Scientific aspects

Content

1 Description of the research programme

1.1. Problem definition, aim and central research questions

Problem definition

Infrastructures are the backbones of our society. Citizens, companies and government have come to rely on and expect uninterrupted availability of electricity, water and ICT networks. Road, railroad and shipping infrastructure represent the vital link between farmers, the food industry and consumers; water, road, rail and air transport enable affordable, reliable and timely logistics for industrial operators, traders, retailers and commuters. Water infrastructure is crucial to maintain safety and public health, sustain intensive horticulture, industrial manufacture and power generation (e.g. drinking water, waste water and water for cooling).

Since infrastructures are vital to society, climate change calls for timely adaptation and transformation of our on-surface and sub-surface infrastructures and networks. "Warming of the climate system is unequivocal" (IPCC, 2007:5).

In a recent study on climate change adaptation measures for transport infrastructure, the US Transportation Research Board concludes that the climate conditions during the past decades are most likely no longer a reliable source for future investment decisions (US National Research Council, 2008). On energy, the U.S. Climate Change Science Program notes that "Because of the lack of research to date, the prospects for adaptation to climate change effects by energy providers, energy users and society at large are speculative, although the potentials are considerable." (.U.S. Climate Change Science Program, 2008)

In the Netherlands we must prepare for climate change and anticipate a higher North sea level, more hot and dry summers, low Rhine and Meuse water loads in summer but autumn surges, and more frequent and intense (thunder)storms and rainfall. But where to begin, when and how to do this on the basis of what knowledge, facts or predictions? And how to deal with uncertainty? To address these questions, the central theme of INCAH is "what are the impacts of climate change on the operation of infrastructures and how to induce their timely adaptation and transformation".

Aim and central research questions

The aim of the INCAH program is to provide strategic and scientifically underpinned intelligence on the interconnection between climate change, hotspots, infrastructures and governance for adaptation. The focus is on transport, energy and water networks in Rotterdam-Rijnmond and Amsterdam/Schiphol.

Central questions addressed are what are relevant effects of climate change on infrastructures? To what extent do these effects threaten the safe, sound, reliable operation of infrastructures, their availability and socio-economic productivity? How can we avoid congestion, service interruption, system breakdown or even systemic crisis through reinforcing effects rippling through interconnected infrastructures? Through what policies, strategies and governance can we adapt infrastructure networks and make our economic hot-spots robust and resilient to climate change?

1.2. Programme outline and research approach

Research approach

Getting to grips with the effects of climate change on infrastructure and to underpin adaptation strategies represents a formidable challenge. We believe underpinning actors' decisions in response to climate change multidisciplinary models and simulations of infrastructure operation and development that may span days to several decades.

Such models must be built upon state-of-the-art knowledge on physical infrastructure components, their behavior in a changing physical environment and potential failure due to gradual deterioration. Furthermore, the operational failure, congestion if not systemic breakdown of transport networks due to extreme weather must be elucidated and represented.

To address the research questions in concert, the INCAH programme adopts a systemic approach to model infrastructure operation and development and complete models on transport, energy, ICT and water infrastructure networks in the hotspot Rotterdam-Rijnmond and, for road and rail networks, at a national scale (see Figure 1).

Any infrastructure is an assemblage of tangible (physical) and intangible (knowledge) assets that must be created, operated, maintained and renewed. Infrastructures are large-scale socio-technical systems – technical networks operated, used, maintained and developed by a social network of actors in the civil society, the private commercial and public sector (e.g. Nikolic et al., 2009). This socio-technical system is, inter alia, driven by incidents and changes in its external world, viz. climate change.

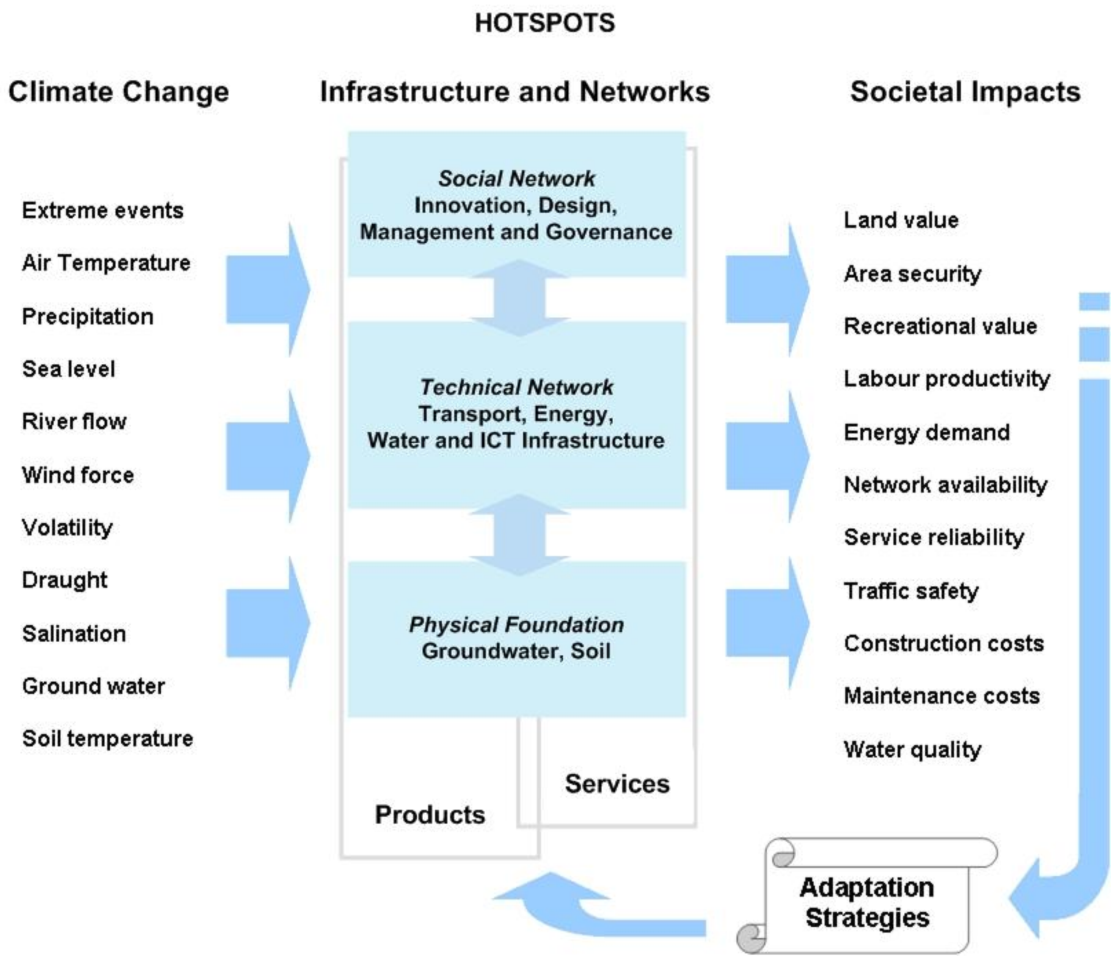

Figure 1: Scope of INCAH (Infrastructure Networks Climate Adaptation and Hotspots)

Simulating a year of road use, for example, given sufficient modeling resolution will reveal the effects of increased and more variable rainfall on congestion. Changing climate may lead to altered weather patterns and more frequent if not intense extremes. These may or may not influence infrastructure operation or cause failures, which translate into socio-economic effects for cities and mainports. Adaptation strategies thus must provide leverage on infrastructure technologies, system operation or network resilience.

Integrating models of technical and social subsystems allows the simulation of infrastructure development, stability, operation, resilience and socio-economic performance. Investigating the effects of climate scenarios, tipping points of infrastructure performance can be determined. Adaptation by quick-fixes using proven technology, innovation and renewal of assets can be tested and interconnected networks (ICT/energy, energy/transport) may be simulated. Thus, INCAH's integrated modeling will allow one to play-out the consequences of climate change, quick-fixes and determine whether they are indeed 'no-regret' and match long-term adaptation strategy and lead to increased infrastructure resilience and sustained performance.

Programme outline

INCAH consists of four work packages (WP's). Availability and quality of infrastructure is addressed by considering the structural and functional performance characteristics of infrastructure components. A second work package focuses on the performance and robustness of infrastructure networks. The economic tools for decision making are developed in a third work package. These three work packages comprise the core of the research work done in the programme. In each of these work packages, the research carried combines scientific analysis, exploration and modeling with the setup and completion of case studies on national, regional and local transport, water and energy infrastructures. To increase the relevance and utilization of the work, the experience and insights gained in these 3 work packages are brought together in one integrative work package, where adaptation strategies will be developed for the Netherlands.

- In the integrative WP1, the focus is on knowledge management, scientific and stakeholder dialogue and representing the program results by integrating all WP results in a system model and adaptation strategies. Initially, WP1 will provide a reality-check: which infrastructure networks are affected by what climate change? The nature and magnitude of climate change on design and operation of infrastructure will be assessed and the consequences for adaptation and governance explored.
  The system model will be built and integrated using results and insights from all WP's; via iteration these will be improved to provide greater resolution and reliability. Interfacing with WP2, 3 and 4, performance changes in infrastructure networks will be elucidated. The work will provide input for governance, and policy and regulatory incentives for climate resilient infrastructure will be developed and analyzed. Applying the work to case studies (a.o. for Rotterdam-Rijnmond) leads to hotspot specific insights and conclusions on the impact of climate change, what adaptation is required and how these can be realized.

- WP2 revolves around the theme "How may sub-surface conditions change and affect physical infrastructure?" Sea level and river load rise may work their way to influence infrastructures via changing sub-surface conditions and slowly wreck havoc on roads, railroads, pipelines and power cables. Ground water pressure, salinity and temperature can lead to accelerated corrosion, weakening of pipes, cables and their joints. Soil stability and contact may change and eventually cause local structural collapse or land-sliding of on-surface infrastructure. Building on hydraulic and geotechnics engineering it will be investigated what effects can be expected, what their consequences may be, and by what measures they may be prevented or neutralized. Most relevant aspects for the hotspots appear to be the effect of drought and higher soil temperature on pipe integrity and drinking water quality, possibly changing groundwater tables affect soil stability, pipelines and cables and infrastructure foundations, and flooding of (rail)roads and tunnels.

- The central theme in WP3 is Network Robustness and Adaptation.

  0. What is the vulnerability of interconnected networks? A mainport impact assessment will address accessibility and capacity for passengers and goods transshipment using models on the network effects of extreme weather.
  1. short-term adaptation: how to make existing infrastructure robust to climate change? Changing the structure and design of infrastructure requires decades; intelligent control, modified infrastructure technology assets and infrastructure use may increase robustness.
  2. long-term adaptation: how can we develop climate change resilient infrastructure networks? With time, infrastructure hubs, links and network structure change. Resilience and robustness can be built in at the network level to reduce the effect of single points of failure. Agent-based models of infrastructure development and growth will be extended to represent system resilience to climate change induced single- or multiple points of failure (Davis et al., 2009). Clever asset management can help increase component and network resilience.
     In both cases, developing models and simulations eventually will help hotspots and other stakeholders and let increase the chance of 'no-regret' decisions.

- In WP4, the socio-economic consequences of climate change impacts for several infrastructures and hotspots will be determined. The loss of infrastructure capacity or breakdown may have substantial socio-economic consequences (see for example Jonkeren et al., 2007, 2009). Deciding on adaptation not only requires that the effects of climate change on infrastructures are elucidated, but also that their impact on the economy is determined to enable cost-benefit analysis. General equilibrium approaches will be used to incorporate climate change effects on infrastructure and to allow the calculation of regional economic effects.

1.3. Innovative aspects and scientific output

Both climate change and the effects on the infrastructure imply many contradictions and uncertainties. To deepen our understanding of the type of climate related threats and to explore their effects on infrastructure and society, INCAH adopts a systemic approach.

At the technology and component level, advanced insight is gained in the behavior (strength and settlements) of soils under a changing climate and the effects of subsoil behavior to different infrastructures. This programme enables a scientific substantiation of physical adaptation measures.

The system level in INCAH inevitably involves modeling and simulation. Approaches from multiple domains will be applied to similar or the same cases and where possible, models of technical infrastructure and networks, social networks, economy an decision-making will be integrated and connected. Traditionally, models either address operation of infrastructure systems of “fixed” content and structure, or the long-term development if not evolution of new network structure due to stakeholders decisions. To combine these is at the frontier of modeling science and represents a formidable challenge (e.g. Lukszo and Dijkema 2009).

INCAH adopts a socio-technical system perspective: the stakeholders not only are concerned with the continued quality, safety and reliability of infrastructure networks, but also with the economic aspects of climate impacts on infrastructure. Innovative aspects in cost/benefit analysis concern the use of various valuation approaches in order to assess the impacts of climate change in transport and non-transport infrastructures. The development of adaptive approaches implies a shift from static to dynamic cost benefit analysis.

The scientific output will consist of dissertations of the PhD candidates. The involvement of senior researchers and postdocs ensures production of high quality journal papers, international conference papers, workshops and working reports. Relevant fields include but are not limited to transport and energy economics and policy, geo and civil engineering, systems theory and engineering, infrastructure planning and forecasting.

1.4. Relevance of the research programme in an international context

Climate change is a global phenomenon that will affect all nations. On all continents governments, research institutes, citizens and corporation are beginning to address adaptation; a number of governmental bodies and research institutes have been formed in the past five years.

In INCAH we will develop and a systemic approach to structure and expand our knowledge of climate change impacts on infrastructure, explore adaptation strategies at component, network and management level and develop methods to assess the economic consequences.

It is the quintessence of scientific work that the methodological part of this work can be transferred to and augmented by work done in other countries and institutions.

1.5. International cooperation

The consortium partners have invited a selection from their extensive international partner network. Their involvement is of eminent importance for the exchange of knowledge on infrastructure networks in densely populated areas in a changing climate. The international cooperation involves cross examination of studies and papers, exchanges of PhD’s and dedicated workshops in an international setting (see WP1).

Programme Level:
The INCAH programme aim and research questions overlap with the mission of Purdue Climate Change Research Center (PCCRC) and the University's System-of-Systems research thrust in engineering. The PCC research center mission is to increase scientific and public understanding of the causes and impacts of climate change, including mitigation and adaptation strategies, through fundamental research and effective education and outreach.

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) is Australia's national science agency. CSIRO's Climate Adaptation National Research Flagship is a large-scale, long-term, multidisciplinary scientific program, analyzing future climate changes in Australia, deliver strategies to manage their impact, and develop new ways to combat and even benefit from these challenges.

Work packages

(WP1/WP3) The design oriented projects of WP1 and WP3 will benefit form Tottori's experience with planning and design under severe risk of natural disasters. Tottori's approach to system-engineering will be of great value to develop the system models. In both WP's, a link will be forged with the Massachusetts Institute of Technology, through its MIT-USGS Science Impact Collaborative (MUSIC), a partnership between MIT and the US Geological Survey (USGS). MUSIC focuses on the development and evaluation of adaptive strategies to climate change within a participatory, stakeholder collaborative process, and as such will provide valuable expertise and input to the WP3 postdocs and to organize the dialogue between researchers, stakeholders and practitioners (WP1).

(WP2) The Swedish Geotechnical Institute (SGI) is the national centre of excellence responsible for geotechnical research and information. SGI works with the built environment and the physical infrastructure. In 2003 SGI presented a national research program on the geotechnical consequences of climate change, a specific "action plan" was presented to and adopted by the government in 2006. The involvement of SGI is important for the exchange of knowledge on effects of climate change on the substructure of infrastructure.

(WP3) The Tourism and Asset Management Group, Southern Cross University, Australia engages in the Cooperative Research Centre for Infrastructure and Engineering Asset Management (CIEAM). Their technology and management innovations for more efficient operations to extend the life of assets, increase their capacity and whole of life value and reduce the risk of catastrophic failure will be of great benefit to the projects in WP3.

(WP4) The research 'Group Transport & Mobility' (GTM), Louvain School of Management was created in 1990 and focuses on research in transport economics. Their expertise is in the realm of cost-benefit analysis, multi-modal network models, multi-criteria analysis, optimal location problems and quality assessment of transport services. The GTM team has disposal over a powerful tool called NODUS for detailed analysis of freight transportation over extensive multimodal networks.

(WP2/3/4) The Center for Sustainable Systems at the University of Michigan focuses on sustainable infrastructure including buildings, pavement systems, and water and wastewater systems. Supported by the National Science Foundation they develop an Integrated Life Cycle Design Framework integrating social, environmental and economic issues into the R&D and application of new materials to enhance the sustainability of infrastructure. UMich will provide valuable insight and knowledge on how to assess infrastructures and provide directions how to make them more sustainable.

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2 Interdisciplinarity

INCAH adopts a socio-technical system perspective to bring together knowledge and expertise from a variety of disciplines and develop novel insights on the possible impact of climate change on infrastructure. Structured, codified knowledge results which serves as the foundation for models and simulations that together yield building-blocks for and underpin adaptation strategies.

Transport, energy and water networks in or around hotspots can be seen to comprise a technical network that is controlled by a network of stakeholders (Figure 2). This socio-technical network must live in a physical and societal environment. Climate change occurs in the physical environment, while culture, institutions, policy and regulation govern the behaviour and decision-making of stakeholders, the formal and informal rules they abide to.

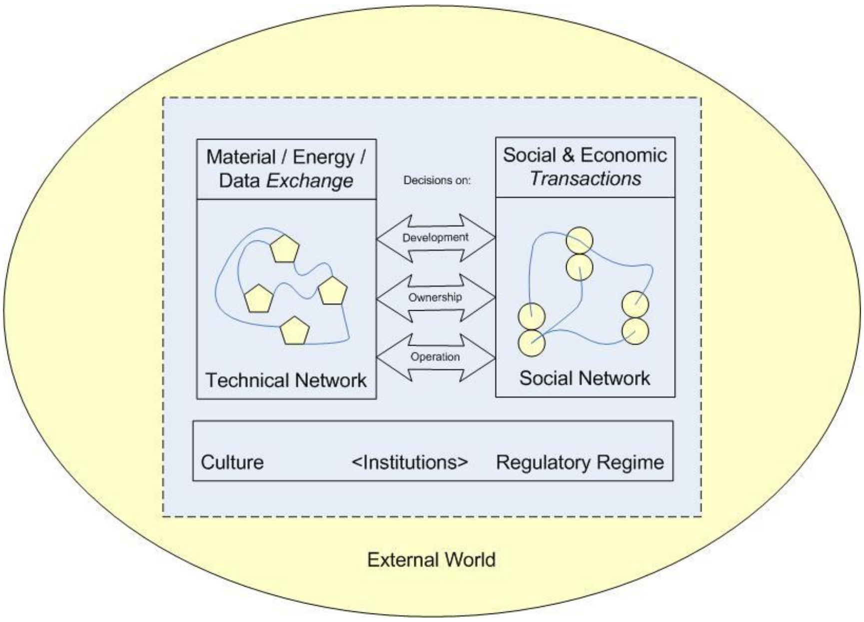


Figure 2: Socio-technical systems perspective (from Dijkema and Basson, 2009)

By using this socio-technical systems framework, we can organize, connect and integrate knowledge from a variety of domains:

- WP2 concerns technical and engineering know-how on the technical components of the infrastructure networks, which requires geotechnic, civil and mechanical engineering knowledge, hydraulics and sanitation.
- WP3 concerns the robustness of the technical networks, the long-term evolution of the network and asset management. This requires system and network theory, system modeling and simulation theory, knowledge management, artificial intelligence and policy and management science.
- In WP4, the focus is on the socio-economic performance of technical networks subject to climate change. This work will be grounded in transport economics, general-equilibrium modeling and cost/benefit analysis.

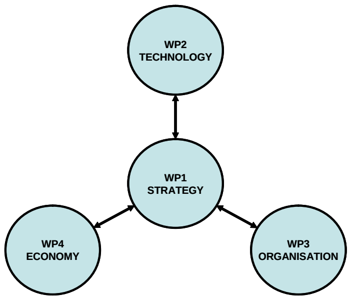
Furthermore, all projects will address existing transport, energy or water networks of relevance to the hotspots. This implies domain knowledge and expertise on transport, energy and water must be incorporated.

In all projects, there is a strong emphasis on modeling, and the projects in WP3 and 4 bridge technical network aspects and social network aspects. This not only requires and interfacing knowledge from a variety of disciplines, but preferably also linking technical models with models of stakeholder behaviour subject to various economic conditions and regulatory regimes. This requires formalisation and structuring of domain and case study specific knowledge. The synthesis project of WP3 will use our system decomposition method to facilitate the social process of model-building, and develop a common language that in principle will allow connecting models and the underlying knowledge. This will be done in concert with WP1, where the link is made to integrate all knowledge into a system model that facilitates communication with the hotspots and other stakeholders.

Given the ambition of this programme of developing adaptation strategies, an interdisciplinary approach is vital for success, and adoption of a socio-technical systems approach is key. Thereby, the programme will combine knowledge and perspectives on economic, technological and governance aspects of the respective infrastructures. It connects to technology and engineering know-how and devotes attention to both research development and applicability of the results in practice, working closely together with stakeholders to produce valid and useful recommendations.

3 Coherence between and synthesis of outcomes from the individual work packages

As the ambition of INCAH is not only to create knowledge but also to engage in an interaction with policy makers, we need to accommodate two types of tasks in the programme, one contents oriented and one process oriented task. We have decomposed the contents oriented task into three work packages: focusing on issues dealing with infrastructure technology (WP2), on issues related to the functional organization and management of our mobility system (WP3) and on the economic impacts of climate change and adaptation policies (WP4). WP1 is the process oriented work package that binds the three together through a platform where the stakeholder and research communities come together to develop a systems model and integrative adaptation strategies.



WP2, 3 and 4 provide the essential thematic building blocks and focus on fundamental and applied research to reduce uncertainties concerning the expected impacts of climate change, sub-surface changes, infrastructure performance, robustness and network resilience. WP2, WP3 and WP4 focus on analysis and provide inputs for adaptation strategy development.

WP 1 integrates and applies the work towards the adaptation strategies. By developing integrated models, the scope of the other WP's is further defined. Building upon WP2, 3 and 4 elements of technical design, socio-economic performance and governance are combined.

The relation between disciplines reflects the relation between infrastructure system levels in figure 1: the sub-surface, infrastructure and management layers interface to provide infrastructure products and services to society. Issues dealing with the “wet” elements of the system such as groundwater physics and the “dry” elements such as infrastructure design are jointly addressed to allow for cross-fertilization and exchange between multiple knowledge domains. Each of these WP’s 2-4 has its own research thrust and will operate one or more PhD’s or post-docs who work independently and feed the programme with knowledge. Each of these WP’s in addition has an applied project where the researchers reserve time for the application of the generated knowledge through case studies and ad-hoc participation in the platform created in WP1. The time path of the programme (almost 4 years) includes one integrative workshop per year, where the knowledge developed is exchanged and steps are made towards developing adaptation strategies at different levels of detail. These will be the 4 key moments where the outcomes of the research work will be synthesized towards the stakeholders in the different case studies.

4 (Expected) cooperation and coherence with other research themes

We expect that co-operation with the other themes will develop along mainly along the following lines.

In general, all themes will have a direct contribution of the adaptation strategies from the participating hot spots and other stakeholders involved in case studies. Co-operation between the themes could provide to be beneficial for the Knowledge for Climate programme. From the perspective of INCAH this collaboration will be facilitated through the platform hosted by WP1. Themes that have a relation to the different case studies in the development of adaptation strategies will be invited to participate in the workshops.

Input is provided to selected programmes:

- Theme 1 (Flood risk): Infrastructure will play a role in the reduction of the risk of flooding. As infrastructures are ageing and maintenance costs are increasing dramatically, the replacement of infrastructures will need to be considered as well. These investments can be dovetailed with investments for reinforcement of protection infrastructure.
- Theme 4 (Urban): As the participating hotspot Rotterdam will be interested in case studies around in a strongly urbanized area, co-operation with theme 4 will be important. At the proposal stage, the two programmes have shown to be complementary; however, during the course of the project, further communication will be necessary to anticipate the emergence of double work or lacunae on the way.
- Theme 7 (Governance): INCAH will develop new tools and insights for asset management for specifically on infrastructures and network, that may be of use for Theme 7. Although no specific lines of co-operation have been programmed, this will be encouraged by inviting contributions from this theme to the yearly workshops.

The strongest relation in terms of dependence of INCAH on the output of other themes are the following:

- Climate projections (Theme 6) and flooding risks (theme 1) are important inputs for the design of adaptation measures for infrastructures and networks. Ideally, this information should be available at the start of the programme. In preliminary discussions it became clear, however, that these themes will deliver new research results only in the course of years. Agreements were made to provide additional detail in existing forecasts (e.g. temperature and precipitation) by the KNMI (Royal NL Meteorological Institute) and funds were reserved in our programme to acquire this detailed data.

- Opportunities for synergy exist with themes 4 (Urban), Theme 7 (Governance) and Theme 8 (Decision Support). With the Urban theme, new infrastructural solutions will need to be harmonized with other urban concerns in the area of health care, public safety, quality of life. A common concern with Theme 7 will be to address the institutional aspects of capturing the value of robustness in new business models of public and private actors. Theme 8 will produce decision support systems which could facilitate our platform for the development of adaptation strategies, enriched by the contents produced in WP2-4.

5 Connection to finalized and current projects in KfC and other research programmes

INCAH elaborates on the first stage KfC project HSRR08, theme “water and transport”, with title “The effects of climate change for the inland waterway transport sector via the Port of Rotterdam. This project is currently in the execution phase and expected to be finalized on 01/01/2011. It focuses on the effects of climate change on costs and reliability of inland waterway transport. An increase in costs and decrease in reliability is likely to lead to a loss of cargo to other modes. In addition, the change in costs and reliability may have negative effects for the competitive position of inland waterway dependent sea-ports. The aim is (1) to analyze the change in costs/reliability/modal split and (2) to identify promising adaptation measures.

Clearly, the focus of project HSRR08 is much narrower as it only focuses on the mode inland waterway transport and on the hotspot Rotterdam. INCAH comprises more types of transport infrastructure (roads, railway) plus energy and water infrastructure and has a larger geographical scope.

Another project which is linked to INCAH is project A8 (consequences of climate change for the transport sector) of the ‘Climate changes, Spatial Planning’ research programme. Research topics within this project are: the effects of low water levels in the river Rhine on inland waterway transport (Ph.D. thesis finished), the effect of weather on transport mode choice, accidents and congestion and the relationship between extreme weather and disturbances in railway transport. The geographical scope of this project is broader than that of INCAH because it focuses on North West Europe however only a limited number of infrastructures get a change.

There is also a link with the 7th framework programme ECCONET, which has two objectives:

1. Analysis of various effects of climate change on inland waterway transport and related sectors.
2. Analysis of adaptation strategies and their impacts as well as development of recommendations and a strategic framework for the further development of the inland waterway transport sector.

The scope of this project is on the European level. It focuses on several corridors such as the Rhine and Danube waterways. Although the centre of gravity will lie on inland waterway transport in ECCONET, competing modes will also be elaborated on.

The last project with a link to INCAH is RIMAROCC (risk management for roads in a changing climate). RIMAROCC is a cross European research project for ERA NET ROAD that will finish in 2010. Within RIMAROCC a framework is being developed with which road owners will be able to weigh different options with regard to adaptation to climate change. In the basis this framework is also usable outside the road infrastructure. With INCAH, we provide relevant input (knowledge) and tooling for the RIMAROCC framework.

Climate change is a research topic on its own and it is important to have good links with up to date climate knowledge. For the research in all work packages and application at the hotspot we will take best opportunity of existing data bases of meteorological extreme climatic events to characterize probabilities and severities (e.g. 6th framework programme project ENSEMBLE, 2009).
The EU FP7 project WEATHER (Weather Extremes: Assessment of Impacts on Transport Systems and Hazards for European Regions) is carried out by a consortium of 8 international partners and started 1 November 2009. The objective of this 2,5 year project is to "Determine the physical impacts and the economic costs of climate change on transport systems and identify the costs and benefits of suitable adaptation and emergency management strategies." The INCAH and WEATHER project coordinators have agreed to bring together their networks in workshops in the coming years.

Specific for work package 2 the following projects are relevant:

WP2 uses parts of the work done in 2009 for the Rijkswaterstaat PAWN Instrument (Policy Analysis for Water Management in the Netherlands), where water issues such as drought are related to economic sectors such as transport infrastructure. Within this project effects of changes in water tables on road infrastructures are systematically determined.

Another relevant project for WP2 is Climate Proof Areas. This INTERREG IVB North Sea Program aims at the development, demonstration and dissemination of transnational and integrated adaptation strategies, based on impact analysis. This project includes a pilot on climate proof regional roads. (Deltares, 2007, Schelfhout).

The last project to be mentioned is High water: Free Road. An innovation project for keeping road infrastructure available during flooding (Dutch Ministry of Transportation and Water Management, Deltares).