Climate proofness of physical infrastructure

Work package leader: dr.ir. M. Van, Deltares

Content

1 Description work package

1.1 Problem definition, aim and central research questions

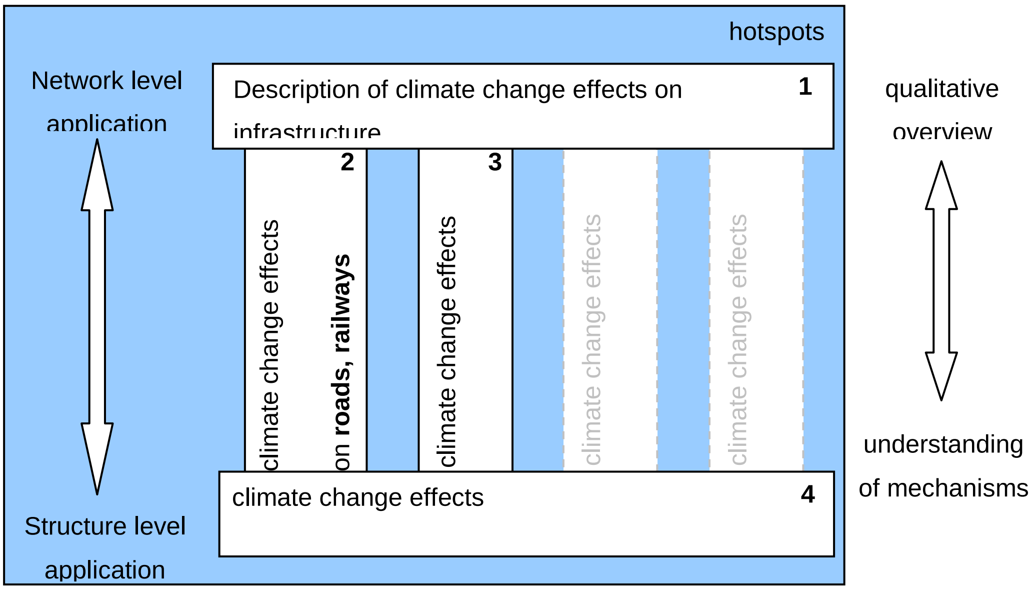
It is generally accepted that the adaptability of physical infrastructures to climate changes is rather large due to the gradual, average change of our climate and the relatively short life span of the infrastructure components (for instance pipes, rails, structures). On the other hand, the vulnerability of physical infrastructures to more frequent weather extremes is expected to be substantial and the insight in the magnitude of this vulnerability is little (Planbureau voor de Leefomgeving, 2009). There is general understanding of the type of climate related threats affecting infrastructure (TRB, 2008), (Oostrom, 2008), (Van Hove, 2007). But, there still is a lack of insight in the nature and magnitude of the resulting effects (De Wit, 2009). WP2 addresses the effects of climate change on physical infrastructure (transport on land, (underground) services and ICT). Relevant aspects which affect the hotspots performance are for instance effects of extensive droughts and high temperatures on pipe integrity and drinking water quality, effects of changing groundwater tables, extensive precipitation, floods and temperature extremes on linear infrastructures such as roads and railways and resistance of tunnels against floods.

The challenges for WP2 are (1) to gain insight in type and magnitude of the effects of changing climate factors (with input from WP1) on infrastructure, directly and indirectly. Consequently (2) to determine and quantify vulnerabilities and (3) consequences on integrity and quality with corresponding tipping points, and (4) to conclude with adequate adaptation measures. Parallel, (5) the effects of climate change on subsoil behavior are investigated to be able to predict its effects on infrastructure.

Causes and consequences of climate factors effecting infrastructure and the uncertainty thereof are estimated, as well as promising adaptation measures improving robustness and flexibility of the physical assets themselves. Uncertainties in both threats and vulnerabilities will be addressed explicitly by means of a probabilistic approach. Already the US Transportation Research Board (2007) highlights the benefits of using probabilistic risk assessment, "*The greatest challenge is the uncertainty as to exactly what changes to expect and when. Thus, transportation decision makers will need to adopt a more probabilistic risk management approach to infrastructure planning, design and operations.*".

1.2 Interdisciplinarity and coherence between the projects

The coherence between projects in WP2 is described with help of the figure below. Project 1 is the interface between the other work packages and the projects in work package 2. Project 1 starts with a qualitative survey in order to create an overview of the relations between climate change and physical infrastructures and is closely related to ongoing work in work package 1. This project furthermore focuses on the hotspots Rotterdam and Schiphol and uses the networks and infrastructure sections in these hotspots to combine and present the results of the other projects. The projects 2 and 3 concentrate on specific infrastructures. These projects use a more quantitative approach (than project 1) in determining the magnitude of climate changes on different types of infrastructure. Project 4 provides the other projects with knowledge on the effects of climate changes on soils and ground water systems. In terms of levels of scale project 1 has a focus on networks and infrastructure sections within the hotspots (a hinterland connection, a road network). The projects 2 to 4 concentrate on more specific cases in both hotspots (a specific tunnel, bridge or road) from a quantitative perspective. The applied levels of scale are shown in the figure below as well.



Road and railway infrastructure, together with subsurface infrastructure are of major economic and societal importance. This work package therefore focuses on these types in projects 2 and 3. Other types of infrastructures such as waterways and ICT infrastructures are qualitatively dealt with in project 1. Further scientific exploration on these infrastructures within this program is possible whenever new questions emerge.

1.3 Stakeholders

Relevant stakeholders within this work package are the administrations of different infrastructures. Administrators in both hotspots will be provided with the necessary understanding on climate effects and corresponding adaptation measures from project 1. With the approach in project 1 specific questions from other stakeholders (i.e. ICT infrastructures or other) can be answered, though in a less detailed manner. The questions answered in project 2 are driven by the Ministry of Public Works and Water Management and by ProRail. They will directly benefit from the output of the work package in terms of climate effects on different levels of scale (network, section, structures) and adaptation measures. The watercycle company Waternet and the joined organization of sewage administrators Rioned put focus on the questions answered in project 3.

2 Project 2.1 Hotspots: climate effects and adaptation measures on physical infrastructures

Project leader: dr ir M. Kok

2.1 Problem definition, aim and central research questions

The assignment of quantitative effects and adaptation measures requires a description of relations between climate changes and physical infrastructures. This project describes these relations and the accompanying propagation mechanisms for relevant infrastructures with a qualitative approach. Relevant physical infrastructures in this project are: roads, tunnels, railroads, subsurface infrastructures, air traffic utilities, ICT infrastructure and waterways. This project combines the acquired knowledge in the other projects to get a full overview for all types of infrastructure. This will be presented it in the infrastructure networks of both hotspots from a quantitative perspective. This results in an overview of vulnerabilities and the robustness of networks and sections in the hotspots. Corresponding adaptation measures are identified as well as tipping points for necessary changes in strategies. This overview is considered to be the main accomplishment of this project. The central research questions therefore are:

- Which relations and propagation mechanisms between climate change and physical infrastructures can be addressed for all types of infrastructure?
- How can this be integrated with the results from the other projects on roads, railways and drinking water infrastructure?
- What are the effects of climate change to physical infrastructure networks and sections within the hotspots?
- What is the vulnerability and robustness of these infrastructures?
- Which suitable adaptation measures can be determined suitable for the vulnerabilities of the infrastructures?

Major focus in this project is on the infrastructures in and around Schiphol and the hinterland connections of the Rotterdam Harbour Area. The project allocates a part of its budget for more or less urgent hotspot questions or emerging scientific questions on other types of infrastructures. For instance the railway infrastructure to the hinterland of these hotspots is explicitly part of the focus of this project. Another part of the budget is reserved to acquire more accurate climate information of KNMI. The general KNMI scenarios are insufficient to determine effects of climate changes to infrastructures and further detailing of information is necessary for instance on precipitation extremes, temperatures near railroad surfaces etc.

2.2 Approach and methodology

The project integrates the results from projects 2-4 in WP2 and forms the interface of WP2 with the other WP's. Especially with WP1. First the project relates different climate effects to physical effects on the infrastructures and addresses their interconnections and propagation mechanisms (both direct and indirect via the subsurface). In an analysis of these mechanisms loads and resistance are assigned to each mechanism. This results in a qualification of vulnerabilities for different sections and networks. Based on the acquainted knowledge in the other projects from this WP the assigned relations can be quantified and insight on the magnitude of effects and quantitative robustness of infrastructures in the hotspots is acquired. By applying different climate scenarios, tipping points can be determined as well as physical adaptation measures for the hotspots.

2.3 Scientific deliverables and results

The result of the described approach is a systematic structure of connections and mechanisms between climate changes and various physical infrastructures. By quantifying these connections insight is gained in the magnitude of climate related threats that effect infrastructures. This systematic approach is considered to be the main scientific deliverable of this project. By applying this approach on both hotspots the value of the approach can be shown. Scientific dissemination of these results is achieved through at least two scientific papers.

Following results are foreseen:

1.1 answers on emerging and ad hoc questions of hotspots and stakeholders within the scope of the project

1.2 qualitative description of climate effects: inventory of the most relevant knowledge and information with regard to the effects of climate change. Insight is gained in the existing influence of climate and weather parameters on infrastructure (roads, tunnels, railroads, subsurface infrastructures, air traffic utilities, ICT infrastructure and waterways). Executed in close cooperation with project 2.1

1.3 accumulation of project results: Information of other projects in WP2 translated and fitted for the hot spots.

1.4 application at cases within the hot spots (accumulation of information on existing infrastructures, determining vulnerabilities and effects and suitable adaptation measures)

2.4 Integration of general research questions with hotspot-specific questions

The described approach is applied on the hotspots Rotterdam area and Schiphol area and more specific on the infrastructures in and around Schiphol (for instance the Schiphol Tunnel) and Rotterdam's hinterland connections (such as the A15 highway or Betuweroute). This results in an overview of the hotspots most vulnerable physical infrastructures on various levels of scale (section and network) and corresponding adaptation measures. Within this approach more specific hotspot questions are answered, for instance:

- How vulnerable are infrastructure services such as gas, water, electricity and ICT in the Rotterdam area?
- How vulnerable is urban and regional transport infrastructure (road and railways) to climate change (Rotterdam)?
- Vulnerability transport infrastructure: How vulnerable/sensitive is urban and regional transport infrastructure (rail, road, etc.) for climate change with respect to 1) accessibility/congestion and 2) the quality of the infrastructure with regard to management and maintenance?
- How vulnerable is the connection with the hinterland?

For upcoming questions, the systematic approach enables us to answer emerging questions concerning the effects of climate changes on the hotspots and other stakeholders physical infrastructure. For instance a scoping study to new railway lines as Utrecht-Breda and the IJmeerlijn could be executed. As stated earlier, the project reserves a part of its budget for these questions.

2.5 Societal deliverables and results

Within this project, the most vulnerable components of both hotspots are determined in terms of their physical infrastructure. Not only does this provide the hotspots with the necessary information on the climate change robustness of their network and their specific structures such as tunnels, it also enables an effective assignment of various adaptation measures. The hotspots and system managers as DVS and ProRail gain insight in the climate robustness of their infrastructure. Economical consequences are dealt with in work package 4. Both hotspots are of great economic importance on national as well as regional scale with a focus on transportation of people and goods. Robust infrastructures are considered to be the pillars of these economic centers.

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3 Project 2.2 Quantification of climate effects and measures for rail, roads and tunnels

Project leader: prof.ir. A.W.C.M. Vrouwenvelder

3.1 Problem definition, aim and central research questions

Problem definition

Changes in climatic conditions, both in mean values and in more pronounced variations and extremes may affect the condition of roads and railways and thereby their functionality in terms of e.g. reliability, availability, maintainability and safety (RAMS). Tunnels are vulnerable parts of roads and railways and are expected to be effected by climate change. In The Netherlands, more than 50% of all traffic and transport takes place via roads and railways. The Netherlands functions as a hinterland connection for Europe, especially for container transport. Therefore the functionality of roads and railways, including tunnels, are of utmost importance for the economy.

Especially in the Schiphol and Rotterdam hotspot regions, with a high level of economic activity and with high density rail and road networks including tunnels, the pressure on the network is high, often leading to congestion or delays, which deteriorates the landside accessibility of both the mainports, Port of Rotterdam and Schiphol Airport. The effects of climatic changes on the condition of infrastructure may further reduce the functionality of these transport (both passenger and cargo) networks. For instance, in case of the Port of Rotterdam, the supply of cargo to the seaport by road may take longer because of increased congestion on the motorway A15. For Schiphol Airport the timely arrival for passengers and freight is largely dependent on the functionality of supplying railways and road infrastructure (including tunnels).

Possible effects of climate change on roads and railways include effects on the structural behavior due to changing groundwater levels (increase of alternating dryer and wetter circumstances). Also influence on the durability of road surfaces due to water damage (erosions, flooding), periods of high temperature (melting asphalt), frost damage, rutting and wear and tear of ZOAB and ageing under influence of e.g. UV radiation are foreseen. For railways especially the effects of higher extreme temperatures seem to be an important aspect. In tunnels, problems with flooding and extreme precipitation are foreseen.

Scope

This project focuses on existing as well as new roads and railways, including tunnels. For existing roads and railways, the main importance is to <u>quantify the effects</u> of climate change for the use and maintenance thereof and to develop <u>measures</u> to limit the consequences thereof. Special attention goes out to concealed faults that, under influence of changing circumstances, gradually develop, after which they suddenly develop into large damages followed by large reconstructions. The focus lies on both the physical infrastructure (for instance for roads, road rutting and drainage systems, and for railways buckling of rails) and the subsurface below the infrastructure (for instance settlements or instability). Research dealing with the subsurface will be executed in close collaboration with project 4.

For new roads and railways it is important that the effects of climate change are taken into account in the design principles and criteria for new infrastructure. In the design and construction of roads, railways and tunnels, the effects of climate change should be incorporated. Since there is a tendency towards design, construct (and maintain) contracts, the specifications should contain requirements regarding the climate proofness of the new structure. With this project we will provide technical data and know-how for these design principles, criteria and requirements, but we will not provide the principles, criteria and requirements themselves.

Measures to limit the consequences of climate change are identified and their effectiveness analyzed. Priority should be given to measures applicable for climate effects with 1) a high risk (high probability of occurrence and large impact) and 2) with impact on construction and/or maintenance requiring research on short term (< 5 years).

Aim

1. For now, we foresee to:
    a. Identify, model and quantify (where possible) the most relevant effects of climate change on the condition of roads, railways and tunnels, including failure mechanisms and tipping points, and
    b. Estimate the consequences for the functionality (RAMS) of roads, railways and tunnels (in cooperation with WP 3).
2. Furthermore, we aim to identify a set of possible adaptation measures to preserve a required level of functionality of roads, railways and tunnels, and to rank their effectiveness.

Central research questions

1. To what extent will climate change affect the condition of existing roads, railways and tunnels, and what will be the consequences for the functionality (in terms of RAMS) thereof?
2. Which adaptation measures can be identified 1) to preserve a required level of functionality of existing roads, railways and tunnels, and 2) to design climate proof roads, railways and tunnels. How effective are these measures?

This project uses input from other WP's, projects and vice versa. The general, qualitative relation between climate change and physical infrastructure will be used from project 1. In depth knowledge of the behavior of the subsurface in changing climate conditions will be used from project 4. The results of the project serve as input to strategic decisions regarding investments in the climate proofing of transport networks and will we implemented in the systems model of WP1.

3.2 Approach and methodology

Analysis of effects:

1. Make an inventory of the most relevant knowledge and information of a) existing and b) emerging insights from ongoing research, both in this program (WP1) and other programs. Resulting information will be of diverse nature, both in content (e.g. measured data, (computer) models, expert judgements) and form (databases, articles and reports, interviews, logs, etcetera). Information will be incomplete, possibly partly contradictory, and of different 'reliability'/trustworthiness. If necessary, new research can be executed to get advanced insight in mechanisms and processes.
2. Combine information in one or more causal models, which relate climate effects to the condition of infrastructure. The causal relations will be quantified if possible. Results of project 4 will be used. Due to incompleteness, and occasional contradictory nature of basis material, causal relations will be uncertain. Therefore we need a modeling approach, which allows for uncertainty to be modeled explicitly, and which can deal with diverse input. For instance a probabilistic, Bayesian approach will be used to that end.

Adaptation measures

To identify suitable adaptation measures, workshops and brainstorm sessions will be held, with diverse groups (science – practice, national (hotspots) – international, citizens – professionals, public – private parties) to avoid blind spots. The most promising measures will be incorporated in the model (1) and evaluated on their merits and effectiveness (2).

Case(s):

To be defined. The in-depth modeling of measures and effects will be done in a case study such as new railway lines as e.g. Utrecht-Breda and the IJmeerlijn. This case will be closely tied to the hotspot regions of Rotterdam and Schiphol.

3.3 Scientific deliverables and results

Four papers to be presented in at least one peer reviewed journal and at national and international conferences.

Following results are foreseen:

2.3 climate change effects: inventory of the most relevant knowledge and information with regard to the effects of climate change. Insight is gained in the magnitude of the effects. Executed in close cooperation with project 1.2

2.2 causal model: the information gathered will be presented in the form of a causal model, representing the causal relations between the effects of climate change and (part of) the road, railway or tunnel infrastructure. Relations are quantified if possible.

2.3 adaptation measures: inventory of most promising adaptation measures and analysis of their effectiveness: the adaptation measures are prioritized according to their effectiveness

3.4 Integration of general research questions with hotspot-specific questions

The described approach is applied to roads, railways and tunnels that are managed by Rijkswaterstaat, Provinces, municipalities and ProRail, but also the hotspots benefit from this research. Hot-spot specific questions that are dealt with in this project under research question 1 are:

- What is the effect of climate change on surface and subsurface infrastructure (structure level)?
- What are the effects on e.g. foundations of constructions?
- What are the effects of larger precipitation extremities in the functioning of the Schiphol tunnel?

Furthermore a hot-spot specific question regarding the way the infra-network can be made robust (raised constructions, parallel structure) is dealt with under research question 2.

3.5 Societal deliverables and results

The insight and knowledge gained in this project enables stakeholders (e.g. DVS, RWS ZH, ProRail, HSRS, HSRR) to support strategic decisions. It is possible to weigh different options concerning maintenance and construction based on the reliability, availability, maintainability, safety and durability of railways, roads and tunnels. With the answers on the physical effects of climate change this project provides necessary input for the effects on economy and societal needs. The economical consequences for the stakeholders are dealt with in work package 4.

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4 Project 2.3 Effects of climate change on subsurface pipe infrastructure

Project leader: dr.ir. J.H.G. Vreeburg

4.1 Problem definition, aim and central research questions

Climate change has an effect on the shallow subsoil. In urban areas this shallow subsoil contains piped infrastructures for public services like drinking water supply, sewerage water discharge, gas en electricity supply, cable and rain water discharge. This project concentrates on the water related infrastructures like drinking water supply and sewerage and rain water discharge.

Modern cities are very dependant on well functioning subsoil infrastructures and in this respect develop a customer paradigm: the better the service, the more dependent a customer will be. If failure is rare then the customer tends to be less prepared to deal with the failure. On the other hand the customer gets so dependent on the service that functioning without it is almost impossible. Imagine a modern office without drinking water or without Internet. Modernizing, maintaining and replacing the existing subsurface infrastructures is one of the most challenging tasks for the government of modern cities.

In this study the focus is on drinking water and sewerage infrastructures, because they are probably the most vulnerable infrastructure with respect to climate change. Relevant effects of climate change for this study are effects on soil settling and temperature change. Effects on rain intensity are also relevant.

The direct effects of climate change on soil settling are studied in projects 2 and 4; the results will be used to predict the behaviour of the infrastructure in the settling ground. With a dominantly push-fit joint type for all water related piped infrastructure the integrity or functionality of the pipe can be compromised.

With a changing temperature due to climate change, the temperature in the subsoil will change accordingly. This can have a tremendous effect on the quality of the water in the pipes. Drinking water is most vulnerable in its direct effect on public health, but also sewerage water will experience an increased activity with increased temperature. This in sewer activity might lead to uncontrolled release of greenhouse gasses from sewerage systems.

Finally the recovery of energy from the water caused by the increased temperature might contribute to more energy efficiency and to cooling down the water to stop unwanted processes.

Additionally, climate change will influence the use of drinking water and consequently the load of the sewer system, both in quantity and quality. Recovering of energy from the 'fresh' sewerage is an interesting issue, but slightly outside of the direct scope of the project. It will, however be explored as it might add significantly to the energy efficiency of households and industry.

Basic research question to unravel the effect of climate change on the subsoil pipeline infrastructure and accordingly on their performance and serviceability.

4.2 Approach and methodology

The approach of the research will be targeted at practical application. Soil settling will partly be researched in project 4 and will be used as input for the model that will be made for the effect of soil settling on the integrity of the pipe. The goal of the project are models that can be used to determine the effect different scenarios for climate change on the underground water related infrastructure and the water related services as supply of drinking an discharge of sewerage water.

The model will be derived as a combination of a deterministic approach and validated with probabilistic measurements on temperature, pipe settling, joint integrity and water quality. The research is tuned to the needs of end users, especially the watercylce company Waternet, and the water companies in general and RIONED. The research is done in close cooperation with the research program of the water companies BTO (Bedrijfstakonderzoek) and the research program of Rioned and the University of Technology Delft.

4.3 Scientific deliverables and results

The primary scientific result of the research will be calibrated models that are able to simulate the effects of climate change and mitigating or adapting measures. The research will be reported in the form of a dissertation based on several scientific articles.

Next to that there will be a practical result through insight in the mechanisms and measuring methodologies to assess the impact of climate change. These measuring methods can be incorporated in operational practice to determine the optimal moments of intervention.

4.4 Integration of general research questions with hotspot-specific questions

The described approach is applied to subsurface infrastructures managed by the water companies and municipalities. In this respect also some of the hotspots benefit directly from this research. Hot-spot specific questions that are dealt with is this project under research question 1 are:

- What is the effect of climate change on surface and subsurface infrastructure?
- Vulnerability transport infrastructure: How vulnerable/sensitive is urban and regional transport infrastructure (rail, road, etc.) for climate change with respect to the quality of the infrastructure with regard to management and maintenance?

4.5 Societal deliverables and results

The results of this project will enable a clear planning of rehabilitation needs of underground pipe infrastructure. Good planning is necessary to minimize street disruption and maximize the serviceability of the infrastructures. Combination of knowledge and interchanging of knowledge between the different owners and operators will enhance more cooperation and will result in societal optima to maintain underground infrastructures.

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5 Project 2.4 Subsoil effects due to climate changes

Project leader: prof. F. Barends

5.1 Problem definition, aim and central research questions

There is general understanding that climate changes have effects on the subsurface environment. Longer periods of drought lead to lower groundwater tables and settlements due to oxidization of peat and organic clays. Extensive rainfall leads to loss of stability of embankments, higher sea levels to salinization and higher temperatures to changes in groundwater temperatures. Some of these effects appear in everyday practice. The collapse of a peat dike near Wilnis due to drought in 2003, the ongoing salinization of the Haarlemmermeer polder and the ongoing settlements of railway embankments near Gouda, can all be assigned to the mechanisms described above. Climate changes enhance these mechanisms through gradually changing averages with higher extremes. For instance, we know that peat slightly strengthens and settles due to drought, but the effects and the extent under changing circumstances are unknown and potentially over- or underestimated (Stowa, 2005). Effects of extreme rainfall and droughts on slope stability are for instance described in Blatz (2004), Rahardjo (2008) and

Krahn (1989). With the subsurface as the foundation of all physical infrastructures, this project focuses on the effects of soils under a changing climate. The aim of the project is to determine the physical effects on soils due to changing climate circumstances. Central research questions are:

- How sensitive is subsoil behavior to climate change?
- What loads on soils can be determined as a result of climate changes?
- How do soils behave under these loads?
- How can this behavior be quantified?
- What is the robustness (resilience, resistance, adjustment) of soils?
- What implications on infrastructures can be determined due to subsoil behavior?
- How can resistance and resilience of the soil and water system itself be increased (q.v. van Paassen, 2009)?

By answering these questions this project aims at a physical description of subsoil behavior under climate related loads. Subsoil settlements due to drought is the main subject of research, although related mechanisms (slope stability or subsoil weakening) can be considered as well.

5.2 Approach and methodology

The project is approached with the primary results of project 1 in WP2. Based on literature studies, project 1, and in close collaboration with project 2, the most evident mechanisms between climate changes and subsoil effects are determined and addressed as object of study. As stated earlier it is assumed that permanent drought with frequently changing ground water loads will be one of the key subjects of this research. After a more detailed assignment of issues and scope, physical testing and computational modeling will be used to quantify the subsoil behavior under these loads on a small scale. Not only the physical resistance is of interest here but also the resilience of soils due to natural soil processes. The small scale results will be upscaled in order to determine subsoil effects to relevant infrastructures. Long term measurements on an in-situ pilot in one of the hotspots is among the possibilities and is necessary for valorization of theoretical concepts.

5.3 Scientific deliverables and results

The scientific result of this project is a physical description and quantification of subsoil behavior under climate related loads. This result is based on small scale testing, computational modeling and in situ testing. The results can be used in the causal model of project 2. Dissemination of the results is achieved through four reviewed papers.

5.4 Integration of general research questions with hotspot-specific questions

With this research the effects of climate changes on subsoils obtains a scientific basis. This can easily be translated to the physical infrastructures supported by subsoils. With the foreseen quantification of subsoil settlements due to changing groundwater tables the effects on pipelines, embankments and surrounding foundation elements can accurately be determined. With this project focusing on clay and peaty soils, the project results are suited for the subsoil conditions in the western part of the Netherlands where both hotspots are situated. This makes it possible to use the results in project 1.

5.5 Societal deliverables and results

The results of this project clarify the way subsurface will behave under changing climate conditions. Subsequently the effects on infrastructure (e.g. stability, settlements) are estimated. With all infrastructures placed in or on the subsurface this provides understanding of the vulnerability of all infrastructures to the physical effects of climate change. This can be translated to economical and societal consequences (in the packages 3 and 4).

5.6 Most important references

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