one area may have an impact on another significant part of the system if the affected train or link cannot be bypassed. It therefore becomes increasingly important that the rail network is not only of good quality during regular operations, but also performs well when encountering unexpected situations. Plans to decrease uncertainty, or to ensure well enough performance despite uncertainty increase the adaptive capacity of the rail. Adaptive capacity in this case, is the capacity to continue at a particular level when faced with disruptions such as delay, or inaccessibility.

The capacity of the rail system is usually assessed by measuring the maximum number of trains that can be operated on the network within a certain unit of time (Delorme, Gandibleux & Rodriguez, 2009). This alone, is however insufficient since rail capacity is a multidimensional concept and other elements ought to be considered, such as the stability of the timetable, the uniformity of train characteristics, and the capacity of a junction or station that a train passes or stops at (UIC, 2004; Delorme et al., 2009). Stations are often limiting the capacity of a railway network (Delorme et al., 2009; Lender & Jensen, 2013; Armstrong & Preston, 2017).

The capacity of stations is determined by the characteristics of the track layout, the platforms, the timetable, and the number of railway vehicles and signals (Hansen, 2000). Studies show that a station becomes a bottleneck when the station does not have enough platform tracks, or if the station layout is not designed in a way that it efficiently guides travellers to and from the train or other forms of transport (Landex & Jensen, 2013; DeWilde, 2014). Station capacity may be further complicated due to extended dwell times because of overcrowding or (impeded) transfer possibilities (Landex & Jensen, 2013), or due to deficiencies of equipment and infrastructure (e.g. expansion of bridges, deformation of rails) due to weather influences.

Overcrowding at stations can be caused by flooding which causes a shift of the waiting domain towards unflooded areas within or outside the station. Furthermore, extreme temperatures and a lack of opportunities to cool down will lead to overcrowding in the cooler areas of the station, e.g. areas with shade, wind or water. Lastly, overcrowding could be caused by the failure of (the access control of) technical functions since the breakdown of for example information systems could lead to confusion and thereby unpredictable and unprecedented behaviour. All this could affect the punctuality of the timetabling. If the technical equipment for train traffic is located within the station premises, the flooding or overheating of technical spaces could have far-reaching consequences for both train traffic, transfer possibilities and adjacent stations in the rail network. This would affect the technical functionality of the system. ProRail has identified which stations are the most important nodes in the network, referred to as “red nodes” (27). The spokes (corridors, “baanvlakken”) that cross these nodes may never go out of service simultaneously. In addition, ProRail has also identified “green nodes” (16). The spokes running over these nodes may be out of service simultaneously, but never at the same time as the spokes over the red nodes. Extended dwell times or system failures will therefore have the greatest impact on the red and green nodes, respectively. These nodes can be seen in figure 11 and 12.

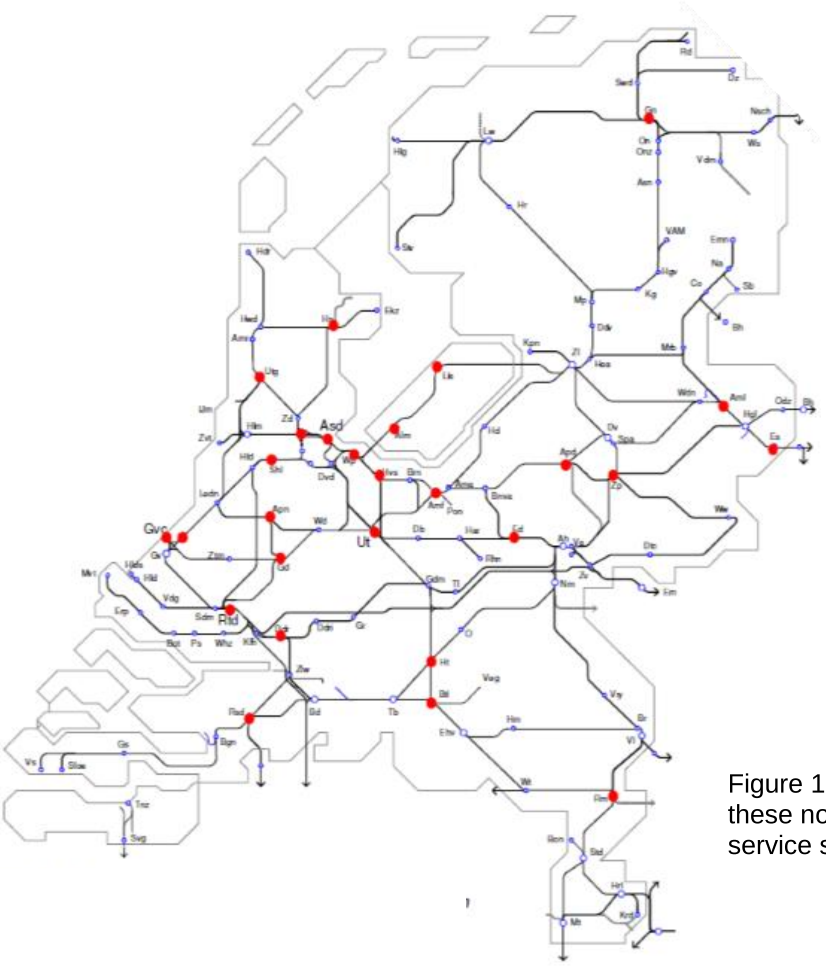

Figure 11: Red nodes. Corridors over these nodes should never go be out of service simultaneously (ProRail, 2020c)

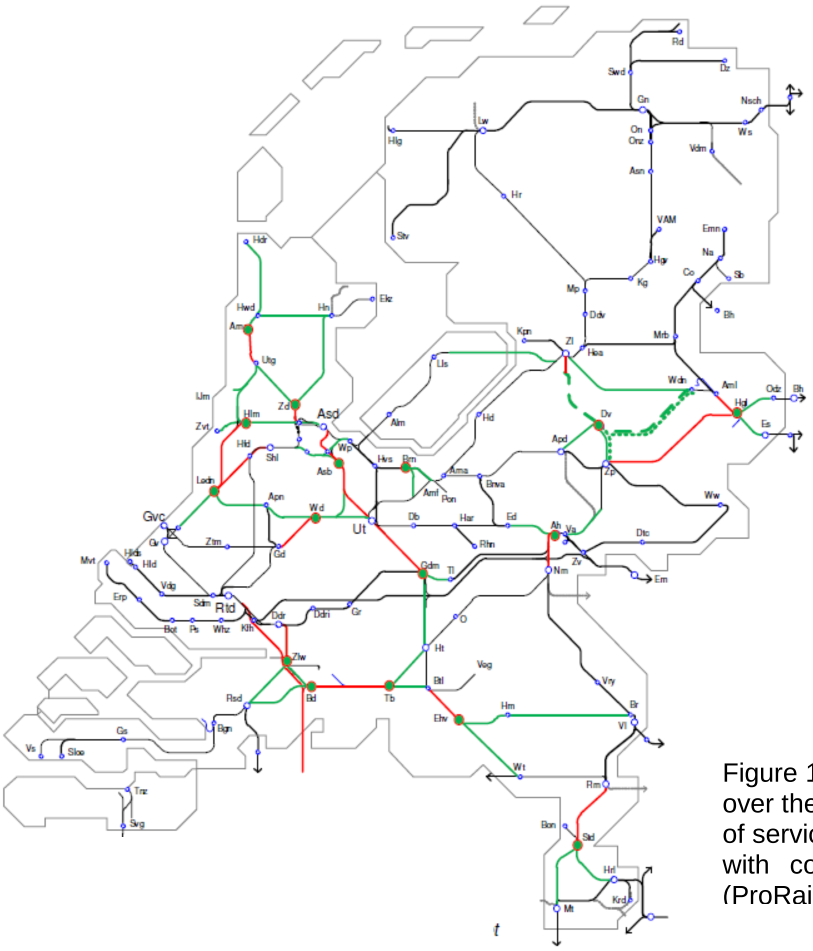

Figure 12: Green nodes. Corridors over these nodes should never be out of service simultaneously with corridors over the red nodes (ProRail, 2020c)

Furthermore, the (temporary) inaccessibility of the important red- and green nodes is very unfavourable because these stations have an essential transfer function, meaning that inaccessibility of such stations would affect the entire rail planning system, automatically leading to longer travel times for a significant number of travellers. This reduces and complicates passenger transport and causes socio-economic damage. Generally, from the interpretation of the importance of red and green nodes, it can be concluded that the number of affected travellers plays a role in the assessment of “important” stations, referring to stations that should not go out of service. This is also reflected in the distinction ProRail makes between different station classes, based on the number of passengers per day, for which ProRail charges a tariff to NS for the use of passenger platforms and transfer space. For ‘Kathedralen’, the rate that ProRail charges NS is 8 times higher than for a ‘Halte’ station, meaning that the inaccessibility of Kathedralen is also up to 8 times worse for ProRail than the inaccessibility of Haltes since this has direct implications for the financial losses that ProRail would suffer. In principle, for almost all risk categories, a higher value rating seems to be given to the number of affected passengers, over the duration or severity of failure. An exception to this rule, is the safety of passengers, for which all potentially severe effects will have highest priority, regardless of the station's size, location, or the importance of the station in the rail network.

5.3. The probability of exposure to a selection of threats

This section presents the threats used in the study to assess the probability of exposure of Dutch railway stations to climate change on. Each threat was linked to the functions of the station that it would negatively effect in case of exposure. This gives an indication of which threats could occur on what stations, based on general characteristics. A summary of all Dutch railway stations with per station, an indication of its relevant threats is provided in appendix B.

5.3.1. Extreme rainfall

R.1: Station tunnels and platform viaducts experiencing disturbance from heavy rainfall (F_1, F_3, F_5)

This threat provides an insight into the location and extent of disturbance from heavy rainfall for all station tunnels and platform viaducts in the Netherlands. This has been analysed by creating a polygon around the locations of the station underpasses and by comparing this to the inundation map from the climate effect atlas, to identify the vulnerability to flooding per station tunnel and platform viaduct. Subsequently, the stations with station tunnels are the only access route to the platforms were identified, as flooding in such tunnels could lead to inaccessibility of the station premises. This provides an insight into (sub)threat ***R1.2: Platforms that have tunnels as their only access route, which therefore have a greater risk of becoming inaccessible (F_1, F_3, F_5)***

In total, 131 out of 182 station tunnels and platform viaducts are within 2 meters of waterlogging with a storm event of 70 mm in 2 hours. These 131 underpasses are connected to 106 stations that are therefore at risk. There are 94 stations for which underpasses are the only access route to the platform, of which 63 station have underpasses that are within 2 meters of waterlogging with a storm event of 70 mm in 2 hours. In figure 14 the locations of station tunnels and platform viaducts are shown with a background of an inundation map from the climate effect atlas.

R.2: Uplift of station tunnels in sandy soil (F_1)

This threat gives an indication of the risk of floating underground structures as a result of rising groundwater levels and pressure differences in the soil. This has been analysed by comparing station tunnels in areas with sandy soil, with the expected rise in groundwater levels in 2050. Locations of the station tunnels on sand have been visualized by comparing tunnels from an internal ProRail database with the soil map of the Netherlands (NCG, n.d.). The expected rise in groundwater level is based on the results of the National Water Model, which shows the extent to which the probability of groundwater disturbance increases between now and 2050 (Rijskoverheid, 2016). A map of current groundwater disturbance - based on a detailed inventory - is not available for the Netherlands. National models are often inadequate for predicting groundwater disturbance. Whether disturbance occurs at a location often depends on very local conditions and processes, for which the model resolution is too limited (Climate Adaptation Services et al., 2017).

Out of 79 station tunnels, there are critical 5 station tunnels are located on sandy soil, which may cause the tunnel to float on the groundwater. These stations are all located in North Holland or the North-East of the Netherlands.

R.3: Short circuit and/or electrocution in flooded tunnels with equipment cabinets at floor level (F_4)

This threat gives an indication of the risk of short circuit in equipment cabinets in tunnels due to flooding. To analyse this threat, all station buildings with technical rooms below ground level and all tunnels with technical rooms at floor level were identified. In this analysis, only technical rooms belonging to the station (radius ≤ 20 m) are included, which also comprises the technical areas that are not completely below ground level (+/- 30 cm). For the south of the Netherlands, a detailed assessment was carried out by NS, but for the middle and north of the Netherlands, less data was available. To study the risks of short circuit in the tunnels located in these regions, a list of all tunnels, that have lifts/escalators below ground level and that have experienced disturbance from leakage or flooding in the past was used. There is no data from ProRail or NS that provides a national overview of the pumps or drains that could be present in the technical rooms, which is why they are not incorporated in this general national risk analysis. In the case studies, the presence of pumps or drains were considered when studying the risk of short circuit or electrocution. In total, there are 50 stations that have equipment cabinets located below floor level and are thus potentially at risk of short circuit or even electrocution.

Figure 13: Left: Railway tunnel Zwolle (Wever, 2015). Right: Platform canopy at station Geldrop (Heins, 1997)

R.4: Platform canopy on stations suffering from heavy rainfall (F_2, F_4)

This threat gives an insight into the risk of overloading or uncontrollable runoff from platform canopy due to heavy rainfall. According to NEN 3215 (1992, rev. 2018), the drainage system of roofs must be designed to be able to drain 300 L/s/ha. In the design regulations for platforms of ProRail, however, a drainage capacity for roofs and platform canopy is deemed sufficient if it can withstand a storm event of 200 L/s/ha (ProRail, 2020b). This means that the drainage capacities of station roofs or platform canopy are not up to current national standards and are therefore certainly not designed to cope with the increasingly intense storm events due to climate change. This threat has been analysed by projecting all roofs of station buildings obtained from a ProRail dataset over the inundation map of the climate effect atlas (ProRail & Arcadis, 2020). Out of 403 railway stations, 160 stations have platform canopy with a probable drainage capacity of ≤ 200 L/s/ha. No clear pattern can be distinguished in platforms with and without canopy in terms of station class or region.

R.5: Rainwater accumulation around stations (F_3, F_5)

Several stations are at a lower level than their surrounding area which causes rainwater to flow from the surrounding streets and squares towards the station in case of an (extreme) precipitation event. Even if the station is designed to handle its design precipitation, excess water flowing in from the surrounding area could cause flooding. This threat gives an indication of the risk of rainwater accumulation around stations. This threat has been identified in the climate stress test of ProRail, which makes use of the inundation map of the climate effect atlas, in combination with the buildings and pavements around stations in BGT (n.d.) and the AHN 3 map showing the ground level of the area surrounding the station (Ministerie BZK & ICTU, 2020; Rijkswaterstaat, n.d.). The results of a study into the vulnerability of the track to rainwater along the track route are projected onto the inundation map (Bles et al., 2012). Stations located in areas where the permeability of the soil is poor (< 60mm / day) and the water depth with a storm event of 70 mm in 2 hr is high (>20 mm), fall into the highest risk class (Bles et al., 2012; ProRail & Arcadis, 2020). This is portrayed in figure 15. In total, 183 out of 401 stations have a medium high, high, or very high chance of flooding in the case of an extreme storm event of 70 mm in 2 hours. There is no clear pattern in the national spread of these stations or their station classes.

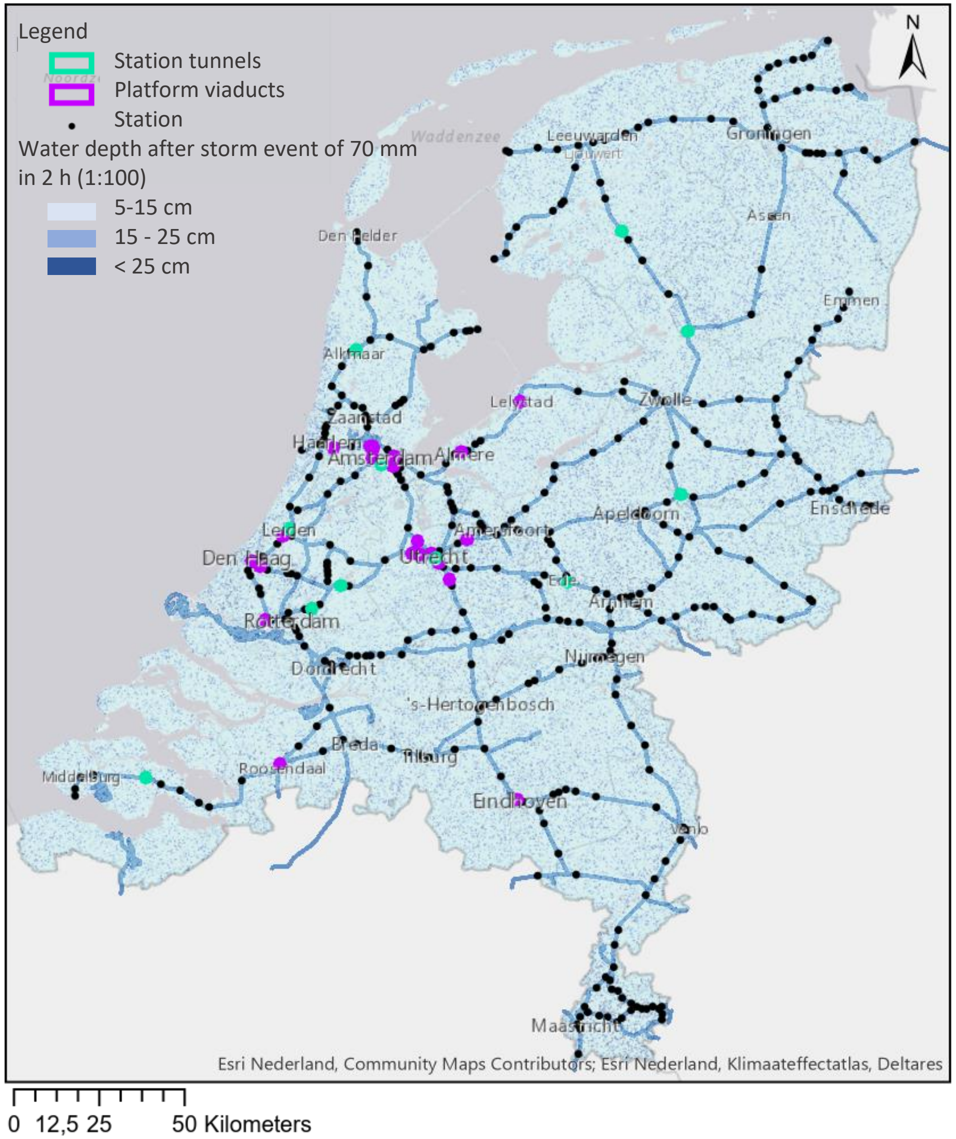

Figure 14: R1: Platform tunnels and station viaducts projected the inundation map from the climate effect atlas

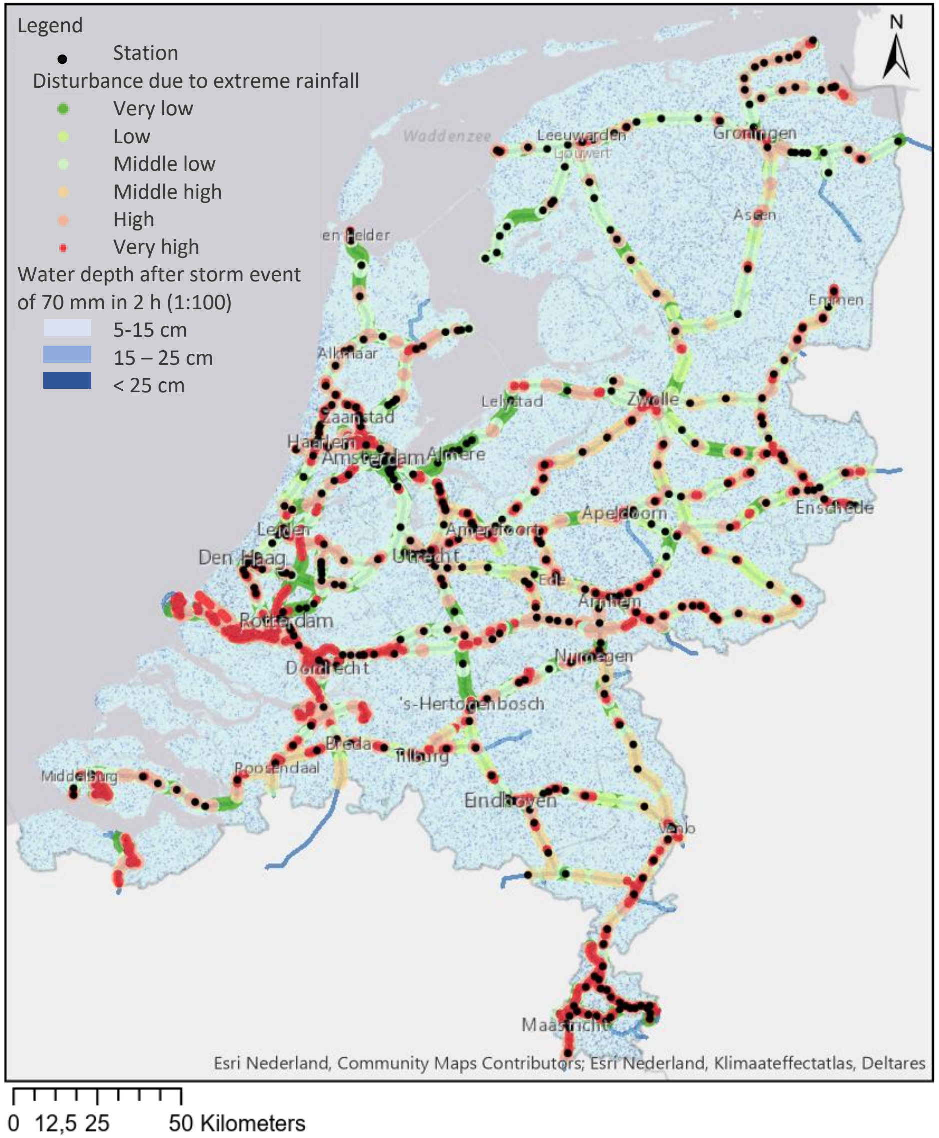

Figure 15: R5: Stations and the vulnerability of the track to extreme rainfall, projected over the inundation map from the climate effect atlas

5.3.2. Heat

Persistent warm weather can cause passengers waiting for the train to suffer from heat exhaustion, which poses a health risk for the elderly, chronically ill and overweight people. The main measures to help limit the effects of heat recommended in the Heat Plan of the RIVM, is to drink enough water and to provide yourself with coolness (through shade, ventilation or thin clothing) (n.d.). This section describes whether NS and ProRail have made it possible for passengers to follow the recommendations of the RIVM and gives an insight into the risk of an increase in disturbance in relay houses and cabinets due to (more extreme) heat.

H.1: Travellers become overheated due to a lack of shade (F_1, F_2, F_5)

Shelter on the platform can help passengers to keep cool and to provide relief from the sun. This threat shows all stations where shade can be provided to some extent, in the form of waiting rooms or shelters, roofs, a station building or platform or forest canopy. The bus shelters and waiting shelters on platforms come from ProRail's internal map services. The location of trees at or around the station were found in an internal ProRail dataset. These elements are projected over a map with the expected average number of summer days (> 25 ° C) in 2050. Stations located in areas where the expected increase in summers days is high, fall into the highest risk class.

Figure 16: Left: Waiting shelter at station Nieuweschans. Right: Station Waddinxveen Triangel with no form of shade present. (ProRail, 2018c)

In total, there are 29 out of 401 stations where no form of shade is present. These are only stations with station class “Halte” and “Basis” and therefore have a maximum of 10,000 boarding and disembarking passengers per day.

It is worth mentioning that closed waiting shelters are only able to provide shade on summer or tropical days if they are ventilated (e.g. by creating open spaces on the bottom/below the ceiling of the shelter). If not, the shelters are at risk of becoming overheated and as a result, travellers will not move inside the shelter, but instead they will wait outside in the sun. Out of the 372 stations with shade, 341 have glass waiting shelters, of which 84 stations are located in areas with more than 40 summer days per year in 2050. If closed, the shelters at these stations, located mainly in the south of the Netherlands, are at a higher risk of becoming overheated.

H.2: Travellers become overheated due to a lack of water taps (F_2, F_5)

Water taps on or near stations where travellers can (re)-fill their water bottle can help travellers to drink enough water and prevent dehydration. NS made a first inventory of all the installed water taps on and near stations or platforms. The water taps that are not from NS but that are present near stations (r ≤ 200 m) were also registered in this inventory. Consequently, the water taps were projected over a map with the expected number of summer days in 2050 from the climate effect atlas (Climate Adaptation Services, 2017). There are 152 stations that don't a water tap installed within a radius of 200 m around the station area. 21 stations have two or more water taps installed. The stations that do not have a water tap installed are all “Halte” and “Basis” stations, except for Maastricht which has the station class “Plus”.

H.3: Platforms become overheated due to a lack of planted vegetation (F_2, F_5)

Vegetation influences local temperatures and global climatic conditions at the land surface. The transpiration of plants recycles almost 50% of the precipitation during the vegetative season and induces evaporative cooling (Tesař, Šír, Krejča, & Váchal, 2008). In addition, Steeneveld et al., found that with 1% more greenery in the city, the heat island effect could decrease by 0.06 ºC (2011). Furthermore, vegetation offers particular benefits in the handling of surface water runoff, by capturing rainwater and by supporting its natural infiltration into the soil (Dunne et al ., 1991; Xiao and McPherson, 2002; Inkiläinen et al ., 2013). Lastly, vegetation (e.g. shrubs or green facades) can be effective in cooling down the surface temperatures of facades; up to 15.5 ° C on the outside wall and 1.7 ° C on the inside wall (Hoelscher et al., 2016). This threat gives an insight into the stations without any planted vegetation on their platforms. This has been analysed with use of the inventory of the greenery that was planted at stations, created for this study by NS. The object group “ornamental plants” was used for this analysis, which includes perennials, ground covers and small low shrubs. In total, there are 217 out of 401 stations without planted vegetation present. Figure 18 shows all stations without water taps (r ≤ 200m), shade and vegetation projected over a map with the expected number of summer days (> 25 ° C) in 2050 (CAS, 2017).

Figure 17: Left: Ornamental plants at Leiden CS (NS, 2020). Right: Water tap at station Alkmaar (NS, 2018c).

H.4: Disturbances increase in technical rooms, relay houses and cabinets due to heat (F_4)

This threat gives an insight into the increase in disturbances in technical rooms, relay houses and cabinets due to (extreme) heat. On summer days the temperature in the technical rooms increases, putting pressure on the electronic systems. A lot of extra electronics have been added in these technical rooms over the years to supply the extra energy needed for the increasing number of trains and passengers, which further increases the temperature and the risk of a power outage in both stations and trains (ProRail, 2012; ProRail & Arcadis, 2020). The climate stress test provides a first insight into this risk, by projecting the relay houses and -cabinets over the map of the expected number of summer days in 2050, and a map of the expected urban heat island effect at 2050 from the climate effect atlas (Climate Adaptation Services, 2017). The locations of the relay boxes come from a separate data set created by ProRail, and all other energy supplies locations were found in the internal map services of ProRail. In theory, it is mandatory to install air conditioning or ventilation in technical rooms, which must be maintained and must have a high enough capacity to ventilate the entire room (ProRail, 2012). However, in practice, 95% of the relay- boxes or cabinets do not have mechanical ventilation, and it is not yet exactly known which cabinets do and do not have air-conditioning to prevent heat stress (ProRail & Arcadis, 2020). For the case studies it was analysed specifically which cabinets are critical and whether additional cabinets should be added to reduce the risks of overheating in vulnerable systems. Figure 19 shows the locations of vulnerable systems projected over a map of the expected number of summer days in 2050 and a map of the expected urban heat island effect in 2050 from the climate effect atlas (CAS, 2017). In total, 5241 out of 7176 energy supply systems are located in an area with more than 40 summer days in 2050, which increases the risk of failures in these energy supply systems. Due to a lack of data, it is difficult to directly link these energy supply systems to the energy supply of a specific station.

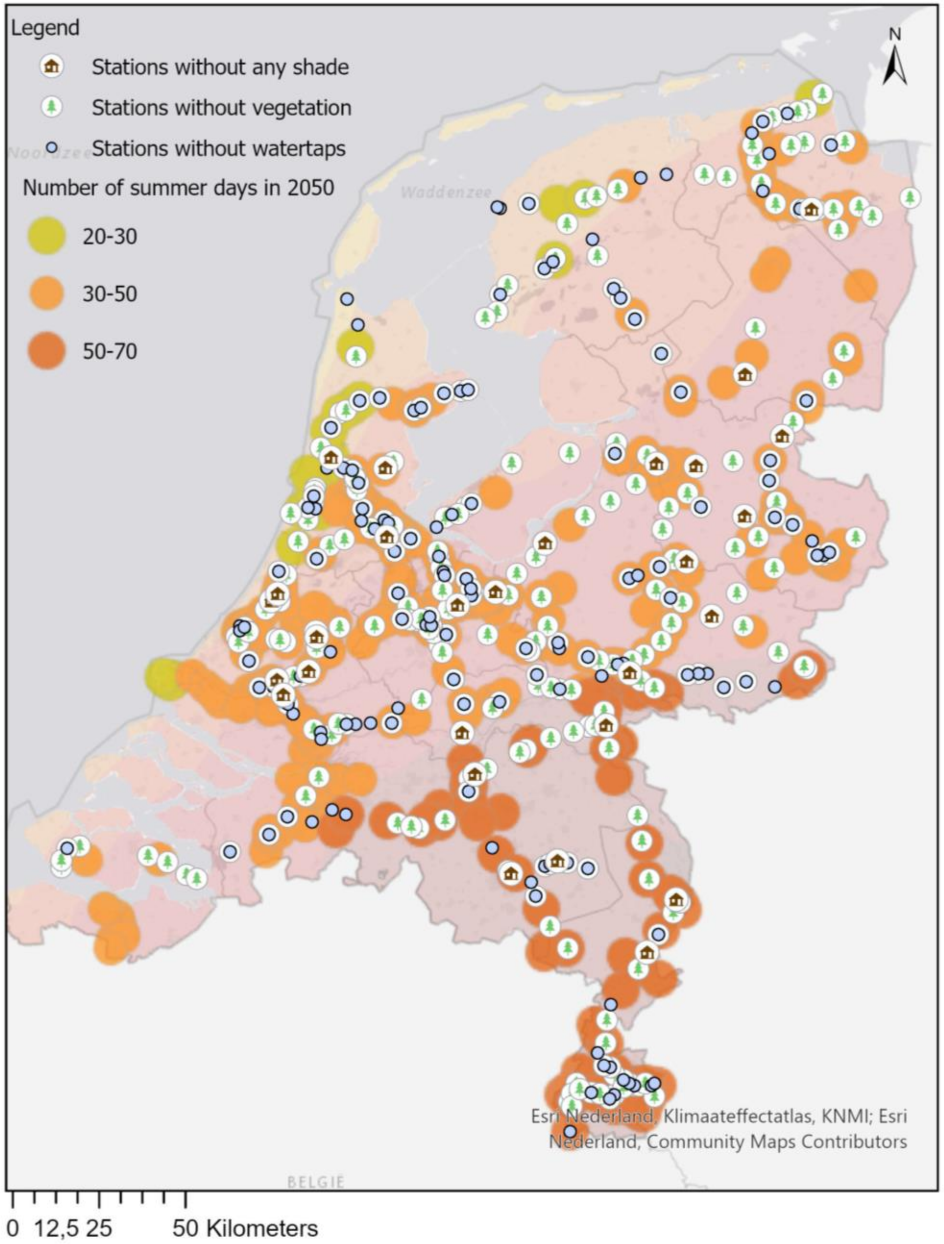

Figure 18: H1, H2, H3. Stations without shade, water taps, and vegetation projected over the increase in the number of summer days from the Climate Effect Atlas

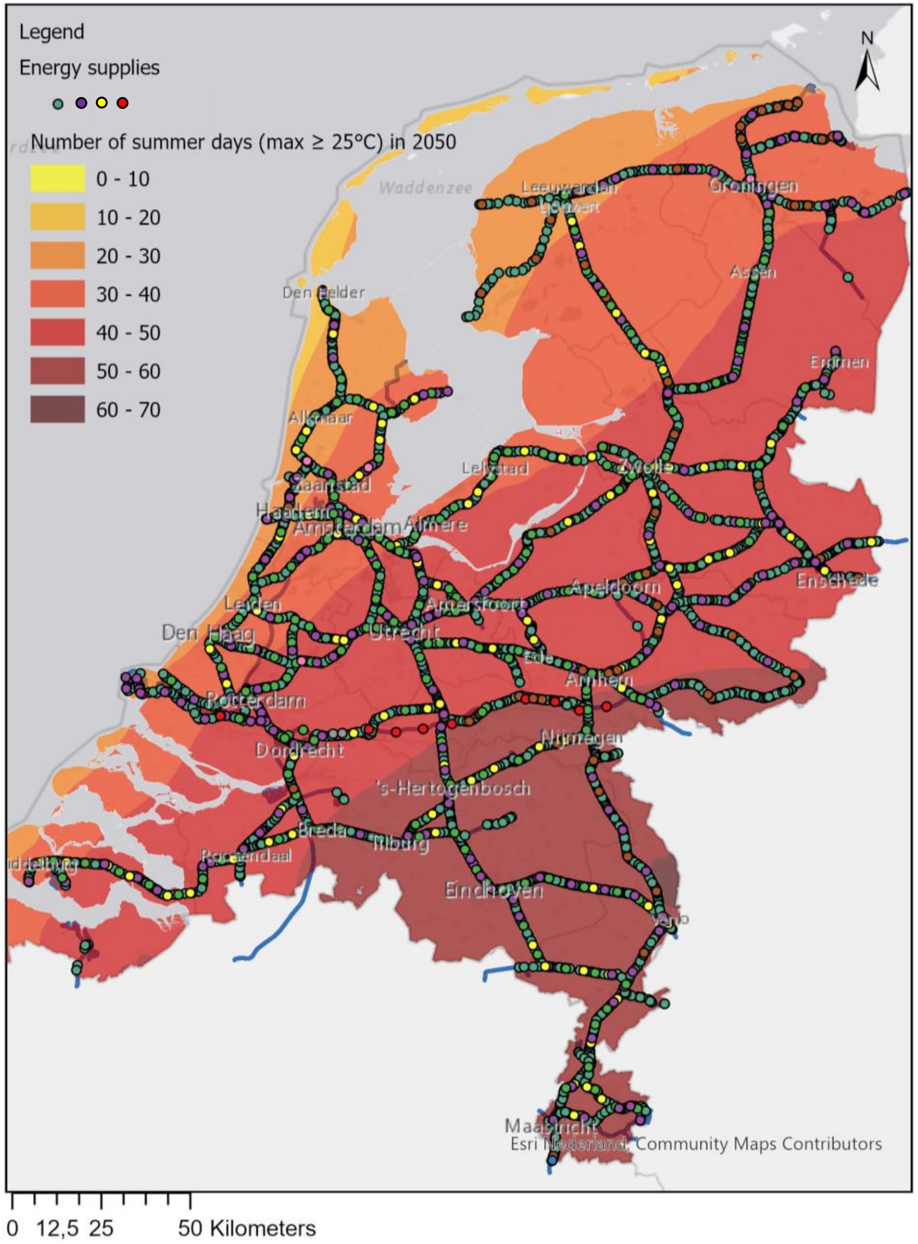

Figure 19: H4: Relay- cabinets and other energy supplies projected over the increase in number of summer days from the Climate Effect Atlas

5.3.3. Drought

D.1: Platforms are subsiding, while the track remains at normal level (F_1)

The difference between the platform and track height must always equal 76 cm (+/- 3.5 cm) to ensure an accessible and safe entrance (ProRail, 2020a). With track maintenance, tracks can be relatively easily restored to their former height compared to the larger, heavier platforms. It is assumed that with subsidence, the track height w.r.t. NAP remains constant. The subsidence map from Deltares, TNO-GDN and WEnR (2017), projected over the station platforms, will thus give an indication of the difference in subsidence between the platform and the track, compromising an accessible and safe entrance.

Figure 20 shows which parts of the Netherlands may be affected by subsidence due to low groundwater levels between 2016 and 2050, compromising the maximum- and minimum difference in height of 76 cm. In areas with the highest expected subsidence, the additional subsidence because of climate change will also be greatest. For example, for a soil subsidence of 3 to 10 cm, +/- 0 to 5 cm extra soil subsidence is to be added and with a soil subsidence of greater than 60 cm, 15 cm extra subsidence is to be added (CAS, 2017). In total, 142 of 1860 platforms risk a subsidence of 20 cm in 2050 while the track remains at the same height. This puts 28 stations at risk.

D.2 Groundwater subsidence leading to damage to the station buildings (F_3, F_5)

This threat gives an insight into the exposure of station buildings to damage due to groundwater subsidence. Buildings that are supported by wooden piles are particularly sensitive to groundwater subsidence because this can lead to pole rot. According to a report by Movares, in which a risk inventory was made for station canopy (2018), the foundation of station buildings differs between regions. The soil structure in the Netherlands can roughly be divided into sandy soils in the south and the east, and into clay/peat soils in the north and the west (PDOK, n.d.) Before 1915, foundations on sandy soils were usually constructed as masonry piers, and after 1915 as concrete piers. Station buildings on clay/peat soils were predominantly founded on wooden poles before 1970. After 1970 there was a shift and buildings were found on concrete poles (Movares, 2018).
Out of 401 stations, there are 76 registered stations that were built before 1970 and are located on clay/peat soils and are therefore at risk of groundwater subsidence leading to damage to their station building. These stations are also portrayed in figure 20.

D.3 Damage to stations in or near forest areas due to forest fires (F_3, F_4)

As the length and duration of dry periods increase, as indicated in the W_H-scenario (KNMI, 2014), the humus layer on the topsoil dries out, increasing the risk of wildfires. This wildfire risk depends on the type of vegetation (heather, coniferous forest), the number and type of users (hikers, campers) and the weather conditions (drought, wind) (CAS, 2017). This threat gives an indication of the risk of disturbance from fires in nature reserves for railway stations. This was analysed with the use of a map from the climate effect atlas showing a “flammable” nature reserve with a continuous size of at least 1 km^2, and by projecting stations onto this map. In total, 46 stations are in areas at risk of wildfires. Figure 21 shows these stations, projected over a map showing all areas with wildfire risk. The colours on the map indicate what percentage of the adjacent tracks overlaps with the risk area.

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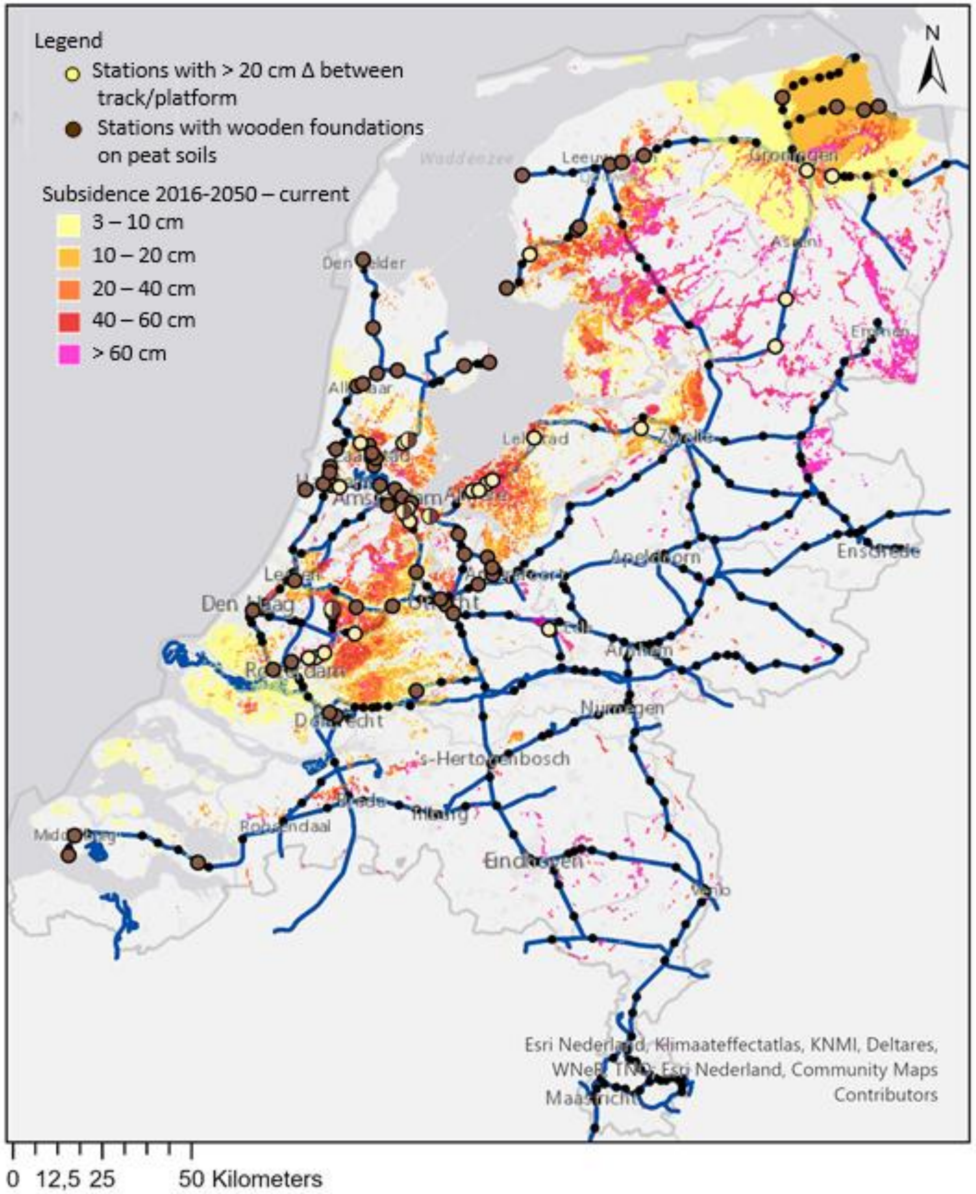


Figure 21: D1, D2. Stations with a large difference between the rail and the platform and the station buildings on wooden foundations projected over the increase in number of summer days from the climate effect atlas

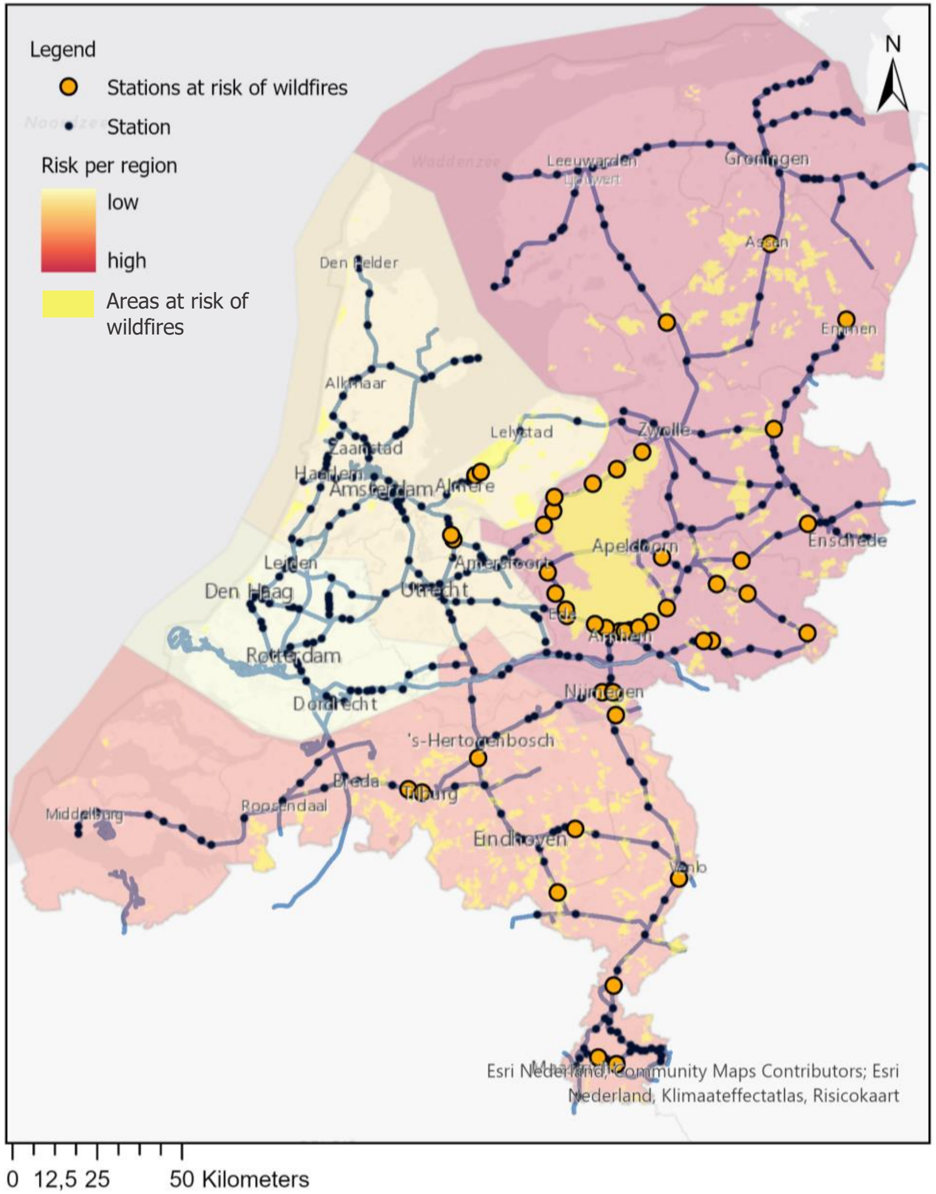


Figure 22: D3. Stations located in areas with a high wild fire risk, projected over a map indicating the percentage of the track that overlaps with the risk area

Function	**Threat**		
	Extreme Rainfall	Heat	Drought
F_1	R1 R2	H1	D1
F_2	R4	H1 H2 H3	
F_3	R1 R1.2 R5		D2 D3
F_4	R3 R4	H4	D3
F_5	R1 R1.2 R5	H1 H2 H3	D2

Table 3: Overview of the station functions and the climate threats that could affect their functionality

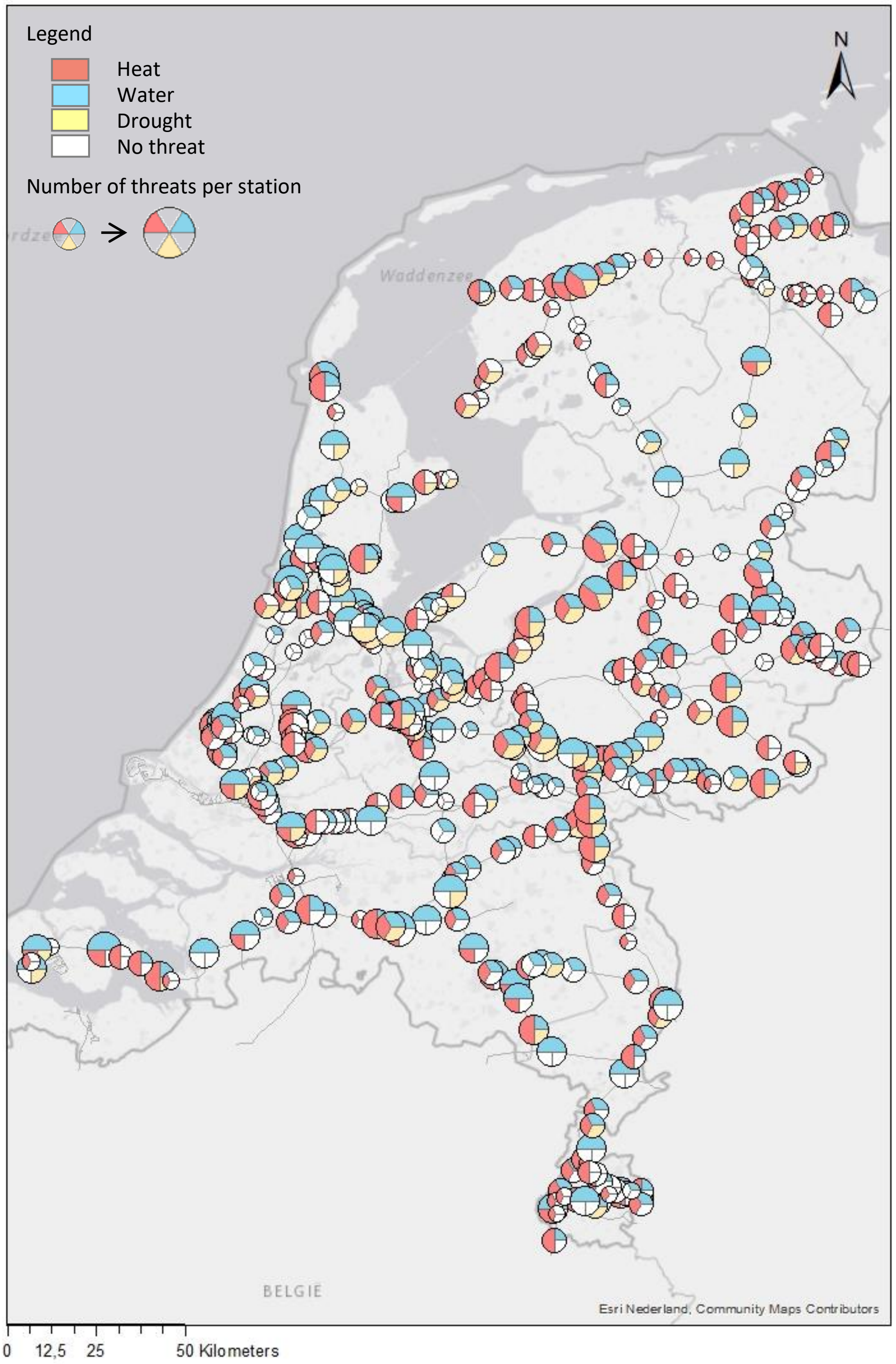


Figure 22: All 401 stations showing the size and emphasis of risk at each station, differentiated between extreme rainfall, heat and drought risks.

5.4. Implications of the probability of exposure for critical stations

From the analysis on the potential network effects for stations, it follows that it would cause the biggest distress if there were significant delays and/or failures of technical systems on red or green nodes, respectively. These issues are most distinctly expressed through threats R3 and H4. There are 27 red nodes, and 16 green nodes. Each of the red nodes have at least 2 threats associated with them, and the red and green nodes both have a median of 4 threats, compared to the national median of 3 threats (see table 4). Furthermore, threat R3 is relevant at 33.3% of the red nodes and 38 % of the green nodes, compared to the national relevance of threat R3 at only 12.4% of the stations. As stated in section 5.3.2, due to a lack of data, it is difficult to directly link threat H4 to stations. From the analysis on potential network effects for stations, it furthermore followed that the degree of impact on society, customer satisfaction and ProRail's reputation is generally larger if more passengers are exposed. This is the case at the red and green nodes due to their important transfer function, but also at stations with a high station class or at stations that are in a denser station network. There are 27 stations in the Netherlands with class 'Mega' or 'Kathedraal', which too, have a median of 4 threats. The densest station network is in the Randstad: almost 40 % of all stations are located here. These stations have a median of 3 associated threats.

Station category	**Number of stations**	**Median number of threats**
All	401	3
Red nodes	27	4
Green nodes	16	4
> 25,000 passengers per day	27	4
Randstad	153	3

Table 4: Summary of critical stations with their average number of threats applicable

The most important nodes in the station network and the stations that have a higher number of boarding and disembarking passengers per day are at higher risk than average. The red and green nodes, which form the most important nodes in the Dutch network, are also at a significantly higher risk of short circuit in the technical rooms and/or electrocution. The consequences of failure at these stations are still relatively difficult to oversee. It is clear, however, that it could have implications for a relatively high number of travellers (compared to smaller stations with a less significant transfer function) in terms of their safety and contentment, and it could have socio-economic impacts for both ProRail as a company as well as for the role ProRail plays in the accessibility of The Netherlands. The specific threats to these critical stations are summarized in appendix B1.

5.5. The Risk Matrices and risk attitude

In this section, the risk matrices for assessing climate risks for railway stations are presented, and the risk attitude of ProRail is discussed. All individual completed rubrics complementary to the matrices are presented in Appendix C (C1-C5).

By interpreting the assigned levels of risk acceptance in the matrix below, it can be concluded that ProRail is rather risk neutral. This is defined as the attitude whereby low probability - high damage events are assigned an equal level of acceptance as high probability - low damage events – provided that the expected risk is similar. Risk neutrality, however, does not fully comprise the scope of the chosen risk acceptance levels that come forward out of the risk matrices. For extreme rainfall and drought risks, out of ten different possible RPN's ranging from 0 to 15, only an RPN of 0 or 2 is (fully) acceptable. Hence, despite being risk neutral, still very little damage is accepted. This could indicate that ProRail is not risk averse per se, but loss averse, whereby loss aversion is defined as the tendency to prefer avoiding losses to acquiring equivalent gains. The gains, in this case, would be the money unspent to avoid the loss.

Furthermore, it can be observed that ProRail perceives damages of extreme rainfall or drought hazards to be more serious and unwanted than a uniform damage as result of extreme heat. The reason for this unbalanced weighing of risks, is mainly related to a different feeling of responsibility or culpability for the consequences of the three hazards. For customer satisfaction, it for example became apparent that ProRail considers flooding and the implications this would have on the cleanliness of the station to be more of their responsibility than the effects on comfort due to heat. This is in line with the weighing of the reputation and safety of travellers, as injuries or reputation damage related to flooding or subsidence were found to be worse than reputation damage or damage to one's health due to heat. From the risk matrix dialogues, it became apparent that this is because ProRail thinks of heat as a broader, societal issue that is bothering people not only at stations, but in the entire country, whilst impacts from floodings or damage to structures are a more local issue, and a direct result of their inadequacy within the station premises. Furthermore, the possibility and simplicity of avoiding risk plays a role. For the technical functionality of the station, the effects of extreme rainfall- and drought hazards were considered unwanted more quickly than effects of heat, because the effects of a temperature increase in equipment rooms were seen as more gradual than defects due to fire hazards or flooding, and the measures to prevent the negative effects of a temperature increase were seen as more straightforward.

EXTREME RAINFALL	**Damage sensitivity**					**Probability of exposure**	
	Technical functionality Function 4	**Societal** Function 3, 5	**Reputation** Function1-5	**Customer satisfaction** Function 2	**Safety** Function 1, 4	**Low** 1	**High** 1.5
Very severe 10	Very serious effect on (access control of) technical functions on Green/Red node ≤Kathedraal stations due to flooding. Infoplussystem at red/green nodes has been damaged beyond repair	Green/Red node ≤Kathedraal station inaccessible for ca. 5h due to flooding	Long-term negative attention in the international press / Very severe damage to relationships with carriers and / or stakeholders / Resignation of more than 1 director	The transfer area is very seriously polluted on ≤Kathedraal stations. Very severe feeling of discomfort.	1 or more fatalities or serious injuries with permanent severe disability (e.g. danger of electrocution in tunnel, serious risk of slipping)	10	15
Severe 8	(Very) serious effect on the (access control of) technical functions on regular ≤Mega or Green/Red node ≤Basis station due to flooding. Infoplussystem reparably damaged, information at green or red nodes impossible for an extended period	Regular ≤Mega, Green/Red node ≤Basis station inaccessible for ca. 5h due to flooding	Long-term negative attention in the (inter) national press. Extensive damage to relationships with carriers and / or stakeholders. Resignation of director	The transfer area is (very) seriously polluted on ≤Plus stations. Severe feeling of discomfort	Serious injury or permanent damage to health (e.g. complicated fracture or whiplash due to slipping hazard)	8	12
Considerable 6	Considerable effect on (access control of) technical functions and information provision on Green/Red node ≤Kathedraal station due to flooding	Limited access on Green/Red node ≤Kathedraal station for ca. 4h due to flooding	Negative attention in the national press. Damage to relationships with carriers and / or stakeholders	The transfer area is considerably polluted on ≤Kathedraal stations. Considerable feeling of discomfort	Recoverable injury or damage to health (e.g. a broken arm due to slipping hazard)	6	9
Limited 4	Considerable effect on the information provision and (access control of) technical functions of regular ≤Mega or Green/Red node ≤Basis station due to flooding	Limited access on regular ≤Mega, Green/Red node ≤Basis station for ca. 4h due to flooding	Short term negative attention in the national press, concern with province or government	The transfer area is considerably polluted on ≤Plus stations.	Limited injury or damage to health, limited medical treatment necessary (e.g. a sprained ankle due to slipping hazard)	4	6
Minor 2	(Very) limited effect on the information provision and (access control of) technical functions on Green/Red node ≤Kathedraal station due to flooding	Green/Red node ≤Kathedraal station partially accessible for ca. 3. due to flooding. Station is accessible, but disabled people have difficulty getting to the train	Negative attention in the local or regional press, concern with the local government	The transfer area is somewhat polluted on ≤Kathedraal stations.	Minor injuries, no medical treatment necessary, no hospitalization (e.g. bruises due to slipping hazard)	2	3
None to very minor 0	Very limited effect on the information provision and (access control of) technical functions on regular* ≤Mega or Green/Red node ≤Basis stations due to flooding	Regular ≤Mega station or Green/Red node ≤Basis station partially accessible for ca. 3h due to flooding. Station is accessible, but disabled people have difficulty getting to the train	Little negative attention in the local press. No damage to relationship with carriers and / or authorities	The transfer area is a somewhat polluted on ≤Plus stations.	No injury or damage to health	0	0

Table 5: Risk matrix for extreme rainfall

* a station that is not a green or red node

HEAT	Damage sensitivity				Probability of exposure	
	Technical functionality Function 4	**Reputation** Function1-5	**Customer satisfaction** Function 2	**Safety** Function 1, 4	**Low** 1	**High** 1.5
Very severe 10	Very serious effect on (access control of) technical functions on Green/Red node ≤Kathedraal stations due to overheating. Infoplussystem at red/green nodes has been damaged beyond repair	Long-term negative attention in the international press / Very severe damage to relationships with carriers and / or stakeholders / Resignation of more than 1 director	Very severe feeling of discomfort due to heat on ≤Kathedraal stations	3 or more fatalities or serious injuries per year with permanent serious consequences (e.g. a very severe / fatal heat stroke)	10	15
Severe 8	(Very) serious effect on the (access control of) technical functions on regular ≤Mega or Green/Red node ≤Basis station due to overheating. Infoplussystem reparably damaged, information at green or red nodes impossible for an extended period	Long-term negative attention in the (inter) national press. Extensive damage to relationships with carriers and / or stakeholders. Resignation of director	(Very) severe feeling of discomfort due to heat on ≤Plus stations	1-2 fatalities or serious injuries per year with permanent serious consequences (e.g. a very severe or fatal heat stroke)	8	12
Considerable 6	Considerable effect on (access control of) technical functions and information provision on Green/Red node ≤Kathedraal station due to overheating	Negative attention in the (inter)national press. Damage to relationships with carriers and / or stakeholders	Considerable feeling of discomfort due to heat on ≤Kathedraal stations	Limited permanent damage to health (e.g. heat stroke, heart problems)	6	9
Limited 4	Considerable effect on the information provision and (access control of) technical functions of regular ≤Mega or Green/Red node ≤Basis station due to overheating	Short term negative attention in the national press, concern with province or government	Considerable feeling of discomfort due to heat on ≤Plus stations	Repairable damage to health (e.g. respiratory problems, fainting)	4	6
Minor 2	(Very) limited effect on the information provision and (access control of) technical functions on Green/Red node ≤Kathedraal station due to overheating	Negative attention in the local or regional press, concern with the local government	Minor feeling of discomfort due to heat on ≤Kathedraal stations	Minor damage to health, no medical treatment necessary (e.g. headaches due to heat stress)	2	3
None to very minor 0	Very limited effect on the information provision and (access control of) technical functions on regular* ≤Mega or Green/Red node ≤Basis stations due to overheating	Little negative attention in the press. No damage to relationship with carriers and / or authorities	Minor feeling of discomfort due to heat on ≤Plus stations	No injury or damage to health	0	0

Table 6: Risk matrix for heat
* a station that is not a green or red node

DROUGHT	**Damage sensitivity**				**Probability of exposure**	
	Technical functionality Function 4	**Societal** Function 3, 5	**Reputation** Function1-5	**Safety** Function 1, 4	**Low** 1	**High** 1.5
Very severe 10	Very serious effect on (access control of) technical functions on Green/Red node ≤Kathedraal stations due to fire hazards. Infoplussystem at red/green nodes has been damaged beyond repair.	Green/Red node ≤Kathedraal station inaccessible for ca. 5h due to damage to constructions.	Long-term negative attention in the international press / Very severe damage to relationships with carriers and / or stakeholders / Resignation of more than 1 director	1 or more fatalities or serious injuries with permanent severe disability (e.g. loss of limb, hearing, sight due to unsafe boarding distance, unsafe damage to station construction)	10	15
Severe 8	(Very) serious effect on the (access control of) technical functions on regular ≤Mega or Green/Red node ≤Basis station due to fire hazards. Infoplussystem reparably damaged, information at green or red nodes impossible for an extended period.	Regular ≤Mega, Green/Red node ≤Basis station inaccessible for ca. 5h due to damage to constructions	Long-term negative attention in the (inter) national press. Extensive damage to relationships with carriers and / or stakeholders. Resignation of director	Serious injury or permanent damage to health (e.g. complicated fracture or trauma due to unsafe boarding distance, unsafe damage to station construction)	8	12
Considerable 6	Considerable effect on (access control of) technical functions and information provision on Green/Red node ≤Kathedraal station due to fire hazards	Limited access on Green/Red node ≤Kathedraal station for ca. 4h due to damage to constructions	Negative attention in the (inter)national press. Damage to relationships with carriers and / or stakeholders	Recoverable injury or damage to health (e.g. broken arm, burns due to unsafe boarding distance, unsafe damage to station construction)	6	9
Limited 4	Considerable effect on the information provision and (access control of) technical functions of regular ≤Mega or Green/Red node ≤Basis station due to fire hazards	Limited access on regular ≤Mega, Green/Red node ≤Basis station for ca. 4h due to damage to constructions.	Short term negative attention in the national press, concern with province or government	Limited injury or damage to health, limited medical treatment necessary (e.g. sprained ankle due to unsafe boarding distance, unsafe damage to construction)	4	6
Minor 2	(Very) limited effect on the information provision and (access control of) technical functions on Green/Red node ≤Kathedraal station due to fire hazards	Green/Red node ≤Kathedraal station partially accessible for ca. 3. due to damage to constructions. Station is accessible, but disabled people have difficulty getting to the train	Negative attention in the local or regional press, concern with the local government	Minor injuries, no medical treatment necessary, no hospitalization (e.g. bruises due to unsafe boarding distance, unsafe damage to construction)	2	3
None to very minor 0	Very limited effect on the information provision and (access control of) technical functions on regular* ≤Mega or Green/Red node ≤Basis stations due to fire hazards	Regular ≤Mega station or Green/Red node ≤Basis station partially accessible for ca. 3h due to damage to constructions. Station is accessible, but disabled people have difficulty getting to the train	Little negative attention in the press. No damage to relationship with carriers and / or authorities	No injury or damage to health due to unsafe boarding distance / unsafe damage to station construction	0	0

Table 7: Risk matrix for drought
* a station that is not a green or red node

5.6. Questionnaire

The past three summers were characterized by many hot summer days, with the maximum daytime temperature exceeding 30 degrees Celsius (KNMI, n.d.). An important question is how passengers experience heat at the station and which measures worsen or improve the passengers' perception of heat. The results of the perception survey are discussed in this section. Various subjects were discussed, including the perceived warmth, the possibilities for shelter and the pleasant and unpleasant places at the station.

Station	Region	Class	Response	Max. Apparent Temp (°C)
Arnhem Centraal	North-East	Mega	104	32.1
Barneveld Centrum	North-East	Basis	73	32.8
Dordrecht Stadspolders	Randstad South	Basis	58	33.2
Eindhoven Strijp-S	South	Basis	88	31.2
Houten	Randstad North	Basis	85	32.8
Maastricht Randwyck	South	Basis	26	33.8
Rotterdam Centraal	Randstad South	Kathedraal	106	33.4
Swalmen	South	Halte	2	34.1
Tilburg	South	Mega	108	31.1
Zaandam	Randstad North	Plus	106	32.9

Table 8: Stations with their classes and response numbers

On the days when the questionnaire was held, about the same number of travellers from a cool (47%) and a warm environment (48%) came to the station. Travellers from a warm environment did not feel significantly warmer than travellers from a cool environment, implying that the temperature of the environment one comes from has no influence on one's perception of heat. Almost one fifth of the respondents felt very to extremely hot at the station. At Dordrecht Stadspolders, Eindhoven Strijp-S and Barneveld Centrum, all stations with class Basis, travellers relatively felt the hottest. Arnhem Central, a station with class Mega, was perceived as the coolest. In general, smaller stations, with a maximum of 10,000 boarding- and disembarking passengers a day, are perceived as being significantly warmer than bigger stations, with over 10,000 boarding- and disembarking passengers a day. This confirms the hypothesis that larger stations are perceived as being cooler, but adds that above a certain size, class and number of facilities, this perception does not differ significantly anymore. The influence of location seems to be minimal since the stations that are perceived as hottest, are located both in the south, the south of the Randstad and the north-east.

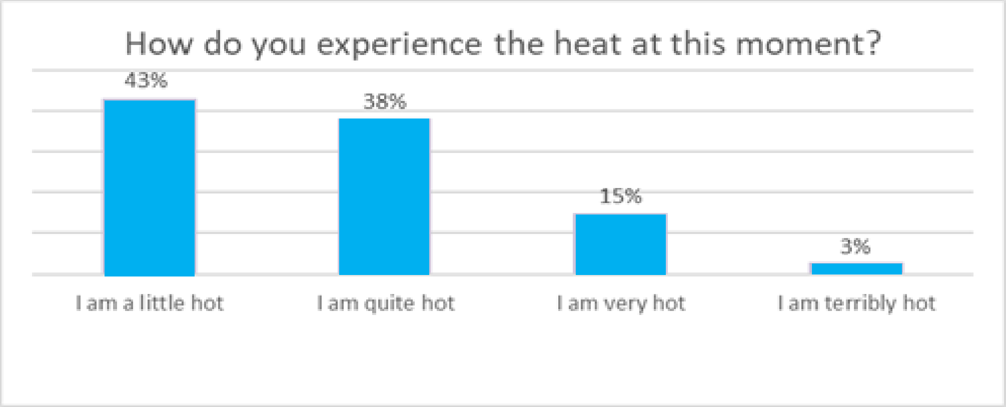


Figure 23: Experienced heat

Travellers were also asked for their opinions on options to find cool spots within the station premises; in the form of seeking shelter from the sun, ventilation on the platform, or opportunities to cool down or get free water. Most travellers find that there are insufficient possibilities to obtain free water at the station. The average score for this is a 3.5, whereby Halte and Basis stations score the lowest. According to the analysis of threat H2 in section 5.3, the stations that do not have water taps, are Dordrecht Stadspolders, Eindhoven Strijp S, Maastricht Randwijck, Swalmen and Tilburg. In table 9, it can be seen that Tilburg scores above average and above some stations with a water tap, and that all stations have an insufficient score. This could indicate that the location of water taps is unclear or that on larger stations, one water tap is not perceived as being enough. These results make it impossible to draw conclusions on the relation between the presence of water taps and the perception of heat. The possibility to find shelter from the sun on the platform is rated a 6.1, and the opportunities to cool down at the station during a hot day is rated, on average, a 5.1. Having enough ventilation on the platform was rated a 6.0.

There are big differences between stations: at the Kathedraal, Mega and Plus stations, travellers generally feel that they have more options for cooling down and finding shelter from the sun than at the other stations, which is reflected in their perception of heat. The best conditions on the platform are at Tilburg station (Mega), followed by Arnhem Central (Mega) and Rotterdam Central (Kathedraal). Again, the location in the Netherlands does not seem to play a role. The statements about finding cooling at the station (rated on a ten-point scale) can be found in table 9.

	Opportunities to obtain free water	Shelter from the sun on the platform	Opportunities to cool down	Ventilation (wind) on the platform	Average of scores, assuming equal weigh
Arnhem Central	4.3	7.6	6.5	7.0	6.4
Barneveld Centrum	4.8	4.6	5.1	5.6	5.0
Dordrecht Stadspolders	2.0	2.6	2.4	4.3	2.8
Eindhoven Strijp S	2.6	3	3.1	4.9	3.4
Houten	3.0	7.3	4.7	6.1	5.3
Maastricht Randwijck	3.0	5.1	4.6	5.5	4.6
Rotterdam CS	3.4	7.0	6.0	6.8	5.8
Swalmen	1.0	2.5	3.0	2.5	2.3
Tilburg	3.8	8.4	6.0	6.3	6.2
Zaandam	3.9	6.5	5.4	6.1	5.5
Average (n=756)	3.5	6.1	5.1	6.0	5.2

Table 9: Average judgements about heat statements at the station and platform (scores below 3 dark red).

Table 10 shows the pleasant and unpleasant places according to travellers, in the case the maximum daytime temperature exceeds 30 degrees Celsius. Shadow on the station, in the form of platform canopy, station halls, tunnels and bicycle sheds, is generally experienced as pleasant. Glass roofs such as in Zaandam, Houten and Tilburg were experienced as very unpleasant during hot days. In Houten, it also mattered whether travellers had to wait on the sunny or shaded side of the station. Waiting areas that are fully in the sun were experienced as unpleasant not only because there was no shade, but also because there was no ventilation. At some stations, such as at Dordrecht Stadspolders and Eindhoven Strijp-S there is little or no shade on the platform, which is experienced as very unpleasant. This is reflected in the perceptions of heat on these stations. Interesting to mention, is that travellers sometimes answered that they sought coolness at the bottom of stairs, away from the platform, because that was the only place with shelter from the sun. This supports the theory that the behaviour and distribution of travellers change as the weather gets warmer. There are four stations that do not have vegetation on the platforms. These stations were not perceived as being significantly warmer than stations with vegetation on the platforms. The hypothesis that vegetation has a cooling effect on platforms, is therefore unconfirmed.

Pleasant places	**Unpleasant places**
Downstairs in parts of the station such as halls, tunnels, near the metro and in bicycle sheds, if applicable at the station	On the platform or other places in full sun without any shelter
Under platform canopy, small roofs, in the shade of buildings, underneath walkways and stairs	On benches / seats in the full sun.
In the shade of smaller objects such as waiting shelters, billboard	Under glass roofs.
In station halls, (covered) shopping areas (ground level) and covered areas.	In glass waiting shelters that are in the sun, where there is no cooling air flow and / or that are closed.
In other shady areas on benches.	Sometimes people also experience the station hall as warm.
In shady areas on the platform where there is wind.	Depending on the station, at no place at all
Near water fountains.	
Depending on the station in many places.	

Table 10: Pleasant and unpleasant places at > 30 degrees Celsius.

In conclusion, the influence of location within the Netherlands on how travellers perceive heat is negligible. The location within the station premises, however, is essential. Areas that are covered by a roof, that are ventilated, shaded, or near water fountains, in combination with wind on the platforms makes travellers feel less hot. A place to sit in the shade is also appreciated. Glass roofs generally have a counterproductive effect on the perception of heat, as do closed (glass) waiting shelters or areas behind glass on the platform. The influence of other materials on the perception of heat were not reported.

Smaller stations with fewer facilities are considered the warmest. Since planted vegetation on the platform seems to have a negligible influence, this is likely attributed to the degree of shelter or ventilation at platforms. However, even if there is shelter, this does not automatically mean that travellers are not bothered by the heat. According to the analysis of threat H1 in section 5.3, all ten stations provide some form of shelter, but at for example Eindhoven Strijp S and Dordrecht Stadspolders, still 32,5 % and 48 % of travellers, respectively, answered that they experienced the station as very or terribly hot and sometimes extremely unpleasant. This could mean that for the number of travellers, there is not enough shelter or that there only is shelter in the form of hot, unventilated waiting rooms which forces travellers to wait outside in the sun.

The local situation is very divisive for the experience travellers have on hot days. For this reason, the results of this study cannot be generalized straight away. However, whether a station offers shelter from sun and heat can be assessed relatively easily. There are many small stations that offer little or no shelter during hot days, or that have only closed, unventilated waiting shelters. Larger stations generally provide more shelter, but that does not mean that this is the case for all station platforms, or that there is enough shelter for the number of passengers. Ultimately, travellers will have to enter the platform to board the train, and busy platforms with little shade will not provide cooling for all travellers in the future.

6. Case studies

In this chapter, summaries of results of the case studies are presented. A more detailed analysis with supporting figures is given in Appendix D1-D5. Next, the hydrological difference between storm events and their return periods that were chosen for the stress-test at municipal level were discussed. Lastly, this chapter reveals different adaptation measures found in literature and analyses which of the measures would be a good fit for Amsterdam Amstel station. These case studies could help validate the results found in section 5.3 and could provide strategic long-term quantitative insights on adaptation strategies for all stations the Netherlands, projecting them onto comparative situations.

6.1. Risk and vulnerability analysis

6.1.1. Amsterdam Amstel

Amsterdam Amstel is a train- and metro station that opened in 1939 (ProRail, n.d.). The station has two island platforms and four platform tracks, of which the middle two (tracks 2 and 3) have been in use for the Amsterdam metro since 1977 (NS, 2006). There are about 34,000 boarding and disembarking passengers per day (class: “Mega”) (NS, 2018a). Because the number of visitors has increased enormously over the years and will likely increase even further, several redesign or renovation activities have been carried out at the station in previous years (Municipality of Amsterdam, 2016).

To be able to fit Amsterdam Amstel into its surrounding area, the entire station was divided over different height levels (∆+/- 10.5 m) (AHN3, 2019). These unusual height differences of Amstel station and its surrounding area make the station vulnerable to rainwater flooding. In addition, due to the increase in paved surface during the redevelopment of the station area, the permeability has decreased, resulting in more water running towards the station.

The municipality of Amsterdam has conducted a stress-test to gain insight into the extent to which Amsterdam is vulnerable to extreme storm events (Municipality of Amsterdam, n.d.), for an extreme storm event of 120 mm in 2 hours, corresponding to a return period of once every 1000 years in 2050 (T = 1000 years) (STOWA, 2019). The general aim of the municipality and Waternet is to avoid all damage, or to be “rainproof” with extreme storm events of 60 mm in 1 hour (T = 100 years), and naturally also of all storm events less severe than that (Municipality of Amsterdam, n.d.).

Figure 24: Water depth near Amstel station (CAS, 2017)

There are two bottlenecks near Amsterdam Amstel station:

1. Underneath the train viaduct on the Mr. Treublaan:

Model calculations with use of Infoworks of the square on the east side of Amstel Station and the lower part of Watergraafsmeer show that flooding underneath this viaduct is twofold. Flooding is firstly caused by the flow paths within the hydrological unit on the west side of the Mr. Treublaan (in the van der Kunbuurt) (U04), and secondly by the flooded manholes connected to the rainwater drainage system in this same hydrological unit. With Dutch “leidraad bui” 08 (19.8 mm / hour, T = 2 years) nine manholes flood (up to 0.2m), which are mainly located in the lowest part of the hydrological unit near the Mr Treublaan. In the current situation with bui08, the sewer system in the Van Der Kunbuurt, therefore, does not meet demands, and certainly does not meet the aim of the municipality of Amsterdam and Waternet to be rainproof with extreme storm events of 60 mm in 1 hour. With a storm event of 60 mm in 1 hour, more than 160 m^3 of water flows towards the tunnel in the Mr. Treublaan from the Van Der Kunbuurt, causing a water depth of 62 cm in the tunnel. In addition, according to the model calculations, a lot of water will also remain in the bicycle shed on the west side of the station, limiting access and egress transport modes.

2. Near the station entrance at the Julianalaan (east entrance)

The risk here is related to the ground level design of the Julianalaan. The side of the road is oriented in the direction of the station, which causes a limited amount of water storage to be available on the street. With bui08 there was no nuisance yet, but with a rainproof storm event (60 mm/hour, T = 250 years) there was a water depth of 23 cm in front of the entrance to the station building, which made the water flow into the station. This problem was acknowledged by de municipality of Amsterdam and was attempted to resolve in the recent area developments. The central reservation (median strip) in front of the Julianalaan has been raised so that it functions as a threshold seen from the station, which now has a minimum height of -0.86 m NAP. According to model calculations, with a storm event of 60 mm in 1 h, the water level now rises exactly to the threshold height and remains at that height for 45 minutes. However, the possible consequences of wave action have not been included in this model and this can therefore still cause the entrance of the station to flood.

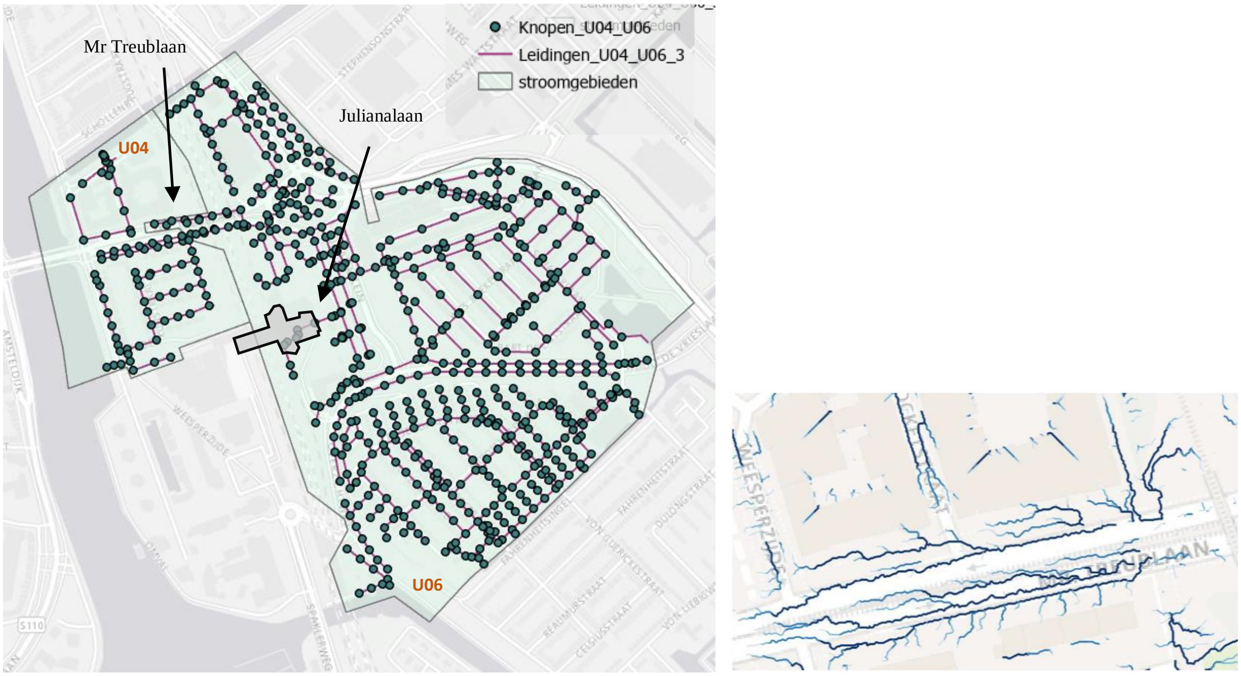


Figure 25: Left: catchment areas U04 and U06 around Amstel station. Right: flow paths towards the tunnel in Mr. Treublaan. (N&S, 2016)

Despite the efforts of the municipality of Amsterdam, the station manager of Amsterdam Amstel still registered a flooding of the east-entrance on the 17th of August 2020 (12,5 mm in 1 hour, two hours later: 8 mm in 1 hour, T = 0.5 years). The rest of that year, the station was not flooded. The water, during this incident, flowed in from the side of the bus station (Julianaplein) to the entrance at the Julianalaan and several shops were flooded (Julia's, Rituals). This means that the threshold that was supposed to stop the flooding, was not enough to withstand a storm event of 12,5 mm in 1 hour, or of T = 0.5 years. This would, in theory, indicate that the station's current coping range is below a storm event of T = 0.5 years. What must be noted here, however, is that this was not the heaviest local storm event in 2020, and that the station withstood all other storm events of 2020, meaning that it is possible that there were some other reasons behind the flooding on this date. The station manager and a hydraulic engineer from Waternet could not explain this occurrence.

The specific drainage capacity of the roof of Amsterdam Amstel is unknown and the station manager only became responsible for Amstel station 1,5 years ago, meaning that incidents that are longer ago cannot be recalled. It is therefore difficult to make definite statements about the coping capacity of the roof. The technical areas of Amstel station are partly below ground level but very far away from the entrance at the Julianalaan, making short circuits or electrocution in these rooms very unlikely.

The heat stress around Amstel station is relatively high (apparent temperatures lay between 40-46 ℃), except for some strips between the tracks of the train station. The platforms are located within the station building and are therefore covered by a roof, which makes that enough shade is provided. A disadvantage of this is that ventilation could be reduced (Katsoulas et al., 2006). Furthermore, the walls near the platforms, and part of the roof are made from glass. From the questionnaire it became apparent that glass generally has a counterproductive effect on the perception of heat which therefore increases the vulnerability of Amstel station to heat. In addition, there are two water taps within the station premises, and the area around Amstel station is richly endowed with vegetation and greenery. This greenery cannot be found within the station premises, but its influence on the perception of heat, especially compared to the influence of shade and ventilation, is negligible according to the results from the questionnaire. Furthermore, the number of seating areas at the platforms is relatively high. The technical rooms are not ventilated, which means threat H4 applies to Amstel station and the technical functionality of the station is at risk.

The entire city of Amsterdam was built on a peat bog (PDOK, n.d.). The station is built on an elongated terrain and is supported by a concrete pile foundation, above which there is a load-bearing construction of steel. The average lowest groundwater levels near Amstel station can drop more than 1.25 m below NAP (Municipality of Amsterdam, n.d.), jeopardizing the safe entry height of 76 cm.

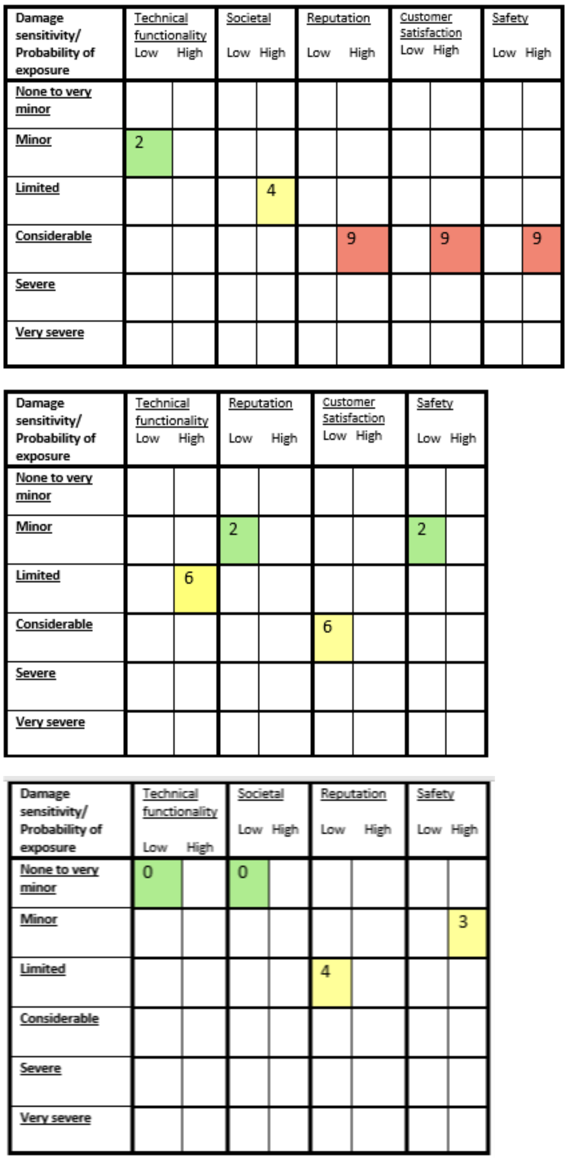
Table 11 shows all the threats introduced in section 5.3 that apply to Amstel Station, adapted based on local studies (see Appendix D1).

Station	**R1**	**R1.2**	**R2**	**R3**	**R4**	**R5**	**H1**	**H2**	**H3**	**H4**	**D1**	**D2**	**D3**	**Total**
Amsterdam Amstel	1	0	0	0	1	1	0	0	1	1	1	0	0	6

Table 11: The threats that apply to Amstel station, adapted based on local studies

Amstel station's adaptive capacity is relatively large since both ProRail and the municipality of Amsterdam have carried out a systematic mapping of different types of climate threats and the probability of exposure to those threats, based on the W_H scenario of the KNMI. In addition, the risks for the adjacent sewer systems and the station have been evaluated and assessed in early stages of the planning process, and steps have been taken by the municipality and Waternet to mitigate the risks in and around the station. The effectiveness of these steps is however somewhat questionable due to the flooding of the Julianalaan entrance on the 17th of August 2020. To further increase the adaptive capacity and decrease vulnerability, a new assessment of the bottlenecks on the east-side of Amstel station is to be made, including the possible effects of wave action. Adaptive measures ought to be explored, and in this process the effects of potential conflicts should be assessed, in order to avoid the implementation of counter-productive measures.

The current estimated risks for Amsterdam Amstel, with their corresponding RPN and level of acceptance can be found in figure 26. For extreme rainfall, it can be found that the risks affecting reputation, customer satisfaction and the safety of travellers are not accepted. All risks related to heat hazards are acceptable to some extent. The risk for the technical functionality and the customer satisfaction, however, are assigned a serious and unwanted risk level. None of the current estimated risk related to drought hazards are found unacceptable. However, the risks to ProRail's reputation and safety of travellers are found serious and unwanted. To reduce these risks, the damage sensitivity and/or probability of exposure to threat R1, R4, R5, H3 and H4 and D1 need to be reduced.



Damage sensitivity/ Probability of exposure	Technical functionality		Societal		Reputation		Customer Satisfaction		Safety	
	Low	High	Low	High	Low	High	Low	High	Low	High
None to very minor										
Minor	2									
Limited				4						
Considerable						9		9		9
Severe										
Very severe										

Damage sensitivity/ Probability of exposure	Technical functionality		Reputation		Customer Satisfaction		Safety	
	Low	High	Low	High	Low	High	Low	High
None to very minor								
Minor			2				2	
Limited		6						
Considerable					6			
Severe								
Very severe								

Damage sensitivity/ Probability of exposure	Technical functionality		Societal		Reputation		Safety	
	Low	High	Low	High	Low	High	Low	High
None to very minor	0		0					
Minor								3
Limited					4			
Considerable								
Severe								
Very severe								

Figure 26: Estimation of current risk and corresponding RPN for Amsterdam Amstel for extreme rainfall (top), heat (middle) and drought (bottom)

6.1.2. Boskoop, Breda-Prinsenbeek, Leeuwarden-Camminghaburen, Ede-Wageningen

This section includes a summary of the risk analyses of station Boskoop, Breda-Prinsenbeek, Leeuwarden Camminghaburen and Ede-Wageningen. The climate risks at Boskoop station are mostly heat- and drought related, the risks at Breda-Prinsenbeek are water- and heat related and the risks at Leeuwarden Camminghaburen are mostly heat related. For station Ede-Wageningen, a redesign of the station area is planned for the end of 2021, in which a whole new station will be developed, built a few tens of meters east of the current station due to the enormous expected increase in the number of passengers (ProRail & NS, 2016). In the new station design, based on the current available design tender, the climate issues will mainly be caused by extreme rainfall. Because the development of station Ede-Wageningen is an ongoing process, definite claims about the new station and its vulnerability to climate hazards cannot be made.

In the new station of Ede-Wageningen, there will be two station tunnels, of which one tunnel will provide the only access route to the platforms. In case of a storm event of 46 mm in 1 hour, corresponding to a storm occurring once every 50 years (T = 50 years) (STOWA, 2019), there are three bottlenecks: underneath the Albertstunnel over which the train runs, near the northern entrance of the western platform tunnel, and near the southern entrance of the eastern platform tunnel. The current station of Ede-Wageningen has flooded two times in the past two years: on the 2nd of October 2019 (28 mm in 2 h, T = 10 years), and on the 2nd of July 2020 (20 mm in 1 hour, T = 2 years). With the last flooding, the water came up through the manholes near the station, indicating that the coping range of the local sewer system can only handle storm events with return periods of below T = 2 years. Because the new station will be connected to the same sewer system and the amount of paved area will only increase in the development of the station environment, it is essential that climate change is considered in the design, and that adaptive measures will be implemented to prevent the new station from flooding. The station's project manager, however, mentioned that any influences of extreme weather and the implications this would have on the station, were not considered in the early formation of the new design.

At Breda-Prinsenbeek, the biggest threat related to extreme rainfall, is that of short circuit and/or electrocution due to flooding of technical rooms. The equipment cabinets at Breda-Prinsenbeek are located under the pedestrian bridge between both platforms. In case of heavy rainfall, water drips from the stairs into these cabinets because they cannot be properly closed off. Furthermore, Breda-Prinsenbeek is vulnerable to heat. The heat risk is largest here compared to the other stations because Breda Prinsenbeek and its surrounding area will have an increase of 50-70 summer days in 2050 (CAS, 2017), and the station is located in a fairly urbanised area with a lot of paved surface. The apparent temperature at the platforms can go up to 46 °C. In addition, the elevators on the platforms are made entirely out of glass, which means that they can become very unpleasant on hot summer days. This will have an especially large effect on vulnerable groups and may limit their ability to reach the station or train.

The main issue at Boskoop station is the extreme soil subsidence: because Boskoop lies on a peat soil, the accelerated subsidence is a major issue here. In some places in Boskoop, the ground level is almost equal to the water level and the soil subsidence can go up to 2 cm per year. This potentially leads to a total soil subsidence that can reach above 60 cm by 2050 (ProRail & Arcadis, 2020; Municipality of Alphen a/d Rijn, 2016), or according to the stress test of ProRail, can even go up to 68.3 cm; seriously compromising the maximum and minimum safe boarding height (ProRail & Arcadis, 2020). This extreme subsidence also compromises the integrity of the station building of Boskoop, as it is founded on wooden poles.

In the general risk assessment, Leeuwarden-Camminghaburen seemed to have a platform tunnel that experienced disturbance from heavy rainfall in case of an extreme storm event. For a storm event with an intensity of 60 mm in 1 hour, the projected water depth near the station entrances was greater than 40 cm. According to the municipality of Leeuwarden however, who manage this tunnel, the tunnel has never flooded in the past 20 years because a pump is installed that can pump approximately 22 m^3 / hour. This is double the amount of water that can end up in the tunnel with an extreme storm event of 60 mm in 1 hour, which means that the tunnel will not flood.

The threats of all four case study stations, adapted based on local studies, are given in table 12. A detailed description and substantiation of all stations with corresponding supporting figures can be found in Appendix D2-D5.

Station	Region	Class	R1	R1.2	R2	R3	R4	R5	H1	H2	H3	H4	D1	D2	D3	Total
Amsterdam Amstel	Randstad North	Mega	1	0	0	1→0	1	1	0	0	1	1	0→1	1→0	0	6
Ede-Wageningen	North-East	Plus	1	1	1	0	?	1	?	0	0	?	0	0	1	5-8
Boskoop	Randstad South	Basis	0	0	0	0	0	1	0	1	1→0	?	1	1	0	4
Breda-Prinsenbeek	South	Basis	0	0	0	0→1	1→0	1	0	1	1	1	0	0	0	4
Leeuwarden-Camminghaburen	North-East	Halte	1→0	1→0	0	0	0	1→0	0	1	1	0	0	0	0	2

Table 12: Threats that apply to Ede-Wageningen, Boskoop, Breda-Prinsenbeek and Leeuwarden-Camminghaburen, adapted based on local studies

6.1.3. Storm events and return periods

KNMI and HKV have delivered a complete set of precipitation products on behalf of STOWA (Stichting toegepast onderzoek waterbeheer), which, among other things, provides the statistics for extreme precipitation for climate scenarios, in the form of rain duration lines. A rain duration line indicates the expected amount of precipitation for several durations at a given exceedance frequency, which is indicated with a certain return period. A return period is then the (estimated) average time between, in this case, precipitation events. What is striking about the above risk analyses of the stations, it that the municipality of Amsterdam, Ede and Leeuwarden use different storm events with different return periods. In fact, the municipalities of all five stations of the case studies use different storm events for their stress test (see table 13 and Appendix D). To illustrate, all used storm events are portrayed in figure 27, projected over STOWA's rain duration lines. To see which return period corresponds to what storm event, one must check the rain duration line that is above the storm event.

The use of one standard storm event is strongly recommended in the Delta plan on Spatial Adaptation (2018), because this contributes to the quality and comparability of the results. In the event of deviating from the standard it is necessary to record the arguments for this and link the results back to the stress test results with standard storm events (Deltacommisie, 2018). The fact that different precipitation events are used throughout the Netherlands without any link to standardized storm events makes it very difficult to compare the municipalities amongst themselves and to the national level as portrayed in the climate effect atlas. This makes it difficult, if not impossible, to make statements about the relative risk or “safety” amongst stations.

Municipality/Government	Storm event	Return period (years)
Klimaateffectatlas / ProRail Climate stress test	70 mm in 2 h	T=100
Amsterdam	120 mm in 2 h	T=1000
Amsterdam Rain Proof	60 mm in 1 h	T=250
Ede	46 mm in 1 h	T=50
Boskoop	100 mm in 2 h	T=500
Breda	70 mm in 1 h	T=250
Friesland	60 mm in 1 h	T=250

Table 13: Stress tests and return periods of municipalities of the case studies

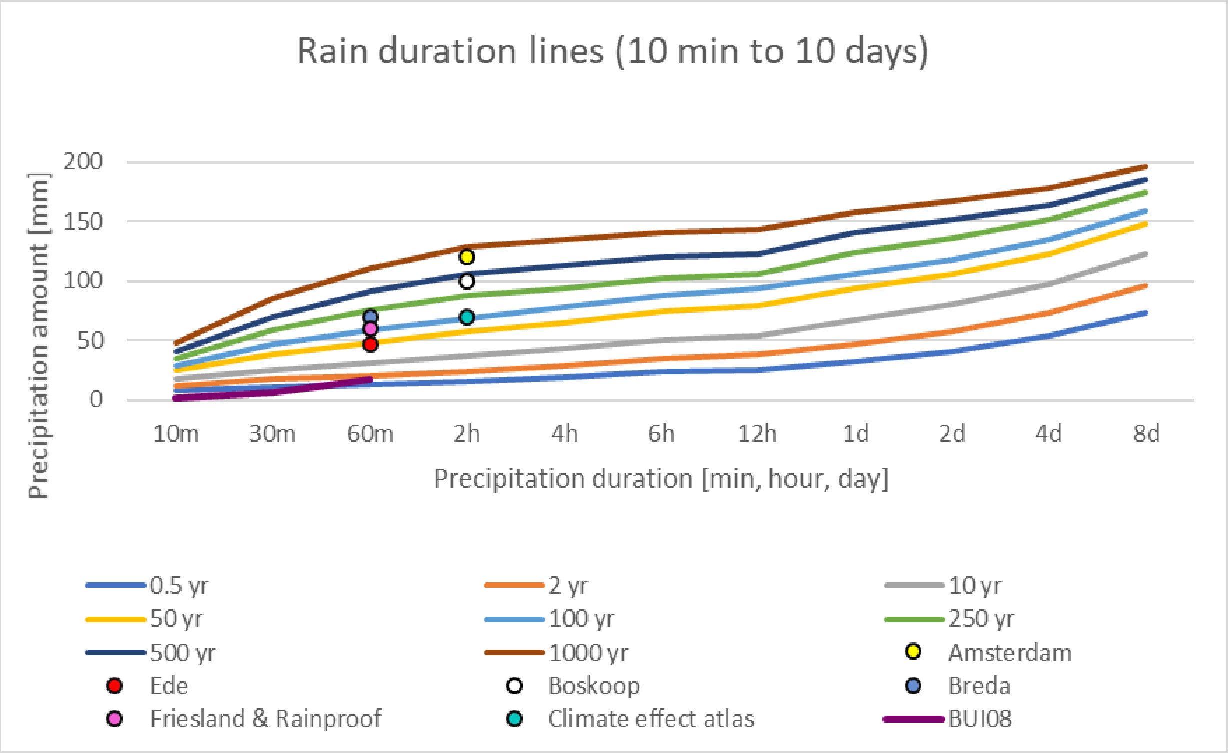


Figure 27: updated rain duration lines for basic statistics for the whole year, adapted from stowa2019-d (Stowa, 2019).

6.2. Potential adaptation measures

In this section, the potential adaptation measures for extreme rainfall, heat and drought that have been successfully implemented both in the Netherlands and abroad will be discussed. Second, this section describes potential suitable adaptation measures for Amsterdam Amstel station to strengthen resilience to extreme rainfall and heat, and sheds light on the risk for Amstel Station after the implementation of (a combination of) these measures.

6.2.1. General adaptation measures

Extreme rainfall

The capacities of the local sewer systems are generally not designed for the extreme storm events that will occur more often due to climate change (IPCC, 2014; Dirven-van Breemen, den Hollander & Claessens, 2011). Adapting the sewer systems to climatic extremes to prevent overflows would however require very large and expensive sewers that will go unused most of the time and for which there is little space left in the ground. A better, less expensive solution would thus be to relieve the sewer system by retaining the water locally, by storing it, or by discharging it above ground. This does however not mean that it is needless to replace or renovate (parts of) old sewer systems to make them meet current standards. In both national and international literature, roughly five types of solutions to relieve the sewer system and to deal with (excess) rainwater can be identified. These solutions, including four or five concrete measures per type of solution are summarized in table 14. With each measure, the advantages and disadvantages were given, and if applicable, specific conditions were mentioned that are needed for the implementation. The advantages were assessed based on whether they have a positive influence on the water quality, air quality, biodiversity, heat or drought or whether this measure takes up a lot of extra space. The disadvantages were assessed based on costs: construction costs and maintenance/management costs.

Water retention

Water is first retained locally to delay the discharge peak of the rainwater into the sewer system. The most direct way to realize this, is through decreasing the percentage of paved surface in the city, allowing more water to infiltrate into the soil. This restores the groundwater and helps prevents damage to the constructions of buildings but has a limited influence on the prevention of flooding during an extreme storm event because infiltration is a much slower process than runoff over paved surface.

Water storage

Water can be stored in for example ditches, lakes and flood plains to provide relief to the sewer system. This is mainly enhanced by enlarging the flood plains, by relocating dikes or by constructing special reservoirs that are filled when the water supply is large, and drained or pumped empty after the rainy season has ended.

Water drainage

Drainage is the removal of excess water and as such is part of the water cycle. There are two types of drainage: natural drainage, which is when the water leaves the area through the discharge point in a natural way, and artificial drainage, when the water drains from the area using auxiliary means. What should be considered when choosing this solution, is that water that drains from roads with motorized traffic is usually polluted. Before this water can be drained into the surface water, the water must be purified first, or be discharged via the waste water sewer.

Water usage

Water can often be reused. Rainwater that falls on roofs or platform canopy, for example, is clean enough to be used for the toilet or for watering plants. By using the water rather than draining it, the water does not disappear directly into the sewer. In addition, it saves the drinking water that would normally be used for these purposes.

Water-robust constructions

Increasingly extreme precipitation also requires a water-robust design of buildings. All buildings and especially the vital infrastructure such as electricity, communication or drinking water systems must be designed in such a way that they can withstand a period of flooding and continue to function. Sockets, switches, relay- and electrical cabinets in stations could for example be placed higher than the maximum water level, and self-sufficient installations such as solar panels or collectors could be installed as back-up.

Heat

There are many cities in areas that have been struggling with heat stress for far longer than the Netherlands. To prevent the heat island effect at platforms, a lot can therefore be learned from international literature (Schuster, Honold, Lauf & Lakes, 2017; Lemonsu, Viguie, Daniel & Masson, 2015; Huttner, Bruse, Dostal & Katzschner; 2009; Nuruzzaman, 2015). Six major strategies can be found to mitigate and adapt to the urban heat island effect. These strategies, including two to five concrete measures that could be relevant for stations per strategy are summarized in table 15 with their advantages and disadvantages

Cool materials

Cool materials with high albedo reduce the average urban air temperature (Macintyre & Heaviside, 2019) because high albedo materials, with similar insulation properties to low albedo materials, do not get warmed significantly (Akbari et al. 2001). A proper selection of materials is therefore very important in reducing the urban heat island effect.

Vegetation

Increasing the amount of vegetation in the urban area is a strategy that is often mentioned throughout literature as one of the most effective strategies to mitigate the urban heat stress. (Wilmers, 1988; Synnefa et al., 2008; Takebayashi and Moriyama, 2009; Xua et al., 2010). An additional benefit is that vegetation also has a direct effect on reducing the urban heat island as it absorbs CO_2, which could be especially beneficial at platforms where the human gathering is large (Akbari et al. 2001). In the questionnaire of this study, however, the influence of vegetation on the perception of heat on platforms could not be confirmed, and the effects of shade and ventilation are considered to be far more important. Nonetheless, vegetation (e.g. shrubs or green facades) can still be effective in cooling down the surface temperatures of facades, in increasing the aesthetic value of the station, and it offers particular benefits in the handling of surface water runoff. Since this section discusses adaptation measures to reduce heat within the station premises, however, only the measures that cool down the surface temperatures of station buildings or waiting shelters will be considered.

Water

Water in urban areas reduces the temperature due to the high absorption capacity of water, and due to evaporation and enhanced wind speed (Robity et al., 2006).

Shade

By creating enough shadow spots, it is possible to reduce the average urban heat island intensity. In the shade, the perceived temperature is 10-15 °C lower than in the sun (Kluck et al., 2020). Creating shadow is therefore the most effective way to lower the apparent temperature.

Smart urban planning

Proper urban planning could play a vital role in the mitigation of the urban heat island effect. According to Yamamoto (2006) placing buildings in such a way that a path is created for cool airflow from a water body into the city could play a major role in cooling down the city. Furthermore, enough free space and a channel to circulate the wind could help minimize the effect of the urban microclimate (Yamamoto, 2006).

Decrease anthropogenic heat

In urban areas a lot of heat is released through human activities, such as the heating and cooling of buildings or spaces, motorized transport, technical rooms/areas, etc. A German study on the anthropogenic heat release from the highly industrialized Ruhr area region, concluded that the warming over the Ruhr area is 3,5 times higher than over land (Block et al., 2004). Reducing anthropogenic heat exhaust could therefore reduce the intensity of the urban heat island effect.

Drought

Although land subsidence does not date from today or yesterday, the urgency is increasing as the risks increase. To counter this, more and more techniques are being developed for raising or stabilizing the soil. These solutions can be divided into strategies for constructing new buildings or for limiting the damage to current buildings and can be divided into adaptation measures (adapt to subsidence) and mitigation measures (prevent subsidence), Since this study focuses on adaptation-relevant science, only potential adaptation measures were discussed. When constructing new buildings in (peat) areas, there are multiple strategies to make sure the building does not subside. A few of these are listed below:

Fixative building

Fixative building takes place according to the usual principle whereby (wooden) foundation piles are placed on the solid sand layer underneath the layer of peat. On top of these foundation piles, a granulate mattress (pole mattress) or concrete floor is placed to increase the load-bearing surface. This method is settlement-free.

Moving along with the ground

This technique assumes that houses, gardens and the entire public space (roads, sewers, cables and pipes, greenery, furniture) move along with / float on the ground. Any future subsidence - or water level rise because of peak storm events - is absorbed in this way: the floating "plate" adapts to the conditions of the surrounding area. This type of construction is possible on peat soil or on water (with a partially excavated peat layer underneath).

Soil improvement

Soil improvement is improvement of the condition of the soil, usually to increase the bearing capacity or stability of the soil.

To limit the damage of subsidence to existing (station) buildings or platforms, multiple strategies are possible, which can be divided into two categories.

Pile head lowering

With this method, the wood of the pile foundation that is damaged through pole rot is sown off to about 50 cm beneath the lowest expected groundwater level and is then replaced.

Creating extra load-bearing capacity

The load bearing capacity of buildings or platforms can be increased by adding additional or replacement bearing capacity. This can for example be done by installing a new pile foundation, chemical injection or soil mixing.

Another issue that arises as the length and duration of dry periods increase, is the risk of wildfires. In principle, preventing wildfires is a task for the government (Rijksoverheid, 2019). However, by keeping the railway verge free of vegetation, the railway can also act as a buffer to prevent the fire from spreading from one area to another, which could furthermore avert train fires and fires at stations. All the above solution types, including two to five concrete measures that could be relevant for stations are summarized in table 16 with their advantages and disadvantages.

Extreme rainfall

1.Water retention & 2. Water storage	3.Water drainage	4.Water usage	5.Water-robust constructions
Reintroduction of the sidewalk ++WQ - CC ++MS - MC	**Open or covered gutters** ++WQ - - CC +MS - - MC ! There must be a sufficient slope	**Rainwater utilization system** ++WQ - - CC ++MS - MC	**Rainproof utilities** ++WQ - - CS ++MS - MC ++ D
Polder roofs +++WQ ++BD - - - CC ++MS +AQ - - MC	**Guiding the rainwater over the road** ++WQ - CC ++MS - MC	**Helophyte filter** +++WQ - - CC +AQ - MC +++BD +H +MS	**Thresholds / Raised floor level** +WQ - CC +MS - MC - Building entrance less accessible
Infiltration crates +++WQ - CC +++MS - MC - - Can silt up - - Not possible with high groundwater levels	**Drainage to urban waterways** ++WQ - - CC +H - MC +MS ! Water levels in waterways must be low to start with	**Rainwater fence** +WQ - CC +MS - MC + Can be combined with stepped planters	**Threshold for water control** +WQ - - CC ++MS - MC
Infiltration wells +++WQ - CC ++MS - MC ++D - - Not possible with high groundwater levels	**Hollow roads** ++ WQ - - CC ++ MS - MC	**Rain barrels** +WQ - CS +MS - MC	**Building with elevation** ++MS - - - CC - MC
Water-retaining planters ++WQ +++BD - - CC +AQ + H - - MC ++MS + Possible with high groundwater levels/ a non-permeable surface /where water is not allowed to infiltrate due to polluted soil	**Enlarge sewer pipe diameter** - - - CC - - MC - Only possible if there is enough space in the ground		**Water-robust cellars with rain resistant construction/materials** +WQ - CC +MS - MC ! Needs ability to withstand water pressure or flow - There must be a pump or a gutter present
Intensive green roofs ++WQ +++BD - - CC +AQ ++MS - - MC + Saving energy costs + Savings in the lifespan of the roof covering			**Sump pump** **- CC** **- MC** - Electricity required
. **Disconnecting downspouts** ++WQ - CC - MC - - In impermeable soil with high groundwater levels, additional (storage) facilities are necessary			

Table 14: List of adaptation measures for extreme rainfall whereby WQ = water quality, AQ = air quality, BD = biodiversity, H = heat, D= drought, MS = multifunctional use of space, CC = construction costs, MC = maintenance costs, + = pro, - = con, ! = pay attention

Heat					
1. Cool materials	**2. Vegetation**	**3. Water**	**4. Shade**	**5.Smart urban planning**	**6. Decrease anthropogenic heat**
High albedo roofing materials - Glaring - Albedo decreases as roofs get older	**Green roofs** + Saving energy costs + Savings in the lifespan of the roof covering + Positive effect on water management and infiltration	**Pervious pavements** + Positive effect on water management and infiltration	**Shade trees** + Reduction air temperature by evapotranspiration + Improves air quality - Vulnerable to extreme storms/forest fires - Roots affect foundations of buildings/streets	**Green/blue veins** + Positive (psychological) effect.	**Use of natural energy (solar heat)** - Long payback period
High albedo pavements - Glaring - Part of reflection intercepted by surrounding buildings - Lower durability + Less public lighting needed at night	**Green buildings/walls** + Positive effect on water management infiltration and heat reduction - Costs	**Water elements** + Can also provide entertainment hot days. - Can become a source of illness if not well designed and managed.	**Overhanging eaves** + The building itself also heats up less ! When dimensioning the sunlight inlets in winter need to be considered for use of passive solar energy.	**Stimulate wind circulation** - Wind circulation in autumn and winter: protection must be offered	**Improve insulation** + Reduces both costs and CO_2 emissions - Could lead to air exchange or moisture issues
High albedo buildings - Glaring + Less public lighting needed at night		**Blue roofs** + Cooling effect through evaporation + Collecting rainwater - High load-bearing capacity of the construction.	**Sun protection canvasses** + No space on the ground level + Freedom of choice in transparency and location	**Orientation of buildings** - Only possible in new station projects/design	
Solar control glass - Also keeps out warmth from the sun in winter		**Install water taps** + Positive effect on health + May reduce plastic use	**Use of vertical greenery for shading of buildings** + Energy savings + Savings in construction and maintenance of façade and construction work.		
			Placing waiting shelters + Reasonably cheap to install and easy move		

Table 15: List of adaptation measures for heat, + = pro, **-** = con, ! = pay attention

Drought					
Land subsidence					**Forest fires**
New constructions			**Existing construction**		
1. Fixative building	**2. Moving along with the ground**	**3.Soil improvement**	**4. Pile head lowering**	**5. Creating extra load bearing capacity**	**6. Keeping railway verge free**
Pole mattress + Management and maintenance - Non-sustainable use of material/energy - Duration of execution - Flexibility of layout	**Floating buildings** + Duration of execution - Sustainable material/energy - Flexibility of layout - Long preparation time	**Soil replacement:** + High water storage capacity + Very long lifespan + Reuse possible + Flexibility of layout plan - Duration of execution - Not desirable as cables in excavated peat layer	**Pile head lowering** - Only possible with posts where only the pile head is affected and not the rest of the wooden post, and in the situation that the rest of the foundation still has sufficient bearing capacity	**“Tafelmethode”** - Building temporarily out of use + Low risk of damage from work + Use of materials and equipment of limited dimensions	**Keeping railway verge free of trees** - Increases urban heat island effect at platforms
Concrete floors + Long lifespan - Non-sustainable use of material/energy - Low water storage capacity - Difficult to move pipes/cables	**Concrete on polystyrene (EPS)** + Reuse possible + Low maintenance - Low water storage capacity - Limited technical life - Material is flammable	**Preloading the soil** + Reuse possible - Cables must be relocated - Large equipment needed		**New pile foundation with edge beams / or consoles** - Crawl space necessary	
	Modules of hollow containers + They can be used as extra space	**Vertical drainage** + Reuse possible + Goes relatively quick		**Pile foundation with prestressed concrete beams** + Little nuisance: it is often possible to work from outside - Lengths of the building walls cannot be longer than 10 meters for this technique. - More expensive than table construction	
				Poles pushed through the wall + Relatively cheap - Short construction time	
				Inject chemicals - Long execution time - May adversely affect existing wooden posts	

Table 16: List of adaptation measures for drought hazards **+** = pro, **-** = con.

6.2.2. Adaptation measures for Amsterdam Amstel

Extreme rainfall

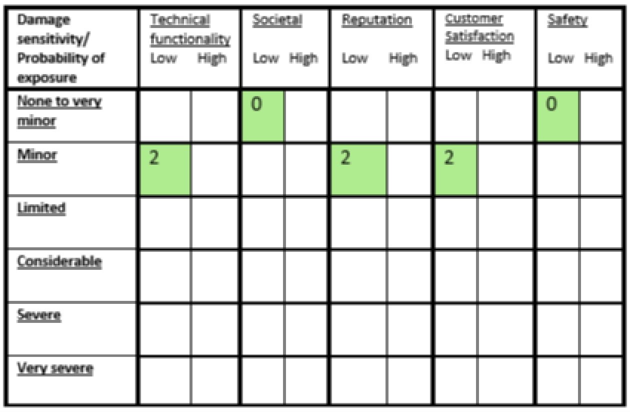
The sewer system from hydrological unit U04 was built in 1950. Model calculations by Waternet, carried out by Nelen & Schuurmans, have shown that the solution to prevent water under the Mr. Treublaan could partly lie in this part of the sewer system. According to Nelen & Schuurmans' internal report, a combination of connecting the sewage system in the Mr. Treublaan and Goudriaanstraat and placing an extra sewage outlet in Amsteldorp (U06), would prevent water from flowing onto the streets in 6 out of 9 flooded manholes in the old situation (for bui08). The rest of the solution then needs to be found above ground. It is for example a possibility to relieve the bottleneck underneath the viaduct on the Mr Treublaan, by elevating the ground level. The entrance to the station on the Julianalaan can be kept dry by adjusting the height levels and layout of the neighbourhood. Additionally, solutions can be found in retaining the rainwater on the plots. This could for example be realised by increasing infiltration or by greening the area around Amsteldorp. Below there is a list of possible measures that could positively contribute to solving the flooding problems at and around the station:

- Placing a threshold at the intersection of Bertrand Russellstraat and Maliebaan
- Creating a higher, wheelchair-friendly threshold in front of the station entrance so that the effects of wave action do not cause the entrance to flood
- Place a threshold on the parallel road next to the Mr. Treublaan and raise the manholes that are flooded. The latter must be done in coincidence with Waternet and the municipality
- Install water storage facilities in the Van der Kunbuurt (U04) such as water retaining planters or infiltration crates, which is only possible because the average lowest groundwater level near Amstel station is > 1.25 m below ground level.
- Create an incline at the Julianaplein entrance from the station building towards the steps. The water can be drained visually and playfully along the stairs, possibly towards (water retaining) planters or an infiltration well. The threshold at the intersection of the Maliebaan and Bertrand Russellstraat ensures that water coming from these steps cannot flow to the Bertrand Russellstraat.
- Apply storage on roofs (green roofs, polder roofs) of buildings in the neighbourhood
- Decrease paved surface in the entire area, e.g. by stimulating green gardens or rain barrels

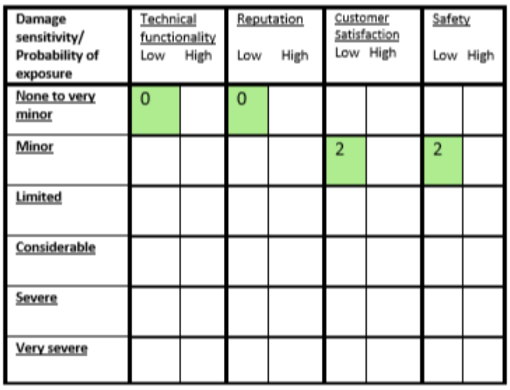
Heat

In principle, Amstel station, due to its largely shaded area, large amount of seating options and an above-average number of water taps, is relatively well prepared to extreme heat. To decrease vulnerability to heat even further, it would be an option to replace the glass plates in the roof with solar-resistant glass. Solar panels could be placed on the roofs, or the solar-resistant glass could be combined with solar cells to increase the use of natural energy and reduce the anthropogenic heat. The closed parts of the roof could be replaced with high albedo roofing materials. In addition, wind circulation can be stimulated by replacing the glass wall plates with windows on opposite sides that can open. Furthermore, the number of benches and seating areas could be further increased so that people have to opportunity to sit down in the shade. More water taps could be installed with a clear sign or guidance towards where they are. In recent developments, green strips have been created on the forecourt of the station and 135 new trees are being planted in the project area. This development could be combined with water elements around the bus station. Finally, it is important that ventilation is placed in the technical rooms, possibly with sensors that are triggered above a certain temperature, so that the technical functionality of the station is no longer at risk.

After the implementation of the hypothetical measures above, a new estimation was made of the risks and corresponding RPN's for Amsterdam Amstel. This is portrayed in figure 28. Further investigation of the above measures based on a cost- benefit analysis is necessary to weigh the measures and determine which (combination) of the measures is to be implemented.



Damage sensitivity/ Probability of exposure	Technical functionality		Societal		Reputation		Customer Satisfaction		Safety	
	Low	High	Low	High	Low	High	Low	High	Low	High
None to very minor			0						0	
Minor	2				2		2			
Limited										
Considerable										
Severe										
Very severe										



Damage sensitivity/ Probability of exposure	Technical functionality		Reputation		Customer Satisfaction		Safety	
	Low	High	Low	High	Low	High	Low	High
None to very minor	0		0					
Minor					2		2	
Limited								
Considerable								
Severe								
Very severe								

Figure 28: Estimation of risk and corresponding RPN for Amsterdam Amstel after hypothetical implementation of measures for extreme rainfall (top) and heat (bottom)

7. Discussion

7.1. Risks for stations and network effects

In this study, the effects of climate change for the Dutch railway station were assessed in terms of technical functionality, society, customer satisfaction, safety and ProRail's reputation. The findings suggest that Dutch railway stations are vulnerable to climate change, and that there are many aspects of climate change that require attention. This is endorsed by Arkell & Darch (2006), who have studied the impacts of climate change on London's transport network. They found that extreme rainfall will increase the risk of disruption to the London Metro stations, and that, unless adaptation measures are implemented, passenger dissatisfaction is likely to increase in the future. They furthermore concluded that the problem of over-heating could be further exacerbated by overcrowding and failed or delayed services. In this study, overcrowding and failed or delayed services appear as possible consequences of extreme weather events, which could, according to Arkell and Darch, further compromise the station if ways to minimize the effects are not considered.

Second, the potential impact of the failure of station functions on the surrounding rail- and station network was discussed. In academic research, few studies deal with analysing capacity and network effects of failing railway stations. To this end, the studies that do focus on railway stations, mainly focus on the number and efficiency of trains, tracks, track crossings, the maximum train speed, etc, rather than on the effect of passenger flows on the network. According to van Hagen (2011), however, who has studied the role of waiting while travelling, speedy and easy movement through the station are principal customer needs and are essential for increasing efficiency and stability of railway timetables. This underlines the relevance to study not only the limiting capacity of railway stations in terms of tracks and train (crossings), but also in terms of (smooth) passenger flows across railway stations. Climate hazards, according to the results of this study, could lead to overcrowding, temporary inaccessibility, or malfunctioning of the rail/station systems; affecting speed and ease of passenger flows within the station, customer satisfaction, dwell times, and the stability of timetables. It can furthermore lead to an increase in the number of passengers at other stations in the network. This cascading effect is in line with the study by van den Top (2005), who conducted research into dynamic rail traffic management at Arnhem station, which shows that a large part of the delay on Arnhem was "imported" from adjacent stations. This was partly attributed to dwell times during rush hour that were longer than planned for due to crowds and overly busy platforms.

Furthermore, ProRail has identified certain important red and green nodes in the station network, based on the corridors and the number of passengers on these corridors that cross and stop at these nodes. In this study, it is assumed that extended dwell times or effects on the technical functionality of the station will have the greatest impact on the red and green nodes, which means that the functioning of these nodes is, in a sense, more important than the functioning of other stations. This is also endorsed by the study of van den Top (2005), in which he explains that a driving time tolerance ('rijtijdspeling') is applied to the Dutch rail timetable to accommodate variations in driving times. According to him, these are not added evenly along the trajectory but are mainly added one stop after a large node. This is firstly done because the chance of a delay is relatively high at the node stations, and secondly because delays at red and green nodes have relatively large consequences (van den Top, 2005). Lastly, for the inaccessibility of stations or the effects on customer satisfaction, ProRail gives a preference to the amount of passenger affected, over the duration or severity of failure. This too, is common in network analysis, in which a large number of passengers is often weighted heavily when analysing system failure (Priemus, 2006; Wang et al., 2013).

According to Zeithaml, Bitner & Gremler (2006), the occurrence of service failures is virtually inherent to the provision of services. By correctly addressing the disruption however, for example by supplying instantaneous and real-time information or by paying attention to the waiting environment, delays will be experienced as less annoying (Pruyn & Smidts, 1998). Furthermore, delays due to extended dwell times can be minimized by for example improving the station layout so that boarding passengers can be prevented from clustering too much due to the lack of facilities to protect travellers from (extreme) wind, rain, or temperature conditions.

7.2. Risk attitude of ProRail

The risk dialogues with ProRail revealed that damages of extreme rainfall or drought hazards were perceived as being more serious and unwanted than a uniform damage as result of extreme heat. The reason for this is mainly related to a different feeling of responsibility or culpability. That sense of responsibility can play a significant role in triggering corrective action is endorsed by Weber (2010), in her study on the factors that shape perceptions of climate change. She highlights that many (environmental) decisions are only made if one recognizes the situation as one for which a rule exists. This can be laws or self-imposed policies, many of which derive from the social roles of decision makers, or social norms and values that, when harmed, could influence ProRail’s reputation. Promoting a more widespread use of rule-based processes in climate decisions would therefore be effective in encouraging long term sustainable behaviour and in dealing with the negative effects of climate change.

Furthermore, the possibility and simplicity of avoiding risk, and the immediateness of the occurrence play a role in ProRail’s weighing of risk. A temperature increase was for example seen as a more gradual risk than a fire hazard or a flooding, and the measures to prevent its negative effects were found easier and more straightforward. This is also in line with the study of Weber (2010), who established that if people perceive climate change as a rather simple and gradual change from current to future values, the risks posed by climate change seem to be recognized and, at least in principle, controllable. In most cases, this does however not mean that people act upon hazards even if they are aware of them, because their perceived ability to take action is enough to offer them comfort (Leiserowitz, 2004). Climate change that is seen as swift is more likely to be feared than climate change that is expected to be gradual.

For the determination of risk attitude, this study has been limited to the existing functionality of stations. As mentioned in section 4, due to its central location and excellent accessibility, a station could however also function as a disaster support hub in times of crisis (e.g. a corona vaccination hub or as a resource distribution point after a catastrophic event). Such potential functionalities were not evaluated in terms of risk attitudes but could change demands for accepted levels of climate resilience. This is something that could be further explored.

7.3. Case studies

The case studies had a dual function in this study. First of all, they were used to help validate the risk assessment methodology. The case studies have demonstrated that risks and the damage sensitivity and probability of exposure to threats are very situation-specific. It is therefore not a given that there is no threat if a station is assigned a low probability of exposure according to the analysis in section 5.3, and vice versa. Breda-Prinsenbeek, for example, runs the – initially unforeseen – risk of short-circuit in technical rooms due to a leakage in the room enclosures, and Leeuwarden-Cammingaburen, with its low-lying tunnel entrances, is conversely not at risk of inaccessibility due to flooding, because of the presence of a sump pump in the tunnel. Also, the coping and adaptive capacity of the stations vary widely, meaning that the probability of exposure in practice requires more differentiation than ‘high’ or ‘low’, and that damage sensitivities can differ extensively for identical hazards. Hence, further research is needed into the specific situation for each station separately, so that it is clear which stations are, in fact, critical.

Secondly, the case studies were effective for assessing the underlying causes of risks to study adaptation strategies and display strategies to build resilience to extreme weather. This could encourage decisionmakers, asset- and project managers as they address climate change through the implementation of real climate actions and could provide strategic long-term quantitative insights on adaptation strategies for stations in the Netherlands. The risk analyses of the stations of the case studies have shown that potential adaptation strategies for extreme rainfall hazards, are very situation specific. In general, water retention and storage measures are very relevant. A major advantage of these measures is that the problem of excess water can be solved directly and locally, and that they can be combined with other services, so that there is no unilateral use of space. However, due to the specific nature of flooding problems, further analysis into the specific causes of threats is required before being able to proceed to solutions.

Solutions or adaptation strategies to cope with heat have proven to be much more straightforward. The cause of heat stress is always the (extended period of) increasingly high temperatures and the lack of protection. Glass roofs, walls or closed glass waiting shelters enhance the heating effect. From the questionnaire it was apparent that increasing the shaded surface is an efficient strategy to reduce heat and, if there is space, water elements, vegetation, wind circulation and possibly albedo-enhancing materials could be applied. With drought, the issue lies in the fact that there is a strong division in responsibilities in dealing with drought related issues. Solutions to counteract local soil subsidence or fire hazards for example, such as the seasonal wetting of peat or measures to make forests more resilient to external influences, are to be managed by the government and is out of ProRail’s hands. It is therefore particularly important for ProRail to monitor the subsidence of their platforms and station buildings and, in the event of exceedance of accepted limits, to switch to the maintenance of track height or to create extra load bearing capacity. In new constructions, modern techniques such as fixative building or soil improvement could be used to prevent drought problems in future projects.

In general, the responsibility for the realisation and maintenance of measures is strongly divided. To solve the problem of flooding, the responsibility partly lies with the municipality - or the water board -, due to their ownership of the sewerage, drainage canals, the paved forecourts and immediate area around the station. The responsibilities also rest partly with NS, responsible for the commercial operations and implementation of daily management at stations, or with ProRail, in charge of building and managing stations. The responsibility for realisation of heat measures lies with NS, possibly with other carriers, and with ProRail. For drought, the responsibility for creating resilience generally lies with the central government, the municipality and/or ProRail and NS. When assessing the need for measures to strengthen climate resilience, the benefits to ProRail should be considered along with benefits to other involved actors that may be affected. Determining different stakeholders’ responsibilities, interests, and contributions is a challenging part in the development of climate adaptation measures and strategies. To come up with effective and efficient adaptation strategies, cooperation between actors must be organized first, and responsible person(s) or actor(s) need to be appointed for implementation and maintenance of the adaptive measures. Objectives and acceptance criteria need to be clear and accepted by all stakeholders.

7.4. Methodological limitations and implications for further research

In this study, a method was created to investigate the risks of climate extremes for train stations and risk matrices were created for ProRail to be able to assess their attitude towards these risks. The risk and vulnerability analyses of five specific stations with completely different characteristics, and a questionnaire held at stations on the traveller's perception of heat, confirm the relevance and applicability of this method for stations in The Netherlands. With use of this method, a first insight can be obtained into the vulnerability of Dutch railway stations to climate extremes, and into the negative aspects of climate change for stations that require attention. This study does not reveal anything yet on the actual likelihood of occurrence and the quantification of risk, or what the precise damage would be if something was to go wrong. In this section, the limitations and constraints of the used methodology and implications for further research are therefore discussed.

7.4.1. Implications of the sum of threats for total risk

The analysis on the probability of exposure includes a total of 13 threats that, in theory, together must account for the total potential risk for railway stations, in terms of extreme rainfall, heat and drought. Although these threats have been carefully selected and validated based on academic literature, historical data from ProRail, and experts from ProRail and Arcadis, the sum of threats do not provide a complete picture of the vulnerability of railway stations to climate change. There are certain additional threats that are worth mentioning, but of which not enough data is currently available. A detailed analysis must follow into the probability of exposure of these threats for railway stations and their significance for their functionalities. Examples of such unaccounted threats are:

- Extreme rainfall: softening of the subsurface due to heavy precipitation around foundation (blocks) (ProRail & Arcadis, 2020). A possible method to investigate this effect could be to properly monitor their movement.
- Heat: stations located in urban environments with a high density of buildings and paved surface, are at higher risk of suffering from the urban heat island effect.
- Heat: deformation of tunnel structures due to heating and the resulting horizontal displacement.
- Heat: construction or rail workers could in the future not be allowed to continue their work with temperatures being too high, while nowadays many large projects are carried out during the summer holidays. It has not yet been considered whether heat could cause a delay to such projects, in case work cannot be carried out or is to be carried out more slowly in extreme temperatures.

In conclusion, the thirteen threats mentioned in this study provide a good initial insight into the vulnerability of stations to climate change, but further research into the additional threats such as the ones mentioned above and others could make the vulnerability analysis even more exhaustive.

7.4.2. Weighing of threats

When adding the probability of exposure of threats to estimate the total risk of a station, it is assumed that each threat, independent of the hazard, has the same weighting factor and thereby the same relative importance. This is not in line with the studies of Black (1997) Zhu et al, (2000) and Holt (2005), who argue that the weighing of threats or risks is essential in the determination of total risk. In this study, however, applying a weight and thereby determining the relative importance of a threat, is dependent on a variety of factors. Creating shadow (H1), for example, is the most effective way to lower the perceived temperature and can lead to a reduction in the apparent temperature of up to 10-15 ° C (Kluck et al., 2020). Results of the same research show that evaporative cooling by vegetation (H3) only has a limited cooling effect on the apparent temperature; up to 3 ° C in the immediate vicinity, if the vegetation surface is considerable (> 4m^2). This, in combination with the results of the questionnaire, would give reason to assign a different, less significant weighing factor to the absence of vegetation, than to the absence of shadow. This reasoning, however, is too simple, since many other factors play a role in the assessment of the importance or significance of a threat. Vegetation, for example, in contrast to waiting shelters, increases the aesthetic value of the station, improves costumer experience, and it positively contributes to the water management on the platform. In addition, the absence of water taps (H2), or the potential failure of technical systems (H4) cannot be compared to the absence of vegetation or shelter in any case since they have implications for physical well-being and the technical functionality, respectively, rather than the apparent temperature. In assigning an appropriate weighing factor which allows for a fair comparison between threats, it is more valuable to consider the implications the threats might have on the functioning of the station, than the magnitude of the individual threat. In this study, this is done in the form of the risk matrix. Each threat was linked to the station function(s) that if would affect, and the station functions were linked to one or more risk categories. The acceptance level that is assigned to each combination of damage sensitivity and probability of exposure in the risk matrix is therefore an indirect weighing of the threats. Furthermore, the creation of three separate matrices for extreme rainfall, heat and drought hazards rather than one, allows for comparisons between the relative acceptance of risks associated with the different hazards. A different, more direct way to be able to compare the different hazards would for example be to attach monetary values to each risk.

7.4.3. Use of a single storm event

In the analysis of the risk of extreme rainfall for stations, a storm event of 70 mm in 2 hours was considered, corresponding to a storm occurring once every 100 years in 2050. This was based on the climate effect atlas that gives an insight into the water depth that occurs for two storm events: a shower with 70 mm in 2 hours (T=100 years) and a shower with 140 mm of precipitation in 2 hours (T=1000 years). In the rural environment, that react more slowly to rainfall than the urban environment, prolonged storm events over several days are often more critical than short storm events. A single storm event of 70 mm in 2 h is therefore representative assessing flood risks in urbanized rather than rural environments.

7.4.4. Risk matrix

The application of a risk matrix requires the use of discrete classes or categories for probability and damage sensitivity. This characteristic has been criticized by some authors (ISO, 2010; Duijm, 2015). The ISO (2010), for example argues how difficult it is to define scales unambiguously and warns that subjective use could cause variation in interpretation between raters. Discrete, subjective estimates for level or category descriptions are subject to a number of cognitive biases. (Kent; 1964; Hubbard & Evans, 2010). This includes observer bias (detection bias leading to different assessments of subjective criteria), optimism bias (bias that causes someone to believe that they themselves are less likely to experience a negative event) or confirmation bias (tendency to interpret information in a way that confirms one's prior beliefs), which would all affect personal judgement of probability and damage sensitivity. In this study however, to avoid cognitive bias, examples within the risk categories were given in great detail, and where possible, quantitative descriptions (ranges or anchor points) were added to definitions. Furthermore, individual results were compared and discussed between respondents in the risk matrix dialogues leading to consensus in interpretation, limiting the variability in understanding of verbal descriptions of categories.

Secondly, the risk matrix of this study includes six levels of damage sensitivity and two levels of probability of exposure; a low and a high probability. For the probability of exposure, this distribution was chosen because it is in accordance with the approach for the exposure to threats in section 5.3 (0 or 1). To be able to distinguish more probability categories, a difference could for example have been made between degree of inundation, the proportion of shaded or vegetated surface, or the degree of soil subsidence in an area. For certain threats, however, such as the drainage capacity of roofs which are all designed to the same storm event, the uplift of station tunnels in sandy soil or the number of water taps, such a differentiation is not possible. As a result, it was decided to differentiate only between a 'low' and 'high' probability of exposure, as this was the only method for which reliable and comparative assumptions could be made for all threats. A disadvantage of having only two probability categories is that it lowers the resolution of risk categories, which means that the number of risk ties (combinations of damage and likelihood leading to the same colour or RPN), increases (Ni et al., 2010). For the risk matrix of this study, however, and its purpose of determining general risk acceptance within multiple risk categories it is not necessary to obtain a single ranking of risk. It “simply” suffices to identify whether risks are acceptable, unacceptable, or somewhere in between. According to Duijm (2015), a sufficient and practicable resolution of categories means that there will be no drawbacks of the limited resolution in the risk cells. In the risk dialogues, categories for probability and damage were deemed applicable and practicable by the Management Team of ProRail stations, meaning that they were able to select the correct categories for (potential) events without major ambiguity. Nonetheless, six levels of damage sensitivity were chosen because ISO (2010), observes with respect to the resolution of the damage sensitivity scale that it “should cover the range of different types of consequence to be considered (…) and should extend from the maximum credible consequence to the lowest consequence of concern.” Six damage sensitivity categories therefore provide a more complete representation of the total extent of damage sensitivity than three. Having six categories allows for a more detailed differentiation between types of stations and number of potentially affected passengers.

Thirdly, this matrix distinguishes only three levels of risk acceptance. A larger number of risk levels could be favourable to obtain sufficient resolution to rank hazards or risks in order of priority (Duijm, 2015). In this study, it was chosen to use only three levels to decrease complexity and to fit the time schedule of ProRail’s MT. In further design or application of this matrix, it could be valuable to increase the amount of levels of risks acceptance.

Lastly, in this study a choice was made to split the risk matrix into three analyses; one for heat, one for drought, and one for extreme rainfall. This was chosen because splitting the analyses was most valuable for ProRail, since it leads to better prioritization per risk category for different hazards, and ProRail makes a distinction between consequences of the same order of magnitude for different hazards. In the future, however, it could be of value to combine the three analyses into one, for the purpose of making well-balanced investment decisions as a department.

7.4.5. Case studies

A problem encountered when conducting the case studies was often the lack of reliable data. First of all, for extreme rainfall, the municipalities of all five stations use different storm events with different return periods for their stress tests (see table 13 and figure 27). For the inundation maps, the stress tests seldom included the interaction with the sewer or surface water system, sometimes incorporated soil type or land use, and occasionally included a road access map. For heat, the stress test often indicated actual apparent temperatures (PET) for the 1st of July 2015 between 12-18h, sometimes showed the relative apparent temperatures compared to actual temperatures and sometimes showed the apparent temperature relative to rural areas. For drought, the stress tests were even less consistent. Hence, there is no way to compare these municipal stress test results amongst themselves or to national data as portrayed in the climate effect atlas. It is therefore difficult, if not impossible, to make statements about the relative risk, vulnerability or “safety” amongst municipalities and stations located in these different municipalities.

Secondly, the registration of past floodings of the station’s vulnerable places were - or sometimes seemed - incomplete or incorrect. For example, floodings were registered on days with only light or no storm events, not even in previous days. In addition, there is no recollection of incidents before the time of employment of station managers, meaning that the registration of past incidents due to weather influences sometimes only went back 1 or 2 years. Furthermore, it was difficult to gain insight into the hydraulic calculation models of the sewer or surface water system because these are often owned by the municipalities and outsourced to an engineering firm. This makes it difficult to determine the station’s current exposure to flood hazards.

7.4.5. Questionnaire

Due to the heat, the holiday period and the corona pandemic, the number of passengers at the stations was relatively low. The response at Swalmen and Maastricht Randwyck stations was even very low (n = 2, n = 26, respectively). At the other stations it varied from n = 58 to n = 108. The number of interviewees at Swalmen and Maastricht Randwyck is too small to derive statistical correlation. To generate a statistical analysis, it is recommended to have at minimum 10 observations per variable, and in the case of more than 3 variables, a minimum of 30 respondents (VanVoorhis & Morgan, 2007).

The heat, holiday period and corona pandemic also resulted in a different population than usual at the station. Across the entire survey, 40.1 % of the respondents indicated that work, a business trip or school/study was the main reason for the train journey that day. Normally, in the yearly questionnaires on customer satisfaction over the years 2013-2020, this was 74.0 %. Research shows that there is a difference between utilitarian customers and hedonic customers in the way they experience an environment (Babin et al., 2003; Kaltcheva & Weitz, 2006). NS customers can also be divided into utilitarian and hedonic customers, with commuting passengers or passengers that travel for education purposes being the utilitarian customers and passengers going on family visits, holidays or going shopping being the hedonic customers (van Hagen, 2015). Travellers from both groups are therefore also likely to perceive (the disturbance from) heat in a different way. This is acknowledged by Kluck et al (2016), who showed that there is a large psychological component in the perception of heat; perception depends on the objectives that people have on a hot day. People find it warmer when their activity has an obligatory, hasty or unavoidable element. This finding was also demonstrated in this study; 22% of utilitarian travellers found it very or terribly hot, compared to 16 % of hedonic travellers. The relatively low representation of utilitarian travellers due to the holiday period and the corona pandemic, could therefore have caused an underestimation of the *severity* of the perception of heat at stations.

8. Conclusion & Recommendations

8.1. Conclusion

This research aims to provide an insight into the risks of climate change-induced hazards for Dutch railway stations, and the associated effects on the station's functionality for passengers. For this risk assessment, the W_H-scenario of the KNMI was used (2014), and climate risks were assessed for rainfall-, heat- and drought extremes for a passenger's station. The research presented here demonstrates whether climate extremes could affect Dutch railway stations. Using this information, the efficacy of ProRail's current climate policy can be assessed, climate resilience can be increased and the negative effects of climate change on Dutch stations can be minimised.

The current degree of attention that ProRail pays to climate adaptation can be assessed based on the Safety Culture Ladder ("Veiligheidsladder") of the NEN (Nederlands Normalisatie Instituut) (NEN, n.d.). This ladder distinguishes five steps that could indicate the development phase in which ProRail finds itself in the field of climate risk awareness. The ladder begins at a pathological development stage and develops into a reactive, a calculating, a proactive and finally a progressive development stage. Based on the results of this study, ProRail's awareness level of potential climate risks for stations can currently be characterized as somewhere between pathological and reactive: little is yet being invested in improving adaptative capacity and ProRail generally responds to events after they have happened. To this day, there have been only a few station development projects whereby climate adaptation was considered, and even the climate adaptation experts within ProRail are not fully aware of the amount or the scope of these projects, because climate adaptation was often non-deliberate or only a secondary concern in the design. At the Ede-Wageningen station project, for example, climate adaptation was not considered in the early stages of the design process and was considered a 'complementary effect' rather than (one of) the fundamental objectives. This indicates a level of random- or reactiveness in the implementation of measures rather than an organized approach as part of a strategy. Secondly, this study showed that ProRail does not always follow its own requirements as described in design regulations (such as placement of ventilation in technical rooms), and that ProRail's own design standards do not always meet national requirements as described in the Dutch Buildings Decree (Bouwbesluit) or Water Law (Waterwet) (e.g. for roof drainage capacities). The large degree of uncertainty and inconsistency in decision-making and climate research, in combination with the increased risk of a higher frequency of extreme climate-related events beyond the present coping range, result in increasing deficiencies in the climate resilience of the stations.

In this study, thirteen potential climate threats for Dutch railway stations were identified and analysed based on current knowledge on the characteristics, features and surroundings of the station, given current design criteria. Results show that out of 401 Dutch railway stations, there are 6 stations with zero associated threats for 2050, 181 stations with 1 or 2 threats, 154 stations with 3 or 4 threats and 60 stations with 5, 6 or 7 threats, with a national median of 3 threats. The most important transport nodes in the Dutch network and the "mega" stations with over 25,000 travellers per day have a median of 4 threats per station, meaning that these stations are at a higher risk than national average. The consequences of these threats can vary from damage to structures, inaccessibility of the rail network, negative effects on the safety and wellbeing of travellers, failures of electrical and/or telecom systems, or negative effects on customer satisfaction and the reputation of ProRail. Furthermore, extreme weather events could lead to a different use of the train and public transportation system and to different behaviour, causing overcrowding or congestion, increasing dwell times and causing delays. These findings suggest a certain vulnerability of the current system and demonstrate that there are many aspects of climate change at stations that require attention.

The station’s dominant sensitivity to extreme rainfall is the result of its often relatively low-lying position compared to its surrounding area, combined with its high amount of paved surface. Almost half of stations are vulnerable to flooding because of water flowing in from the surrounding area. Secondly, 40 % of stations are vulnerable to uncontrolled drainage from roofs or platform canopy, since roofs and platform canopies are designed to drainage capacities below the current Dutch national standards. The dominant sensitivity to heat is the lack of water taps at about 35 % of stations, enhancing the risk of overheating or dehydration at these stations. For drought risks, the dominant sensitivity is related to the fact that around 20% of stations have wooden foundations and are located on peat soils, which poses a risk of damage to station buildings or platform structures.

The local applicability of the findings of the risk assessment was tested in five case studies on stations with very different characteristics, sizes and locations. In addition to this, a heat risk assessment was made with use of a questionnaire on a traveller’s heat perception. The questionnaire showed that more than half of travellers felt fairly (38%), very (18%) or terribly hot (3%) on the station on hot summer or tropical days, and on average, the opportunities to cool down or find shelter, water or ventilation were rated insufficient. The case studies have demonstrated that many of the identified threats appear to be relevant and appropriate on a local scale as well, but that risk is situation-specific since other threats than those initially identified could be applicable. This confirms the understanding that stations are or could be vulnerable to climate change, but also emphasizes the importance of further research into the specific local risks and vulnerability to climate extremes.

8.2. Recommendations

The results of this study imply an opportunity for ProRail to rethink the efficacy of their current, pathological or reactive, approach to climate resilience of their railway stations. Therefore, in this final section, implications of this research for ProRail’s policy design regarding climate adaptation are discussed. To minimize the effects of climate change on the functionality of railway stations, it could be beneficial for ProRail to aim for the proactive step of the safety culture ladder, which is characterised by proactivity and initiative. In order to reach this step; climate adaptation is to become a higher concern and improvements to increase resilience should be introduced and evaluated more systematically. The specific climate risks and underlying root causes at each station need to be studied and quantified. It is important to find out what the exact implications of climate threats are at specific stations; stormwater runoff from platform roofs can flow towards the tracks but can also flow towards more vulnerable areas such as shops, technical areas or platform tunnels, and an inundation of 30 cm in station tunnel that forms the only access route to the platforms has different implications for accessibility than an inundation of 2 cm in a tunnel that is one of many access routes. In addition, more research into the exact coping range of each station regarding storm events or soil subsidence would be valuable, to get a deeper insight into the precise vulnerabilities.

It is recognized that it is challenging, if not impossible, to fully capture the diversity between the stations and the climate risks these stations have to cope with. Standardization of the methods of determining the risks is therefore beneficial, as it reduces confusion and increases simplification, optimization and coordination (Walters, 1986). This does not imply that standardization is not a process of evolution: research initiatives on climate risks for stations should be constantly updated based on new climate scenarios, threats and the expected change in mobility (behaviour) in the future. Additionally, to reach a proactive climate awareness level, a thorough evaluation and implementation of own design regulations and current national regulations regarding buildings, climate or weather is fundamental. Since various actors are involved in making stations climate-proof (e.g. multiple carriers, municipalities and water boards) it helps to create a common strategy to guide initiatives with all involved parties. And last but not least it is recommended to accurately register floodings and other climate-related incidents in an (online) database.

8.2.1. Strategy design

To decrease vulnerability and provide focus for adaptation, it is valuable to develop a climate adaptation strategy with clear goals and ambitions from now until 2050, in line with the national climate policy on spatial adaptation (Deltacommissie, 2018). This strategy should follow from the study and quantification of risks at individual stations, which can be assessed with use of the risk matrix. Also, the interests, contributions and responsibilities each involved actor has - or accepts – is to be discussed. Again, this strategy can only be based on current understandings of the consequences of climate change and is therefore a process of constant evolution and development. Different climate strategies can be developed for new projects, including the involvement of climate adaptation in ProRail’s investment programs for in the foreseeable future, and projects to increase the climate resilience of existing stations. For new projects, the pertinency of policy and design requirements ought to be verified and updated if necessary (e.g. at least x water taps per y number of visitors, or no station entrances below ground level without water drainage and storage facilities). The current guide for climate adaptation of ProRail (‘Handreiking Klimaatadaptatie’) can be improved with the inclusion of the updated policy and design requirements for new station projects, and the emphasis on the need for adaptability on the long run. Furthermore, the findings of the risk assessments for each station or project area should become widely available in internal databases and require mandatory consultation with all new projects. Improvements should be implemented, monitored and evaluated systematically, so that lessons can be learned from previous activities.

The inventory of quantified risks, and the portraying of these risks over the risk matrix, will demonstrate whether there are climate effects at stations that are urgent or in need of (immediate) action. A strategy to compare estimated severity of risk and to prioritize adaptive action is to analyse how much climate change would cost ProRail in terms of monetary values, if no action were taken. Also, a “checklist” for prioritisation can be created, whereby the stations that tick the most boxes, are to be given immediate attention in the following year. Depending on the chosen climate adaptation strategy and the urgency of climate risks for ProRail, an X number of stations could then be made climate-resilient every year.

The most relevant countermeasures for strengthening resilience to extreme rainfall, are water retention and storage measures. A major advantage of these measures is that the problem of excess water can be solved directly and locally, and that they can be combined with other services, so that there is no unilateral use of space. Water storage or retention measures can for example simultaneously contribute to green recreation, biodiversity, water and air quality. Secondly, to manage and maintain a station’s technical functionality, it is essential to design the vital infrastructure in such a way that it can withstand a period of flooding and continue to function. Increasing shade is the most effective strategy to reduce heat. Sun protection canvasses or (green) waiting shelters are examples of simple and effective measures to increase shade, as they are low cost, relatively simple to install and move, and, in the case of the sun canvasses, need little to no space on the platforms. For drought, it would be most efficient to start monitoring the movements of buildings and platform structures in critical areas. Extended dwell times or delays as a result of weather extremities can be minimized by improving the station layout, so that clustering of boarding passengers due to the lack of facilities to protect travellers from (extreme) wind, rain, or heat conditions can be prevented. And to conclude, when assessing the need for measures to strengthen climate resilience, it is important to discuss different stakeholder's responsibilities, interests, and intended contributions. Responsible person(s) or actor(s) need to be appointed for implementation and maintenance of the adaptive measures.

The recommendations mentioned above are aimed to improve resilience of Dutch railway stations to climate change. They provide a basis for a climate resilience strategy and for designing relevant adaptation measures for railway stations. In short, it would be beneficial for ProRail to adopt a more proactive attitude in the researching of risk and in the development of a climate adaptation strategy.

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10. Appendix

A. Questionnaire Dutch

1. Uit wat voor een omgeving komt u zojuist?
   - ☐ Ik kom uit een koele omgeving
   - ☐ Ik kom uit een warme omgeving
   - ☐ Anders namelijk: ________________

2. Hoe ervaart u de warmte op dit moment?
   - ☐ Ik heb het een beetje warm
   - ☐ Ik heb het behoorlijk warm
   - ☐ Ik heb zeer warm
   - ☐ Ik heb het verschrikkelijk warm

3. Heeft u lichamelijke klachten van de warmte op dit moment? Zo ja, welke? Er zijn meerdere antwoorden mogelijk.
   - ☐ Dorstig
   - ☐ Rillen
   - ☐ Benauwd
   - ☐ Duizelig
   - ☐ Hoofdpijn
   - ☐ Misselijk
   - ☐ Verwarring
   - ☐ Anders namelijk: ______________
   - ☐☐ Nee, ik heb geen lichamelijke klachten

4. In hoeverre bent u het eens met onderstaande stellingen?

(1=helemaal mee oneens, 10=helemaal mee eens. Kruis n.v.t. aan als de uitspraak voor u niet van toepassing is)

	1	2	3	4	5	6	7	8	9	10	n.v.t
Ik vind dat er op dit station voldoende mogelijkheden zijn om gratis water te verkrijgen.	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Op dit station zijn er voldoende mogelijkheden om tijdens een warme dag verkoeling te vinden.	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Ik vind dat er op dit perron voldoende beschutting (schaduw) is tegen de zon.	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Ik ervaar voldoende verkoeling (ventilatie/wind) op dit perron.	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Geef aan welke van de volgende antwoorden voor u van toepassing zijn.

5. Ik vind het op dit perron …
   - ☐ koeler dan in de directe omgeving van het station
   - ☐ warmer dan in de directe omgeving van het station
   - ☐ er is geen verschil

6. Op dit perron waait …
   - ☐ meer wind dan in de directe omgeving van het station
   - ☐ minder wind dan in de directe omgeving van het station
   - ☐ er is geen verschil

7. Op dit perron is er …
   - ☐ minder beschutting tegen zon/warmte dan in de directe omgeving van het station
   - ☐ meer beschutting tegen zon/warmte dan in de directe omgeving van het station
   - ☐ er is geen verschil

8. Wat vindt u prettige plekken op dit station als het meer dan 25 graden is?	9. Wat vindt u onprettige plekken op dit station als het meer dan 25 graden is?

10. Wat zou u willen verbeteren op dit station op zomerse dagen > 25 graden?

11. Geef a.u.b. een rapportcijfer voor de volgende onderwerpen.

(1=zeer slecht, 10=zeer goed)	1	2	3	4	5	6	7	8	9	10	n.v.t
Uw algemeen oordeel over het perron waar u wacht of heeft gewacht	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Uw algemeen oordeel over dit station	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

12. Wat is voor u de belangrijkste reden om <u>vandaag</u> deze treinreis te maken?
- ☐ Van / naar werk
- ☐ Zakenreis / dienstreis
- ☐ Van / naar school, studie, cursus, opleiding
- ☐ Bezoek aan familie / kennissen, zieken(huis)bezoek
- ☐ Winkelen
- ☐ Vakantie / uitstapje / dagje weg
- ☐ Sport / hobby
- ☐ Ik reis niet met de trein

13. Hoe vaak reist u met de trein?
- ☐ 4 dagen per week of meer
- ☐ 1 tot 3 dagen per week
- ☐ 1 tot 3 dagen per maand
- ☐ 6 tot 11 dagen per jaar
- ☐ 3 tot 5 dagen per jaar
- ☐ 1 of 2 dagen per jaar
- ☐ Minder dan 1 dag per maand

14. Wat is uw leeftijd?

____

15. Wat is uw geslacht?
- ☐ Vrouw
- ☐ Man
- ☐ Overig

A1. Questionnaire English

1. What kind of environment have you just come from?
   - ☐ I come from a cool environment
   - ☐ I come from a warm environment
   - ☐ Other, namely: ____________________

2. How do you experience the heat at the moment?
   - ☐ I am a little warm
   - ☐ I am quite hot
   - ☐ I am very hot
   - ☐ I am terribly hot

3. Do you currently have physical complaints from the heat? If yes, which one? Multiple answers are possible.
   - ☐ Thirsty
   - ☐ Shivering
   - ☐ Stuffy
   - ☐ Dizzy
   - ☐ Headache
   - ☐ Nausea
   - ☐ Confusion
   - ☐ Other, namly: __________________
   - ☐☐ I have no physical complaints

4. To what extent do you agree with the following statements?

(1 = totally disagree, 10 = totally agree. Check n/a if the statement does not apply to you)

	1	2	3	4	5	6	7	8	9	10	n/a
I think there are plenty of options at this <u>station</u> to obtain free water.	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
At this <u>station</u> there are plenty of opportunities to cool down during a hot day.	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
I think there is enough shelter from the sun (shade) on this <u>platform</u>	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
I experience enough cooling (ventilation / wind) on this <u>platform</u>.	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Please indicate which of the following answers apply to you.

5. On this platform I find it’s…
   - ☐ cooler than the immediate vicinity of the station
   - ☐ warmer than in the immediate vicinity of the station
   - ☐ there is no difference

6. On this platform.. …
   - ☐ there is more wind than in the immediate vicinity of the station
   - ☐ there is less wind than in the immediate vicinity of the station
   - ☐ there is no difference

7. On this platform there is..
   - ☐ less shelter from the sun/heat than in the immediate vicinity of the station
   - ☐ more shelter from the sun/heat than in the immediate vicinity of the station
   - ☐ there is no difference

8. What do you find pleasant places at this station when the temperature is higher than 25 degrees?	9. What do you find unpleasant places at this station when the temperature is higher than 25 degrees?

8. 8. What would you like to improve at this station on summer days> 25 degrees?

9. Please rate the following

(1=very bad, 10=very good	1	2	3	4	5	6	7	8	9	10	n/a
Your general opinion of the platform where you are waiting or have been waiting	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Your overall opinion of this station	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

10. What is your main reason for this journey today?
- ☐ From / to work
- ☐ Business trip
- ☐ From / to school, study, course, education
- ☐ Visit to relatives/ acquaintances, hospital
- ☐ Shopping
- ☐ Vacation / excursion / day trip
- ☐ Sports / hobby
- ☐ I don’t travel by train today

11. How often do you travel by train?
- ☐ 4 days per week or more
- ☐ 1 to 3 days per week
- ☐ 1 to 3 days per month
- ☐ 6 to 11 days per year
- ☐ 3 to 5 days per year
- ☐ 1 or 2 days per year
- ☐ Less than 1 day per month

12. What is your age?

____

13. Wat is your gender?
- ☐ Female
- ☐ Male
- ☐ Other

B. Summary of all threats for all 401 stations

	Name	**Region**	**Class**	**R1**	**R1.2**	**R2**	**R3**	**R4**	**R5**	*R_Total*	**H1**	**H2**	**H3**	*H_Total*	**D1**	**D2**	**D3**	*D_Total*	**Total**
1	Aalten	North-East	Basis	0	0	0	0	0	1	*1*	0	1	1	*2*	0	1	0	*1*	4
2	Abcoude	Randstad North	Basis	0	0	0	0	1	0	*1*	0	1	0	*1*	0	0	0	*0*	2
3	Akkrum	North-East	Halte	0	0	0	0	0	0	*0*	0	1	0	*1*	0	0	0	*0*	1
4	Alkmaar	Randstad North	Plus	1	1	0	0	1	1	*4*	0	0	0	*0*	0	1	0	*1*	5
5	Alkmaar Noord	Randstad North	Basis	1	1	0	0	1	1	*4*	0	0	0	*0*	0	1	0	*1*	5
6	Almelo	North-East	Plus	1	1	0	0	1	1	*4*	0	0	1	*1*	0	0	0	*0*	5
7	Almelo de Riet	North-East	Basis	0	0	0	0	0	0	*0*	0	0	0	*0*	0	0	0	*0*	0
8	Almere Buiten	Randstad North	Basis	0	0	0	0	1	0	*1*	0	0	0	*0*	1	0	1	*2*	3
9	Almere Centrum	Randstad North	Mega	1	0	0	0	1	0	*2*	0	0	1	*1*	1	0	0	*1*	4
10	Almere Muziekwijk	Randstad North	Basis	1	0	0	0	1	0	*2*	0	0	0	*0*	0	0	0	*0*	2
11	Almere Oostvaarders	Randstad North	Basis	0	0	0	0	0	0	*0*	0	1	0	*1*	1	0	1	*2*	3
12	Almere Parkwijk	Randstad North	Basis	0	0	0	0	1	0	*1*	0	0	0	*0*	1	0	0	*1*	2
13	Almere Poort	Randstad North	Basis	0	0	0	0	0	0	*0*	0	1	1	*2*	0	0	0	*0*	2
14	Alphen a/d Rijn	Randstad South	Plus	1	1	0	1	1	1	*5*	0	0	1	*1*	0	0	0	*0*	6
15	Amersfoort Centraal	Randstad North	Mega	0	0	0	0	1	1	*2*	0	0	0	*0*	0	0	0	*0*	2
16	Amersfoort Schothorst	Randstad North	Basis	0	1	0	0	0	0	*1*	1	0	0	*1*	0	0	0	*0*	2
17	Amersfoort Vathorst	Randstad North	Basis	0	0	0	0	1	0	*1*	0	1	1	*2*	0	0	0	*0*	3
18	Amsterdam Amstel	Randstad North	Mega	1	0	0	1	1	1	*4*	0	0	1	*1*	0	1	0	*1*	6
19	Amsterdam ArenA	Randstad North	Halte	0	0	0	0	0	0	*0*	1	1	1	*3*	1	0	0	*1*	4
20	Amsterdam Bijlmer ArenA	Randstad North	Mega	0	0	0	0	1	0	*1*	0	0	1	*1*	1	0	0	*1*	3
21	Amsterdam Centraal	Randstad North	Kathedraal	1	1	0	1	1	0	*4*	0	0	1	*1*	0	1	0	*1*	6
22	Amsterdam Holendrecht	Randstad North	Basis	0	0	0	0	1	0	*1*	0	0	1	*1*	1	0	0	*1*	3
23	Amsterdam Lelylaan	Randstad North	Plus	1	0	0	0	1	0	*2*	0	0	1	*1*	0	0	0	*0*	3
24	Amsterdam Muiderpoort	Randstad North	Plus	1	0	0	0	1	0	*2*	0	0	0	*0*	0	1	0	*1*	3
25	Amsterdam RAI	Randstad North	Basis	0	1	0	0	1	0	*2*	0	0	1	*1*	0	0	0	*0*	3
26	Amsterdam Science Park	Randstad North	Basis	1	0	0	0	1	1	*3*	0	0	1	*1*	0	0	0	*0*	4
27	Amsterdam Sloterdijk	Randstad North	Mega	1	0	0	0	1	1	*3*	0	0	0	*0*	0	1	0	*1*	4
28	Amsterdam Zuid	Randstad North	Mega	1	1	0	0	1	0	*3*	0	0	0	*0*	0	1	0	*1*	4
29	Anna Paulowna	Randstad North	Basis	0	0	0	0	0	0	*0*	0	0	1	*1*	0	0	0	*0*	1

30	Apeldoorn	North-East	Plus	1	1	0	0	1	1	*4*	0	0	0	*0*	0	0	0	*0*	4
31	Apeldoorn De Maten	North-East	Halte	0	0	0	0	1	0	*1*	0	0	1	*1*	0	0	0	*0*	2
32	Apeldoorn Osseveld	North-East	Basis	0	0	0	0	1	0	*1*	0	1	1	*2*	0	0	0	*0*	3
33	Appingedam	North-East	Halte	0	0	0	0	0	0	*0*	0	1	0	*1*	0	1	0	*1*	2
34	Arkel	Randstad South	Halte	0	0	0	0	0	0	*0*	0	1	1	*2*	0	1	0	*1*	3
35	Arnemuiden	South	Halte	0	0	0	0	0	0	*0*	0	1	0	*1*	0	0	0	*0*	1
36	Arnhem Centraal	North-East	Mega	1	1	0	1	1	1	*5*	0	0	0	*0*	0	0	1	*1*	6
37	Arnhem Presikhaaf	North-East	Basis	0	0	0	0	0	0	*0*	0	1	1	*2*	0	0	1	*1*	3
38	Arnhem Velperpoort	North-East	Basis	0	0	0	0	1	0	*1*	0	0	1	*1*	0	1	1	*2*	4
39	Arnhem Zuid	North-East	Basis	1	0	0	0	1	0	*2*	0	1	1	*2*	0	1	0	*1*	5
40	Assen	North-East	Basis	0	0	0	1	1	1	*3*	0	0	1	*1*	0	0	1	*1*	5
41	Baarn	Randstad North	Basis	1	1	0	0	1	1	*4*	0	0	0	*0*	0	1	0	*1*	5
42	Bad Nieuweschans	North-East	Halte	0	0	0	0	0	0	*0*	0	1	0	*1*	0	0	0	*0*	1
43	Baflo	North-East	Halte	0	0	0	0	0	0	*0*	0	0	1	*1*	0	1	0	*1*	2
44	Barendrecht	Randstad South	Basis	0	1	0	0	0	1	*2*	0	0	1	*1*	0	0	0	*0*	3
45	Barneveld Centrum	North-East	Basis	0	0	0	0	0	1	*1*	0	0	1	*1*	0	0	1	*1*	3
46	Barneveld Noord	North-East	Halte	0	0	0	0	0	0	*0*	0	1	0	*1*	0	0	0	*0*	1
47	Barneveld Zuid	North-East	Halte	0	0	0	0	0	0	*0*	0	1	1	*2*	0	0	0	*0*	2
48	Bedum	North-East	Halte	0	0	0	0	0	0	*0*	0	1	1	*2*	0	0	0	*0*	2
49	Beek - Elsloo	South	Basis	0	0	0	0	0	1	*1*	0	0	1	*1*	0	0	0	*0*	2
50	Beesd	South	Halte	0	0	0	0	0	0	*0*	0	0	1	*1*	0	0	0	*0*	1
51	Beilen	North-East	Basis	0	0	0	0	0	0	*0*	0	0	0	*0*	1	0	0	*1*	1
52	Bergen op Zoom	South	Basis	1	1	0	1	1	1	*5*	0	0	0	*0*	0	0	0	*0*	5
53	Best	South	Basis	0	1	0	1	0	1	*3*	0	0	1	*1*	0	0	0	*0*	4
54	Beverwijk	Randstad North	Basis	1	1	0	1	1	1	*5*	0	0	1	*1*	0	1	0	*1*	7
55	Bilthoven	Randstad North	Basis	0	1	0	0	1	1	*3*	0	0	0	*0*	0	0	0	*0*	3
56	Blerick	South	Basis	0	1	0	0	0	0	*1*	1	1	0	*2*	0	0	0	*0*	3
57	Bloemendaal	Randstad North	Basis	0	1	0	1	1	1	*4*	0	0	0	*0*	0	1	0	*1*	5
58	Bodegraven	Randstad South	Basis	0	0	0	0	0	1	*1*	0	0	0	*0*	0	1	0	*1*	2
59	Borne	North-East	Basis	0	0	0	0	0	1	*1*	0	0	1	*1*	0	0	0	*0*	2
60	Boskoop	Randstad South	Basis	0	0	0	0	0	1	*1*	0	1	1	*2*	1	1	0	*2*	5
61	Boskoop Snijdelwijk	Randstad South	Halte	0	0	0	0	0	0	*0*	1	1	1	*3*	1	0	0	*1*	4
62	Boven - Hardinxveld	Randstad South	Halte	0	0	0	0	0	0	*0*	0	1	1	*2*	0	0	0	*0*	2
63	Bovenkarspel - Grootebroek	Randstad North	Halte	0	0	0	0	0	0	*0*	0	0	1	*1*	0	0	0	*0*	1

64	Bovenkarspel Flora	Randstad North	Basis	0	0	0	0	0	0	*0*	0	1	0	*1*	0	0	0	*0*	1
65	Boxmeer	South	Basis	0	0	0	0	0	1	*1*	0	0	1	*1*	0	0	0	*0*	2
66	Boxtel	South	Basis	0	0	0	0	1	1	*2*	0	0	1	*1*	0	0	0	*0*	3
67	Breda	South	Mega	0	0	0	1	1	0	*2*	0	0	1	*1*	0	0	0	*0*	3
68	Breda - Prinsenbeek	South	Basis	0	0	0	0	1	1	*2*	0	1	1	*2*	0	0	0	*0*	4
69	Breukelen	Randstad North	Basis	1	0	0	0	1	0	*2*	0	1	0	*1*	0	1	0	*1*	4
70	Brummen	North-East	Basis	0	0	0	0	0	0	*0*	0	1	0	*1*	0	0	0	*0*	1
71	Buitenpost	North-East	Basis	0	0	0	0	1	0	*1*	0	0	1	*1*	0	0	0	*0*	2
72	Bunde	South	Halte	0	0	0	0	0	1	*1*	0	1	0	*1*	0	0	0	*0*	2
73	Bunnik	Randstad North	Basis	0	0	0	0	0	1	*1*	0	0	0	*0*	0	0	0	*0*	1
74	Bussum Zuid	Randstad North	Basis	0	0	0	0	0	1	*1*	0	0	0	*0*	0	1	0	*1*	2
75	Capelle Schollevaar	Randstad South	Basis	0	0	0	0	1	0	*1*	0	0	0	*0*	1	0	0	*1*	2
76	Castricum	Randstad North	Basis	1	1	1	0	1	1	*5*	0	0	0	*0*	0	0	0	*0*	5
77	Chèvremont	South	Halte	0	0	0	0	0	1	*1*	0	1	0	*1*	0	0	0	*0*	2
78	Coevorden	North-East	Basis	0	0	0	0	1	1	*2*	0	0	0	*0*	0	0	0	*0*	2
79	Cuijk	South	Basis	0	0	0	0	0	1	*1*	0	0	1	*1*	0	0	0	*0*	2
80	Culemborg	South	Basis	1	1	0	1	1	0	*4*	0	0	0	*0*	0	0	0	*0*	4
81	Daarlerveen	North-East	Halte	0	0	0	0	0	0	*0*	0	1	1	*2*	0	0	0	*0*	2
82	Dalen	North-East	Halte	0	0	0	0	1	1	*2*	0	0	1	*1*	0	0	0	*0*	3
83	Dalfsen	North-East	Basis	0	0	0	0	0	0	*0*	1	0	0	*1*	0	0	0	*0*	1
84	De Vink	Randstad South	Basis	1	1	0	0	0	0	*2*	1	0	1	*2*	0	0	0	*0*	4
85	De Westereen	North-East	Halte	0	0	0	0	0	0	*0*	0	0	1	*1*	0	0	0	*0*	1
86	Deinum	North-East	Halte	0	0	0	0	0	0	*0*	0	1	1	*2*	0	0	0	*0*	2
87	Delden	North-East	Basis	0	0	0	0	0	1	*1*	0	0	1	*1*	0	0	1	*1*	3
88	Delft	Randstad South	Mega	1	0	0	0	0	1	*3*	0	0	1	*1*	0	0	0	*0*	4
89	Delft Campus	Randstad South	Basis	0	0	0	0	1	1	*2*	0	1	0	*1*	0	0	0	*0*	3
90	Delfzijl	North-East	Halte	0	0	0	0	1	1	*2*	0	0	0	*0*	0	1	0	*1*	3
91	Delfzijl West	North-East	Halte	1	0	0	0	0	0	*1*	0	1	1	*2*	0	0	0	*0*	3
92	Den Dolder	Randstad North	Basis	1	0	0	0	0	0	*1*	1	0	0	*1*	0	1	0	*1*	3
93	Den Haag Centraal	Randstad South	Kathedraal	1	0	0	0	0	1	*2*	0	0	1	*1*	0	0	0	*0*	3
94	Den Haag HS	Randstad South	Mega	1	1	0	0	1	0	*3*	0	0	1	*1*	0	1	0	*1*	5
95	Den Haag Laan van NOI	Randstad South	Plus	1	1	0	1	1	0	*4*	0	0	0	*0*	0	0	0	*0*	4
96	Den Haag Mariahoeve	Randstad South	Basis	1	1	0	1	1	0	*4*	0	0	1	*1*	0	0	0	*0*	5
97	Den Haag Moerwijk	Randstad South	Basis	0	0	0	0	0	0	*0*	0	0	0	*0*	0	0	0	*0*	0

98	Den Haag Ypenburg	Randstad South	Basis	0	0	0	0	1	0	*1*	0	1	1	*2*	0	0	0	*0*	3
99	Den Helder	Randstad North	Basis	0	0	0	0	1	1	*2*	0	0	1	*1*	0	1	0	*1*	4
100	Den Helder Zuid	Randstad North	Basis	1	0	0	1	0	0	*2*	0	1	1	*2*	0	0	0	*0*	4
101	Deurne	South	Basis	0	0	0	0	0	1	*1*	0	0	0	*0*	0	0	0	*0*	1
102	Deventer	North-East	Plus	1	1	0	1	1	0	*4*	0	0	0	*0*	0	0	0	*0*	4
103	Deventer Colmschate	North-East	Basis	0	1	0	0	0	0	*1*	1	1	0	*2*	0	0	0	*0*	3
104	Didam	North-East	Basis	0	0	0	0	0	1	*1*	0	1	1	*2*	0	0	0	*0*	3
105	Diemen	Randstad North	Basis	0	0	0	0	0	1	*1*	0	0	0	*0*	0	1	0	*1*	2
106	Diemen Zuid	Randstad North	Basis	0	0	0	0	1	0	*1*	0	0	1	*1*	1	0	0	*1*	3
107	Dieren	North-East	Basis	0	1	0	0	1	1	*3*	0	0	0	*0*	0	0	1	*1*	4
108	Doetinchem	North-East	Basis	0	0	0	0	0	1	*1*	0	0	1	*1*	0	0	1	*1*	3
109	Doetinchem De Huet	North-East	Basis	0	0	0	0	1	1	*2*	0	0	0	*0*	0	0	1	*1*	3
110	Dordrecht	Randstad South	Mega	1	1	0	1	1	1	*5*	0	0	1	*1*	0	1	0	*1*	7
111	Dordrecht Stadspolders	Randstad South	Basis	0	1	0	0	0	0	*1*	0	1	0	*1*	0	0	0	*0*	2
112	Dordrecht Zuid	Randstad South	Basis	0	0	0	0	0	0	*0*	0	0	1	*1*	0	0	0	*0*	1
113	Driebergen - Zeist	Randstad North	Basis	1	1	1	0	1	0	*4*	0	0	0	*0*	0	0	0	*0*	4
114	Driehuis	Randstad North	Basis	0	1	1	0	0	0	*2*	0	1	0	*1*	0	0	0	*0*	3
115	Dronryp	North-East	Halte	0	0	0	0	0	0	*0*	0	1	1	*2*	0	0	0	*0*	2
116	Dronten	Randstad North	Basis	1	0	0	0	0	0	*1*	0	1	0	*1*	0	0	0	*0*	2
117	Duiven	North-East	Basis	0	0	0	0	0	1	*1*	0	0	0	*0*	0	0	0	*0*	1
118	Duivendrecht	Randstad North	Plus	0	1	0	0	1	0	*2*	0	0	0	*0*	1	1	0	*2*	4
119	Echt	South	Basis	0	0	0	0	1	1	*2*	0	0	1	*1*	0	0	0	*0*	3
120	Ede - Wageningen	North-East	Plus	1	1	0	1	1	1	*5*	0	0	0	*0*	0	0	1	*1*	6
121	Ede Centrum	North-East	Halte	0	0	0	0	0	1	*1*	0	1	0	*1*	0	0	1	*1*	3
122	Eemshaven	North-East	Basis	0	0	0	0	0	0	*0*	0	1	0	*1*	0	0	0	*0*	1
123	Eijsden	South	Halte	0	0	0	0	0	1	*1*	0	1	1	*2*	0	0	0	*0*	3
124	Eindhoven Centraal	South	Mega	1	1	0	0	1	0	*3*	0	0	0	*0*	0	0	0	*0*	3
125	Eindhoven Stadion	South	Halte	1	0	0	0	0	0	*1*	1	1	1	*3*	0	0	0	*0*	4
126	Eindhoven Strijp-S	South	Basis	0	1	0	0	1	0	*2*	0	1	0	*1*	0	0	0	*0*	3
127	Elst	North-East	Basis	0	0	0	0	0	1	*1*	0	0	1	*1*	0	0	0	*0*	2
128	Emmen	North-East	Basis	0	0	0	0	1	1	*2*	0	0	0	*0*	0	0	1	*1*	3
129	Emmen Zuid	North-East	Halte	1	0	0	0	1	0	*2*	0	1	1	*2*	0	0	0	*0*	4
130	Enkhuizen	Randstad North	Basis	0	0	0	0	0	0	*0*	0	0	0	*0*	0	1	0	*1*	1
131	Enschede	North-East	Plus	0	0	0	0	1	0	*1*	0	0	1	*1*	0	0	0	*0*	2

132	Enschede De Eschmarke	North-East	Halte	0	0	0	0	0	0	*0*	0	1	1	*2*	0	0	0	*0*	2
133	Enschede Kennispark	North-East	Basis	0	1	0	0	0	0	*1*	0	0	1	*1*	0	0	0	*0*	2
134	Ermelo	North-East	Basis	0	0	0	0	0	1	*1*	1	0	1	*2*	0	0	1	*1*	4
135	Etten - Leur	South	Basis	0	0	0	0	0	1	*1*	0	0	1	*1*	0	0	0	*0*	2
136	Eygelshoven	South	Halte	0	0	0	0	0	0	*0*	0	1	1	*2*	0	0	0	*0*	2
137	Eygelshoven Markt	South	Halte	0	0	0	0	0	1	*1*	0	1	1	*2*	0	0	0	*0*	3
138	Feanwalden	North-East	Halte	0	0	0	0	0	1	*1*	0	0	1	*1*	0	0	0	*0*	2
139	Franeker	North-East	Basis	0	0	0	0	0	1	*1*	0	1	0	*1*	0	0	0	*0*	2
140	Gaanderen	North-East	Halte	0	0	0	0	0	1	*1*	0	0	1	*1*	0	0	0	*0*	2
141	Geldermalsen	South	Basis	0	0	0	0	1	0	*1*	0	0	0	*0*	0	0	0	*0*	1
142	Geldrop	South	Basis	1	1	0	0	1	0	*3*	0	0	1	*1*	0	0	0	*0*	4
143	Geleen - Lutterade	South	Halte	0	0	0	0	0	1	*1*	0	1	0	*1*	0	0	0	*0*	2
144	Geleen Oost	South	Basis	0	0	0	0	0	0	*0*	0	0	1	*1*	0	0	0	*0*	1
145	Gilze - Rijen	South	Basis	0	0	0	0	0	0	*0*	0	0	1	*1*	0	0	0	*0*	1
146	Glanerbrug	North-East	Halte	0	0	0	0	0	0	*0*	0	1	1	*2*	0	0	0	*0*	2
147	Goes	South	Basis	1	1	0	1	1	1	*5*	0	0	1	*1*	0	0	0	*0*	6
148	Goor	North-East	Basis	0	0	0	0	1	0	*1*	0	0	0	*0*	0	0	0	*0*	1
149	Gorinchem	Randstad South	Basis	1	1	0	0	1	1	*4*	0	0	0	*0*	0	0	0	*0*	4
150	Gouda	Randstad South	Mega	1	1	0	1	1	0	*4*	0	0	1	*1*	0	0	0	*0*	5
151	Gouda Goverwelle	Randstad South	Basis	0	0	0	0	0	1	*1*	0	0	1	*1*	1	0	0	*1*	3
152	Gramsbergen	North-East	Halte	0	0	0	0	0	0	*0*	0	0	0	*0*	0	0	0	*0*	0
153	Grijpskerk	North-East	Halte	0	0	0	0	0	0	*0*	0	1	0	*1*	0	0	0	*0*	1
154	Groningen	North-East	Mega	1	0	0	0	1	1	*3*	0	0	1	*1*	0	0	0	*0*	4
155	Groningen Europapark	North-East	Basis	0	0	0	0	1	1	*2*	0	0	1	*1*	0	0	0	*0*	3
156	Groningen Noord	North-East	Basis	1	0	0	0	1	0	*2*	0	0	0	*0*	0	0	0	*0*	2
157	Grou - Jirnsum	North-East	Halte	0	0	0	0	0	0	*0*	0	0	0	*0*	0	0	0	*0*	0
158	Haarlem	Randstad North	Mega	1	0	0	0	1	0	*2*	0	0	1	*1*	0	1	0	*1*	4
159	Haarlem Spaarnwoude	Randstad North	Basis	1	0	0	0	0	1	*2*	0	1	1	*2*	1	0	0	*1*	5
160	Halfweg - Zwanenburg	Randstad North	Basis	0	0	0	0	1	0	*1*	0	1	1	*2*	0	0	0	*0*	3
161	Hardenberg	North-East	Basis	0	0	0	0	0	1	*1*	0	0	1	*1*	0	0	0	*0*	2
162	Harderwijk	North-East	Basis	0	1	0	0	0	1	*2*	1	0	1	*2*	0	0	1	*1*	5
163	Hardinxveld - Giessendam	Randstad South	Halte	0	0	0	0	0	0	*0*	0	1	1	*2*	0	0	0	*0*	2
164	Hardinxveld Blauwe Zoom	Randstad South	Basis	0	0	0	0	0	0	*0*	0	1	1	*2*	0	0	0	*0*	2
165	Haren	North-East	Basis	0	0	0	0	0	0	*0*	0	0	0	*0*	1	0	0	*1*	1

166	Harlingen	North-East	Basis	0	0	0	0	1	1	*2*	0	0	1	*1*	0	1	0	*1*	4
167	Harlingen Haven	North-East	Halte	0	0	0	0	0	1	*1*	0	1	1	*2*	0	0	0	*0*	3
168	Heemskerk	Randstad North	Basis	0	0	0	0	0	1	*1*	0	1	1	*2*	0	0	0	*0*	3
169	Heemstede - Aerdenhout	Randstad North	Basis	1	0	0	0	1	0	*2*	0	0	0	*0*	0	0	0	*0*	2
170	Heerenveen	North-East	Basis	0	1	0	0	1	0	*2*	0	0	0	*0*	0	0	0	*0*	2
171	Heerenveen IJsstadion	North-East	Halte	0	0	0	0	0	1	*1*	0	1	1	*2*	0	0	0	*0*	3
172	Heerhugowaard	Randstad North	Basis	0	0	0	0	1	0	*1*	0	0	0	*0*	0	1	0	*1*	2
173	Heerlen	South	Basis	1	1	0	1	1	1	*5*	0	0	1	*1*	0	0	0	*0*	6
174	Heerlen De Kissel	South	Halte	0	0	0	0	0	1	*1*	0	1	1	*2*	0	0	0	*0*	3
175	Heerlen Woonboulevard	South	Halte	0	0	0	0	0	0	*0*	0	1	1	*2*	0	0	0	*0*	2
176	Heeze	South	Basis	1	1	0	0	1	1	*4*	0	0	1	*1*	0	0	0	*0*	5
177	Heiloo	Randstad North	Basis	0	0	0	0	1	1	*2*	0	0	0	*0*	0	0	0	*0*	2
178	Heino	North-East	Halte	0	0	0	0	0	0	*0*	0	1	1	*2*	0	0	0	*0*	2
179	Helmond	South	Basis	0	0	0	1	1	1	*3*	0	0	1	*1*	0	0	0	*0*	4
180	Helmond Brandevoort	South	Basis	0	0	0	1	0	0	*1*	1	0	1	*2*	0	0	0	*0*	3
181	Helmond Brouwhuis	South	Basis	0	0	0	0	1	0	*1*	0	0	0	*0*	0	0	1	*1*	2
182	Helmond 't Hout	South	Basis	0	0	0	1	0	0	*1*	0	0	0	*0*	0	0	0	*0*	1
183	Hemmen - Dodewaard	North-East	Halte	0	0	0	0	0	1	*1*	0	0	1	*1*	0	0	0	*0*	2
184	Hengelo	North-East	Plus	1	1	0	1	1	0	*4*	0	0	1	*1*	0	0	0	*0*	5
185	Hengelo Gezondheidspark	North-East	Halte	0	0	0	0	0	1	*1*	0	1	0	*1*	0	0	0	*0*	2
186	Hengelo Oost	North-East	Halte	0	0	0	0	0	0	*0*	0	1	1	*2*	0	0	0	*0*	2
187	Hillegom	Randstad North	Basis	0	0	0	0	1	0	*1*	0	0	0	*0*	0	0	0	*0*	1
188	Hilversum	Randstad North	Mega	1	1	0	0	1	1	*4*	0	0	1	*1*	0	0	1	*1*	6
189	Hilversum Media Park	Randstad North	Basis	0	0	0	0	1	1	*2*	0	0	0	*0*	0	0	1	*1*	3
190	Hilversum Sportpark	Randstad North	Basis	0	0	0	0	0	1	*1*	0	0	0	*0*	0	1	0	*1*	2
191	Hindeloopen	North-East	Halte	0	0	0	0	0	0	*0*	0	1	0	*1*	0	0	0	*0*	1
192	Hoensbroek	South	Halte	0	0	0	0	0	0	*0*	0	1	1	*2*	0	0	0	*0*	2
193	Hoevelaken	North-East	Basis	0	0	0	0	0	0	*0*	0	1	1	*2*	0	0	0	*0*	2
194	Hollandsche Rading	Randstad North	Halte	0	0	0	0	0	0	*0*	0	0	0	*0*	0	0	0	*0*	0
195	Holten	North-East	Basis	0	0	0	0	0	0	*0*	0	1	1	*2*	0	0	0	*0*	2
196	Hoofddorp	Randstad North	Plus	0	0	0	0	1	0	*1*	0	0	0	*0*	0	0	0	*0*	1
197	Hoogeveen	North-East	Basis	1	1	0	0	0	0	*2*	0	0	0	*0*	1	0	0	*1*	3
198	Hoogezand - Sappemeer	North-East	Basis	0	0	0	0	0	0	*0*	1	0	1	*2*	0	0	0	*0*	2
199	Hoogkarspel	Randstad North	Basis	0	0	0	0	0	0	*0*	1	0	1	*2*	0	1	0	*1*	3

200	Hoorn	Randstad North	Plus	0	0	0	0	1	1	*2*	0	0	0	*0*	0	0	0	*0*	2
201	Hoorn Kersenboogerd	Randstad North	Basis	1	0	0	0	1	1	*3*	0	0	1	*1*	0	0	0	*0*	4
202	Horst - Sevenum	South	Basis	0	0	0	1	0	0	*1*	0	0	1	*1*	0	0	0	*0*	2
203	Houten	Randstad North	Basis	1	0	0	0	1	0	*2*	0	0	1	*1*	0	0	0	*0*	3
204	Houten Castellum	Randstad North	Basis	1	0	0	0	1	0	*2*	0	1	1	*2*	0	0	0	*0*	4
205	Houthem - St.Gerlach	South	Halte	0	0	0	0	0	0	*0*	0	1	1	*2*	0	0	1	*1*	3
206	Hurdegaryp	North-East	Halte	0	0	0	0	0	1	*1*	0	1	0	*1*	0	1	0	*1*	3
207	IJlst	North-East	Halte	0	0	0	0	0	0	*0*	0	1	0	*1*	0	0	0	*0*	1
208	Kampen	North-East	Basis	0	0	0	0	1	0	*1*	0	0	1	*1*	0	0	0	*0*	2
209	Kampen Zuid	North-East	Basis	1	0	0	1	1	0	*3*	0	1	1	*2*	1	0	0	*1*	6
210	Kapelle - Biezelinge	South	Basis	0	0	0	0	0	0	*0*	0	1	1	*2*	0	0	0	*0*	2
211	Kerkrade Centrum	South	Halte	0	0	0	0	0	1	*1*	0	1	0	*1*	0	0	0	*0*	2
212	Kesteren	North-East	Halte	0	0	0	0	0	1	*1*	0	1	1	*2*	0	0	0	*0*	3
213	Klarenbeek	North-East	Halte	0	0	0	0	0	0	*0*	0	0	1	*1*	0	0	1	*1*	2
214	Klimmen - Ransdaal	South	Halte	0	0	0	0	0	1	*1*	0	0	1	*1*	0	0	0	*0*	2
215	Koog aan de Zaan	Randstad North	Basis	1	1	0	0	1	1	*4*	0	0	0	*0*	0	1	0	*1*	5
216	Koudum - Molkwerum	North-East	Halte	0	0	0	0	0	0	*0*	0	1	0	*1*	0	0	0	*0*	1
217	Krabbendijke	South	Halte	0	0	0	0	0	1	*1*	0	1	1	*2*	0	1	0	*1*	4
218	Krommenie - Assendelft	Randstad North	Basis	1	0	0	0	1	1	*3*	0	0	1	*1*	1	0	0	*1*	5
219	Kropswolde	North-East	Halte	0	0	0	0	0	0	*0*	0	0	0	*0*	1	0	0	*1*	1
220	Kruiningen - Yerseke	South	Halte	0	0	0	0	0	1	*1*	0	1	1	*2*	0	0	0	*0*	3
221	Lage Zwaluwe	South	Halte	0	0	0	0	0	0	*0*	0	0	1	*1*	0	0	0	*0*	1
222	Landgraaf	South	Halte	0	0	0	0	0	1	*1*	0	0	0	*0*	0	0	0	*0*	1
223	Lansingerland-Zoetermeer	Randstad South	Basis	0	0	0	0	0	0	*0*	0	0	1	*1*	0	0	0	*0*	1
224	Leerdam	Randstad South	Basis	0	0	0	0	0	0	*0*	0	1	1	*2*	0	0	0	*0*	2
225	Leeuwarden	North-East	Plus	1	1	0	0	1	1	*4*	0	0	1	*1*	0	0	0	*0*	5
226	Leeuwarden Camminghaburen	North-East	Halte	1	1	0	0	0	1	*3*	0	1	1	*2*	0	0	0	*0*	5
227	Leiden Centraal	Randstad South	Kathedraal	1	1	0	0	0	0	*2*	0	0	1	*1*	0	0	0	*0*	3
228	Leiden Lammenschans	Randstad South	Basis	0	0	0	0	0	0	*0*	1	0	0	*1*	0	1	0	*1*	2
229	Lelystad Centrum	Randstad North	Plus	1	0	0	0	1	0	*2*	0	0	0	*0*	1	0	0	*1*	3
230	Lichtenvoorde - Groenlo	North-East	Basis	0	0	0	0	0	0	*0*	0	1	1	*2*	0	0	0	*0*	2
231	Lochem	North-East	Basis	0	0	0	0	0	0	*0*	0	1	1	*2*	0	0	1	*1*	3
232	Loppersum	North-East	Halte	0	0	0	0	0	1	*1*	0	1	0	*1*	0	1	0	*1*	3
233	Lunteren	North-East	Halte	0	0	0	0	0	0	*0*	0	1	0	*1*	0	0	1	*1*	2

234	Maarheeze	South	Basis	0	0	0	0	0	0	*0*	0	1	1	*2*	0	0	1	*1*	3
235	Maarn	Randstad North	Basis	1	0	0	0	0	0	*1*	0	0	0	*0*	0	0	0	*0*	1
236	Maarssen	Randstad North	Basis	1	0	0	0	1	0	*2*	0	1	0	*1*	0	0	0	*0*	3
237	Maastricht	South	Plus	1	0	0	1	1	1	*4*	0	1	0	*1*	0	0	0	*0*	5
238	Maastricht Noord	South	Halte	0	0	0	0	1	0	*1*	0	0	1	*1*	0	0	0	*0*	2
239	Maastricht Randwyck	South	Basis	0	0	0	0	0	0	*0*	0	1	0	*1*	0	0	0	*0*	1
240	Mantgum	North-East	Halte	0	0	0	0	0	0	*0*	0	1	0	*1*	0	0	0	*0*	1
241	Mariënberg	North-East	Halte	0	0	0	0	0	1	*1*	0	0	0	*0*	0	0	1	*1*	2
242	Martenshoek	North-East	Basis	0	0	0	0	0	0	*0*	0	1	0	*1*	0	0	0	*0*	1
243	Meerssen	South	Basis	0	0	0	0	0	0	*0*	0	0	1	*1*	0	0	0	*0*	1
244	Meppel	North-East	Basis	1	0	0	1	1	1	*4*	0	0	0	*0*	0	0	0	*0*	4
245	Middelburg	South	Basis	1	1	0	1	1	0	*4*	0	0	1	*1*	0	1	0	*1*	6
246	Mook Molenhoek	North-East	xxx	0	0	0	0	0	1	*1*	0	1	1	*2*	0	0	1	*1*	4
247	Naarden - Bussum	Randstad North	Basis	1	1	0	1	1	1	*5*	0	0	0	*0*	0	0	0	*0*	5
248	Nieuw Amsterdam	North-East	Halte	0	0	0	0	0	1	*1*	0	0	0	*0*	0	0	0	*0*	1
249	Nieuw Vennep	Randstad North	Basis	0	0	0	0	0	0	*0*	0	0	0	*0*	0	0	0	*0*	0
250	Nieuwerkerk a/d IJssel	Randstad South	Basis	1	0	0	0	1	0	*2*	0	0	0	*0*	1	0	0	*1*	3
251	Nijkerk	North-East	Basis	0	0	0	0	0	1	*1*	1	0	1	*2*	0	0	0	*0*	3
252	Nijmegen	North-East	Mega	0	1	0	0	1	1	*3*	0	0	1	*1*	0	1	0	*1*	5
253	Nijmegen Dukenburg	North-East	Basis	0	0	0	0	1	0	*1*	0	0	0	*0*	0	1	0	*1*	2
254	Nijmegen Goffert	North-East	Basis	0	0	0	0	1	0	*1*	0	1	1	*2*	0	1	1	*2*	5
255	Nijmegen Heyendaal	North-East	Basis	0	0	0	0	0	1	*1*	0	1	1	*2*	0	0	1	*1*	4
256	Nijmegen Lent	North-East	Basis	1	0	0	0	0	0	*1*	1	1	1	*3*	0	1	0	*1*	5
257	Nijverdal	North-East	Basis	0	1	0	0	0	1	*2*	0	1	1	*2*	0	0	0	*0*	4
258	Nunspeet	North-East	Basis	0	0	0	0	0	1	*1*	1	0	0	*1*	0	0	1	*1*	3
259	Nuth	South	Halte	0	0	0	0	0	1	*1*	0	0	1	*1*	0	0	0	*0*	2
260	Obdam	Randstad North	Basis	0	0	0	0	0	0	*0*	0	0	0	*0*	0	1	0	*1*	1
261	Oisterwijk	South	Basis	0	1	0	1	1	1	*4*	0	0	0	*0*	0	0	0	*0*	4
262	Oldenzaal	North-East	Basis	0	0	0	0	1	1	*2*	0	0	1	*1*	0	0	0	*0*	3
263	Olst	North-East	Basis	0	0	0	0	0	1	*1*	0	1	1	*2*	0	0	0	*0*	3
264	Ommen	North-East	Basis	0	0	0	0	0	1	*1*	0	0	0	*0*	0	0	0	*0*	1
265	Oosterbeek	North-East	Halte	0	0	0	0	0	1	*1*	0	1	1	*2*	0	0	1	*1*	4
266	Opheusden	North-East	Halte	0	0	0	0	0	1	*1*	0	0	0	*0*	0	0	0	*0*	1
267	Oss	South	Basis	0	0	0	0	1	1	*2*	0	0	0	*0*	0	0	0	*0*	2

268	Oss West	South	Basis	0	0	0	0	0	1	*1*	0	1	0	*1*	0	0	0	*0*	2
269	Oudenbosch	South	Basis	0	0	0	0	0	1	*1*	0	0	0	*0*	0	0	0	*0*	1
270	Overveen	Randstad North	Basis	0	0	0	0	0	1	*1*	0	0	1	*1*	0	1	0	*1*	3
271	Purmerend	Randstad North	Basis	0	0	0	0	1	0	*1*	0	0	0	*0*	1	1	0	*2*	3
272	Purmerend Overwhere	Randstad North	Basis	0	0	0	0	1	0	*1*	0	0	0	*0*	0	0	0	*0*	1
273	Purmerend Weidevenne	Randstad North	Basis	1	0	0	0	1	0	*2*	0	1	1	*2*	1	0	0	*1*	5
274	Putten	North-East	Basis	0	0	0	0	0	0	*0*	1	0	0	*1*	0	0	1	*1*	2
275	Raalte	North-East	Basis	0	0	0	0	0	0	*0*	0	0	1	*1*	0	0	0	*0*	1
276	Ravenstein	South	Basis	0	0	0	0	0	0	*0*	0	1	1	*2*	0	0	0	*0*	2
277	Reuver	South	Basis	0	0	0	0	0	1	*1*	0	1	0	*1*	0	0	0	*0*	2
278	Rheden	North-East	Halte	0	0	0	0	0	1	*1*	0	1	0	*1*	0	0	1	*1*	3
279	Rhenen	Randstad North	Basis	0	0	0	0	0	1	*1*	0	0	0	*0*	0	0	0	*0*	1
280	Rijssen	North-East	Basis	0	0	0	0	0	1	*1*	0	0	1	*1*	0	0	0	*0*	2
281	Rijswijk	Randstad South	Basis	0	1	0	0	0	1	*2*	0	0	1	*1*	0	0	0	*0*	3
282	Rilland - Bath	South	Halte	0	0	0	0	0	0	*0*	0	1	0	*1*	0	0	0	*0*	1
283	Roermond	South	Plus	1	1	0	1	1	1	*5*	0	0	0	*0*	0	0	0	*0*	5
284	Roodeschool	North-East	Halte	0	0	0	0	0	1	*1*	0	1	1	*2*	0	0	0	*0*	3
285	Roosendaal	South	Plus	1	0	0	1	0	1	*3*	0	0	1	*1*	0	0	0	*0*	4
286	Rosmalen	South	Basis	0	0	0	0	1	1	*2*	0	0	0	*0*	0	0	0	*0*	2
287	Rotterdam Alexander	Randstad South	Plus	1	0	0	0	1	0	*2*	0	0	1	*1*	1	0	0	*1*	4
288	Rotterdam Blaak	Randstad South	Plus	0	1	0	1	0	1	*3*	0	0	1	*1*	0	0	0	*0*	4
289	Rotterdam Centraal	Randstad South	Kathedraal	1	1	0	1	1	0	*4*	0	0	1	*1*	0	0	0	*0*	5
290	Rotterdam Lombardijen	Randstad South	Basis	1	1	0	1	1	0	*4*	0	0	1	*1*	0	0	0	*0*	5
291	Rotterdam Noord	Randstad South	Basis	0	0	0	0	0	0	*0*	0	0	0	*0*	0	1	0	*1*	1
292	Rotterdam Stadion	Randstad South	Halte	0	0	0	0	0	1	*1*	1	1	1	*3*	0	0	0	*0*	4
293	Rotterdam Zuid	Randstad South	Basis	0	0	0	0	1	1	*2*	0	0	0	*0*	0	0	0	*0*	2
294	Ruurlo	North-East	Halte	0	0	0	0	0	1	*1*	1	0	1	*2*	0	0	1	*1*	4
295	's Hertogenbosch	South	Mega	0	1	0	0	1	0	*2*	0	0	0	*0*	0	0	0	*0*	2
296	's Hertogenbosch Oost	South	Halte	1	0	0	0	0	0	*1*	0	1	0	*1*	0	0	0	*0*	2
297	Santpoort Noord	Randstad North	Halte	1	1	1	0	0	0	*3*	1	0	0	*1*	0	1	0	*1*	5
298	Santpoort Zuid	Randstad North	Basis	0	0	0	0	1	1	*2*	0	0	0	*0*	0	1	0	*1*	3
299	Sappemeer Oost	North-East	Halte	0	0	0	0	0	0	*0*	0	1	0	*1*	0	0	0	*0*	1
300	Sassenheim	Randstad South	Basis	0	0	0	0	0	0	*0*	0	1	1	*2*	0	0	0	*0*	2
301	Sauwerd	North-East	Halte	0	0	0	0	0	0	*0*	0	1	1	*2*	0	0	0	*0*	2

302	Schagen	Randstad North	Plus	1	1	0	1	0	1	4	0	0	0	0	0	1	0	1	5
303	Scheemda	North-East	Halte	0	0	0	0	0	1	1	0	1	1	2	0	0	0	0	3
304	Schiedam Centrum	Randstad South	Halte	1	1	0	0	1	0	3	0	0	1	1	0	1	0	1	5
305	Schin op Geul	South	Kathedraal	0	0	0	0	0	1	1	0	0	0	0	0	1	1	2	3
306	Schinnen	South	Mega	0	0	0	0	0	0	0	0	1	1	2	0	0	0	0	2
307	Schiphol Airport	Randstad North	Basis	0	1	0	0	0	1	2	0	0	1	1	0	0	0	0	3
308	Sittard	South	Plus	1	1	0	1	1	1	5	0	0	0	0	0	0	0	0	5
309	Sliedrecht	Randstad South	Basis	0	0	0	0	1	0	1	0	1	1	2	0	0	0	0	3
310	Sliedrecht Baanhoek	Randstad South	Basis	0	0	0	0	0	0	0	0	1	1	2	0	0	0	0	2
311	Sneek	North-East	Basis	0	0	0	0	0	1	1	0	0	0	0	0	1	0	1	2
312	Sneek Noord	North-East	Basis	0	0	0	0	0	0	0	0	1	0	1	0	1	0	1	2
313	Soest	Randstad North	Halte	0	0	0	0	0	1	1	0	1	0	1	0	1	0	1	3
314	Soest Zuid	Randstad North	Basis	0	0	0	0	0	0	0	0	0	1	1	0	1	0	1	2
315	Soestdijk	Randstad North	Halte	0	0	0	0	0	1	1	0	0	0	0	0	1	0	1	2
316	Spaubeek	South	Halte	0	0	0	0	0	0	0	0	1	1	2	0	0	0	0	2
317	Stavoren	North-East	Halte	0	0	0	0	0	0	0	0	1	0	1	0	1	0	1	2
318	Stedum	North-East	Halte	0	0	0	0	0	1	1	0	1	0	1	0	0	0	0	2
319	Steenwijk	North-East	Basis	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	2
320	Susteren	South	Halte	0	0	0	0	0	1	1	0	0	1	1	0	0	1	1	3
321	Swalmen	South	Halte	0	0	0	0	0	1	1	0	1	1	2	0	0	0	0	3
322	't Harde	North-East	Halte	1	1	0	0	0	1	3	1	1	0	2	0	0	1	1	6
323	Tegelen	South	Halte	0	0	0	0	0	0	0	0	1	0	1	0	0	1	1	2
324	Terborg	North-East	Basis	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1
325	Tiel	South	Basis	0	0	0	0	0	1	1	0	0	1	1	0	1	0	1	3
326	Tiel Passewaaij	South	Basis	0	0	0	0	1	0	1	0	1	1	2	0	0	0	0	3
327	Tilburg	South	Mega	1	1	0	1	1	1	5	0	1	0	1	0	0	0	0	6
328	Tilburg Reeshof	South	Basis	0	0	0	1	1	0	2	0	1	1	2	0	0	1	1	5
329	Tilburg Universiteit	South	Basis	1	0	0	0	0	1	2	0	0	1	1	0	0	1	1	4
330	Twello	North-East	Basis	0	0	0	0	1	1	2	0	1	0	1	0	0	0	0	3
331	Uitgeest	Randstad North	Basis	0	1	0	1	1	1	4	0	0	0	0	0	0	0	0	4
332	Uithuizen	North-East	Halte	0	0	0	0	0	1	1	1	1	1	3	0	0	0	0	4
333	Uithuizermeeden	North-East	Halte	0	0	0	0	0	1	1	0	1	0	1	0	0	0	0	2
334	Usquert	North-East	Halte	0	0	0	0	0	1	1	0	1	1	2	0	0	0	0	3
335	Utrecht Centraal	Randstad North	Kathedraal	1	1	0	0	1	1	4	0	0	1	1	0	1	0	1	6

336	Utrecht Leidsche Rijn	Randstad North	Basis	1	1	0	0	1	0	*3*	0	1	1	*2*	0	0	0	*0*	5
337	Utrecht Lunetten	Randstad North	Basis	0	0	0	0	0	0	*0*	0	1	1	*2*	0	1	0	*1*	3
338	Utrecht Maliebaan	Randstad North	Halte	0	0	0	0	1	1	*2*	0	1	1	*2*	0	0	0	*0*	4
339	Utrecht Overvecht	Randstad North	Basis	1	1	0	0	1	1	*4*	0	0	0	*0*	0	0	0	*0*	4
340	Utrecht Terwijde	Randstad North	Basis	1	0	0	0	1	0	*2*	0	1	1	*2*	0	0	0	*0*	4
341	Utrecht Vaartsche Rijn	Randstad North	Basis	0	0	0	0	1	0	*1*	0	1	1	*2*	0	0	0	*0*	3
342	Utrecht Zuilen	Randstad North	Basis	1	0	0	0	1	0	*2*	0	1	1	*2*	0	1	0	*1*	5
343	Valkenburg	South	Basis	1	1	0	1	1	1	*5*	0	0	0	*0*	0	0	0	*0*	5
344	Varsseveld	North-East	Halte	0	0	0	0	0	1	*1*	0	0	0	*0*	0	1	0	*1*	2
345	Veendam	North-East	Basis	0	0	0	0	0	0	*0*	0	1	1	*2*	0	0	0	*0*	2
346	Veenendaal - De Klomp	North-East	Basis	0	1	0	0	0	0	*1*	0	0	0	*0*	0	1	0	*1*	2
347	Veenendaal Centrum	Randstad North	Basis	0	0	0	0	1	1	*2*	0	0	0	*0*	0	1	0	*1*	3
348	Veenendaal West	Randstad North	Basis	0	1	0	0	1	0	*2*	0	1	0	*1*	1	0	0	*1*	4
349	Velp	North-East	Basis	0	0	0	0	0	1	*1*	0	0	1	*1*	0	0	1	*1*	3
350	Venlo	South	Basis	1	1	0	1	1	1	*5*	0	0	0	*0*	0	0	0	*0*	5
351	Venray	South	Basis	0	0	0	0	0	0	*0*	0	0	1	*1*	0	0	0	*0*	1
352	Vierlingsbeek	South	Halte	0	0	0	0	0	0	*0*	0	1	1	*2*	0	0	0	*0*	2
353	Vleuten	Randstad North	Basis	1	0	0	0	1	0	*2*	0	1	1	*2*	0	0	0	*0*	4
354	Vlissingen	South	Basis	0	0	0	1	1	1	*3*	0	0	0	*0*	0	1	0	*1*	4
355	Vlissingen Souburg	South	Halte	0	0	0	0	0	0	*0*	0	1	0	*1*	0	0	0	*0*	1
356	Voerendaal	South	Halte	0	0	0	0	0	0	*0*	0	0	1	*1*	0	0	0	*0*	1
357	Voorburg	Randstad South	Basis	1	0	0	0	1	0	*2*	0	0	1	*1*	0	0	0	*0*	3
358	Voorhout	Randstad North	Basis	1	1	0	0	0	0	*2*	0	0	0	*0*	0	0	0	*0*	2
359	Voorschoten	Randstad South	Basis	0	0	0	0	1	0	*1*	0	0	1	*1*	0	0	0	*0*	2
360	Voorst - Empe	North-East	Halte	0	0	0	0	0	0	*0*	0	0	1	*1*	0	0	0	*0*	1
361	Vorden	North-East	Basis	0	0	0	0	0	0	*0*	0	0	1	*1*	0	0	1	*1*	2
362	Vriezenveen	North-East	Halte	0	0	0	0	0	1	*1*	1	1	1	*3*	0	0	0	*0*	4
363	Vroomshoop	North-East	Halte	0	1	0	0	1	1	*3*	0	1	1	*2*	0	0	0	*0*	5
364	Vught	South	Basis	1	1	0	1	0	1	*4*	0	0	0	*0*	0	0	1	*1*	5
365	Waddinxveen	Randstad South	Basis	0	0	0	0	0	0	*0*	0	1	1	*2*	0	0	0	*0*	2
366	Waddinxveen Noord	Randstad South	Halte	0	0	0	0	0	0	*0*	0	1	0	*1*	0	0	0	*0*	1
367	Waddinxveen Triangel	Randstad South	Halte	0	0	0	0	0	0	*0*	1	1	1	*3*	0	0	0	*0*	3
368	Warffum	North-East	Halte	0	0	0	0	0	1	*1*	0	1	1	*2*	0	0	0	*0*	3
369	Weert	South	Basis	1	1	0	1	1	0	*4*	0	0	0	*0*	0	0	0	*0*	4

370	Weesp	Randstad North	Plus	1	1	0	0	0	0	*2*	0	0	0	*0*	1	1	0	*2*	4
371	Wehl	North-East	Halte	0	0	0	0	0	1	*1*	0	0	1	*1*	0	0	0	*0*	2
372	Westervoort	North-East	Basis	1	0	0	0	0	0	*1*	0	0	1	*1*	0	0	0	*0*	2
373	Wezep	North-East	Basis	0	0	0	0	0	1	*1*	1	1	0	*2*	0	0	1	*1*	4
374	Wierden	North-East	Basis	1	1	0	0	0	1	*3*	0	0	1	*1*	0	0	0	*0*	4
375	Wijchen	North-East	Basis	0	0	0	0	0	1	*1*	0	0	1	*1*	0	0	0	*0*	2
376	Wijhe	North-East	Basis	0	0	0	0	0	0	*0*	0	1	0	*1*	0	0	0	*0*	1
377	Winschoten	North-East	Basis	0	0	0	0	1	1	*2*	0	0	0	*0*	0	0	0	*0*	2
378	Winsum	North-East	Basis	0	1	0	0	0	0	*1*	0	0	0	*0*	0	0	0	*0*	1
379	Winterswijk	North-East	Basis	0	0	0	0	1	1	*2*	0	0	1	*1*	0	0	0	*0*	3
380	Winterswijk West	North-East	Basis	0	0	0	0	0	0	*0*	0	1	1	*2*	0	0	1	*1*	3
381	Woerden	Randstad North	Plus	0	0	0	0	1	1	*2*	0	0	1	*1*	0	1	0	*1*	4
382	Wolfheze	North-East	Halte	1	1	1	0	0	0	*3*	0	0	0	*0*	0	0	1	*1*	4
383	Wolvega	North-East	Basis	0	0	0	0	0	1	*1*	0	0	0	*0*	0	0	0	*0*	1
384	Workum	North-East	Halte	0	0	0	0	0	0	*0*	0	1	0	*1*	1	0	0	*1*	2
385	Wormerveer	Randstad North	Basis	1	1	0	1	1	1	*5*	0	0	0	*0*	0	1	0	*1*	6
386	Zaandam	Randstad North	Plus	0	1	0	0	1	1	*3*	0	0	0	*0*	0	1	0	*1*	4
387	Zaandam Kogerveld	Randstad North	Basis	0	0	0	0	1	0	*1*	0	0	0	*0*	0	1	0	*1*	2
388	Zaandijk Zaanse Schans	Randstad North	Basis	1	1	0	1	1	1	*5*	0	0	0	*0*	0	1	0	*1*	6
389	Zaltbommel	South	Basis	0	1	0	0	1	0	*2*	0	0	0	*0*	0	0	0	*0*	2
390	Zandvoort aan Zee	Randstad North	Basis	0	0	0	0	0	0	*0*	1	0	0	*1*	0	1	0	*1*	2
391	Zetten - Andelst	North-East	Halte	0	0	0	0	0	1	*1*	0	0	0	*0*	0	0	0	*0*	1
392	Zevenaar	North-East	Basis	0	1	0	0	0	1	*2*	0	0	0	*0*	0	0	0	*0*	2
393	Zevenbergen	South	Basis	0	0	0	0	0	1	*1*	0	0	1	*1*	0	0	0	*0*	2
394	Zoetermeer	Randstad South	Basis	0	0	0	0	1	0	*1*	0	0	0	*0*	0	0	0	*0*	1
395	Zoetermeer Oost	Randstad South	Basis	0	0	0	0	0	1	*1*	0	0	0	*0*	0	0	0	*0*	1
396	Zuidbroek	North-East	Halte	0	0	0	0	0	0	*0*	0	1	0	*1*	0	0	0	*0*	1
397	Zuidhorn	North-East	Basis	0	0	0	0	0	0	*0*	0	0	1	*1*	0	0	0	*0*	1
398	Zutphen	North-East	Plus	1	1	0	0	1	0	*3*	0	0	1	*1*	0	0	0	*0*	4
399	Zwijndrecht	Randstad South	Basis	1	1	0	1	1	0	*4*	0	0	1	*1*	0	1	0	*1*	6
400	Zwolle	North-East	Mega	1	1	0	1	1	1	*5*	0	0	1	*1*	0	0	0	*0*	6
401	Zwolle Stadshagen	North-East	Basis	0	0	0	0	0	0	*0*	1	1	1	*3*	0	0	0	*0*	3
	Median																		3

Table 17: Summary of threats for all Dutch railway stations

B1. Summary of threats on critical stations

Station	**Region**	**Class**	R3	R_Total	H_Total	D_Total	**Total**
Almelo	North-East	Plus	0	*4*	*1*	*0*	5
Almere Centrum	Randstad North	Mega	0	*2*	*1*	*1*	4
Alphen a/d Rijn	Randstad South	Plus	1	*5*	*1*	*0*	6
Amersfoort Centraal	Randstad North	Mega	0	*1*	*0*	*0*	1
Amsterdam Centraal	Randstad North	Kathedraal	1	*4*	*1*	*1*	6
Amsterdam Sloterdijk	Randstad North	Mega	0	*3*	*0*	*1*	4
Apeldoorn	North-East	Plus	0	*4*	*0*	*0*	4
Boxtel	South	Basis	0	*2*	*1*	*0*	3
Den Haag Centraal	Randstad South	Kathedraal	0	*2*	*1*	*0*	3
Den Haag HS	Randstad South	Mega	0	*3*	*1*	*1*	5
Dordrecht	Randstad South	Mega	1	*5*	*1*	*1*	7
Ede - Wageningen	North-East	Plus	1	*5*	*0*	*1*	6
Enschede	North-East	Plus	0	*1*	*1*	*0*	2
Groningen	North-East	Mega	0	*3*	*1*	*0*	4
Gouda	Randstad South	Mega	1	*4*	*1*	*0*	5
Hilversum	Randstad North	Mega	0	*4*	*1*	*1*	6
Hoorn	Randstad North	Plus	0	*2*	*0*	*0*	2
Lelystad Centrum	Randstad North	Plus	0	*2*	*0*	*1*	3
Roermond	South	Plus	1	*5*	*0*	*0*	5
Roosendaal	South	Plus	1	*3*	*1*	*0*	4
Rotterdam Centraal	Randstad South	Kathedraal	1	*4*	*1*	*0*	5
's Hertogenbosch	South	Mega	0	*2*	*0*	*0*	2
Schiphol Airport	Randstad North	Basis	0	*2*	*1*	*0*	3
Uitgeest	Randstad North	Basis	1	*4*	*0*	*0*	4
Utrecht Centraal	Randstad North	Kathedraal	0	*4*	*1*	*1*	6
Weesp	Randstad North	Plus	0	*2*	*0*	*2*	4
Zutphen	North-East	Plus	0	*3*	*1*	*0*	4
Median							4

Table 18: Total threats for the red nodes, summarized for water, heat, drought and threat R3

Station	**Region**	**Class**	R3	R_Total	H_Total	D_Total	**Total**
Alkmaar	Randstad North	Plus	0	*4*	*0*	*1*	5
Amsterdam Bijlmer ArenA	Randstad North	Mega	0	*1*	*1*	*1*	3
Arnhem Centraal	North-East	Mega	1	*5*	*0*	*1*	6
Baarn	Randstad North	Basis	0	*4*	*0*	*1*	5
Breda	South	Mega	1	*2*	*1*	*0*	3
Deventer	North-East	Plus	1	*4*	*0*	*0*	4
Eindhoven Centraal	South	Mega	0	*3*	*0*	*0*	3
Geldermalsen	South	Basis	0	*1*	*0*	*0*	1
Haarlem	Randstad North	Mega	0	*2*	*1*	*1*	4
Hengelo	North-East	Plus	1	*4*	*1*	*0*	5
Lage Zwaluwe	South	Halte	0	*0*	*1*	*0*	1
Leiden Centraal	Randstad South	Kathedraal	0	*3*	*1*	*0*	4
Sittard	South	Plus	1	*5*	*0*	*0*	5
Tilburg	South	Mega	1	*5*	*1*	*0*	6
Woerden	Randstad North	Plus	0	*2*	*1*	*1*	4
Zaandam	Randstad North	Plus	0	*3*	*0*	*1*	4
Median							4

Table 19: Total threats for the green nodes summarized for water, heat drought and threat R3

Name	**Region**	**Class**	*R_Total*	*H_Total*	*D_Total*	**Total**
Almere Centrum	Randstad North	Mega	*2*	*1*	*1*	4
Amersfoort Centraal	Randstad North	Mega	*2*	*0*	*0*	2
Amsterdam Amstel	Randstad North	Mega	*4*	*1*	*1*	6
Amsterdam Bijlmer ArenA	Randstad North	Mega	*1*	*1*	*1*	3
Amsterdam Centraal	Randstad North	Kathedraal	*4*	*1*	*1*	6
Amsterdam Sloterdijk	Randstad North	Mega	*3*	*0*	*1*	4
Amsterdam Zuid	Randstad North	Mega	*3*	*0*	*1*	4
Arnhem Centraal	North-East	Mega	*5*	*0*	*1*	6
Breda	South	Mega	*2*	*1*	*0*	3
Delft	Randstad South	Mega	*3*	*1*	*0*	4
Den Haag Centraal	Randstad South	Kathedraal	*2*	*1*	*0*	3
Den Haag HS	Randstad South	Mega	*3*	*1*	*1*	5
Dordrecht	Randstad South	Mega	*5*	*1*	*1*	7
Eindhoven Centraal	South	Mega	*3*	*0*	*0*	3
Gouda	Randstad South	Mega	*4*	*1*	*0*	5
Groningen	North-East	Mega	*3*	*1*	*0*	4
Haarlem	Randstad North	Mega	*2*	*1*	*1*	4
Hilversum	Randstad North	Mega	*4*	*1*	*1*	6
Leiden Centraal	Randstad South	Kathedraal	*2*	*1*	*0*	3
Nijmegen	North-East	Mega	*3*	*1*	*1*	5
Rotterdam Centraal	Randstad South	Kathedraal	*4*	*1*	*0*	5
's Hertogenbosch	South	Mega	*2*	*0*	*0*	2
Schin op Geul	South	Kathedraal	*1*	*0*	*2*	3
Schinnen	South	Mega	*0*	*2*	*0*	2
Tilburg	South	Mega	*5*	*1*	*0*	6
Utrecht Centraal	Randstad North	Kathedraal	*4*	*1*	*1*	6
Zwolle	North-East	Mega	*5*	*1*	*0*	6
Median						4

Table 20: Total threats for the ‘Mega’ and ‘Kathedraal’ stations summarized for water, heat, drought

C. Rubrics

C1. Climate adaptation expert 1

	Risk acceptance level		
Risk category	Green *Low, acceptable risk level* *Lowest priority*	Yellow *Serious, undesirable risk level*	Red *High, unacceptable risk level* *Highest priority*
Technical functionality	Little effect on the small stations is acceptable. There are always alternatives for travellers in the event of disruptions: gates can for example be opened completely if the gates do not work. There is always static information (and broadcasting) when the digital boards fail.	Malfunctions and loss of functions are not desirable, but unfortunately this does happen in practice and then we accept the damage.	If the effect and the probability of occurrence are high, the loss of function will no longer be acceptable. Another factor is that restoring these functions costs a lot of social money.
Society	In principle, we want all stations to be accessible to everyone. However, in the event of a malfunction, it may happen that a station is less accessible. When the probability of occurrence is low, I find it acceptable that the disabled at some point "have trouble getting to the train".	If the chance of occurrence is high, I do not think it would be desirable for travellers to have trouble getting to the train. Nevertheless, they could still use the train if the station is partially accessible and the station therefore, to some extent, still fulfills its function.	Long-term disruptions at medium to large stations, especially if these can occur frequently, are unacceptable and also affect the assessment of our reputation and the Customer's opinion.
Reputation	We cannot completely prevent negative attention. As long as the probability of occurrence is low, and the scope is limited, I find this acceptable. Then this will be compensated with other positive attention that is in return.	It is not desirable that the chance of negative messages is high and that there is concern among local authorities.	It is unacceptable if due to the actions or negligence of ProRail there is concern among the provinces or the government as to whether this is harmful to the relationship.
Customer satisfaction		It is not desirable for stations that customers are very dissatisfied. Although this may occur, this will also (certainly if the probability of occurrence is high) have an effect on reputation.	Anything that is structurally insufficient is unacceptable
Safety	We do not always have the means to achieve a perfect score at stations and we and therefore mainly focus on a well-functioning station.	Minor or repairable injury becomes undesirable if the probability of occurrence is high or the effect is greater.	ProRail has the ambition to have 0 avoidable accidents. Killing or personal injury due to our failure is therefore unacceptable.

Table 21: Rubric of Climate adaptation expert 1

C2. Climate adaptation expert 2

	Risk acceptance level		
Risk category **Level**	Green *Low, acceptable risk level* *Lowest priority*	Yellow *Serious, undesirable risk level*	Red *High, unacceptable risk level* *Highest priority*
Technical functionality	Facilities must be in order. Only no effect and small possibly acceptable, but chance is an important aspect here.		From a considerable damage sensitivity, it also entails security risks and that is unacceptable to me in all cases
Society	When I look at this from an economic point of view, disabled people have less impact on the economy. So, his is acceptable	Everything between accessibility of regular or small stations and green nodes is unwanted but not completely unacceptable to me	Again, from an economic point of view, Utrecht and Leiden, (red/green node) are too central and socially speaking it costs a lot of money if these stations are inaccessible. In addition, Utrecht can serve as an evacuation area and it is also bad for safety in the event of (partial) inaccessibility
Reputation	Minor reputation damage can happen and is much less of an issue to me than the rest.	In relationships with governments, something will likely go wrong more often than “incidentally” and I would therefore rather not accept this	
Customer satisfaction	Customer judgment is a result of all other factors.		
Safety	Only no security risk is acceptable	It is highly undesirable up to and including repairable injury, but it can happen once. I would prefer to avert this entirely, but this is not realistic	ProRail will have to do everything it can to prevent serious injury or fatalities. This applies to travellers or workers who work on the railway or station. The smallest chance is sufficient to mark it as unacceptable as a whole.

Table 22: Rubric of Climate adaptation expert 2

C3. Manager Stations 1

	Risk acceptance level		
Risk category **Level**	Green *Low, acceptable risk level* *Lowest priority*	*Yellow* *Serious, undesirable risk level*	Red *High, unacceptable risk level* *Highest priority*
Technical functionality	Little or no effect is acceptable because everything will continue to work	A moderate effect is undesirable but partly acceptable as long as nothing fails	Our goal is to make the systems work. Everything where elements completely fail is actually not possible.
Society	Only no loss of accessibility is completely acceptable	We are a public party and must therefore be available to everyone. As soon as disabled people can no longer come there, this is an undesirable risk. A small or limited effect can still be accepted in exceptional cases	Everything from a significant effect unacceptable.
Reputation	This is probably very incidental and therefore acceptable to me	Significant effect: preferably not, but can still happen	From damage to relations unacceptable because it is then no longer incidental and there is probably a problem on too many stations or for a too long amount of time
Customer satisfaction		I find it no longer entirely acceptable if the effect is considerable, because it will then probably go wrong in a more structured way	
Safety	If you offer a public transport service, as a traveller you can expect that there are no safety issues. Only “no effect” is therefore acceptable	A minor, incidental effect is just acceptable	Serious damage to health it is no longer acceptable. We can see climate incidents coming and it is therefore our duty to avert them.

Table 23: Rubric of Manager Stations 1

C4. Manager Stations 2

	Risk acceptance level		
Risk category **Level**	Green *Low, acceptable risk level* *Lowest priority*	Yellow *Serious, undesirable risk level*	Red *High, unacceptable risk level* *Highest priority*
Technical functionality		Poor information provision on station with class Plus is acceptable but undesirable	Technical systems must not fail at stations of class mega or higher. Technical systems must not be irreparably damaged. Then certain facilities are out of service for too long.
Society	Only no loss of accessibility is acceptable		You want to prevent major disruptions in the train service due to the weather, whether this is heat or rain. You don't want flooded tunnels that prevent travelers from disembarking at the station they want.
Reputation	Acceptable if no government concerns and only local press.	Governmental concerns are undesirable.	This only really becomes a problem if a problem at 1 station occurs several times a year, otherwise it is too incidental and explainable. This is the case with long term negative attention in the press.
Customer satisfaction		The customer rating should preferably not be insufficient as a result of the climate, too much damage from rain, hail or heat.	
Safety	Only no risk is completely acceptable	It is not desirable for someone to break something, but it is acceptable.	There may be no deaths or serious injuries

Table 24: Rubric of Manager Stations 2

C5. Manager Stations 3

	Risk acceptance level		
Risk category **Level**	Green *Low, acceptable risk level* *Lowest priority*	Yellow *Serious, undesirable risk level*	Red *High, unacceptable risk level* *Highest priority*
Technical functionality	Little or no effect is still acceptable because everything will continue to work	Moderate effect is acceptable at a low probability; otherwise unwanted. In principle we can predict it and it costs little to avert it so we just have to do it.	Our goal is to make the systems work. Everything where something fails is not possible.
Society	All stations must be accessible at all times. Low probability and moderate effect acceptable because you have to make choices regarding budget		Everything inaccessible is unacceptable
Reputation		Anything local or receiving brief attention: probably a one-time incident	Anything that indicates long-term, structural problems (e.g. damage to relationships, long-term attention in the national press/ resignation of manager) = unacceptable.
Customer satisfaction		We do not want (seriously) polluted transfer areas and an effect on comfort, but in the event of a small chance of pollution, this may be partially acceptable.	Anything that is largely or seriously affected is unacceptable, again because it indicates a serious problem, or multiple problems
Safety	Only "no effect" is completely acceptable	Only a very small chance of minor injury is acceptable, as that implies that it would not be our fault	Injuries at our hands, even minor injuries, must be avoided at all cause

Table 25: Rubric of Manager Stations 3

D. Case studies

D1. Amsterdam Amstel

Amsterdam Amstel is a train- and metro station that opened in 1939 (ProRail, n.d.). The station has two island platforms and four platform tracks, of which the middle two, tracks 2 and 3, have been in use for the Amsterdam metro since 1977 (NS, 2006). There are about 34,000 boarding and disembarking passengers per day (class: "Mega") (NS, 2018a). Because the number of visitors has increased enormously over the years and will likely increase even further, several redesign or renovation activities have been carried out at the station in previous years. A new bus station was constructed, a new tram platform with a traverse loop for trams was built and a new bicycle parking facility has been completed underneath the station. The station hall was renovated and redesigned; the lowered ceilings were removed so that the original incidence of daylight is restored, and adjustments were made to the shops and wall paintings (Municipality of Amsterdam, 2016).

The area around Amstel station is an important traffic junction: motorists, bus drivers, cyclists, pedestrians, trams and trains are crossing each other every day, and the number of traffic users and travellers, like the number of train passengers, is growing (NS, 2016). That is why the municipality of Amsterdam is not only working on the resign of the station area, but also of the public space around Amstel station, together with ProRail, NS Stations and the GVB. This development will start around the end of 2020.

Table A-1 shows all the threats that apply to Amstel Station according to section 5.3 and the assumptions made in this section. The next section will go into more depth on all threats and will verify whether these threats indeed apply to Amstel station.

Station	Region	Class	R1	R1.2	R2	R3	R4	R5	H1	H2	H3	D1	D2	D3	Total
Amsterdam Amstel	Randstad North	Mega	1	0	0	1	0	1	0	0	1	0	1	0	5

Table A-1: The threats that apply to Amstel station according to section 5.3, whereby 1 = risk, 0 = no risk

Extreme rainfall

To be able to fit the station into its surrounding area, the entire station was divided over different height levels. The entrance at the Julianalaan on the east (-1 m NAP), runs from two higher ends to a "low" around the station entrance (see figure A-5), with a difference of approximately 0.8 m (AHN3, 2019). From the Julianalaan to the station hall (6.5 m NAP) the height difference is compensated by a staircase inside the station building. The entrance at the Julianaplein (2.2 m NAP) is also accessible via a staircase that leads to the station hall. The entrance in the northwest (+4.6 m NAP) is accessible via both a staircase connected to the Goudriaanstraat (0.6 m NAP) and a ramp that leads past de Hogeschool v Amsterdam (1.04 m NAP). At this entrance there is an outdoor bicycle parking. The platforms are again one level higher than the station hall because the platforms had to be connected to the tracks placed on a dike body at the Spoorwegwerken Oost (9.6 m NAP) (NS, 2016; AHN3, 2019).

The unusual height differences of Amstel station and its surrounding area make the station vulnerable to rainwater flooding. In addition, due to the increase in paved surface during the redevelopment of the station area, the permeability has decreased, resulting in more water running towards the station.

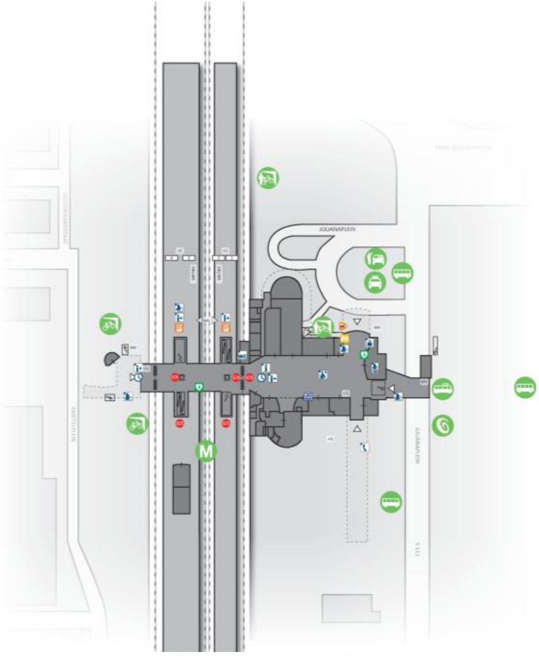


Figure A-1: Topview of Amsterdam Amstel station (Municipality of Amsterdam, 2016)

Figure A-2: Entrance at the Goudriaanstraat

Figure A-3: Entrance at Julianaplein (NS, 2016)

Figure A-4: Bicycle shed at the Goudriaanstraat (Municipality of Amsterdam, 2016)

Figure A-5: Entrance at the Julianalaan (GoogleMaps, n.d.)

To meet the requirements of the Delta Plan for Spatial Adaptation, the municipality of Amsterdam has conducted several climate stress tests. In one of these stress tests, a “rainwater-bottleneck map” was created to gain insight into the extent to which Amsterdam is vulnerable to extreme storm events (Municipality of Amsterdam, n.d.). This can be seen in figure A-6. This map gives an insight into the water depth after a storm event of 120 mm in 2 hours, corresponding to a storm events that occurs once every 1000 years. This model is more detailed than the national climate effect atlas or climate stress test of ProRail, as it includes both the underground sewer system (which can drain 20 mm per hour) and the topsoil (streets, squares, buildings, gardens). The general aim of the municipality and Waternet is to avoid all damage of extreme storm events of 60 mm in 1 hour, corresponding to a return period of once every 100 years in 2050 (STOWA, 2019) - and naturally also of all storm events less severe than that (Municipality of Amsterdam, n.d.).

There are three types of bottlenecks on the map below: urgent (yellow), very urgent (orange), or extremely urgent (red). With extremely urgent bottlenecks, there is a risk of serious damage to for example real estate, vital infrastructure, hospitals and museums, and there is also a risk of serious traffic disruption in the area. The aim is to resolve these bottlenecks within 5 years. With very urgent bottlenecks there is a risk of property damage and traffic nuisance; these are desirably resolved within 10 years. For urgent bottlenecks there is a risk of traffic disruption or damage to real estate and these are desirably resolved within 15 years (Municipality of Amsterdam, n.d.).

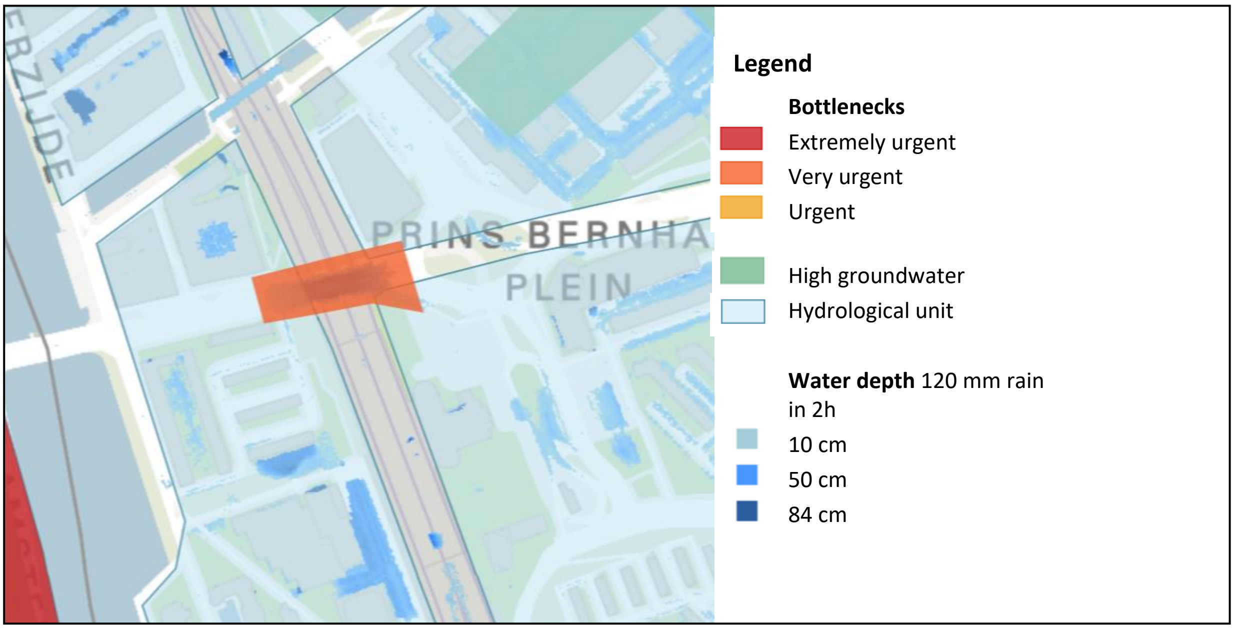


Figure A-6: Rainwater bottleneck map zoomed in at Amsterdam Amstel station (Municipality of Amsterdam, n.d.)

The map layer "High groundwater" in figure A-6 shows the areas in Amsterdam where the difference between the groundwater level and ground level is less than the desired 0.90 meters that is laid down in the Guidance Note Groundwater (Adviesnota Grondwater; Hoogheemraadschap van Rijnland, 2011). It follows from figure A-6 that there is no issue of high groundwater levels near Amstel station.

There are two bottlenecks near Amsterdam Amstel station:

2. Underneath the train viaduct on the Mr. Treublaan:

Model calculations with use of Infoworks of the square on the east side of Amstel Station and the lower part of Watergraafsmeer show that flooding underneath this viaduct is twofold. Flooding is firstly caused by the flow paths within the hydrological unit on the west side of the Mr. Treublaan (in the van der Kunbuurt) (U04), and secondly by the flooded manholes connected to the rainwater drainage system in this same hydrological unit. The rainwater system of U04 was tested with the Dutch “Leidraad bui08” and the “Rainproof” storm event of 60 mm in 1 hour. “Leidraadbuien” are ten artificial precipitation events with increasing statistical recurrence times (Rioned, 2019). Bui08 has a return period of 2 years, and a total of 19.8 mm of precipitation falls in an hour (19.8 mm / hour, T = 2) and the rainproof storm event of 60 mm / hour has a return period of 250 years (60 mm / hour, T = 250). With bui08, nine manholes flood (+ 0m - 0.2m), which are mainly located in the lowest part of the hydrological unit near the Mr Treublaan. In the current situation with bui08, the sewer system in the Van Der Kunbuurt does not meet demands, and certainly does not meet the aim of the municipality of Amsterdam and Waternet to be rainproof with extreme storm events of 60 mm in 1 hour. With a storm event of 60 mm / hour, more than 160 m^3 of water flows towards the tunnel in the Mr. Treublaan from the Van Der Kunbuurt, leading to a waterdepth of 62 cm in the tunnel. In addition, according to the model calculations, a lot of water will also remain in the bicycle shed on the west side of the station, limiting access and egress transport modes.

2. Near the station entrance at the Julianalaan.

The risk here is related to the ground level design of the Julianalaan. The side of the road is oriented in the direction of the station, which makes that there is a limited amount of storage available on the street. With bui08 there was no nuisance yet, but with a rainproof storm event (60 mm/hour, T = 250 years) there was a water depth of 23 cm in front of the entrance to the station building, which made the water flow into the station. This problem was acknowledged by de municipality of Amsterdam and was attempted to resolve in the recent area developments. The central reservation (median strip) in front of the Julianalaan have been raised so that it functions as a threshold seen from the station, which now have a minimum height of -0.86 m NAP. According to model calculations, with a storm event of 60 mm in 1 h, the water level now rises exactly to the threshold height and remains at that height for 45 minutes. However, the possible consequences of wave action have not been included in this model and this can therefore still cause the entrance of the station to flood. The local sewer system in the hydrological unit east to the station (U06) has furthermore been renewed in 2018 (Waternet, 2018).

Despite the efforts of the municipality of Amsterdam, the station manager of Amsterdam Amstel still registered a flooding of the east-entrance on the 17th of August 2020 (12,5 mm in 1 hour, two hours later: 8 mm in 1 hour, T = 0.5 years). This was the only flooding of this year (2020). The water, during this incident, flowed in from the side of the bus station (Julianaplein) to the entrance at the Julianalaan and several shops were flooded (Julia’s, Rituals). The threshold that was supposed to stop the flooding, was not enough to withstand a storm event of 12,5 mm in 1 hour, or of T = 0.5 years. This would, in theory, indicate that the station’s current coping capacity is below a storm event of T = 0.5 years. What must be noted here, however, is that this was not the heaviest local storm event in 2020, and that the station withstood all other storm events of 2020, meaning that it is possible that there were some other reasons behind the flooding on this date. The station manager and a hydraulic engineer from Waternet could not explain this.

The specific drainage capacity of the roof of Amsterdam Amstel is unknown and the station manager only became responsible for Amstel station 1,5 years ago, meaning that previous incidents before that time cannot be recalled, and it is therefore difficult to make definite statements about the coping capacity of the roof. The technical areas of Amstel station are partly below ground level but very far away from the entrance at the Julianalaan, making short circuits or electrocution in these rooms very unlikely.

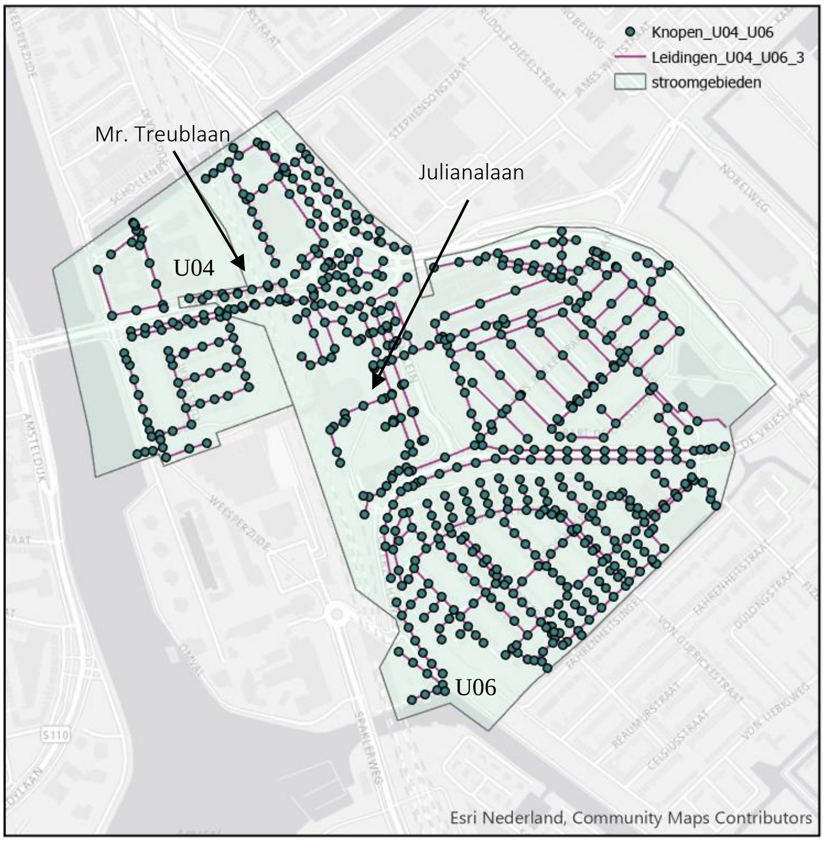


Figure A-7: Catchment areas U04 and U06 around Amstel station

Figure A-8: Flow paths towards the tunnel in Mr Treublaan.

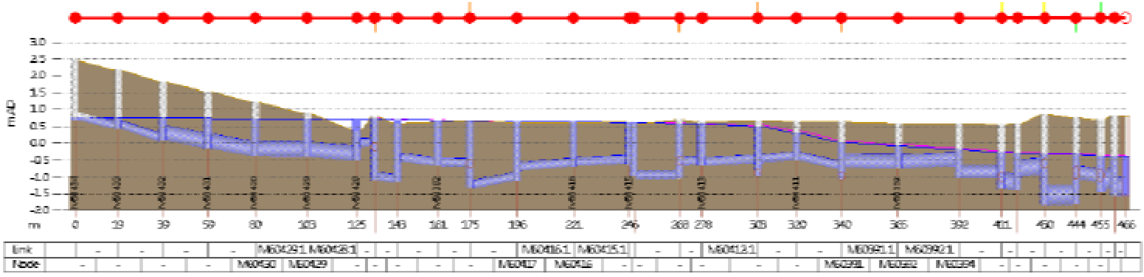


Figure A-9: Section from Berlagebrug (left) to the outlet route to the Amstel (right) with the maximum occurring water levels for bui08

Heat

The heat stress around Amstel station is relatively high (apparent temperatures of between 40-46 °C), except for some strips between the tracks of the train station. The platforms are covered by a roof, which makes that enough shade is provided. A disadvantage of this is that ventilation could be reduced (Katsoulas et al., 2006). Furthermore, the major part of the roofs and walls near the platforms are made out of glass. From the questionnaire it became apparent that glass generally has a counterproductive effect on the perception of heat which therefore increases the vulnerability of Amstel station. There are two water taps within the station premises, and the area around Amstel station is richly endowed with vegetation and greenery. This greenery cannot be found within the station premises. The technical rooms are not ventilated, which means threat H4 is relevant for Amstel station.

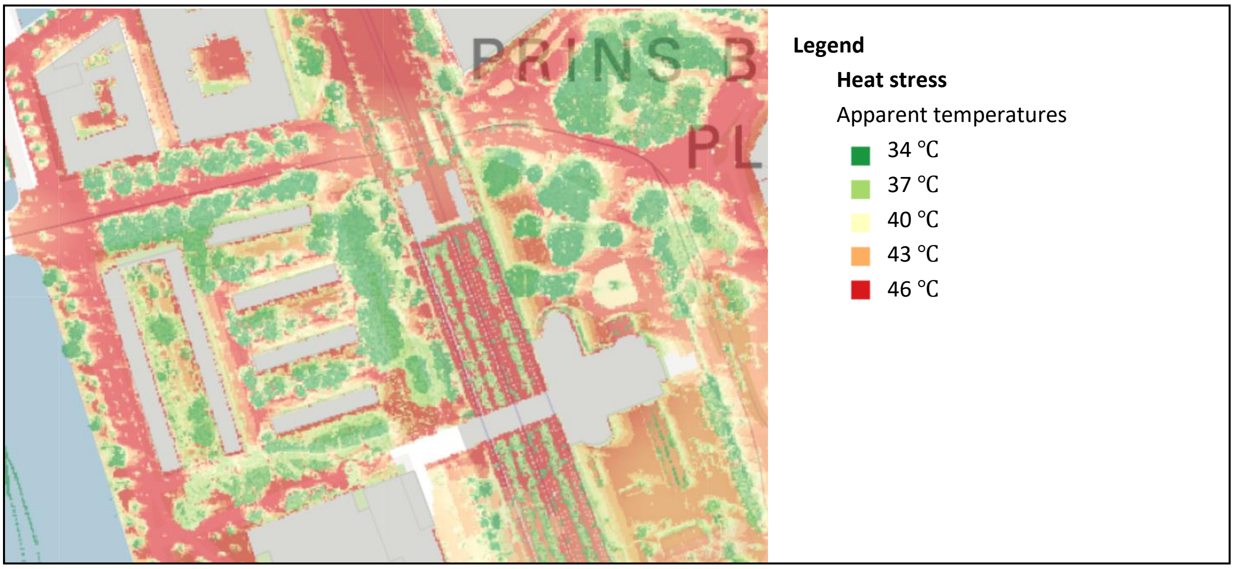


Figure A-10: Apparent temperature at ground level, zoomed in at Amsterdam Amstel (Municipality of Amsterdam, n.d.)

Drought

The entire city of Amsterdam was built on a peat bog (PDOK, n.d.). Almost every square meter is of Amsterdam is founded on wooden poles that reach all the way to the deepest layer of sand at -20 m with respect to ground level, except for Amsterdam Amstel (Municipality of Amsterdam, 2016). This station is entirely built on an elongated terrain and is supported by a concrete pile foundation, above which there is a load-bearing construction of steel. Threat D2 does therefore not apply to Amstel station. According to ProRail's climate stress test, the current soil subsidence in the area is between 3 and 10 cm (CAS, 2017) (figure A-11). The municipality of Amsterdam however measure their groundwater levels in public areas with the use of approximately 2500 monitoring wells, for which the Average Lowest Groundwater Level (ALGL) per monitoring well is shown in figure A-12. The ALGL groundwater levels near Amstel station can drop more than 1.25 m below NAP. This would mean that the study of Deltares, TNO-GDN and WEnR (2017) on the national land subsidence have underestimated the local subsidence near Amstel station, meaning that the safe entry height of 76 cm would, in fact, be jeopardized. The threats for Amstel station, adapted based on local studies can be found in table A-2.

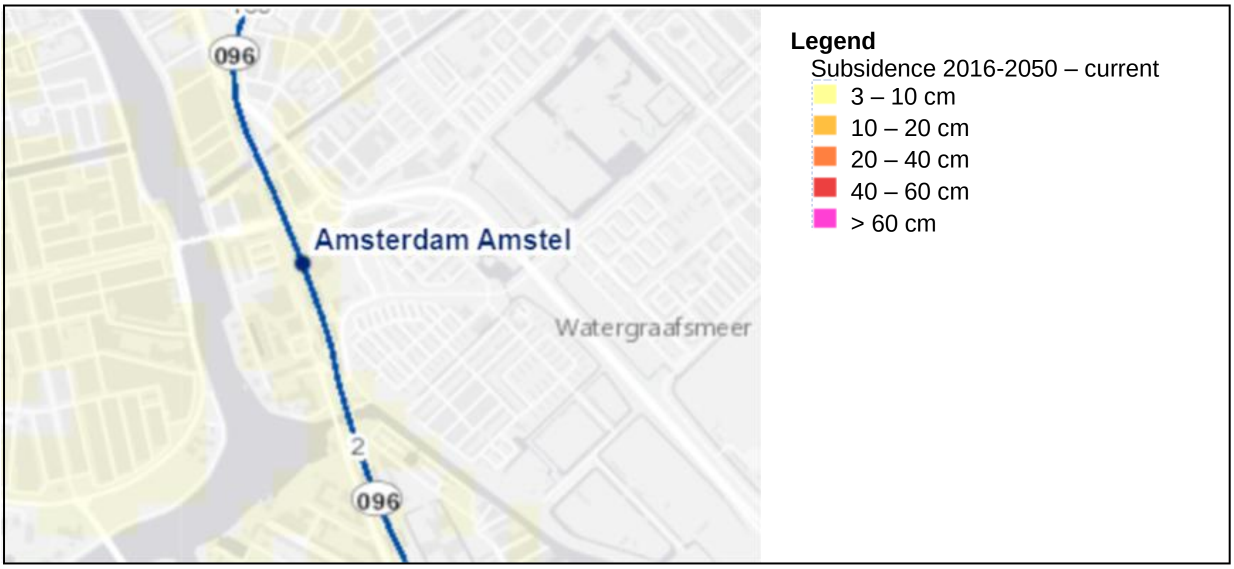


Figure A-11: Soil subsidence map of Amstel station (ProRail & Arcadis, 2020)

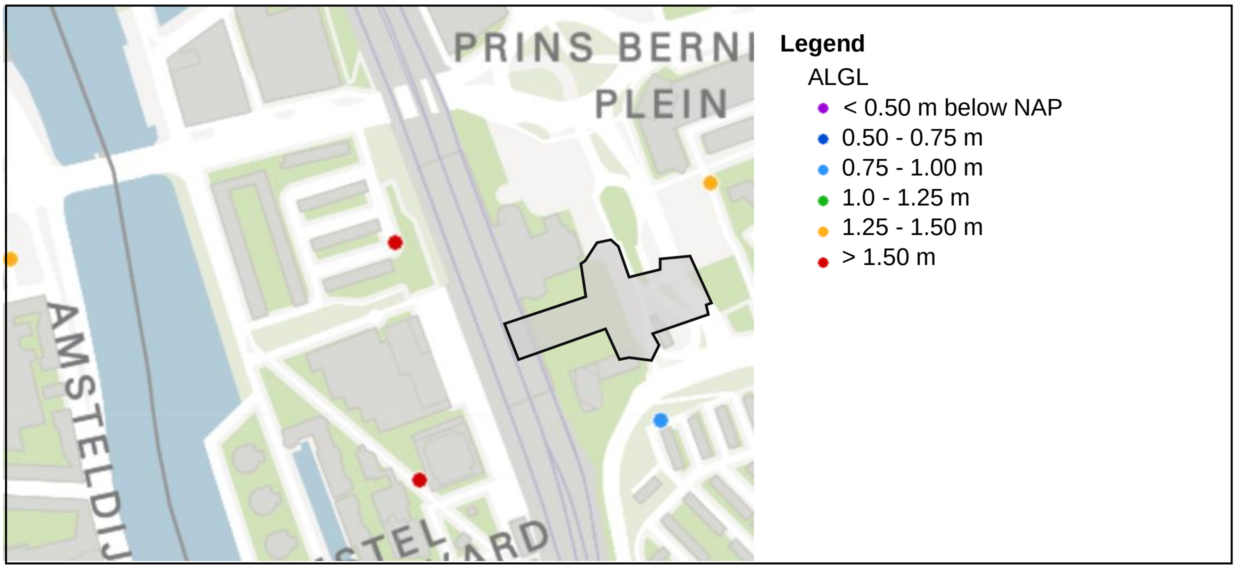


Figure A-12: ALGL map per monitoring well from the municipality of Amsterdam (Municipality of Amsterdam, n.d.)

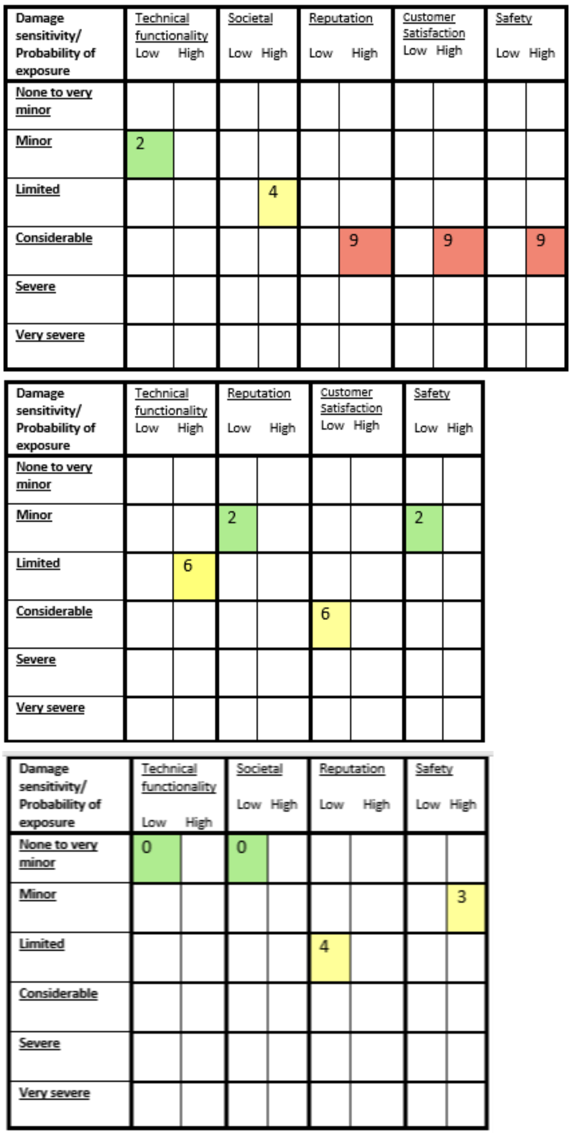
Station	R1	R1.2	R2	R3	R4	R5	H1	H2	H3	H4	D1	D2	D3	**Total**
Amsterdam Amstel	1	0	0	1	0	1	0	0	1	1	1	0	0	5

Table A-2: The threats that apply to Amstel station, adapted based on local studies

Adaptive capacity

Amstel station's adaptive capacity is relatively large since both ProRail and the municipality of Amsterdam have carried out a systematic mapping of different types of climate threats and the probability of exposure to those threats, based on the W_H scenario of the KNMI. In addition, the risks for the adjacent sewer systems and the station have been evaluated and assessed in early stages of the planning process, and steps have been taken by the municipality and Waternet to mitigate the risks in and around the station. The effectiveness of these steps is however somewhat questionable due to the flooding of the Julianalaan entrance on the 17th of August 2020. To further increase the adaptive capacity and decrease vulnerability, a new assessment of the bottlenecks on the east-side of Amstel station ought to be made to increase the station's coping capacity, including possible effects of wave action. Adaptive measures are to be explored with an evaluation of the effects of potential conflicts, in order to avoid the implementation of counter-productive measures.

The current estimated risks for Amsterdam Amstel, with their corresponding RPN and level of acceptance can be found in figure A-13. For extreme rainfall, it can be found that the risks affecting reputation, customer satisfaction and the safety of travellers are not accepted. All risks related to heat hazards are acceptable to some extent. The risk for the technical functionality and the customer satisfaction, however, are assigned a serious and unwanted risk level. None of the current estimated risk related to drought hazards are found unacceptable. However, the risks to ProRail's reputation and safety of travellers are found serious and unwanted. To reduce these risks, the damage sensitivity and/or probability of exposure to threat R1, R4, R5, H3 and H4 and D1 need to be reduced.



Damage sensitivity/ Probability of exposure	Technical functionality		Societal		Reputation		Customer Satisfaction		Safety	
	Low	High	Low	High	Low	High	Low	High	Low	High
None to very minor										
Minor	2									
Limited				4						
Considerable						9		9		9
Severe										
Very severe										

Damage sensitivity/ Probability of exposure	Technical functionality		Reputation		Customer Satisfaction		Safety	
	Low	High	Low	High	Low	High	Low	High
None to very minor								
Minor			2				2	
Limited		6						
Considerable					6			
Severe								
Very severe								

Damage sensitivity/ Probability of exposure	Technical functionality		Societal		Reputation		Safety	
	Low	High	Low	High	Low	High	Low	High
None to very minor	0		0					
Minor								3
Limited					4			
Considerable								
Severe								
Very severe								

Figure A-13: Current risk and corresponding RPN for Amsterdam Amstel for extreme rainfall (top), heat (middle) and drought (bottom)

D2. Ede-Wageningen

Station Ede-Wageningen is in the middle of Ede, on the railway line from Utrecht to Arnhem, the Rhijnspoorweg, and the start and end point of the line to Barneveld and Amersfoort. The original station was opened in 1845 and was later replaced by a new station in 1984 (ProRail, n.d.). There are currently three tracks for passenger transport, two platforms, and about 19,000 boarding and disembarking passengers per day (class: "Plus") (NS, 2018a). This is expected to increase to 28,000 to 30,000 per day in the coming years (ProRail & NS, 2016). For this reason, and because Ede-Wageningen station is part of the national High-frequency Rail Transport Program (Programma Hoogfrequent Spoorvervoer) (Ministerie IenW, 2019) - meaning that by the end of 2020 six intercity trains and six sprinters will be running across Ede-Wageningen per hour- a redesign of the station area is planned. In this redesign plan, that would originally start at the end of 2016 but is now postponed until 2021, a whole new station will be developed, built a few tens of meters east of the current station. This new station includes one extra platform, and the existing platforms will get wider and longer. The station will have a large tower build as an eye-catcher and will, in the provisional design, get a gigantic translucent roof made entirely of wood (ProRail, 2016). There will be extra shops at the station, an increased number of waiting areas, extra toilets and elevators, a new parking building with places for 500 cars and bicycle sheds will be built for a total of 7650 bicycles (ProRail, 2016).

Table A-3 below shows all the threats for station Ede-Wageningen that became apparent from the analysis as described in section 5.3. The next section will go more into depth on all threats and will verify whether these threats will also apply to new design of Ede-Wageningen station.

Station	**Region**	**Class**	**R1**	**R1.2**	**R2**	**R3**	**R4**	**R5**	**H1**	**H2**	**H3**	**D1**	**D2**	**D3**	**Total**
Ede - Wageningen	North-East	Plus	1	1	0	1	1	1	0	0	0	0	0	1	6

Table A-3: The threats that apply to Ede-Wageningen according to section 5.3, whereby 1 = risk, 0 = no risk

Extreme rainfall

In the new station design, there will be two tunnels that provide access to the platforms; the eastern- and western platform tunnel. The eastern tunnel will become the main entrance to the platforms. The spacious tunnel has a diagonal position, which leads to a better view of the connecting stairs, escalators, and elevators, providing social safety and orientation for the user (figure A-14) (ProRail, NS & Municipality of Ede, 2016). The front square with the busses is slightly higher than this platform tunnel, which is compensated by a slight slope from the front square to the tunnel entrance (1:25). The western platform tunnel forms an inter-city connection for slow traffic and provides access to all platforms by stairs. The western wall in this tunnel is at a slight angle, which, together with the relatively large clearance height, provides good transparency and a sense of space (figure A-15) (ProRail, NS & Municipality of Ede, 2016).

Figure A-14: Eastern platform tunnel (ProRail, NS & Municipality of Ede, 2016)

Figure A-15: Western platform tunnel (ProRail, NS & Municipality of Ede, 2016).

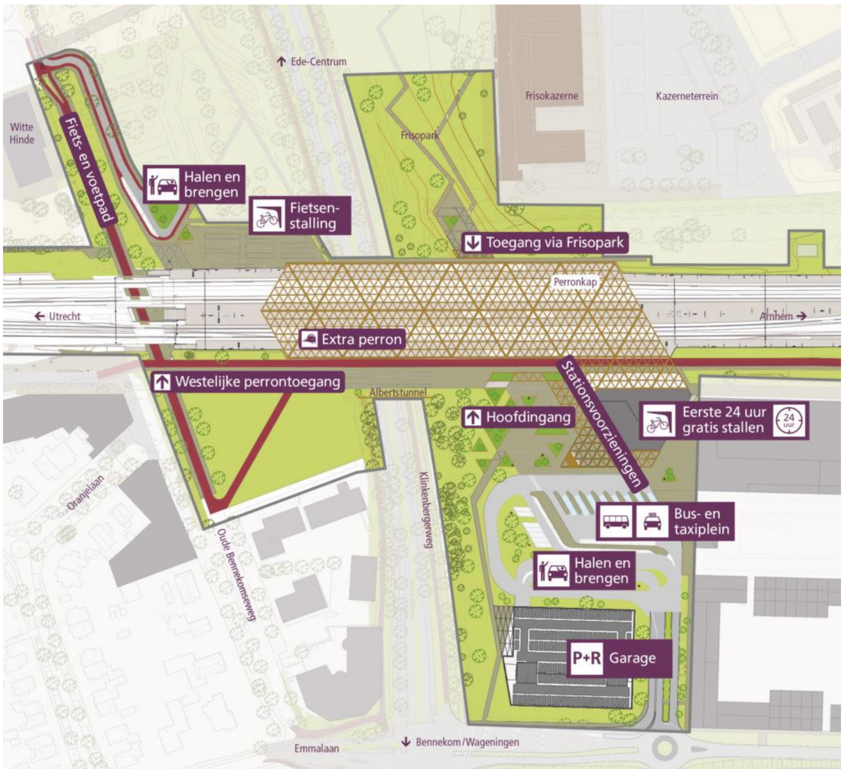


Figure A-16: Top view of the new railway zone of Ede-Wageningen (ProRail, NS & Municipality of Ede, 2016)

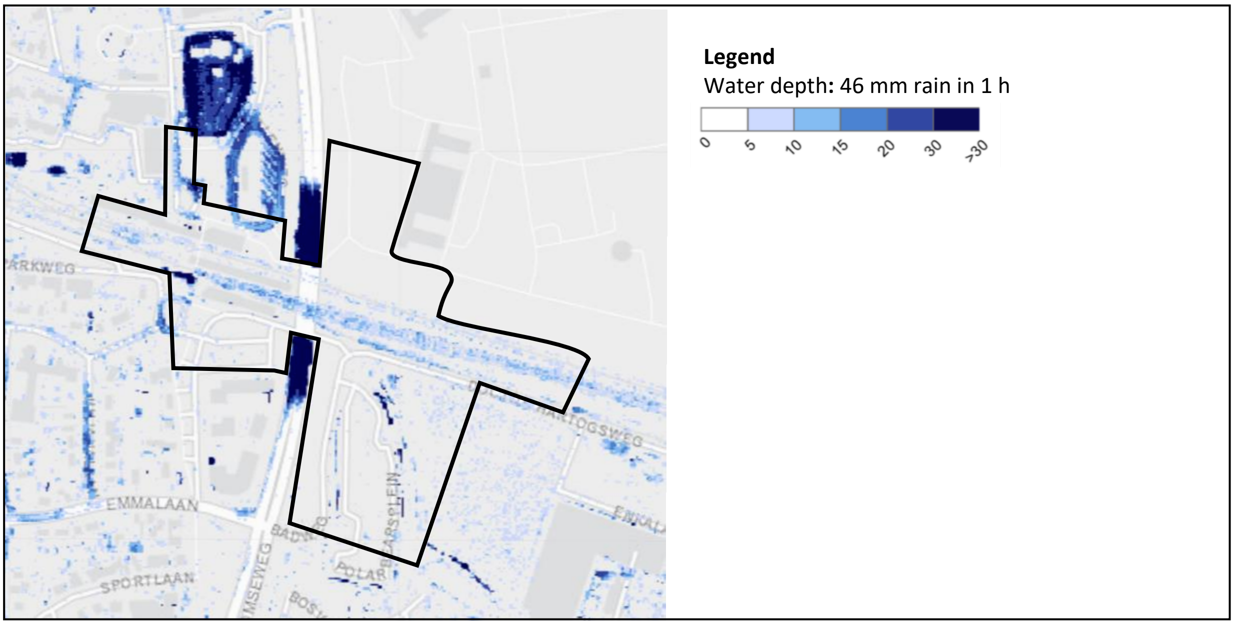


Figure A-17: Flooding map of the municipality of Ede, zoomed in at Ede-Wageningen station (Sweco, Municipality of Ede, & Wageningen Environmental Research, 2018)

To study the local effects of climate change, the municipality of Ede has created a climate effect atlas with an overview of the effects of climate change in 2050. This atlas includes a map that provides insight into the flooding in urban areas for storm event of 46 mm in 1 hour, corresponding to a storm occurring once every 50 years (STOWA, 2019). In this stress test, the interaction with the sewer system and the surface water are not included (Sweco, Municipality of Ede, & Wageningen Environmental Research, 2018). Figure A-17 portrays the inundation map from this stress test zoomed in at (the new) Ede-Wageningen. Three bottlenecks can be identified in the design:

- Underneath the Albertstunnel

- Near the northern entrance of the western platform tunnel

- Near the southern entrance of the eastern platform tunnel: a water depth of 15 to 30 cm can be observed at the front bus and taxi square, and there is a slope of 1:25 from the square towards the station entrance

The current station of Ede-Wageningen has flooded two times in the past two years: on the 2nd of October 2019 (28 mm in 2 h, T = 10 years), and on the 2nd of July 2020 (20 mm in 1 hour, T = 2 years). With the last flooding, the water came up through the manholes near the station, indicating that the coping range of the sewer system is limited to storm events with return periods of T = 0.5 years.

The facilities in the station building are all accessible via one logistics corridor. The technical rooms are all connected to this corridor, which is accessible from the east side of the building, from a logistics square where, near the entrance, parking space is reserved for loading and unloading, breakdown services, etc. Therefore, in the new design, all technical areas will be above ground level in the new station design and threat R3 will no longer be an issue.

Furthermore, the station canopy in the new station design will be built from wooden triangles, extending over all platforms like forest canopy, providing shelter and a diffuse entry of daylight. From an interview with the project manager of the new station Ede-Wageningen, it became apparent that the design plan of this roof is not quite finished. In the first design version, all triangles were going be filled with glass with PV cells (ProRail, NS & Municipality of Ede, 2016). This was however too expensive, and as a result, a new design was created in which only 30 % of the roof would be filled with glass and the other 70% would be closed with sedum on top (ProRail, 2019d). According to the project manager, this had the “bonus” that it would help with water management and that it would decrease the heat on the platform. This plan turned out to be constructively impossible, and ProRail is now working on a new tender for the roofs, which should be finished in February 2021 (ProRail, 2019d). The project manager however implied that influences of extreme weather and the implications this would have on the station, were not considered in the early formation of the new design. It is therefore unclear whether the platform canopy will be able to cope with the future weather extremities.

Figure A-18: Design of the roof in the version whereby 100 % of the roof would be glass (ProRail, NS & Municipality of Ede, 2016)

Heat

Ede-Wageningen and its surrounding area will have an increase of 30-50 summer days in 2050 according to the W_H-scenario (CAS, 2017). In addition, the municipality of Ede has conducted a stress test for heat stress in the city, in the form of a heat map on which the average apparent temperature (PET) is shown on the 1st of June in 2015. The map shows the apparent temperature at ground level (see figure A-19) (Sweco, Municipality of Ede, & Wageningen Environmental Research, 2018). It can be concluded that the heat stress is relatively high around the station, but generally does not increase beyond 41 degrees. Naturally, this was tested without the new station building present, which would shift the temperatures presented on the map.

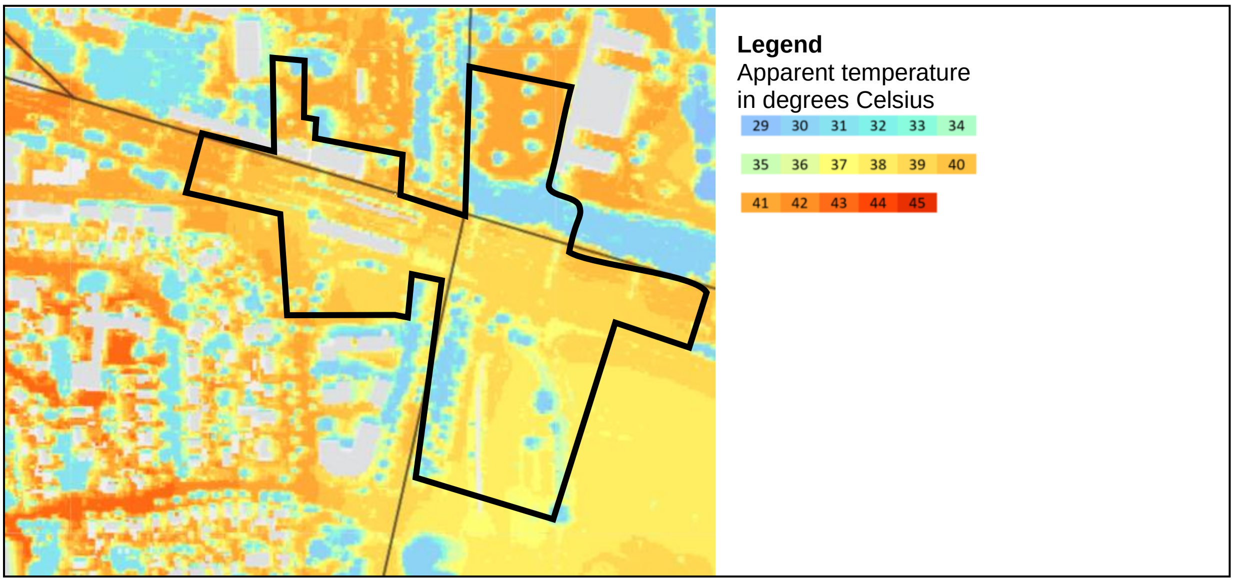


Figure A-19: Heat stress around Ede-Wageningen station (Sweco, Municipality of Ede, & Wageningen Environmental Research, 2018)

Drought

Ede-Wageningen is founded on sand and is not subject to subsidence (CAS, 2017; Sweco, Municipality of Ede, & Wageningen Environmental Research, 2018). This means that both the station building, and the safe boarding distance will not be compromised. The station is adjacent to a nature reserve and has a high probability of exposure to wildfires.

Station	R1	R1.2	R2	R3	R4	R5	H1	H2	H3	H4	D1	D2	D3	Total
Ede - Wageningen	1	1	0	0	?	1	?	0	0	?	0	0	1	4-7

Table A-4: The threats that apply to Ede-Wageningen station, adapted based on local studies

Adaptive capacity

The municipality of Ede has created a climate effect atlas to provide an overview of the effects of climate change in 2050, which was based on the W_H-scenario of the KNMI (2014). For extreme rainfall and heat, the stress tests add to the national stress test and thereby positively influence Ede-Wageningen's adaptive capacity, according to academic literature on adaptive capacity assessment (Adger & Vincent, 2005; Lindgren, Jonsson & Carlsson-Kanyama, 2009; Engle, 2011). For drought, local information is not available in the stress test, and the adaptive capacity to drought hazards is thus relatively small.

In the design of the station, according the ProRail's project manager on the railway zone Ede (spoorzone Ede), climate adaptation was not considered in the early stages in the design process. The idea of sedum on the roofs was considered "a bonus" rather than a necessary means to increase the adaptive capacity of the station to extreme precipitation or heat. Other measures to improve water drainage or heat regulation at the station have also not been considered in the design process, neither has the risk of nearby wildfires been taken into account.

D3. Boskoop

Boskoop station is a railway stop on the Gouda - Alphen a/d Rijn railway line in Boskoop, South Holland, which opened in 1934 (ProRail, n.d.). It has one platform with two platform tracks and approximately 1400 passengers per day (NS, 2018a). It also has a large bicycle shed and a bus stop (NS, n.d.).

Figure A-20: Boskoop station (Studio Alphen, 2019)

Table A-5 below shows all the threats at Boskoop station that became apparent from the analysis as described in section 5.3. The next section will go into more depth on all threats and will verify whether these threats indeed apply to Boskoop station.

Station	**Region**	**Class**	**R1**	**R1.2**	**R2**	**R3**	**R4**	**R5**	**H1**	**H2**	**H3**	**D1**	**D2**	**D3**	**Total**
Boskoop	Randstad South	Basis	0	0	0	0	0	1	0	1	1	1	1	0	5

Table A-5: The threats that apply to Boskoop station according to section 5.3, whereby 1 = risk, 0 = no risk

Extreme rainfall

Boskoop station does not have any tunnels, platform viaducts or platform canopy. The island platform connecting the passengers to the train on both tracks, is accessible via a level crossing. There are no significant height differences within the station area: the platform is at -0.49 m NAP, the track at -1.273 m NAP - maintaining the safe boarding distance - and the entrance of the station building is at -1.142 m NAP (AHN3, 2019).

In line with the Delta Program on Spatial Adaptation, the municipality of Alphen aan de Rijn has created an interactive climate effect atlas to provide insight into the expected effects of climate change (Municipality of Alphen aan den Rijn, 2018). These effects have been determined at a high level of detail using the most recent data and calculation methods. For extreme precipitation, like in the climate stress test from ProRail, the filtered and interpolated AHN3 map was used in combination with information about land use and soil type. The water flow into the sewer system and the interactions with the water system are not included in this model (Municipality of Alphen aan den Rijn, 2018). The inundation map of the climate effect atlas of Alphen, zoomed in on Boskoop station, is portrayed in figure A-21. It can be seen that the two main bottlenecks are the tracks and the entrance of the station building. The coping range of Boskoop station with respect to extreme rainfall is unknown, because Boskoop 's station manager could not be reached.

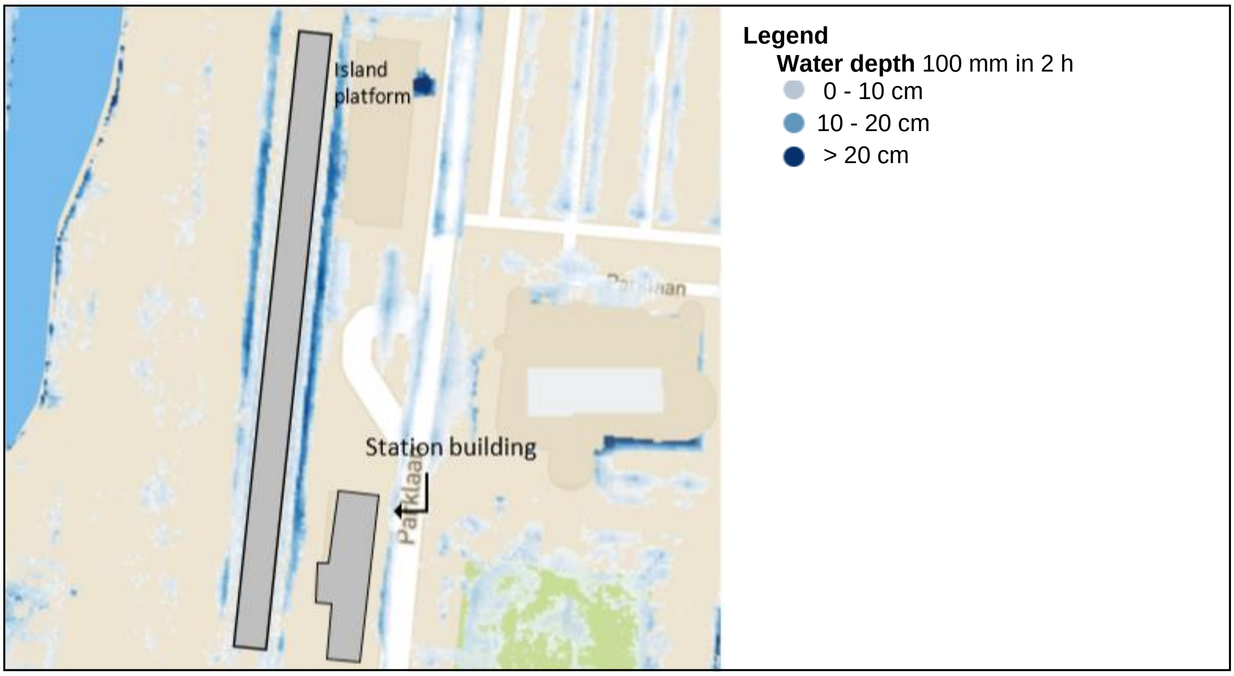


Figure A-21: Inundation map of the climate effect atlas of Alphen, zoomed in on Boskoop station.

Heat

Boskoop station and its surrounding area will have an increase of 30-50 summer days in 2050 according to the W_H-scenario (CAS, 2017). In addition, the municipality of Alphen a/d Rijn has conducted a stress test to measure the heat stress in the city, in the form of a heat map portraying apparent temperatures at ground level (figure A-22). For this map, the elevation data of the AHN2 has been placed over the land use map. To determine the heat stress, only the emissivity and the amount of shade have been considered, which were weighted based on the expected contribution each factor has to the surface temperature (Municipality of Alphen a/d Rijn, 2018). The apparent temperature is scaled in terms of “cooler” and “warmer” compared to the actual temperature and does not give exact values in terms of degree Celsius.

Figure A-22 shows that the apparent temperature around the station building and on the platforms is warmer than the actual temperature. Despite the relatively high apparent temperature on the platforms, there are no water taps installed. Shade is provided in the form of waiting shelters and high forest canopy near the platform. The waiting shelters are open and Boskoop station is located in a rural environment. There is no greenery placed on the station platforms, but since there are trees near the platform, providing the platform with shade, one could argue that there is evaporative cooling due to vegetation. The presence of threat H3 might therefore not be completely accurate. It is unclear whether the technical rooms are ventilated.

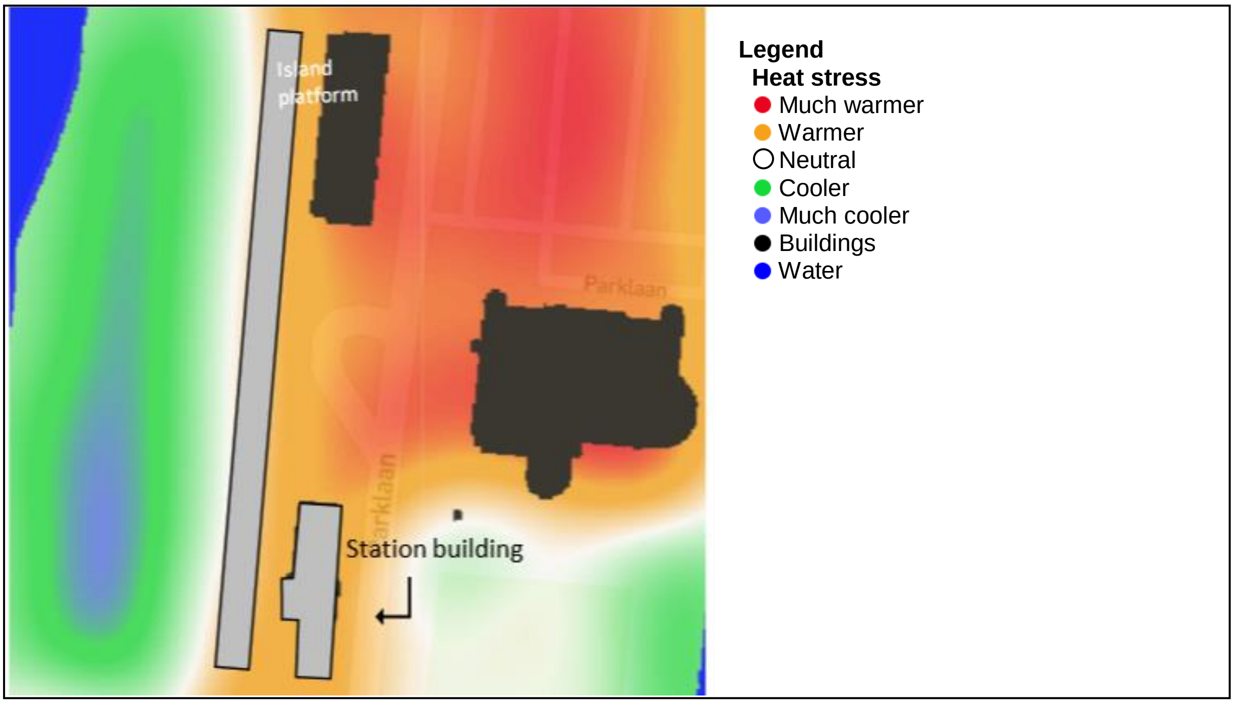


Figure A-22: Heat stress in the municipality of Alphen, zoomed in at Boskoop station

Drought

Boskoop station is located on a peat soil, which causes the accelerated subsidence due to climate change to be a major issue here. Due to the increasingly hot summers, the peat soils dry out further, causing faster subsidence. In some places in Boskoop, the ground level is almost equal to the water level and the soil subsidence can be up to 2 cm per year. This potentially leads to a total soil subsidence that can reach above 60 cm by 2050 (ProRail & Arcadis, 2020; Municipality of Alphen a/d Rijn, 2016), or according to the stress test of ProRail, can even go up to 68.3 cm, seriously compromising the maximum and minimum safe boarding height (ProRail & Arcadis, 2020). This extreme subsidence also compromises the integrity of the station building of Boskoop, as it is founded on wooden poles.

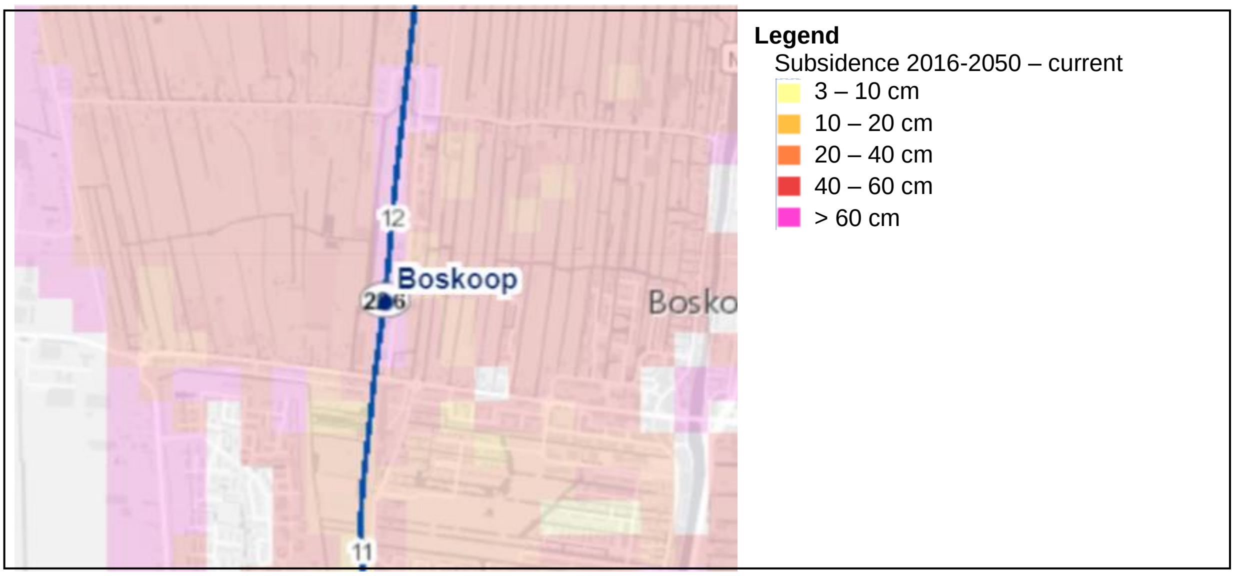


Figure A-23: Land subsidence at Boskoop station (CAS, 2017)

Station	R1	R1.2	R2	R3	R4	R5	H1	H2	H3	H4	D1	D2	D3	Total
Boskoop	0	0	0	0	0	1	0	1	0	1	1	1	0	5

Table A-6: The threats that apply to Boskoop station, adapted based on local studies

Adaptive capacity

Boskoop station was designed in 1934, and the same platforms, tracks and station building have been in use since then. The station, at that time, was not designed for the extremes of today or to withstand the extremes of 2050. The vulnerabilities to climate change induced hazards around Boskoop station have been mapped in the form of a climate stress test. It is unclear whether this stress test was based on a climate scenario and, if so, on which one. For extreme rainfall, the discharge via the sewer system and the surface water is not included, as a result of which it is possible that the presented flooding on the map is not recognized in practice (to that extent) (Municipality of Alphen, 2018). This, together with the ambiguity on the climate scenario makes both the interpretation and the development of adaptation strategies difficult. For heat stress, the apparent temperature, based on AHN2 and a land use map, is being compared to the actual temperature without portraying any actual values in degree Celsius. For drought, the municipality of Alphen a/d Rijn has not done a detailed assessment but has only zoomed in on national maps (soil subsidence, national water model). Altogether, these stress test does not provide detailed insights into absolute water depths, numerical temperatures, or into local subsidence near Boskoop station.

The coping capacity of the station could not be determined because of a lack of response of Boskoop's station manager, and there is no public or internal data available regarding previous hazards on the station. The general risks for this station can therefore not directly be linked to a coping range. Furthermore, a formulation of the accepted coping range has not been determined by ProRail, NS or the municipality of Alphen a/d Rijn, which negatively influences the station's adaptive capacity.

D4. Breda – Prinsenbeek

Breda-Prinsenbeek station is a railway station in the Dutch city of Breda. It is a suburban stop on the Rotterdam - Breda railway line that opened in May 1988 (ProRail, n.d.). It is located between Prinsenbeek and Haagse Beemden and is the second station in Breda. The platforms can be reached via pedestrian bridges and elevators.

Breda Prinsenbeek has two platforms, two platform tracks and around 1700 passengers per day (class: Basis) (NS, 2018a). There are also bicycle lockers, unguarded bicycle sheds and parking spaces for cars.

Figure A-24: Station Breda-Prinsenbeek

In Breda and surroundings, all municipalities have opted for a joint implementation of the stress tests laid down in the Delta Plan for Spatial Adaptation (Klimaatportaal, 2019). In the stress test approach, a division has been made at neighborhood level. Breda Prinsenbeek is on the border of the neighbourhoods Prinsebeek and Breda-Noord. The AHN3 map, aerial photos and data from the municipality were used. In addition, information was collected about which bottlenecks are experienced by the municipalities and other stakeholders involved. Working visits, surveys and interactive meetings have provided a general picture of the situations in the various neighborhoods (Klimaatportaal, 2019).

Table A-7 below shows all threats at Breda-Prinsenbeek station that became apparent from the analysis as described in section 5.3. This next section will go into more depth on all threats and will verify whether these threats indeed apply to Breda Prinsenbeek.

Station	**Region**	**Class**	**R1**	**R1.2**	**R2**	**R3**	**R4**	**R5**	**H1**	**H2**	**H3**	**D1**	**D2**	**D3**	**Total**
Breda - Prinsenbeek	South	Basis	0	0	0	0	1	1	0	1	1	0	0	0	4

Table A-7: The threats that apply to Breda Prinsenbeek according to section 5.3, whereby 1 = risk, 0 = no risk

Extreme rainfall

Breda - Prinsenbeek station does not have a tunnel or a platform viaduct. The platform on the east side is accessible via multiple stairs, as it is positioned 80 cm higher than the surrounding area. The platform on the west side is positioned 90 cm higher than its surrounding area and is connected to this area via a ramp (GoogleMaps, n.d.; AHN3, 2019).

In the climate stress test of Breda, a model has been created to simulate how rainfall flows within the area. The results of this model clearly indicate where water will flow to in case of a storm event of 70 mm in 1 hour, corresponding to a storm that occurs once every 250 years (STOWA, 2019). The drainage via the sewer- and surface water system is not included in the model. Furthermore, a road access map is included. Roads are classified as passable if there is a maximum water depth of 10 cm (green). Roads are accessible for emergency traffic at water depths between 10 and 25 cm and roads with water depths of 25 cm and more are impassable. Furthermore, according to the stress test, the ICT and telecom in the area are very vulnerable to extreme rainfall and flooding, but less so to heat and drought (Klimaatportaal, 2019). The reasons behind these assumptions were not included.

Figure A-25 portrays the inundation map from the climate stress test of Breda, zoomed in at Breda – Prinsenbeek. It can be seen that the track near the southern part of the platform is vulnerable to flooding (Klimaatportaal, 2019). This is because it lays lower than its surrounding area, the track has not been elevated and the permeability of the soil is medium to poor (AHN3, 2019; ProRail & Arcadis, 2020; CAS, 2017). The roads leading to the station are either green or yellow, ensuring accessibility of the station for emergency traffic at all times in case of an extreme storm event. The roof of the waiting room on the station is covered with stonecrops. According to the station manager, who has been the station manager of Breda-Prinsenbeek for the past 1,5 years, there have been no issues with this roof in the time he has worked on the station, and he expects it not be an issue at any time.

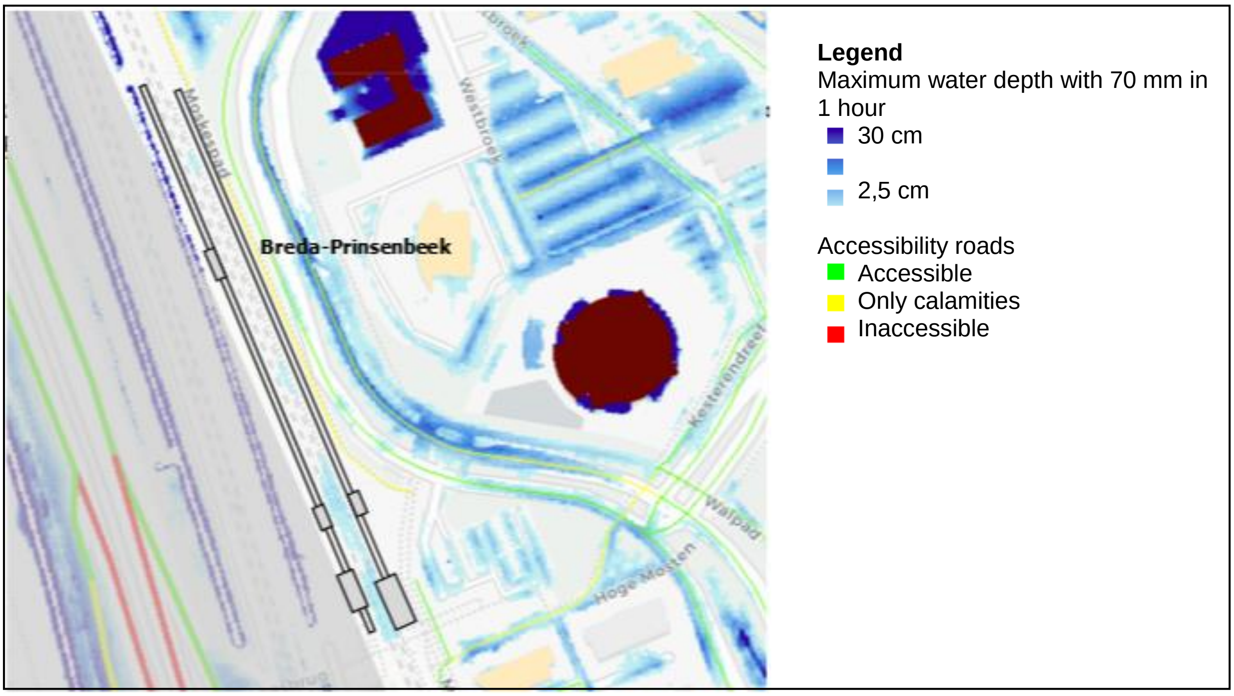


Figure A-25: Inundation map from the climate stress test of Breda, zoomed in at Breda – Prinsenbeek (Klimaatportaal, 2019)

The technical rooms of Breda-Prinsenbeek are located above floor level but remain a risky element for the station. These rooms are located under the pedestrian bridges that can be seen in figure A-24, and in case of heavy rainfall, water drips into these rooms and a small layer of water remains (+/- 1 cm). The reason for this, according to the station manager, is that these rooms are not closed off properly. There is no pump present, only water gutters. However, these do not prevent flooding in the event of an extreme storm event.

According to the station manager of Breda-Prinsenbeek, there was only storm event after which the technical rooms were flooded in the past two years, which was on the 26th of March. This is however quite odd since there was no rain on that day (KNMI, 2020). This makes it difficult to make any statements about the vulnerability of the technical rooms to extreme rainfall.

Heat

Breda-Prinsenbeek station and its surrounding area will have an increase of 50-70 summer days in 2050, according to the W_H-scenario (CAS, 2017). In addition, the heat map of the stress test of Breda shows the local apparent temperature on the 1st of June in 2015 (1:1000 heat day) (RIVM, 2019; Klimaatportaal, 2019). Factors taken into consideration are: shade, wind speed, humidity, air temperature, trees, street width and building height. Figure A-26 portrays this heat map zoomed in at Breda-Prinsenbeek and shows that the apparent temperature at the platforms and especially in between both platforms, can go up to 46 degrees Celsius. The extreme increase in summer days in this region and the urbanised area of the station, in combination with the high heat stress at the platforms and the limited amount of heat-measures taken at the station is alarming. There is no greenery placed on the station platforms, which means that, especially on the western platform, there little to no evaporative cooling (Klimaatportaal, 2019). Furthermore, there are no water taps installed (CAS, 2017). Shade is provided in the form of both open and closed waiting shelters and of high forest canopy near parts of the eastern platform. The elevators on the platforms can get very hot on summer days because they are made entirely out of glass. This could form a health risk to vulnerable passengers, who generally tend to take the elevators. The equipment cabinets are unventilated.

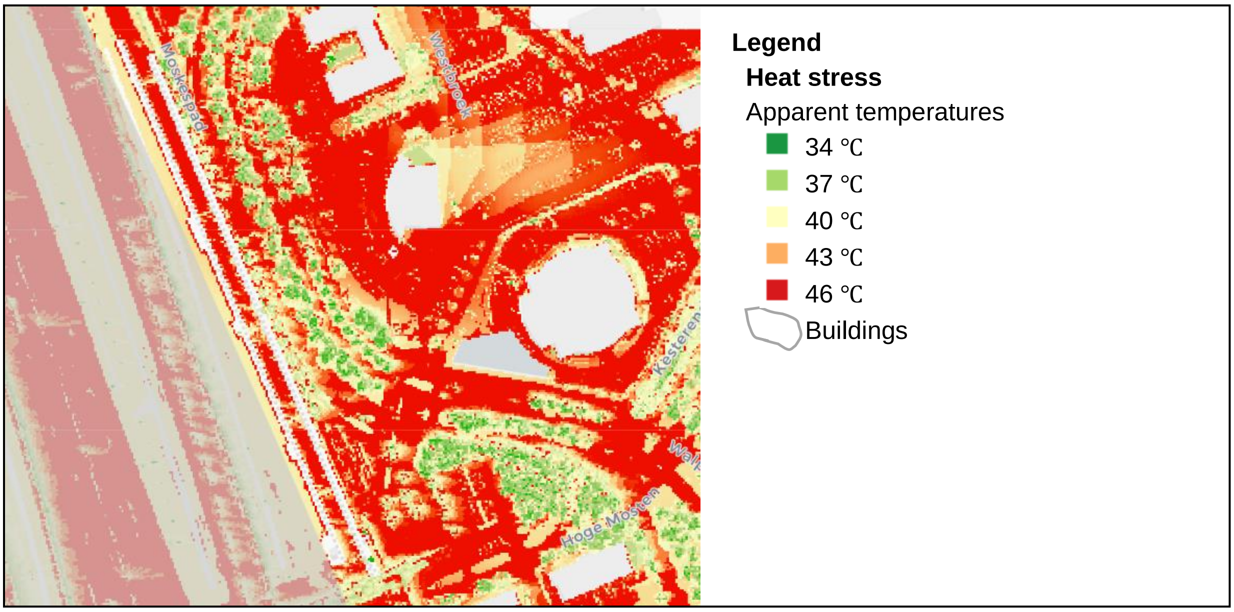


Figure A-26: Heat stress map from the climate stress test of Breda, zoomed in at Breda – Prinsenbeek (Klimaatportaal, 2019)

Drought

Breda-Prinsenbeek is located on a sandy soil that is not subject to subsidence (ProRail & Arcadis, 2020; CAS, 2017). Therefore, neither the integrity of the platforms, nor the safe boarding distance will be compromised. The climate stress test of the municipality of Breda has not covered local subsidence so a more detailed comprehension of drought beyond the climate stress test of ProRail was not available.

Station	R1	R1.2	R2	R3	R4	R5	H1	H2	H3	H4	D1	D2	D3	Total
Breda-Prinsenbeek	0	0	0	0	0	1	0	1	1	1	0	0	0	3

Table A-8: The threats that apply to Breda Prinsenbeek, adapted based on local studies

Adaptive capacity

Breda Prinsenbeek opened in 1988, just before the first edition of the NEN (1992, rev. 2018) in which the Dutch standards for drainage capacities of buildings was published. This implies that climate change was not considered in the design process. The municipality of Breda has created a climate effect atlas to explore their vulnerabilities to climate change for extreme rainfall, heat, drought and flooding. It is unclear whether this atlas was based on a climate scenario and if so, on which one.

For extreme rainfall, an inundation- and road accessibility map have been created for a water depth of 70 mm in 1 hour. In their explanatory note complementary to the maps, they name that this is a storm event that occurs once every 100 years due to climate change. What climate scenario they use as a basis for this return period is unclear, but in none of the scenarios of the KNMI’14 a storm event of 70 mm in 1 hour would occur every 100 years, which detracts from the reliability of the maps. Furthermore, also here, the discharge via the sewer system and surface water is not included in the model, as a result of which it is possible that the presented flooding on the map is not recognized in practice. The heat stress test shows the mean apparent temperature (PET) for July 1st of 2015 between 12 p.m. and 6 p.m. and for drought, a land use map has been created. The specific connection to drought in this case, has not been made entirely clear. Altogether, these stress test do not provide detailed insights into absolute water depths after a storm event, into local subsidence or potential low groundwater levels near Breda-Prinsenbeek. This negatively influences the adaptive capacity of the station.

To conclude, Breda-Prinsenbeek has a medium adaptive capacity, because the municipality of Breda has conducted stress-test in little detail, and the acceptance of risk and thereby the ambition for the coping range of the station, are undetermined. Climate change has not been considered in the design process, but given the conditions and risks for Breda Prinsenbeek, this may be reasonably easy to solve. Lastly, the effects of potential conflicts in the design have not been assessed.

D5. Leeuwarden Camminghaburen

Leeuwarden Camminghaburen station is located on the east side of Leeuwarden. It is located on the Leeuwarden – Groningen railway line and opened in 1991 when the new Camminghaburen district was almost completed (ProRail, n.d.). There is no station building and the station is served by Arriva slow trains. There is one platform, one platform track and has around 780 passengers per day (NS, 2018a; NS, 2006).

Table A-9 below shows all the threats at Leeuwarden Camminghaburen station that became apparent from the analysis as described in section 5.3. The next sections will go into more depth on all threats and will verify whether these threats indeed apply to Leeuwarden Camminghaburen

Station	Region	Class	R1	R1.2	R2	R3	R4	R5	H1	H2	H3	D1	D2	D3	Total
Leeuwarden Camminghaburen	North - East	Halte	1	1	0	0	0	1	0	1	1	0	0	0	5

Table A-9: The threats that apply to Leeuwarden Camminghaburen according to section 5.3, whereby 1 = risk, 0 = no risk

Extreme rainfall

Station Leeuwarden Camminghaburen has a pedestrian tunnel that goes both underneath the platform track and the canal parallel to the track, which allows travellers to reach the platform from the southern side of the station (figure A-27 and A-28). To be able to reach the platform from the northern side, two bridges were constructed across the water. The platform is positioned at 1.91 m NAP, which is about a meter higher than the surrounding area. The track located at 0.1 m NAP (AHN3, 2019), which is around 0,5 m lower than the surrounding area. The tunnel entrances are at -1.12 m NAP. There is no platform canopy.

In line with the Deltaplan on Spatial Adaptation, a Frisian climate effect atlas has been created by all local cooperating authorities (Friese Klimaatatlas, 2020). This includes an inundation map to show to the local water depths after a storm event of 60 mm per hour, corresponding to a storm event that occurs once every 250 years (Friese Klimaatatlas, 2020; STOWA, 2019). The inundation map from the Frisian climate effect atlas, zoomed in at Leeuwarden Camminghaburen is portrayed in figure A-28.

Figure A-27: Entrance of the pedestrian tunnel at Leeuwarden Camminghaburen (GoogleMaps, n.d.)

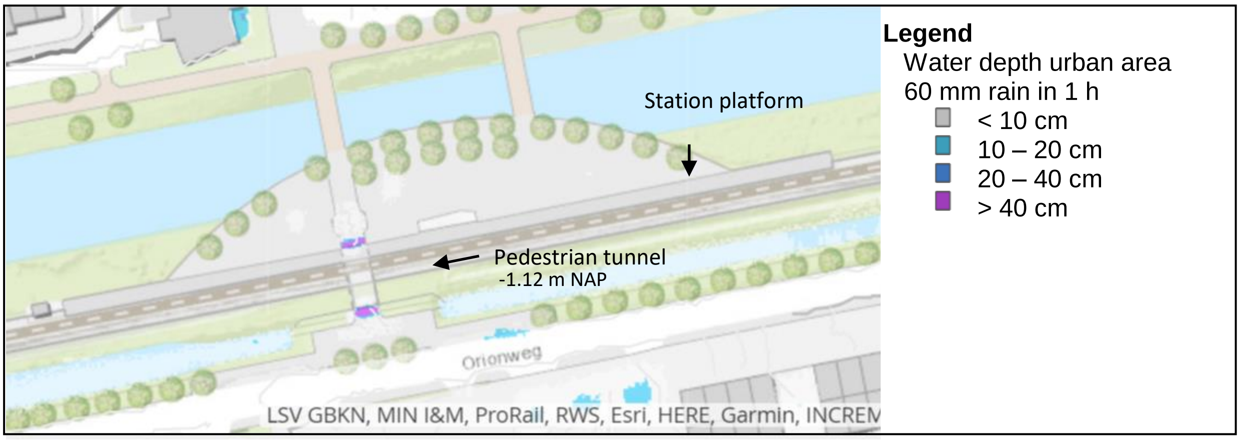


Figure A-28: Water hazard map from the Frisian climate effect atlas, zoomed in at Leeuwarden Camminghaburen (Friese Klimaatatlas, 2020).

The main bottleneck for Leeuwarden Camminghaburen is around the platform tunnel entrances, as the water depth for a storm event with an intensity of 60 mm in 1 hour, is greater than 40 cm. According to the municipality of Leeuwarden however, who manage the tunnel, the tunnel has never been flooded in the past 20 years because a pump is installed that can pump approximately 22 m^3 / hour. Between the stair openings there is an open horizontal surface of 171 m^2, so with an extreme storm event of 60 mm in an hour, 10.3 m^3 of rainwater falls into the tunnel in one hour. The pump can therefore pump approximately double the amount of what can end up in the tunnel during a very heavy storm event.

According to ProRails' climate stress test, there is also a risk of damage due to water accumulation around the station at Leeuwarden Camminghaburen. This is however not reflected in the climate effect atlas of the province of Friesland, for a storm event with a greater return period (1:250 rather than 1:100). A possible explanation for this could be that the interactions with the surrounding water system that are included in the Frisian climate atlas, were not included in ProRail's climate stress test (Friese Klimaatatlas, 2020; ProRail & Arcadis, 2020). According to the station manager, there has been no flooding since he became a station manager five years ago. Furthermore, he mentioned that there are no technical rooms. There is one section house which is above ground level.

Heat

Leeuwarden Camminghaburen and its surrounding area will have an increase of 20-30 summer days in 2050 according to the W_H-scenario (CAS, 2017). A heat stress test was included in the Frisian climate atlas to measure the heat stress in the city, in the form of a heat map showing the difference in apparent temperature between the city and the open countryside (figure A-29). Detailed information on exactly which method was used for this analysis is not available. The apparent temperature is scaled in terms of “cooler” and “warmer” compared to the actual temperature and does not give exact values in terms of degree Celsius.

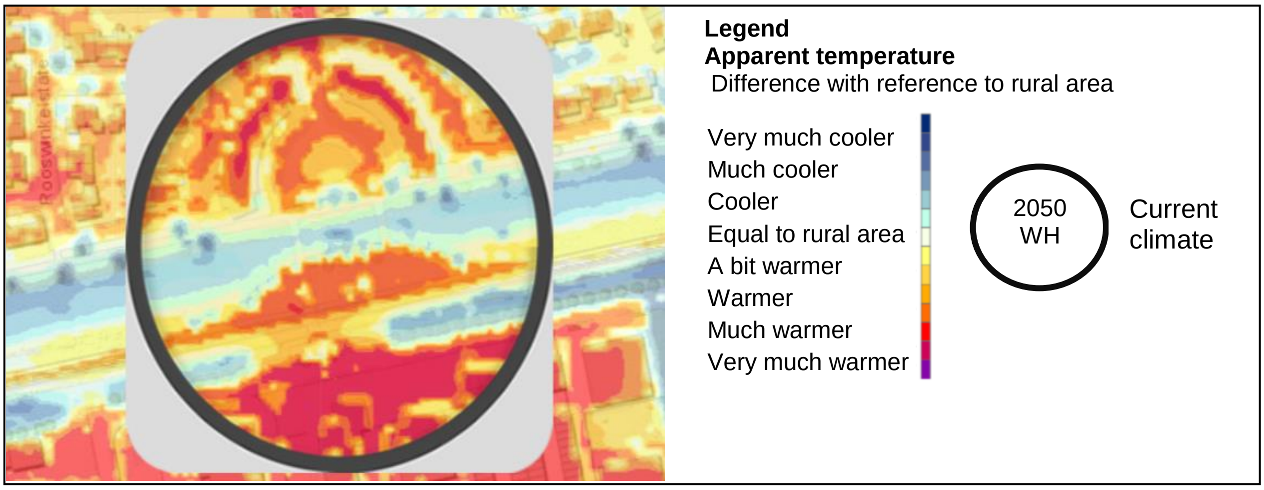


Figure A-29: Heat map from the Frisian climate stress test, zoomed in at Leeuwarden Camminghaburen

The apparent temperature at the platforms is warmer to much warmer than the actual temperature, even though the area around the station is mostly water. This large difference could be related to the fact that the apparent temperature is measured with respect to the rural area round Leeuwarden, which generally has significantly lower temperatures than the city (Terpstra, Huizinga, Hurkmans, & Jacobs, 2019; CAS, 2017). It can furthermore be observed that the apparent temperature at the platform is quite comparable to the surrounding area. There are no water taps installed and there is no greenery at the platform. Shade is provided in the form of one small closed waiting shelter in the middle of the platform.

Drought

Leeuwarden Camminghaburen is located on a clay soil, and locally there is no land subsidence (ProRail & Arcadis, 2020; Provincie Friesland, 2020). This means the safe boarding distance will most likely not be compromised.

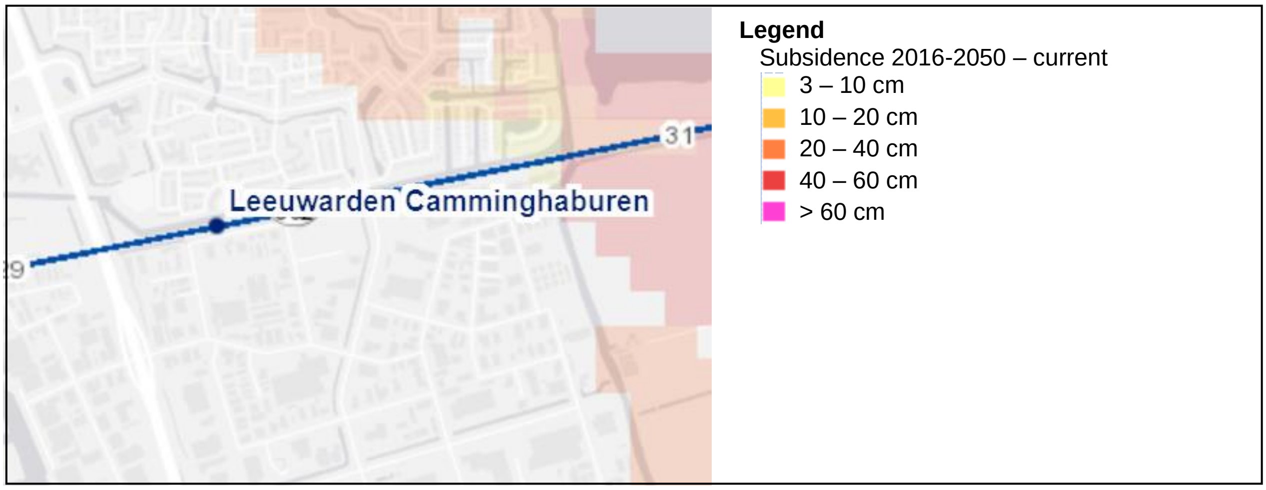


Figure A-30: Land subsidence at Leeuwarden Camminghaburen (CAS, 2017)

Station	R1	R1.2	R2	R3	R4	R5	H1	H2	H3	H4	D1	D2	D3	Total
Leeuwarden Camminghaburen	0	0	0	0	0	0	0	1	1	0	0	0	0	2

Table A-10: The threats that apply to Leeuwarden Camminghaburen, adapted based on local studies

Leeuwarden Camminghaburen opened in 1991, just before the first edition of the NEN (1992, rev. 2018) in which the Dutch requirements for building sewerage and outside sewerage was recorded. This implies that climate change was not considered in the design process. The combined governments in Friesland have conducted several climate stress tests to explore their vulnerabilities to extreme rainfall, heat, drought and flood hazards. Again, it is unclear whether these stress tests are based on a climate scenario and if so, on which one. For extreme rainfall, an inundation map for a storm event with an intensity of 60 mm per hour has been created. Why this intensity was chosen was not mentioned. The discharge via the sewer system and surface water is not included in the model. The heat stress test shows the difference between the city and the open countryside for the apparent temperature, which is not shown in degrees Celsius but in relative terms. The drought map shows the precipitation deficit in an extremely dry year under the current climate, taken directly from the national climate effect atlas, and it shows how this increases under "the" climate scenario for 2050. The fact that this stress test refers to "the" scenario for 2050, while there is more than one scenario, detracts from the reliability of the stress test.

To conclude, Leeuwarden Camminghaburen has a relatively low adaptive capacity as the combined governments of Friesland have conducted stress-test that barely add to the national climate effect atlas. Furthermore, no ambitions have been defined for the station, and climate change has not been considered in the design process. Lastly, the effects of potential conflicts in the design have not been assessed.