Scientific Progress Report

Self assessments of the Knowledge for Climate research consortia

This Scientific Progress Report has been prepared for the Knowledge for Climate Final Evaluation, in addition to the Final Report of the research programme. The report is provided to the (scientific) reviewers of Knowledge for Climate in order to get better insight into the scientific approach and results of the programme.

The Scientific Progress Report is compiled based on the final reporting of the eight research consortia of Knowledge for Climate. The consortia have been asked to perform a self assessment on their scientific approach, implementation of the research programme, main results and achievement of the initial objectives. The most relevant elements of the self assessments, with respect to the scientific review, are included in this report.

For more information, details about the consortia and lists of publications, please visit the Knowledge for Climate review website.

Board of Directors of Knowledge for Climate,

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October 2014

Content

Theme 1 – Climate Proof Flood Risk Management

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1. Reflection on the consortium's position in the international research arena and the contribution to the (inter)national scientific and public debate

The Netherlands has a great international reputation when it comes to managing flood risks. The country's traditional calling cards are the Afsluitdijk and Delta Works, but these have recently been complemented by 'soft' solutions such as the 'Room for the River' programme and sand nourishment along the coast (e.g. the 'Sand Engine' project). The world looks to the Netherlands, not only because of its technical accomplishments (Oosterscheldekering and Maeslantkering), but also because of the way in which knowledge creation ('Delft' and 'Wageningen') and practice (the Directorate-General for Public Works and Water Management and the water boards) influence one another and work together, and not least because of the way in which public authorities, knowledge institutions and local stakeholders arrive at joint solutions with ample public support (knowledge sharing and participative planning).

The Delta Programme has added a new dimension to this positive international reputation, namely that of 'anticipating' what we might be facing in the future, rather than responding to disasters when they have occurred. With the introduction of Adaptive Delta Management, the Netherlands is again setting the pace, as is apparent from the media attention after the recent flooding in the UK ('*To plug floods will mean going Dutch'*) and the enthusiasm with which the Dutch approach and Dutch proposals were received in the USA ('*Dutch Dialogues'* and '*Rebuild by Design'*).

Our consortium has benefited from the warmth of the existing international respect, but has certainly also contributed to it. The broad approach to 'flood risk management' as something that is not merely a technical issue, but also a spatial and social planning issue, had already been explored by some of the partners in the consortium and by our international sub-contractors in the EU project FLOODsite, which helped to lay the foundations for the EU Flood Risk Directive. Our consortium has been able to build on that experience, partly because some of the members already knew each other and were quickly able to reach agreement on the conceptual framework.

The concepts/points of departure and principles that we share are the DPSIR framework, a risk-based approach, 'multiple-tiered flood risk management (measures to reduce the probability of flooding, to limit exposure and to reduce vulnerability) and a consistent focus on achieving goals (risk management at acceptable social costs), but with attention to undesirable side effects and possibilities for synergies with other objectives (objectives for spatial quality and nature). These concepts and points of departure are not only shared within our consortium, but also correspond with international scientific developments and social developments in the Netherlands and other countries. In our view, we have played a demonstrably relevant role in operationalising these concepts, as is apparent from publications in prestigious journals such as *Global Environmental Change* (Jongman et al., 2012), *Nature Climate Change* (Jongman et al., 2014) and *Science* (Aerts et al., 2014), the success of *FLOODrisk2012,* a scientific conference that the consortium jointly

organised (Klijn & Schweckendiek, 2013), but also from the significant contribution it has made to the preparation of policies in various sub-programmes of the Delta Programme ('Wadden Region', 'Large Rivers', 'Flood Security', 'Urban Development & Redevelopment', 'Rijnmond-Drecht cities'), the STOWA programme Delta Proof and the municipal (Rotterdam) and regional adaptation strategies in a number of the KfC hotspots (particularly Rotterdam Region and Major Rivers).

The fact that we, in the Netherlands, are not only concerned with managing existing flood risk, but are explicitly anticipating the development of potential future risks by performing scenario analyses and assessing measures from the perspective of sustainability (not only for their current effectiveness but also their effectiveness and possible side-effects in the future) is regarded as ground-breaking in international terms. The consortium has consciously tried to give substance to this long-term orientation by devoting attention to robustness, spatial quality and nature development in the research.

The interdisciplinary approach that the consortium has adopted is also regarded as state-of-the-art. It encompasses a problem analysis that takes into account not only climate and water, but also demographic and economic developments, an exploration of solutions not only on the basis of technical and scientific knowledge (natural sciences), but also with a feeling for societal relations and as a 'governance problem' (social sciences), and the basic desire to produce good plans and to design technical solutions jointly with stakeholders, as a form of cultural activity (arts). Part of the consortium's added value is therefore attributed to the fact that it brings together engineering (civil engineering at Delft University of Technology, HKV, GfZ), the natural sciences (Environmental Sciences at the Free University (VU) in Amsterdam and Wageningen University and Research Centre (WUR), the social sciences (WUR, the Flood Hazard Research Centre (FHRC)) and arts (Urban Planning at Delft University of Technology).

The public debate about 'flood security' in the Netherlands has been influenced by our research and our – consequently well-informed – participation in this debate. We, for example, have participated in efforts to bring balance into the discussion about 'multiple-tiered flood risk management by, among other things, a) quantifying the potential of spatial policy and developing tools to support this (risk zoning maps; Delta Programme 'Urban Development & Redevelopment''), b) demonstrating the added value of room-for-river measures compared with raising dikes (Delta Programme 'Rivers'), c) quantifying the possible significance of 'fail-free embankments' for preventing flood fatalities (Delta Programme 'Flood Security'), d) outlining the potential role of salt marshes and mudplains for combining functions in flood defences (Delta Programmes 'Wadden Region' and 'Large Rivers'), e) initiating discussion of the significance of the many regional flood defences managed by water boards as compartmentalisation in view of higher sea levels in the future (STOWA's Delta Proof programme).

Our international orientation has also proved very important for the public debate in the Netherlands, since other countries often choose totally different portfolios of measures which has prompted some people to suggest that similar solutions be adopted in the Netherlands. For example, the UK consciously opts for private insurance: our English colleagues extensively analysed the potential of flood insurance, reaching the conclusion that the Netherlands would be better off with a 'government insurance' as implicitly present. We wrote a Delta Fact on the subject. In Germany,

where a lot is done at a smaller spatial scale (municipality, households), our German partners investigated damage-reducing measures at the household level. The possibilities of applying them in the Netherlands appear to be mainly relevant for the Rijnmond-Drecht Cities region, where > 10,000 homes are in unprotected (floodplain) area..

2. Reflection on the initial objectives of the consortium

The main objective of the research was to perform an interdisciplinary assessment of the effectiveness and relevant side effects of individual *measures* to reduce flood risk, and to make a contribution to the development of robust and/or flexible a*daptation strategies* in light of the uncertainties surrounding climate change. Our intention was to complement the research that was already being conducted for the Delta Programme where possible, and at the same time to play 'devil's advocate' – with a constructive attitude – for that Delta Programme.

To start with, a ***conceptual framework*** was developed for the research and measures were identified and investigated that would (1) reduce the probability of flooding, (2) influence the flooding process and pattern, and (3) reduce the vulnerability to flooding. These measures were investigated in separate work packages.

The research relating to limiting the consequences, in particular, built on earlier Dutch and European research and availed of the expertise and experience that exists in Germany and the UK.

The two specific objectives of the research programme were therefore as follows:
1. to develop ***methods*** for assessing the effectiveness of technical measures and policy instruments designed to reduce the risk of flooding, for assessing the implications of their implementation in practice, and for assessing the robustness (resilience and resistance) of integrated strategies for flood risk management in light of uncertainty about climate change (and to perform the assessments themselves);
2. to produce ***guidelines*** for the design of long-term flood risk management alternatives and the application of individual measures based on effectiveness, robustness and contribution to integrated regional development (multi-functional use, natural values and spatial quality).

We still consider these two main objectives to have been correct because they correspond with the task that the consortium had set itself, namely to advance knowledge and develop tools for application (first objective) and to carry out the public task assigned to us of sharing the knowledge with stakeholders and others who could use it (second objective).

In our view, we have achieved the *first* goal for those measures that were specified in the research proposal. The interim and final results were incorporated in the Delta Programme sub-programmes 'Flood Security', 'Urban Development & Redevelopment', 'Wadden Region', 'Large Rivers' and 'Rijnmond-Drecht Cities'.

We pursued the *second* objective mainly in joint activities with STOWA , in the context of its Delta Proof programme. Together, we organised several study days (on 'Dikes for the Future', 'Multiple-tiered Flood Risk Management', 'fail-free dikes') and held workshops (on flood protection involving

salt marsh development, compartmentalisation), which resulted in a number of joint products, in particular concerning 'perspectives for action'.

Each work package (WP) and project in the programme had its own specific objective and is discussed individually below.

WP 1 posed the question of whether a system of flexible flood barriers is sufficiently reliable in a setting of river branches and estuaries with multiple openings to the sea threatened by rising sea levels and increased river discharges. The research focused on the Rhine-Meuse estuary.
This work package contributed to the knowledge base and strategy formulation in the Delta Programme's 'Rijnmond-Drecht Cities' sub-programme, in particular with research into 'the partial functioning' of the Maeslantkering, which can justifiably be described as innovative. One could argue that the social objective was thus achieved , although in another societal setting more might have been achieved in scientific terms, because it became clear quite early during the Delta Programme that a system with many flexible barriers was found to be undesirable. Partly against this background, the PhD research in this work package (Rijcken, TU Delft) took a different turn, away from the hydraulic constructions and more towards searching for methods of knowledge sharing and participatory planning.

In 2014, one of the consortium partners (HKV) conducted further research into types of barriers and their reliability in relation to other desired functions (navigability, tides).

The 'feeling' of the consortium leader: different from the original plans in the research proposal (with reason), innovative in parts. Partly 'incorporated' in the Delta Programme 'Rijnmond-Drecht Cities'.

WP 2 addressed the management of coastal dunes under the pressure of a rising sea level and the possible increase in storm intensity.
Project 2.1 focused on the fundamental question of coastal development due to weather and wind and how it is influenced by sand nourishment and vegetation management. This knowledge – mainly generated by field research on Ameland – was incorporated in models with a view to integrating morphological models for 'aquatic' and 'terrestrial' environments. Major progress was made, but complete integration has not yet been achieved. Most of the research was carried out as part of a PhD project (Keijsers, WUR).
In Project 2.2, this knowledge was integrated into guidance for the management of sandy shores, by combining it with expert knowledge about ecological developments and local practical knowledge. The main purpose of the project was to allow the knowledge to be used immediately in the day-to-day practice of coastal management and for the long-term policy being developed in the Delta Programme 'Coast' . Additional research was conducted into sand nourishment along the banks of the Westerschelde (a tiny 'sand engine') in association with the local water board. That research was mainly of direct practical use. It was found that the sand quickly disappeared due to the rapid tidal currents in the estuary.
The 'feeling' of the consortium leader: the research was sound and generated a lot of publications. It did not produce any major social innovations, but that was not to be expected in view of the lengthy positive experience with sand nourishment. In addition, the influence of climate change on storm frequency and intensity is still highly uncertain (Theme 6). The work package certainly made a

relevant contribution to the knowledge base and safeguarding that knowledge in models, which is particularly relevant in light of the degradation of knowledge on this subject.

WP 3 was intended to provide more insight into the question of what type of flood defence would be most suitable in particular situations. The research concerned both 'practically fail-free' embankments designed to reduce fatality risk and the most effective embankments in economic terms for other locations, as well as additional functions and qualities of flood defences. This work package generated new knowledge about embankment failure and the costs and benefits of methods of reinforcing embankments and combined it with practical knowledge and local wishes regarding additional functions of flood defences (multi-functionality) and the associated forelands (e.g. salt marshes) and hinterland (broad flood protection zone). Most of the research was carried out in PhD projects (Van Loon-Steensma, WUR and Tsimopoulou, TU Delft). Case studies were carried out at various locations (the Wadden region, the Rivers region).
Project 3.1 originally intended to develop tools to support decision-making at local level on the dimensions of embankments and the design of forelands and hinterlands (beach berms), for example with a view to multi-functionality. The project was – partly in consultation with the users of the knowledge and stakeholders engaged in the research in the case studies – amended to devote more attention to the role of forelands in reducing wave load on the flood defence, and synergies by additional functions and nature development. Hence, the focus shifted to salt marshes.
In Project 3.2, the focus was on cost-effective investment in flood protection. To this end, cost-benefit analyses were carried out in relation to investment moments over time. This project extensively reviewed experiences in other countries (including Japan), but also other ways of reducing risks ('multiple-tiered flood risk management').
The 'feeling ' of the consortium leader: Project 3.1 attracted a lot of attention from numerous stakeholders in the Wadden region, which prompted the decision to revise the original objective and to focus on public needs/interests. The scientific added value lies in the trans-disciplinary approach, in which knowledge from various domains is combined. This fits in well with the broad focus that the consortium as a whole had adopted. It is not yet possible to say with certainty whether Project 3.2 will generate any new insights; a factor in this is that a lot of work is being done in this field of research (not least because of the great attention to flood protection in the Delta Programme As a result, the focus repeatedly changed, with repercussions for the progress of the project. The original objective might have been too ambitious. The integration of the research in this work package has not proceeded entirely according to plan, although synergy was created with WP 6 by explicitly considering the impact of flood barriers on spatial quality in the research, in line with our general objectives.

WP 4 had the objective of increasing knowledge about the possibilities of slowing or halting the steady increase in vulnerability: potential economic damage. The research therefore focused on the potential (effectiveness/costs) of spatial policy and/or building codes in both protected and unprotected areas .
The central question addressed in Project 4.1 was to what extent flood risk zoning and building regulations could contribute to reducing risks, particularly in unprotected areas in the Rhine-Meuse estuary (Rijnmond-Drecht cities). Special attention was given to an analysis of legal regulations, which proved complex but offered sufficient possibilities for customisation.

Project 4.2 explored the issue of effectiveness, using models to calculate the possible reduction of flood risk. This project also concentrated on the Rijnmond-Drecht Cities region, but part of the research was more methodological, for which a PhD candidate (Jongman, Free University Amsterdam) used worldwide models and data to perform analyses that attracted international admiration. This project was closely connected with a number of other collaborative projects of the Free University Amsterdam, giving it a very broad international scope that will be continued after the completion of the KfC programme.
The 'feeling' of the consortium leader: an initially relatively small but highly fruitful work package, which produced practical and usable results (specific perspectives for action) and provided greater insight for stakeholders, while at the same time generating publications in prominent scientific journals and attracting international attention. In connected research for the Delta Programme's 'Urban Development & Redevelopment' sub-programme, interesting new methods were developed for flood risk mapping and zoning.

WP 5 focused on the question of how other countries address the challenge of dealing with uncertainty about the rate of climate change in their adaptation policies and what measures or policy instruments they successfully apply in their flood risk management policy. The work package consisted of the following four projects:
Project 5.1 primarily aimed at making an inventory of the pros and cons of insurance arrangements, based on decades of experience in the United Kingdom, but also elsewhere in the world, with a view to helping the Netherlands to decide whether or not to pursue a similar arrangement in addition to the existing policy. The research was largely carried out by our British sub-contractor (*Flood Hazard Research Centre*), whereupon various methods were used to translate the findings to the Dutch situation (including a series of lectures for the Dutch Association of Insurers and the *Delta Fact* 'flood insurance').
Project 5.2 was intended to give an impression of how other European countries deal with the uncertainties of climate change and rising sea levels: what assumptions are made, why, and what can be learned from them? The research was mainly exploratory in nature, with the emphasis on 'governance'. The project was completed in 2012 and a chapter of the interim report was devoted to it.
The aim of Project 5.3 was to describe and assess measures that individuals can take to reduce damage. There is a lot of experience with this in Germany, from which the Netherlands can learn, particularly for unprotected areas . Data was collected from the Rhine and Elbe valleys. The empirical research was carried out by our German sub-contractor (GfZ Potsdam) and led to a PhD at the Free University in Amsterdam (Bubeck).
In Project 5.4, the results of these three projects were integrated and 'translated' to the Dutch situation.
The 'feeling' of the consortium leader: sound empirical studies, which are useful for formulating concrete perspectives for action for the Netherlands. Language (Dutch!) and cultural barriers complicated the investigations of the Dutch situation by our foreign partners, but the outsider's view of how we arrange things in the Netherlands is very enriching. The scientific output was as expected (outstanding and substantial).

WP 6 addressed the fundamental questions of how to deal with uncertainties and how added value – more specifically, spatial quality – can be achieved with measures that are primarily intended to reduce risk.
This work package was therefore not concerned with individual measures, but more with assessing comprehensive strategies comprising a range of different measures and instruments.
Project 6.1 was devoted to an investigation of whether robustness could be a useful/better additional objective to assess adaptation strategies by, in addition to or instead of risk, resilience, resistance, vulnerability, etc. To this end, the concept was operationalised and made practically measureable. The method was applied to the IJssel and the Meuse Rivers (in co-operation with the Delta Programme 'Large Rivers'). The research resulted in half a dissertation (Mens, University of Twente/Deltares).
The aim of Project 6.2 was to explore a) how the infrastructural network of embankments and dams has helped shape the character of the Netherlands, and b) how the ensuing character of the landscape creates new demands that the designers of new flood barriers have to take into account, with the emphasis on countryside environments. In the early years, major progress was made with regard to 'delta dikes' in association with the Delta Programme 'Urban Development & Redevelopment'. The last year was devoted to attempting to provide better scientific underpinning of the concept.
Project 6.3 also concerned the subject of 'spatial quality', but with the emphasis on urban environments. The main question was how flood protection and spatial development coincided and were mutually dependent in the past and what that should mean for their further integrated development in the future.
The bulk of the research was carried out for a PhD (Nillesen, TU Delft), partly in association with the NWO project *Integrated Planning and Design in the Delta* (IPDD), and with the focus on the south-west delta (Delta Programmes Rijnmond-Drecht Cities and South-West Netherlands Delta).
The 'feeling' of the consortium leader: conceptually innovative in part and publicly welcomed research with a practical impact (Delta Programmes Rivers, Rijnmond-Drecht Cities), scientifically less innovative in part ('*art, no science*'), yet societally very relevant work that was well received. A good impact in practice (perspectives for action).

3. Most important scientific and societal results

Scientific:
A better, and to some extent entirely new, quantitative underpinning has been provided for the significance of climate change for flood risks in relation to other drivers/factors (demographics and economic development). This underpinning was based partly on more accurate analysis of the development of the risk of flooding, but has added value mainly by devoting more explicit attention to increased exposure: deeper, larger areas under water (fleshed out for the Netherlands, and in WP4 for global / Europe), as well as increased vulnerability. As a result, it is now possible to provide better underpinning of the potential for 'multiple-tiered safety' in protected and unprotected areas, as well as to better align the 'Flood Security' and 'Urban Development & Redevelopment' sub-programmes of the Delta Programme.

This was facilitated in part by creating greater conceptual transparency about precisely what flood risk is and by connecting the concepts and frames of 'engineers' (probability * effect) and 'spatial

planners' (overlay of risk map and vulnerability maps). In this way, different frames could be reconciled, also internationally, as became clear during the mid-term scientific review (Midterm Assessment 2012). The scientific innovations in that context were mainly incremental, rather than revolutionary, which is not surprising in an area of research that has obtained such a dominant shape in the last decade (partly in the context of FLOODsite) and is now primarily crystallising.
The scientific innovations in the individual work packages were also predominantly incremental, but no less innovative for that. The following innovations can be mentioned for each specific work package:

- Greater insight was gained into the significance of partial functioning of the Maeslantkering for the design flood levels in the Rhine-Meuse estuary and into the reliability of flexible barriers in general (WP1). To this end, new methods of calculation based on Bayesian statistics were developed. This research was very important for the Delta Programme Rijnmond-Drecht Cities and increased confidence in the functional life-time of the Maeslantkering.
- A greater understanding of the behaviour of sand along the coast was gained by combining above-water (aeolian) and underwater (erosion and sedimentation due to the current and waves) morphological research (WP2). This increased the understanding of the significance of sand nourishment for the maintenance of dunes as flood defences, which will help the responsible authorities (the government, water boards and site managers) to formulate joint management plans.
- Knowledge about the function of salt marshes in reducing the size of waves that threaten embankments along the coast was increased, as was knowledge about the ancillary functions of salt marshes, embankments and broad flood protection zones (WP3). This is also significant for water boards and site managers, in this case of flood defences along the Wadden Sea and the (former) estuaries in the provinces of Zuid-Holland and Zeeland.
- There is a better understanding of the possibilities of influencing the probability of failure and the failure behaviour of embankments (WP3), the spatial implications of 'delta dikes' were identified and the perspectives for designing 'unbreachable embankments' with regard to spatial quality were outlined (WP6).
- The legal possibilities of implementing spatial policy and/or imposing technical requirements (Building Decree) in order to reduce the vulnerability of built-up areas were explored and assessed (WP4). These were found not to be an obstacle to designing dedicated policy, but would demand a prudent deliberation process.
- The cost-benefit ratio of modified development proved positive in unprotected areas, but the responsibility for and financing of these measures may prevent implementation of this cost-effective option (WP4).
- A worldwide survey of the factors that determine the success or failure of insurance arrangements (WP5) led to the conclusion that compensation for flood damage due to embankment failure by the government is by far the most efficient arrangement in the Netherlands. Private insurance arrangements seem unappealing for the Netherlands, except with regard to water damage due to excess precipitation (nuisance flooding).
- In other international research (mainly in Germany), it was found that measures taken by individuals can effectively reduce flood damage (WP5). They are particularly effective in unprotected areas where (shallow) flooding occurs sufficiently frequently (in the Netherlands, the unprotected parts of the Meuse River valley and in the Rhine-Meuse estuary (Rotterdam-Drecht Cities)).

- More is known about the possibilities of combining flood protection and enhancing spatial quality (WP6). The concept of spatial quality was better defined and operationalised; a method was also developed to assess quality by connecting expert assessments ('design') with empirical underpinning of appreciations ('socio-scientific research') .
- The term 'robustness of flood risk systems' was operationalised and made measureable, while specific recommendations were made for increasing robustness (WP6).

Articles were published on these subjects in numerous scientific journals and reports. At the time of this evaluation, more than 50 scientific articles had been accepted, researchers had written or contributed to 15 books and more than 20 presentations had been given at conferences (see the attached list of publications, Appendix 3).

Social:

The research has had a substantial impact on the formulation of visions in the Delta Programme, and subsequently on the research programmes and priorities of various sub-programmes. For example:

- the 'Rivers' sub-programme has devoted attention to robustness (WP6), fail-free embankments (WP3) and spatial quality (WP6), and even more attention is now paid to the advantage of making room for the rivers in comparison to strengthening embankments from the point of view of reducing flood risk (WP6);
- the Rijnmond-Drecht Cities sub-programme has made use of new information about the partial functioning of flexible barriers (WP1), the possibilities for modified building (outside dikes) (WP4) and the potential for linking flood protection measures to improvements in spatial quality (WP6);
- the Wadden Region sub-programme has made grateful use of the insights generated regarding broad flood protection zones, where salt marshes function as wave breakers (WP 2 and 3);
- the vision for the sandy coast in the Coast and Wadden Region sub-programmes was formulated with input from partners in the consortium;
- various consortium partners were involved, albeit mainly in a personal capacity, in the research and policy preparation for the Flood Security sub-programme, indicating that the parties in the consortium are regarded as serious partners.
- Finally, the Urban Development & Redevelopment sub-programme made use of our research into the spatial implications of 'delta dikes'. We tailored our research into flood risk zoning for the purposes of spatial planning specifically to this sub-programme. The impact on the local and regional authorities and other stakeholders involved in flood risk management (water boards, provinces and municipalities) is apparent from the steadily growing interest shown during the course of the research and the extensive internalisation of the knowledge and insights gained, particularly among the water boards.
- Through the mediation of STOWA, a lot of knowledge was shared with the water boards in workshops and through various Delta Facts. For example, workshops were organised on 'Embankments for the Future', 'Unbreachable embankments', 'Multiple-tiered flood risk management' and 'Multi-functional embankments'. The Delta Facts on 'Robustness' and 'Insuring flood damage' were written by members of our consortium, partly on the basis of our research. In association with STOWA, perspectives for action are being formulated (in prep.)
- The municipality of Rotterdam used the findings of our research in drafting the municipal adaptation strategy, and the regional adaptation strategies of the KfC 'hotspots' Rivers and Rijnmond-Drecht Cities were produced partly on the basis of our research.

4. Reflection on value creation[1]

I) scientific and social value in terms of high-quality and climate-proof spatial investments

II) contribution to strengthening the knowledge infrastructure

III) valorisation of knowledge

I) Through the involvement of co-financiers and synergies between KfC research and activities for the Delta Programme, we delivered more than was anticipated in advance and the influence on the practical formulation of policy was also greater than expected (benefits of synergy). First, a far larger number of publications, both scientific and social, were produced than promised in the research proposal, but the social impact was also substantial.

Because of the societal orientation of our research, with the focus on managing flood risk with a view to sustainable development, the societal benefits more than outweighed the research costs. In our view, we were able to help the Delta Programmes 'Flood Security' and 'Urban Development & Redevelopment' to design a flood risk management policy that is more *forward looking* than previously by anticipating climate change, that is more *efficient* than former policies due to cost-benefit analyses and in which the entire package of investments is more *effective*, and in which priorities can be set through a tailored schedule of implementation via *adaptive management* in such a way as to minimise public regret. Although the benefits in terms of risk reduction could still be doubtful if the future turns out differently (climate and economy), by increasing the spatial quality the investment will still be justifiable; the objective in terms of risk reduction can then be achieved at a later date.

Examples of improvements in spatial quality are to be found mainly in work package 2: attractive sandy coasts with new dunes; 3: embankments with multiple uses as a residential location (rivers area) and attractive multi-functional flood protection zones with natural values (Wadden); 4 and 5: safe and pleasant area for living and working in unprotected area (Rotterdam - Drecht cities); and 6: a more robust rivers region (Room for the River, fail-free embankments, spatial zoning). These work packages had an impact on the Delta Programme mainly via the regional sub-programmes, in which our knowledge was used in drawing up their respective preferred strategies, particularly those for the sub-programmes Coast, Wadden, Rivers and Rijnmond-Drecht Cities.

II) The knowledge infrastructure has been strengthened mainly because the partners in the consortium learned more about each other and their appreciation of each other grew. Within the consortium, this applied for the partners from Delft (TU Delft, HKV and Deltares), but it also applies to the intensification of the cooperation between Deltares and the Free University of Amsterdam, the expansion of the cooperation between WUR and Deltares in the context of Delta Programmes Coast and Wadden, and, finally, for the cooperation with international partners. For example, the PhD student at the WUR was a guest in the UK for several months, a colleague from Germany obtained a PhD from the Free University and various new research initiatives are being developed, either among Dutch partners or jointly with international partners (STW research into 'Multi-

[1] Knowledge for Climate Final Report, chapter 5

functional embankments'; EU Marie Curie proposal, etc.). The cooperation with knowledge brokers, such as STOWA, was also intensified.

III) In the Netherlands, the domain of our research (adaptation of flood risk management) is regarded first and foremost as a responsibility of the government (or a domain for which it has assumed responsibility in the past). This is connected with the scale and size of the flood risk problem and the manner in which things have been arranged over the centuries in the Netherlands (with the Directorate-General for Public Works and Water Management (standards/policy), the water boards (flood defences), provinces (spatial planning) and municipalities (building policy)). This meant that business development was not a likely outcome of our research. Research, consultancy and engineering firms can of course use the knowledge we have gained, as has been agreed via Partners for Water, and private parties, such as the consortium partners HKV Consultants and D.EFAC.TO *architecture & urbanism*, can commercially exploit their participation in the research. But the most important business development will ensue from the implementation of technical measures, for which we have only provided a number of 'hooks' in the research, for example with regard to making embankments 'unbreachable' by applying geotextiles or sheet piling, by increasing the interest in jacking up houses/allowing houses to be jacked up on or against embankments, and by growing attention to 'alternative building' (flood-free, flood-proof, amphibious). The consortium's contribution therefore lies mainly in directing attention to such 'forgotten' local solutions and by contributing to a paradigm shift from 'exclusively flood protection' to 'risk management with a multiple-portfolio' ('Multiple-tiered Flood Risk Management').

5. Most important social and scientific developments relevant for future research priorities

The most important recent developments relating to flood risk management in the Netherlands are (in order of importance): 1) the announced switch to new, risk-based standards for flood risk protection, 2) the tighter budgets because of the economic crisis, and 3) the decentralisation of spatial policy.

The first of these developments has been facilitated in part by the rapid development in recent decades of scientific knowledge and methods of analysing flood risk and the enormous volume of data that has consequently become available, for example from a) the Flood Risk in the Netherlands project (FLORIS), which has meanwhile almost fully analysed the current flood risk in the Netherlands, b) Flood Security in the 21st Century, a project that has further developed the method of cost-benefit analysis, in the context of which methods have been developed for analysing collective risks and the Local Individual Risk (LIR) of drowning, and c) the mapping of flood hazard and risk to meet the obligations arising from the EU Flood Risk Directive.

Against this social and scientific background, we can identify a number of central challenges for applied research, which are partly normative in nature, partly technical and partly related to 'governance'.

First, we observe that the public debate about the new standards has received little attention in a *normative* sense. There has been little discussion of the choice of a basic level of safety, but above all how it should be realised (and at what cost). There has also been little reflection on how societal risk

(group risk) should be addressed. The question of whether the concept of effectiveness should not be interpreted more widely than on the basis of 'smallest risk at the lowest cost' also requires further consideration. Praiseworthy recommendations were published very recently on this subject by the Scientific Council for Government Policy (WRR) and the Council for the Environment and Infrastructure (RLI) (are the costs of reducing risk proportionate to the benefits and in relation to other risk domains, and should we not also consider opportunities and consequences separately?). These recommendations relate closely to our research into the robustness of 'flood risk systems'.

Moving from normative to *technical,* there are a great many questions surrounding the implementation of the new standards in the context of applying Adaptive Delta Management (ADM) in practice: where to start with the strengthening of embankments, how to set priorities and on what normative grounds (the new Flood Protection Programme), which techniques to apply (innovative or traditional), how far ahead of potential, still unknown technical innovations (over-dimensioning), how to guarantee flexibility (the Rivierenland water board, for example, already requires that it must be possible to jack up or relocate new buildings on the embankment), what type of embankment at which location in relation to the precise goals to be pursued at that location (primarily to prevent victims or to achieve optimum economic benefits)? It is therefore a question of 'priorities', 'design guidelines' and 'design instruments'. A lot of knowledge in this context has already been incorporated in a new statutory assessment instrument (WTI), with which there must be a close relationship. Inherent to this cluster of research questions is the danger of heavy technocratisation and a lack of overview, while at the same time they have a normative dimension that may be lost sight of even more easily. It is a complex challenge, which Deltares, TU Delft and HKV are already addressing.

Other questions relating to implementation concern the 'incorporation' of salt marshes, mudplains and other elements that are not directly part of the flood defence but which do help to reduce flood probabilities. How to give these their appropriate place in design and assessment is a practical, technical and administrative-legal question. There are no field measurements under extreme conditions available and the managers of flood defences do not know how reliable these elements are; far more monitoring of developments over time is therefore required. An associated question is how non-risk-related values, such as natural values or spatial quality, can be incorporated in local design considerations and how any additional costs/funding should be arranged if the central government tightens the purse strings.

A third cluster of research questions concerns the implementation of 'multiple-tiered flood risk management', and more specifically regional spatial policy (structural schemes), zoning plans, specific plans for new developments and accompanying building regulations. With the decentralisation to local authorities, a very large number of individual actors will have to deal with these issues, making the process extremely difficult to direct and creating serious problems of governance. On the one hand, this provides an excellent opportunity for 'local customisation', while on the other it is likely to lead to a knowledge gap. To develop tools to support all these individual actors to reach the same level of knowledge is a task for the research community; work is already proceeding on an MLV tool, digital maps (flood risk zoning) and similar discussion-supporting tools. At the same time, it has become very difficult to finance such developments, precisely because of the trend towards decentralisation.

6. Reflection on the cooperation between the consortium partners in order to stimulate substantive cohesion

In the early years, a launch meeting and various plenary team meetings were held, which led mainly to bilateral and trilateral partnerships at the level of work packages and projects.

Following these meetings, but more importantly because of the formal relationship between the leaders of the work packages and principal contractors for each project as set out in the research proposal (in accordance with the original planning, in other words), there was substantive cooperation between:

- TUD and HKV in WP 1
- WUR and Deltares in WP2
- WUR, TUD, Deltares in WP3
- VUA and Deltares in WP4
- FHRC, GfZ, VUA and WUR/Alterra in WP5
- TUD, UTwente, VUA and Deltares in WP6

The partners also jointly wrote presentations, organised sessions and/or published articles in connection with conferences and workshops (e.g., *Deltas in Times of Change* I (2011) and *FLOODrisk2012*, both in Rotterdam, ECCA in Hamburg, March 2013 and *Deltas in Times of Change* II, 2014).

The joint production of an interim report based on a list of contents drafted in advance by the work package leaders/*editors* also contributed greatly to the substantive cohesion, as will the conception of a special issue of a scientific journal, with which we will conclude the project.

During the course of the project, the individual researchers established an informal form of practical cooperation, which was certainly just as important for the scientific progress. A few of the many individual activities were as follows:
- The WUR (WP 3.1) and Deltares (WP2.2) jointly produced a report entitled '*Een dijk van een kwelder; een verkenning naar de golfreducerende werking van kwelders*'.
- Together with Themes 2 and 8, a 'writing week' was organised under the leadership of an instructor, at which the participants practiced writing abstracts and papers (Mens, Van Loon).
- Van Loon (WUR) spent several months as a guest in Oxford in England.
- The Free University in Amsterdam (WP 4) intensified its collaboration with Deltares (and PBL) on research into flood risk, and expanded its cooperation with global partners. Specifically, it worked on the development of a tool to assess the effects of multiple-tiered flood risk management measures.
· WP 5 (Jongman, Free University of Amsterdam) visited GfZ for a case study.
· WP 5 (Bubeck) worked at GfZ in Potsdam after obtaining his PhD at the Free University.

The 'feeling' of the consortium leader: a communal spirit gradually arose, with partners feeling a greater sense of attachment to the theme. That was far more difficult for the international partners, since they could not be in involved in all of the meetings held in the Netherlands (Delta Programme,

various workshops). The meeting held in connection with the international mid-term review played an important positive role in that respect, however, since it gave the international partners an opportunity to become thoroughly familiar with the entire KfC programme (including the other themes).

7. Reflection on the cooperation with foreign research partner(s)

As set out in the research proposal, cooperation with the international partners was concentrated mainly in the work packages in which they were working (WP 5), but they were also involved in theme-wide activities and joint initiatives were taken in connection with international conferences. In this context, we recall once again that FHRC mainly investigated insurance arrangements, and GfZ individual measures at household level; both measures with which there is little experience in the Netherlands but whose potential may have been underestimated.

The work package leader for WP 5 (Free University of Amsterdam) had frequent contact with the international partners. In the beginning, for example, there was consultation by telephone every two months, and later less frequently, when the main subject was the scoping of the research. Later on, there were some periods of very frequent e-mail contact to discuss specific issues raised by joint studies with the international partners, particularly in relation to the efforts of the English partner to gain an impression of the discussion about insurance in the Netherlands (and which became highly topical and controversial in 2013). The better the parties got to know each other, the more work could be handled by e-mail, whereby very quick responses naturally increased mutual trust. Both the leader of the work package and the international partners deserve to be complimented for this.

At the level of the consortium as a whole, the international partners visited the successive team meetings (Delft in 2011, Amsterdam in 2012) and participated very actively in the Midterm Review. Employees of the international partners were invited to the Scientific Committee of FLOODrisk2012 (organised by the theme leader), at which conference all the partners again held extensive discussions and where presentations were given by all the partners. Also worth mentioning is the fact that, on the initiative of the German partner, the consortium organised a session during ECCA in 2013 in Hamburg.

Naturally, various joint publications were produced with our international partners (see the list of publications, Appendix 3) and both partners are involved in the theme number currently being produced, both as guest editors (Professor Penning-Rowsell of FHRC in London and Professor Merz of GfZ in Potsdam) and as authors. The work package leader and consortium leader ensured that the results of the research performed by the foreign partners also reached the end users in the Netherlands; they gave or organised various lectures and compiled a Delta Fact on flood insurance.

Philip Bubeck's PhD was jointly supervised by the Free University in Amsterdam and the GfZ in Germany, and it is expected that professors from our international partners will be invited to sit on the doctoral examination committees of PhD candidates from the consortium who will be defending their dissertations in 2015.

Theme 2 – Climate Proof Fresh Water Supply

Consortium leaders: Prof. Eelco van Beek and Dr. Ad Jeuken (Deltares)

1. Reflection on the consortium's position in the international research arena and the contribution to the (inter)national scientific and public debate

Practically all of the universities in the Netherlands are members of the consortium, so, in many respects, the consortium partners already occupied a prominent position in national research in the relevant disciplines. It has further enhanced its position during the four years of the programme, and has made significant progress particularly in international research. The group at Wageningen University and Research Centre (WUR), for example, has published a great deal about salinisation in the unsaturated zone in relation to crop damage in the last few years; the KWR Watercycle Research Institute has established an impressive track record with its research into underground water storage; the ecology group at the Free University of Amsterdam brought together the world's leading experts for a workshop and published a special issue about salt-tolerant crops; the Faculty of Technology, Policy and Management at Delft University of Technology (TU Delft) and Deltares jointly published a number of prominent papers on adaptation pathways and exploratory modelling; Twente University of Technology has conducted innovative research into the economic behaviour of farmers; and the groundwater group at Deltares has also enhanced its international reputation in the field of research into the salinisation of groundwater with a number of publications and keynote presentations. The members of the consortium are clearly front-runners in their disciplines. There have also been contributions from a number of young researchers who have advanced rapidly in this field. In addition to a large number of publications (including two special issues), our strong international positioning has been reflected in a number of awards received at conferences (e.g., the Prize XI Premio Carlos Ruiz at TIAC 2012 and 3rd prize at the Delta Water Award 2011-2012) and our success in securing new research funds (including funding from the third tranche of Knowledge for Climate, the EU's Seventh Framework Programme, the NWO's Urbanising Deltas of the World (UDW) programme and a Veni grant).

In *the public debate,* the consortium has been highly visible at the local and regional levels and has been an important supplier of knowledge at the national level (Delta programme), as well as for regions and hotspots. The researchers from Acacia, Alterra, KWR and Deltares have been particularly prominent in this regard, for example by playing an important role in coordinating the case studies. The fact that small-scale solutions (e.g., underwater storage) are now being taken far more seriously (in the conclusions from the Delta programme as well) demonstrates the consortium's success in conveying the results of its scientific research to the general public. The results produced by the consortium have also helped bring far more nuance to the way we think about chloride intake standards and about the effectiveness of the policy on flushing polder systems. There has also been media attention for a number of practical pilot projects (in the regions of Zeeland, Zuid-Holland, Haarlemmermeerpolder, Schermer). Researchers from the consortium have taken part in regional discussions about greater self-reliance, some of them organised by the consortium itself (e.g., the Texel workshop, a workshop on self-sufficiency in the Amsterdam Arena, the Delta Programme Knowledge Conferences).

2. Reflection on the initial objectives of the consortium

The aim of the proposed research was to develop robust, flexible and long-term solutions from a regional or local perspective that can help in finding successful strategies to bridge the growing mismatch between the supply and demand for fresh water (quantity and salinity) in light of the changing conditions in the Dutch Delta. To this end, Work Package (WP) 1 would involve a review of the boundary conditions that need to be considered in evaluating the seriousness of an inadequate freshwater supply (evaporation, precipitation, river discharges, sea level rise and related salt water intrusion, as well as the perceptions and behaviour of farmers). WP2 to 4 would be devoted mainly to investigating local and regional solutions for a more self-sufficient, robust and resilient fresh water supply in the Netherlands, broken down into three categories: smarter water management (WP2), the saline tolerance of crops and ecosystems (WP3) and water technology (WP4). The objective of WP5 was to investigate what approach would be best suited for building robust and flexible adaptation strategies, given the uncertain projections of the long-term effects of climate change and other relevant socio-economic developments. In WP6, finally, the knowledge from all the work packages would be integrated and tested in strategies for selected case studies.

In view of the aforementioned public attention and scientific successes, the consortium's broad objective (to investigate a range of measures that could contribute to a more robust and flexible fresh water supply, and the conditions under which they could do so) proved to be right. Over time, however, some of the emphases ultimately changed:

- The emphasis of the research in work packages 2 and 3 ultimately shifted more to understanding the system than directly investigating solutions. There is a recognizable conflict between the public impression that there has been 'enough research' and it is time to find solutions, and the doctoral candidate who, with an eye for detail, observes that we really do not know the system as well as we may think. This has been resolved in a logical manner by devoting far more attention to the aspect of application in projects in the third tranche of the Knowledge for Climate (KfC) programme, such as the Go-Fresh project (with pilot projects in water buffering in Zeeland) and initiatives and assignments from the Delta Programme (such as the cost-benefit tool, Eureyeopener).

- In WP4, less in-depth research was conducted into various water technologies (with the exception of underground water storage) than was originally intended. Instead, it was decided to conduct broader research, focusing on the needs of the Haaglanden Region hotspot.

- With the exception of the Haaglanden Region hotspot, in none of the cases was the original plan carried out. This was due to administrative dynamics that could not have been anticipated in advance. However, the objective of creating and testing knowledge in practice was not affected.

- The original objective was to investigate how the solutions we explored would contribute to a more climate-robust freshwater supply for the Dutch Delta, which implied that we would also establish the contribution that a particular solution would make on that scale. This would require scaling up the results to the regional and national levels, but the consortium was unable to advance that far. With the knowledge available now, that objective proved too ambitious, since the individual studies at the local level continued until the end of the project. The original plan contained no specific activities for scaling up, other than applications in the cases and estimates by the researchers themselves, which, in hindsight, proved far too little. This is now being addressed in a number of areas, such as Walcheren and Schouwen-Duiveland, and in the KfC follow-up programme, Fresh Water Options Optimizer, in which suitability maps for a number of local measures for water storage, including measures that were launched during this KfC project (Pieter Pauw and Koen Zuurbier), will be fleshed out. The knowledge gained on a local scale about the shallow rainwater lenses have been scaled up to vulnerability maps for rainwater lenses, which are in great demand.

3. Most important scientific and societal results

The most important results:

- Scientific analysis of the findings from an extensive survey among farmers in the South-West Delta shows that entrepreneurs do not always act rationally in economic terms. This means that we need to be more guarded in our models and analyses of rational economic thought. Further relevant conclusions are that the entrepreneurs are triggered far more by actual events than projected risks and that flooding is usually seen as a greater problem than drought.

- Changes in water use in the upstream section of the Rhine are marginal compared to the range of climate uncertainty. This means that this factor can probably be ignored in studies such as the Delta Programme. Possible changes in the operational management of upstream reservoirs, particularly in Switzerland, have not been investigated and could well be relevant in periods of low water.

- Greater insight has been gained (in terms of processes, both qualitative and quantitative) about how salt moves in the coupled groundwater-surface water system of deep polders, also taking salt wells into account. With this knowledge, the current system of flushing in low-lying parts of the Netherlands can be re-evaluated and recommendations can be made for a more effective water management system at a regional and sub-regional level. This will also yield better formulations in the Netherlands Hydrological Instrument (NHI).

- The same applies for the research into salt tolerances. In a *social sense*, this research has laid the basis for a nuanced consideration of the actual temporary exposure of crops and nature to above-average salt concentrations. Although the findings have still to be crystallised, the practical conclusion might be that a greater effort should be devoted to revising the HELP tables, which would lead to more adequate payments for salt damage, since, for example,

the general rules could be differentiated on a regional basis. It would then also be possible to make better estimates of the risks associated with certain rotation schemes in salt-sensitive areas. The scientific basis of research into saline tolerance can be combined with already popular approaches, such as €eyeopener and, for example, the management of fresh water in creek ridges in regions with saline ground water. These findings have also had a social impact by virtue of the discussions in the Delta Programme and with regional managers.

- The research into the mechanisms in samphire that produce the high salt-tolerance of this crop has established a possible basis for enhancing and modifying other food crops. This could have social benefits for areas with marginally saline soil. Accordingly, there is growing interest in the results of research into salt-tolerant crops elsewhere in the world, for example in the Yellow River Delta in China.

- For the time being, it seems that in terrestrial nature reserves in low-lying parts of the Netherlands, the most interesting plants could be sensitive to salt peaks, but that the situation might not be so bad with the salt concentrations to which current policies are tailored. This research has not yet been completed, however, so any conclusions would be premature.

- Specific innovations have been developed in the underground storage of surface water. They have been demonstrated in a number of practical trials and have generated considerable interest amongst horticulturalists, farmers and installation engineers.

- The results of field trials, modelling and studies into costs and benefits in the case studies suggest that local and regional solutions, such as buffering and dynamic control of fresh water storage, could be feasible. As a result, these types of solution are being considered far more seriously than they were four years ago. Overall, this is the most important social result of the research.

4. Reflection on value creation[1]

I) scientific and social value in terms of high-quality and climate-proof spatial investments

II) contribution to strengthening the knowledge infrastructure

III) valorisation of knowledge

I Scientific and social returns

In scientific terms, the principal investment was in establishing a better experimental basis for making judgments, which resulted in a knowledge base that will also be available to others. A lot of data have been collected in the field that have helped to improve the models used in a range of studies, such as SWAT and NHI. There has also been investment in tools for uncertainty analysis, which will continue to prove their value in other studies in the coming years, and not just in the domain of the fresh water supply. The research has also dispelled a number of myths (see the most

[1] Knowledge for Climate Final Report, chapter 5

important scientific results), so that shortages of fresh water will be looked at from a different perspective in future research.

A great deal of effort has been devoted to demonstrating whether solutions work in practice, and we are also observing greater investment in the implementation of some of these solutions. In time, this will lead to a more sustainable fresh-water supply, but for the companies concerned also to more high-value production. Only then will the social benefits in the form of reduced risks of damage and higher yields from agriculture, become really evident.

II Contribution to strengthening the knowledge infrastructure

The intensive cooperation between the partners in the consortium during the research will partly continue after it is completed. Some new coalitions have been formed and existing coalitions have been strengthened – all of which will strengthen the international position of Dutch research. To mention a few examples: the collaboration between Alterra, WUR, Deltares, Acacia and KWR has already generated new proposals, and two projects submitted by a group made up of TU Delft, Deltares and the University of Utrecht recently started under the NWO program Urbanizing Deltas in the World. In addition, seven new doctoral students have been trained and will receive their PhD in the coming months.

III Valorisation of knowledge

Not all of the knowledge created is translated directly into applications. Some (mainly results from WP2 and WP3, in which new insights were gained about systems such as burden of saline seepage from salt wells on surface water systems, tolerances, etc.) has been integrated into parts of the National Hydrological Instrument, and the results from WP1 about upstream water use have been used in the Delta scenarios for fresh water. The Waterbuffer Foundation has been established to promote the valorisation of specific water-buffering techniques that have already been applied in practice in projects such as GO-FRESH and the project with underground water storage at Prominent, a tomato-growing business in the Westland area. The maps showing potential (where specific small-scale solutions could best be applied) that were produced in the third-tranche project Fresh Water Options Optimizer are also expected to support a wider range of applications.

5. Most important social and scientific developments relevant for future research priorities

The extent to which the regional Fresh Water adaptation strategy can be fleshed out and applied in the Delta Programme is decisive with regard to how far the knowledge acquired in this work package can be fully exploited in the pilot regions. If, in the Delta Programme, priority is given to adaptation strategies tailored to the main water system, regional solutions may have to take a back seat. On the other hand, the latest scenarios for the Netherlands by the Royal Netherlands Meteorological Institute (KNMI) forecast a decline in water shortages and a smaller decline in discharges than the KNMI06 scenarios, which means that large-scale measures will become less urgent. Whether climate change has more or less of an impact, small-scale measures can be seen not only as an investment in reducing dependency on external sources, but also as a way of supporting higher-value production.

The implementation of local solutions will benefit from further research into how farmers can also serve as water managers - research that could focus, among other things, on appropriate business models.

Other important new research questions are: how can regional adaptation strategies be scaled up so that they 'matter' in terms of costs and volume of water? How can the knowledge that has been acquired about ground-surface water interactions and salinisation be used for smarter water management at the regional level? And to what extent is damage caused by exposure to salt mainly the result of osmotic or toxic effects, and what does that mean for the way in which damage is modelled?

One of the recommendations of the Delta Programme is to make agreements on service levels for fresh water. This raises a great number of methodological challenges that are closely related to the research in theme 2, such as implementation of a risk-based approach, how to deal with salt tolerances for agriculture and nature in such an approach, and how to determine the effectiveness of solutions, etc.

But the most important development is that many other deltas (Bramaputra/Ganges, Mekong, Yellow River, Magdalena) in the world are struggling with similar but usually far more urgent problems and are more open to and have the resources to hire Dutch expertise. The associated research question is whether and, if so, how, the knowledge created in the Netherlands can be applied in deltas with different geohydrological structures, different cultures and often fewer economic resources.

6. Reflection on the cooperation between the consortium partners in order to stimulate substantive cohesion

Two general meetings of the consortium have been held every year, and during these meetings various cross-links between work packages have been established. Central to the method adopted by the consortium was the cooperation between different work packages in the case studies. This worked particularly well at the start of the project, with joint meetings in the hotspots and extensive communication between the relevant organisations. Researchers and managers continued to consult one another regularly on practical matters such as sharing data and models. Substantive cohesion was also established through the case studies because the knowledge and tools that had been developed were tested in a similar environment. Substantive cohesion was also promoted by interim reports, which were written with a coherent narrative.

7. Reflection on the cooperation with foreign research partner(s)

The original plan provided for an international advisory board comprised of international research partners, with interactions taking place at the level of individual projects. We gained a broader international perspective on this nationally-oriented research project at the mid-term review. In WP 1, international input to the project from the University of Kassel in Germany was actually paid for,

and as already mentioned, the Free University organised an international workshop on salt-tolerant crops in WP 3.

For the individual work packages, articles were written with contributions by international authors, including Professor Keith Beven (Joost Delsman, WP2), staff of the US Army Corps of Engineers, and Dr. Bouksila from Tunisia. The special issue by Rozema et al. consisted largely of international papers, and the final report will also include contributions from international partners. Professor Antonellini (WP2) is the guest editor of this special issue. In 2013, an article was published with Dr. Bouksila (INRGREF, Tunisia) on salt accumulation in the soil under entirely different climatological conditions, and a joint presentation was given at an international conference in Tunisia.

In addition, various fresh-saltwater codes were exchanged with Dr. Langevin of the USGS, a comparative study for the Rhine was carried out with the University of Kassel and a month-long joint study was carried out with Professor Rinaldo's group at the EPFL in Lausanne, Switzerland, on the impact of uncertain weather conditions on exposure to and the effect of salt on salt accumulation in the soil (see Suweis et al., 2010).

Theme 3 – Climate Adaptation for Rural arEas (CARE)

Consortium leader: Prof. Adri van den Brink (Wageningen University)

1. Reflection on the consortium's position in the international research arena and the contribution to the (inter)national scientific and public debate

Climate change could have major consequences for rural areas. Extreme weather conditions, such as periods of serious drought and high temperatures, but also flooding as a result of heavy downpours, will probably occur more often and have an impact on the hydrology, the land use and the prospects for survival of flora and fauna in nature. The impact of these climate effects is complex and differs according to the area and the type of land use. Adaptation to the changing climate is necessary to counter possible threats and exploit opportunities, for example with water buffering and by facilitating the northward migration of species. Rural areas would then probably be potentially capable of absorbing the consequences of climate change. This calls for an integrated approach, however (see also the report 'Klimaatadaptatie in het landelijk gebied' [Climate adaptation in rural areas], KfC 044/2011 and Climate changes Spatial Planning (KvR) (040/2011).

The point of departure of the CARE research is that adaptation – both autonomous and through targeted planning – will take place on different scales and for a variety (i.e., function-specific) purposes. Various actors will play a role in this. Most of the land in rural areas is privately owned. Farmers, nature protection organisations and other resource managers make their own decisions in accordance with the objectives they are pursuing for the unit of land under their management (farming, nature area). An important challenge therefore is to align the government's objectives and social needs in relation to adaptation, such as water storage, protection of natural values and the preservation of a competitive agricultural sector with the objectives of individual resource managers as far as possible. Naturally, these different objectives are potentially conflicting, which means it is necessary to consider the pursuit of those objectives in relation to each other.

An important assumption in the CARE programme is that government measures have the best chance of success if they 'follow' the autonomous reactions of sectors and resource managers. Government policy should support positive developments and, where necessary, provide counterweight to developments that have negative effects at a local or regional level. CARE therefore devoted a lot of effort to identifying these autonomous reactions in a context of future developments in prices of commodities and agricultural products, spatial and environmental policies, climate change, etc. RULEX (RUral Land EXchange), the agent-based model developed for this purpose, provides information about the development of agricultural businesses as a result of economic development, the ageing of the population and business succession, and land transactions (between farmers themselves and with nature organisations). The resulting patterns of land use and business profiles provide valuable information that stakeholders such as policy-makers and nature organisations can base their decisions on.

Although the application of agent-based modelling (ABM) for analysing the perception of agents (in our case, land resource managers) and their reaction to climate change is not new in scientific terms, the following features of RULEX are innovative:

- The powerful integration of statistical analysis (of empirical data) and agent-based modelling;
- The development of a land transaction ABM for rural areas. Up to now, the analysis of land transactions using ABM was confined mainly to urban areas. Rural areas differ from urban areas in as much as agents buy land without changing location themselves, so that land markets are very local;
- Up to now, considerations in the purchase of land by nature managers and the interactions between agriculture and nature had not been explored using ABM;
- The linkage of RULEX with other models. Most ABMs integrate feedback mechanisms, but in this case, the feedback comes from external models relating to nature development and the spatial cohesion of nature , which reflects the complexity of the processes as simulated by these external models.

Thanks to RULEX, we have gained insight into both autonomous and measure-driven changes in the social and biophysical systems (the interaction between humans, institutions and biophysical conditions) as a result of factors such as climate change. It was found, for example, that 1) it will be very difficult to create connected nature areas without the intermediary role of a national or provincial land bank, 2) more competitive bidding for land for nature development could yield a lot, and 3) with the existing system of subsidies, farmers have only a modest interest in engaging in agricultural nature management, but are sensitive to the extent to which agricultural nature management is practised in their vicinity (positive influence).

Climate seems to have an impact on agriculture primarily via the development in price levels in the global market, while local influences such as higher groundwater levels and changes in yields are far smaller. It should be noted here, however, that in our analyses, there were no restrictions on the prevention of drought damage by using irrigation. Climate change could have significant consequences for nature values and the feasibility of objectives for nature in rural areas. For example, the modest scenario G was found to be somewhat positive for groundwater-dependent nature objectives, but the additional drought caused by the warm and dry scenario W+ was very negative. It does seem, however, that these negative effects on nature objectives could be largely compensated by suitable adaptation measures. The RULEX approach was also found to be extremely suitable for the spatial analysis of these adaptation measures.

The chosen interdisciplinary approach proved valuable, because it meant that the interactions and trade-offs between the various sectors and adaptation options could be explored. Examples are the interactions between vegetation and changes in hydrology and between the design of an ecological network and the functioning of species within the network (in terms of chances of survival of species and facilitating northwards migration). Such knowledge was lacking up to now. With this knowledge, it will be possible to design strategies for climate adaptation on a local and regional scale that match the local behaviour and needs, which increases their prospects of success.

The CARE project has yielded important insights for integrated area adaptation on the higher sandy ground. The design sessions with users and the survey of acceptance of adaptation measures show that there is considerable support for adaptation options that resolve more than one climate problem and which provide benefits for more than one sector (see Factsheet report, Adaptation measures CARE on page 9). In other words, it seems as though the synergy between sectors and the broad solutions of these adaptation options are recognised by the various stakeholders. It is therefore also likely that it is precisely these measures that are most likely to achieve integrated adaptation in an area.

What are these measures? Examples of adaptation measures that enjoy broad support are Corridor wet nature and Green Infrastructure wet nature, where we have shown that, in terms of effectiveness, it is essential that the green infrastructure is actually created in wet locations. These measures help to strengthen the cohesion of the nature network and are important for the migration of species and for coping with fluctuations in the weather. They also mitigate drought and heat stress, reduce eutrophication of the water, and reduce diseases and pests by means of natural pest regulation. These are effects that benefit not only the nature manager, but also the (drinking) water manager and the farmer. There are disadvantages for the farmer, however, such as the space that these natural elements take up, which is at the expense of the area of productive land. To persuade farmers to give up land for this, they could be reimbursed for providing these climate adaptation services. There is also widespread support for all measures to improve the soil structure, such as improving the organic-substance level and the soil structure. This agricultural measure will help mitigate climate problems such as drought stress, produce a more gradual water discharge after extreme precipitation and reduces the chance of inundation, eutrophication and soil degradation. The improved retention of water and less extreme water discharge after heavy showers are also favourable for the water manager and nature manager.

There is growing interest in the international research field for combining and linking models for land use, vegetation and climate. Traditionally, the global climate models do not incorporate land use, although it is generally recognised that changes in land use are one of the most important contemporary drivers. In CARE, we have largely integrated those two on a regional scale, which can be seen as an important international scientific contribution.

In ‘Climate Agenda: resilient, prosperous and green’ (Ministry of Infrastructure and Environment, 2013), the government expressed the intention of drafting a National Adaptation Strategy by the end of 2017 at the latest. The strategy will address the climate-robust design of the rural environment (in addition to the urban environment) and will set out plans for the climate-proof development of sectors that are important for the economy, the living environment and welfare (including agriculture and nature) that are already vulnerable to climate change. In preparation for this agenda, on behalf of the Ministry of Infrastructure and the Environment, the KfC programme has been working with the PBL and KNMI on the Climate Adaptation Action Plan since the end of 2013. One aspect of this project is to update risk analyses and explore opportunities for six themes, including agriculture and nature. The analyses will be completed in the course of September 2014. The Dry Rural hotspot is also working on a Regional Adaptation Strategy. The results from the CARE research are considered to be relevant for these activities.

2. Reflection on the initial objectives of the consortium

In the full proposal, the central objective of the CARE research was described as being to assess the effects of climate change and adaptive strategies on agriculture, nature and other land-use functions in the rural landscape of the Netherlands. 'Success factors' for possible adaptive strategies that were mentioned were:

- Achieving a climate-proof ecological network that allows high-standard climate-proof targets to be met;
- Creating the right conditions for agriculture, the drinking water sector and other land-use functions;
- Optimising the functionality of the landscape, in terms of water management, biodiversity, agriculture, drinking water and recreation.

This proved to be the correct objective. The CARE research was carried out along these lines and the results of the research accord with the objective. A number of further choices that restricted the scope of the research did prove necessary, however. The first was that the research related mainly to dry sandy areas. In the course of the research, it was found that there was little interest in the Shallow Lakes and Peat Meadows, Wadden region and South-west Delta hotspots compared with the Dry Sandy Areas, which was also reflected in the co-financing that was raised. This necessarily meant that questions from the former hotspots were not covered in the research. Exceptions to this were relatively small-scale research activities on Texel (Wadden Region hotspot – organisation of an interactive workshop with farmers on the consequences of climate change for agriculture on the island) and in the western peat meadows (Shallow Lakes and Peat Meadows hotspot – development of climate adaptation strategies in the Peat Meadow Climate Corridor, in association with the Theme 2 consortium).

A second restriction arose from a conscious choice to deepen the research rather than expanding it. Whereas the aim in the full proposal was to explore a series of adaptation measures involving a broad range of actors and stakeholders, for the research in the Dry Sandy Areas hotpot we decided, in consultation with the co-financers, to concentrate primarily on the construction of the National Ecological Network (case study Baakse Beek-Veengoot) and adaptation of water management (case study Tungelroyse Beek). Apart from the provinces in their coordinating role, the principal actors in this research were the farmers, the nature organisations and the water boards. We arrived at this decision because there was already a lot of information about individual adaptive measures and the real added value would lie in the cross-sectoral implementation of such adaptation measures. To research that properly, it was necessary to restrict the scope of the research. The final result was extremely intensive cooperation between researchers from different backgrounds, using RULEX as a vehicle for integration of interdisciplinary information and processes. The ensuing approach can serve as a template for possible expansion to adaptation measures for other sectors.

3. Most important scientific and societal results

Climate change will have an impact on the water regime of areas (see Figure 1 on the next page). For two extreme climate scenarios (G and W+), the consortium demonstrated how important hydrological parameters will change, such as groundwater level, seepage intensities and - of direct relevance for plant growth - the moisture deficit and oxygen deficit in the root zone. For the higher sandy areas, where there are large supplies of fresh groundwater, the consortium conducted research into the most important loss item in the water balance: the actual evapotranspiration. This has produced an entirely new insight into the evapotranspiration of barren vegetation, as well as a new system of measuring the actual evapotranspiration. For areas such as the Veluwe and the dunes, creating open and lichen-rich vegetation could be a very effective measure for increasing the freshwater supply and enhancing the landscape.

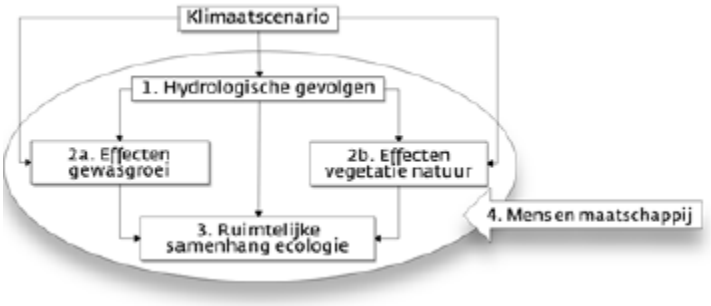

Figure 1. Effect of climate change on water, agriculture and nature.

Climate scenario

1. **Hydrological consequences**
2. **Effects on crop growth**
3. **Effects on natural vegetation**
4. **Spatial cohesion of ecology**
5. **People and society**

With the warming of the earth, the suitable climatic zones for plants and animals will shift to the north (in the northern hemisphere) and to higher elevations. In addition, extreme weather conditions will occur more frequently, causing greater fluctuations in populations and a greater chance of extinction. With the METAPOP model, we investigated how weather extremes will affect the survival of populations and whether it will be possible for them to migrate to suitable climate zones. METAPOP is a spatially explicit individual-based population model. During the CARE project, the METAPOP model was expanded with a module that simulates the influence of weather extremes, such as periods of drought or very mild winters, on population dynamics. Using a model study (with METAPOP, section 3 in Figure 1), we showed that increasing the size of nature areas could be an effective measure for absorbing the effects of extreme weather. To enable species to migrate, however, further spatial cohesion within the nature network is needed. We have shown that corridors between nature areas (green infrastructure in the form of hedgerows, woods and pools) are only sufficiently effective if they (a) are planted in high density (concentrated, thus not spread out over many hectares), (b) in areas with a high groundwater level, and (c) in locations where there is already reasonable connectivity.

Changes in the water regime, the levels of CO_2 and the temperature of the atmosphere affect the growth of plants, whether they are agricultural crops (Figure 1: 2a) or natural vegetation (2b). Under the moderate, and somewhat wet, G scenario, a longer growing season and higher CO_2 levels are in themselves favourable for crop production, but our study showed that that benefit is likely to be negated to a large extent by the greater frequency of extreme weather conditions. Grass will ultimately profit in this scenario, but the production of potatoes will fall off dramatically. Because of technological developments, however, the production of almost all crops is expected to be higher in the target year of 2050. An exception to this is the potato, which will suffer badly from water damage. According to our analyses, the dry W+ scenario will lead to substantial damage to the production of all crops but, with advanced irrigation and the development of new varieties, that damage could probably be reversed to generate higher production than today by 2050. Once again, the exception is the potato, which will be severely affected by heat, warmer winters and heavy rain showers.

Besides local changes in productivity, the growth of crops around the world will react to climate change. Because of the strong globalisation of agricultural markets in the last few decades, it is essential to consider the effects of climate on market prices for agricultural products, and the reaction of farmers to them (section 4 in Figure 1). To this end, we used existing projections from the CAPRI model, which were edited by our partner in the project, Plant Production Systems (WUR), so that they could be used as input for the RULEX model. However, it is difficult to separate effects of climate change (supply), effects of demographics and economic growth (demand) and effects of policy (interventions in the dynamic between supply and demand). It is therefore not possible to say which aspect of a price change is attributable to climate change. In the world market scenario, which is the most appropriate to strong climate change (linking of W+ to the SRES Global Economy scenario), market prices will rise sharply, particularly for arable and horticultural products and to a lesser extent for meat and milk products. In the Regional Communities scenario, which is the most appropriate for the G climate scenario, a similar development is seen, but less strong.

Although the outlook for arable farmers is more favourable than for dairy farmers, the trend of the latters' growing dominance will persist. This is connected with the fact that dairy farmers - as a result of the fertiliser legislation - depend on physical expansion for commercial growth, while other sectors (without livestock) can grow through intensification of their activities. Another factor (in the Baakse Beek case study area, in any case) is that many arable farms (like mixed farms) are smaller businesses that are run by older farmers and these businesses will eventually cease to exist.

The positive developments (to a large extent for W+ / Global Economy and a lesser extent for G/Regional Communities) will lead to an improvement of the economic outlook for farmers, and the willingness to sell land for nature development will decline. Another factor that will further diminish land mobility is the disappearance of a national land bank (the Land Management Service, which is part of the Government Service for Land and Water Management). RULEX simulates land mobility in the total absence of a land bank, and predicts purchases for nature arising from the spontaneous sale of land by farmers. In this way, it simulates an extreme case of a free land market. Our findings show that in such a case, land purchases (a) are small and (b) follow a fragmented pattern. The latter is not necessarily bad for the possibilities for migration of species between nature areas, although it was

found, for the great crested newt, that additional vegetation in non-wet locations has little point (see above). That could be different for other species. Furthermore, the management will become more complex for nature organisations.

For farmers, on the other hand, it is positive, because there is minimal disruption of the market. The costs and benefits that fragmented plots of nature can represent for farmers were further investigated in CARE. On the basis of our analyses in the Baakse Beek area, we formulated the following recommendations with a view to creating the National Ecological Network (since rechristened the Gelderland Nature Network (GNN)) in the province of Gelderland: that the province should maintain a land bank to facilitate the exchange of plots and that nature organisations should (and should be allowed) to offer to buy up to 50% more land. Without these measures, it will not be possible to achieve the province's targets for the GNN.

With the process-based vegetation model PROBE that we designed (Figure 1: 2b), we showed that scenario G could be moderately positive for the feasibility of wet vegetation targets (such as blue grasslands, forests and wet heathland), which are often very valuable nature areas (many rare and threatened plant species, often on the Red List). The dry W+ scenario, however, leads to significant damage to wet vegetation targets (Figure 2), while the feasibility of dry goals (dry heathland, lichen-rich dune vegetation) increases.

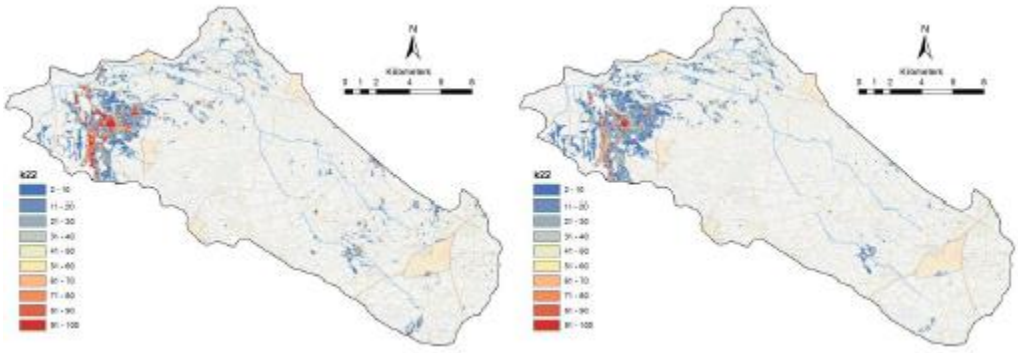

Figure 2. The likelihood (%) in the Baakse Beek area for wet barren grasslands under the current climate (left) and under dry climate W+ in 2050 (right) calculated with the PROBE model. The area of this type will decline by 24% with the W+ scenario.

The damage to wet vegetation targets roughly corresponds with the damage that would have occurred under the current climate as a result of a decline in the groundwater level by roughly 10cm, which also means that, if it is technically possible to raise groundwater levels and sustain seepage flows, this damage could be negated by adaptive measures in the areas of water management. Various possible measures were investigated for the catchment area of the Tungelroyse Beek. Effective measures to cope with the increasing drought are to create large connected nature areas (because they lose less water to the environment than smaller ones), encouraging vegetation with little evapotranspiration in infiltration areas and creating water buffering systems. With water buffers, peaks and dips in water discharge can be captured so that flooding and drought can be minimised. Restoring the meandering course of rivers, the underground capture of water, the

construction of retention basins and level-driven drainage system are examples of water buffering measures.

By combining climate scenarios with a state-of-the-art regional hydrological model and spatially explicit water management measures, we have shown that the impact of (the method of) water management on the availability of water at the correct times in the year is greater than that of climate change. This provides important clues for developing and implementing suitable water management measures to guarantee the availability of water in high dry sandy ground. However, the research also showed that there is a strong interaction between climate change and water management. Water management measures that have a positive effect in the current climate will therefore not be universally suitable in a future climate. Optimisation with local (high resolution) information about climate change is therefore essential.

Water management also has a greater influence than hydrological changes as a result of climate change on the simulated changes in land use. The land use around stream valleys, in particular, can be strongly influenced by water management measures. With regard to the natural vegetation, the most important results were that the vegetation of stream valleys will not be able to adapt to rapid fluctuations in the surface water level. Flooding and temporary droughts will therefore always be accompanied by the loss of biomass and the potential loss of species. Our research also showed that rare species are particularly sensitive to fluctuating water levels. Water management should therefore focus on reducing those fluctuations. It also seems that differences in water quality, in the form of infiltration versus seepage, are more decisive for the presence of certain characteristic species than the simulated differences in water quantity, which emphasises the importance of state-of-the-art regional hydrological models.

4. Reflection on value creation[1]

I) scientific and social value in terms of high-quality and climate-proof spatial investments

II) contribution to strengthening the knowledge infrastructure

III) valorisation of knowledge

The research carried out in the CARE programme into the evapotranspiration of xerophilic vegetation on higher sandy ground, where there are large reserves of freshwater, received a lot of public attention, with articles in *NRC Handelsblad* and the *Nieuwe Veluwe*, as well as leading to a number of invitations to give lectures. The knowledge that was generated was used in two workshops organised by the province of Gelderland on the hydrology of the Veluwe. The responsible professor (J.P.M. Witte) has been asked to serve as an adviser to the Nederlandse Bekenstichting. He has used the knowledge that has been gained to write a proposal for the programme of the Water Technology Top Consortium for Knowledge and Innovation (TKI) (€ 400,000). The proposal, which was accepted, was for a project to develop an instrument for measuring actual evapotranspiration for the market. Parties participating in the consortium are the KWR Watercycle Research Institute, Vitens, Eijkelkamp Agrisearch Equipment BV, Alterra-Wageningen UR, STOWA and KNMI. The instrument consists of

[1] Knowledge for Climate Final Report, chapter 5

small, and therefore handy, mobile minilysimeters and a thermal infra-red camera, with which the lysimeter measurements can be extrapolated to the undisturbed environment (resolution of approximately 200 m^2) (Figure 3).

The interviews with farmers and the deepening of the socio-psychological dimension of land-use modelling inspired one of the researchers, Dr. M.M. Bakker, to write a proposal for research on regime shifts in land-use systems. In this proposal, an analogy is assumed between regime changes in ecological systems and large-scale changes in land use. The application of ecological theory, combined with theories from the social sciences, should contribute to an understanding of the often non-linear response of land-use systems to gradual or small changes in policy, the climate or the market. The NWO (Netherlands Organisation for Scientific Research) rewarded this research proposal with an Aspasia premium of € 200,000, and the research is being financed by the WUR (Wageningen University and Research Center) with a scholarship worth € 700,000.

For the Ministry of Economic Affairs, STOWA (Foundation for Applied **Water** Research of the joint Dutch water boards) and the Water Department of the Directorate-General for Public Works and Water Management, a study was carried out into a module with which the effects of climate scenarios for nature can be calculated. Additional financing for this study came from Theme 6 of KfC. The vegetation model PROBE was used and validated in this study. On the basis of the results, the Water Department decided to use the PROBE vegetation model for analyses (by Deltares) for the 'Freshwater' sub-programme of the Delta Programme.

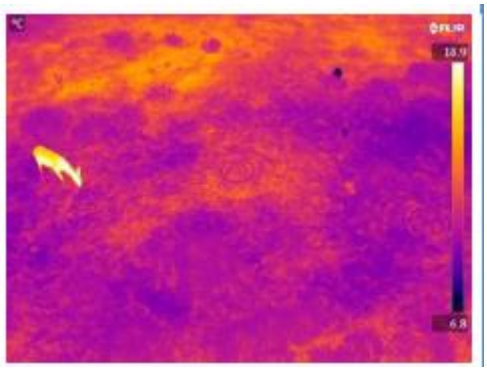

Figure 3. Thermal image in which, besides a curious deer, a number of minilysimeters are visible (the three circles in the landscape).

In the KfC project 'Kansen en Knelpuntenscanner: een tool voor het operationaliseren van klimaatadaptatie ter ondersteuning van regionale gebiedsprocessen' [Opportunities and Bottlenecks Scanner; a tool for operationalising climate adaptation to support regional area processes], the results of the CARE project were further developed for the market via the Climate Adaptation Services foundation. The project, a joint effort by Themes 3 and 8 of KfC, developed a tool for presenting the knowledge more easily and straightforwardly in area processes. The user can 'prick' an area with the tool and so quickly gain an insight into what bottlenecks there are and what adaptation options could be considered. The factsheets with adaptation options written by CARE, the maps showing where there are opportunities for improving the spatial cohesion of the nature network and maps of landscape values under the current and future climate generated by PROBE, have been incorporated in the tool. The drinking water companies found funds to build a user-

friendly shell around PROBE, so that all the water managers in the Netherlands can use the model. These developments are expected to generate new demand in the market.

The knowledge acquired about the relationship between vegetation and location factors (e.g. pH, oxygen stress) to develop PROBE was used in an exploratory study (€ 45,000) for the drinking water companies into the potential of Unmanned Airborne Vehicles (UAVs). Finally, the knowledge was used in a so-called Valorius proposal, on behalf of the province of Noord-Brabant, for the Climate changes Spatial Planning programme (€ 200,000). In this proposal (SWIMM: Soil Water evaluation system based on Integrated Measurements and Modelling), location factors for nature areas will be derived from model calculations (with PROBE, for example), remote sensing images, point measurements and the assessment of field ecologists.

The results of the CARE research were made available to users in area processes by means of an interactive PDF with adaptation options (Factsheet report adaptation measures CARE, see http://climateeffectatlas.wur.nl/kea/). An overview of adaptation options was produced for agriculture, nature management and water management. The possibilities of creating synergy by combining different options was also shown, and the level of acceptance of measures was polled in a survey.

There was intensive cooperation with the stakeholders of the area process Baakse Beek-Veengoot in the CARE programme. On the basis of the results from CARE, stakeholders applied the adaptation options, working out an integrated climate adaptation process for three specific areas. The process manager for the area used the insights from the CARE research to define and substantiate the prospects for the development of the Baakse Beek area, where climate development is the binding factor. There was similar intensive cooperation with the stakeholders (water board, agriculture and nature organisations, Delta Plan for High Sandy Areas, etc.) in the Tungelroyse Beek case study.

To sum up, we feel that the benefits of the research more than outweigh its costs, both in scientific and in social terms.

5. Most important social and scientific developments relevant for future research priorities

With climate change, there will be growing interest in determining the most important, but highly uncertain, loss item of the water balance: the evapotranspiration. As already mentioned, our measurement instrument for evapotranspiration will be developed into a commercial product in a TKI project. A further step will be to use the measurements to calibrate and validate calculations of evapotranspiration based on satellite observations (such as SEBAL, SEBS, ETLook). For this, it will be necessary to establish a network of measurement sites throughout the Netherlands. There is no such measurement network at the moment. We are also trying to use the knowledge about the measurement of evapotranspiration in other countries, for example through the international networks of Eijkelkamp Agrisearch Equipment BV, Alterra-Wageningen UR and the KWR Watercycle Research Institute.

There is currently an ongoing fierce debate in the professional journals about the so-called ‘background dehydration’, the dehydration that actually occurs but cannot be explained by our

hydrological models. The subject of 'numerical dehydration', the alleged phenomenon that observed lower groundwater levels are based on erroneous measurements, is a recurring subject of heated debate, and even of questions in parliament. We expect that this will lead to new research that is important for rural areas. The possibility that increased crop production in agriculture is a possible cause of the phenomenon of 'background dehydration' has not been analysed up to now, for example.

The application of PROBE on both a national (250 m resolution) and regional (25 m resolution) scale has shown us the enormous importance of accurate hydrological modelling. The existing hydrological models often calculate groundwater levels that are far too low for wet nature areas. Furthermore, our study showed that with the use of large calculation cells, occurrences of small-scale ecosystem types (such as blue grasslands) are 'eliminated'. In fact, such types usually represent the highest natural value. An important question will therefore be how the heterogeneity of environmental conditions can best be taken into account in calculation cells without making the computing times unacceptably great.

Climate change alters the dynamics in the build-up and decomposition of organic substances, and hence leads to changes in the availability of water and nutrients for vegetation, but also in the quality of the rain water percolating into the groundwater. Our current models are seriously lacking in that respect. The KWR and Alterra have expressed the intention of conducting joint research in this area. Ecologists have been studying the subject of the dynamic of precipitation lenses in seepage-dependent areas for years, but there is still a lot of research to be done. Finally, it is important for the modelling of vegetation targets that the salt content in the root zone is also taken into account.

The issue of freshwater allocation is very important for the Netherlands as a whole. Drier summers with lower river discharges and the intrusion of salt water from estuaries and deep seepage could form a serious threat to the freshwater supply for the public, agriculture and nature. We therefore anticipate that research into technical measures, such as Aquifer Storage and Recovery (ASR) and controlled drainage to grow in importance.

Heterogeneity is an important factor for absorbing weather extremes in nature, since it can make natural systems more resilient climate-proof. Questions that need to be researched are how this heterogeneity should be reflected in different ecosystems and how better use can be made of existing heterogeneity in the subsurface.

The development of regional adaptive capacity will remain an important landscape issue in the coming decades. How will stakeholders design climate-proof area processes and what research and tools are needed to support these processes with knowledge about the functioning of the natural system? How can coordination be achieved between scale levels and what is a sensible adaptation strategy, given the uncertainties about future climate change and socio-economic developments?

The abolition of the Land Management Service and further decentralisation of responsibilities for creating the National Ecological Network to the provinces is an important development. Provinces can decide for themselves whether, and to what extent, they will create or maintain a 'land bank'. With a small modification in RULEX, it will be possible to investigate how large such a land bank

needs to be to contain sufficient land that can be swapped in order to acquire specific plots for nature development.

Nature development is an important topic at the European level. Major commercial players, such as Rewilding Europe, have raised funds to purchase large plots of land for nature development. However, this process is likely to cause some disquiet in local rural communities. The purchases will substantially disrupt the land and agricultural markets, and there could be serious opposition to nature and wild animals. For the call for the H2020 programme 'Ecosystem restoration: learning from past experiences', a consortium that includes the WUR, the University of Edinburgh, the James Hutton Institute and Rewilding Europe has been formed, which proposes an ABM approach that can simulate these processes based on the experiences with RULEX. The special issue of Landscape Ecology ('Model explorations of ecological network performance under conditions of global change') also make us ideally qualified to carry out this call.

Other important recent developments are (1) the further integration of climate and land-use models. The consortium has performed pioneering work in this area that will be important for future research. New research questions in this area concerned with the further deepening of the interaction between land use and climate, (2) a shift from nature management via the management of species to nature management via the ecosystem services and the functionality. That means a greater emphasis on the properties of plants and the degree to which they will (or could) change in a changing climate, and (3) increasing pressure on and understanding of the influence of climate extremes on nature and land use. The extent to which extremes influence the functioning of nature (and nature's ecosystem services) and land use is an important new research question.

6. Reflection on the cooperation between the consortium partners in order to stimulate substantive cohesion

Figure 4 shows the collaborative relationship within the CARE consortium. Without going into the nature of the relationships and the content of the information that was shared in detail, the figure clearly shows how much the outcomes of the research were the result of the cohesion in the specific contributions of different partners.

Occupying a central position in the figure are the land-use projections based on RULEX and the ABM that was developed by the University of Edinburgh. RULEX was fed with decision rules for nature and agriculture, as well as projections for the development of the agricultural market, soil suitability and crop yields. Data about hydrology and vegetation were entered via the linked models PROBE and METAPOP.

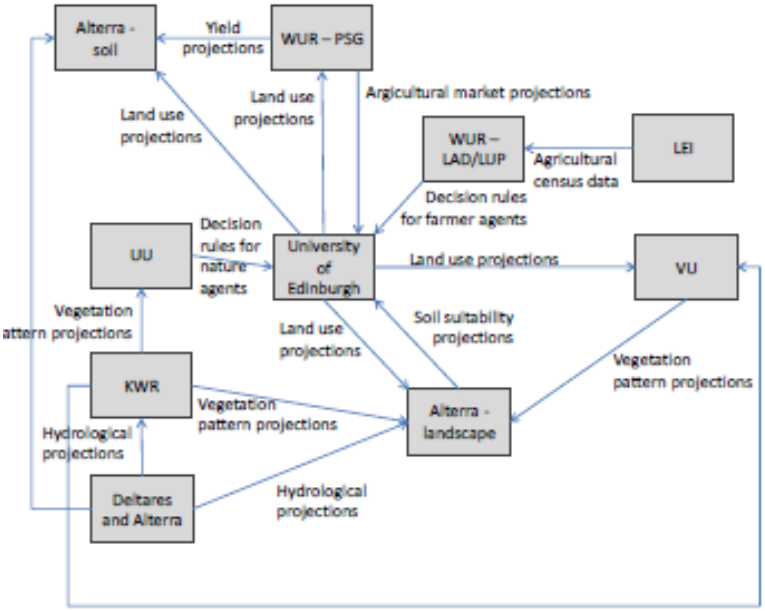

Figure 4. Diagram of the collaborative relationships in the consortium.

What figure 4 also shows is that the original division of CARE into three work packages became less important as time went on. The orientation of the research shifted more to achieving a high degree of integration within the consortium. The benefit of this deepening is that the cross-sectoral effects, in particular, were properly elaborated, particularly regarding the creation of the National Ecological Network in relation to the development of agriculture. This is clearly different, and is in that sense innovative, from other studies, which generally have a monosectoral character. In this endeavour to deepen the study, we were strongly guided by the stakeholders, particularly those in the Baakse Beek-Veengoot area, where there was a great demand for insight into the cross-sectoral effects.

To reach this level of integration, there was intensive consultation between the consortium partners. What contributed to this is the relatively small number of PhD students in relation to post-docs and the involvement of permanent employees. The latter generally have more experience with projects and have less interest in individual, isolated end results. There was considerable investment in consultation on both the goals to be achieved and what was needed to achieve those goals. Besides the annual project meetings, a number of workshops were held in each of the two main case study areas, the Baakse Beek-Veengoot area and the area of the Tungelroyse Beek. In preparation for these workshops, most of the partners attended several meetings to discuss the integration and cohesion of the results and how they would be presented to and discussed with the stakeholders. Representatives of the co-financing parties also attended many of the meetings.

7. Reflection on the cooperation with foreign research partner(s)

The cooperation with international partners in the consortium primarily involved the collaboration with the University of Edinburgh, which took the lead in developing RULEX. This cooperation was extremely intensive and involved visits back and forth to discuss specific subjects, with almost daily e-mail contact at various stages of the research. ‘Edinburgh’ also attended all the annual meetings and were therefore able to gain a clear impression of the situation and the actors in the case study

areas. We experienced this as a unique international collaboration, from which the Dutch partners learned a lot about the development and application of ABM.

In addition, the consortium partners cooperated with international partners in developing and applying knowledge in various CARE sub-projects. This not only provided important input for the programme, but also provided an opportunity to assess and disseminate the (interim) results internationally. Finally, there were contacts with and contributions by researchers affiliated to other universities for the special issue.

Theme 4 – Climate Proof Cities (CPC)

Consortium leader: Ronald Albers (TNO)

1. Reflection on the consortium's position in the international research arena and the contribution to the (inter)national scientific and public debate

Cities in the Netherlands, Europe and the rest of world are vulnerable to the impact of climate change and the extremes in the weather that are already occurring today. That vulnerability ensues in part from the growing urban population. In Europe, 70% of the population lives in urban areas and that figure will rise to over 80% by 2050. Forty percent of the inhabitants of the Netherlands live in the 36 largest cities, which account for three-quarters of the gross national product. The concentration of the population and economic capital makes the cities sensitive to external influences.

Climate change and the variability in the weather threaten the Dutch cities by virtue of the increasing frequency of heat waves, extreme rainfall, drought and the changing risk of flooding by the sea or rivers. Naturally, climate change also presents new opportunities, although they appear to be limited to a few economic sectors.

Climate change is therefore one of the principal challenges in keeping cities healthy, safe and prosperous. Cities are dynamic systems that are consistently evolving. Adaptation to climate change is just one aspect of that development. But decisions on how to adapt existing structures to a changing climate in a sensible way must be underpinned by knowledge: knowledge about the consequences of climate change and the sensitivity of cities, but also about what measures can be taken and how they can be integrated into and benefit urban development. Cities will adopt few measures solely to address climate adaptation. The benefits in other policy areas will usually be the decisive factor in determining whether they are implemented.

Research into the implications of climate change for cities commenced relatively late in the Netherlands. Attention was focused initially on national themes such as water safety and freshwater supply. Other countries, particularly the US, had already been conducting research into the consequences of heat in the city for some time, with research into the characteristics of the urban heat island effect (UHI) and measures to mitigate it. In Germany, methods had been developed to use 'climatopes' to identify the vulnerability of cities to heat and provide a basis for urban planning.

Before the start of the Climate-Proof Cities (CPC) programme, research institutions in the Netherlands, with the possible exception of the Meteorology and Air Quality research group at Wageningen University and Research Centre (WUR), had no track record in research into urban climate adaptation. With the CPC research, the Netherlands has acquired a position in the field of UHI research, urban building physics and Computational Fluid Dynamics (CFD) modelling, as well as landscape architecture. It is still early to substantiate a role in international research in other areas. At the national level, the partners in the CPC programme are among the leaders in university education and research in the field of urban climate adaptation. The most important contributions

(together with those mentioned in section 1c) are the notion that there is substantial local variety in the vulnerability of Dutch cities, which creates the possibility of applying small- scale, local measures, the attention to the building level in relation to adaptation and the underpinning of the 'dedicated' and 'mainstreaming' approaches in urban adaptation policy.

Paper by members of the CPC consortium were published in scientific journals, including the Journal of Geophysical Research, Meteorologica, Resources, Conservation and Recycling, Landscape and Urban Planning, Regional Environmental Change and the American Journal of Climate Change. A selection of the research outcomes will be published in a special issue of the journal Building and Environment entitled 'Climate adaptation in cities' (issue 83, to be published in January 2015). Building and Environment is a journal that sets high standards and has an impact factor of 2.7. Despite the high quality requirements of the journal 13 CPC papers have been accepted.

More or less coinciding with the Knowledge for Climate programme, awareness of climate change also started to grow among Dutch cities. In Rotterdam, the International Architecture Biennale Rotterdam in 2005 marked the start of a process of considering the consequences of flooding for the city. European projects played an important role in the early phase of that process in other cities: Interreg programmes such as Future Cities (with Arnhem, Nijmegen and Tiel), GRaBS (Amsterdam-West), Functional Green (with Tilburg, Sittard-Geleen, Heerlen, Maastricht, Venlo) introduced municipalities to the effects of climate change and tools and strategies for addressing it. Phase 1 of Knowledge for Climate represented a first step in deepening knowledge about Rotterdam and the Haaglanden region in particular.

When the CPC research programme started, there were only a handful of cities (and individuals) engaged with adaptation. There was scarcely any interaction between municipalities and water boards on the subject. A broad movement has emerged in the last few years, fostered in part by the 'New Construction and Restructuring' sub-programme of the Delta Programme. The CPC consortium has consistently played a role in this process. It was one of the organisers of the first major conference (the Knowledge and Networking Day on the Climate-Proof Municipality in 2011) and the very successful conference on practical aspects of the climate-proof city in 2013. CPC also contributed to the launch of activities following the Delta Decision Spatial Adaptation on 9 October 2014. The movement still features a number of front-runners and the cities that took part in the CPC programme all belong to that group: The Hague and Rotterdam were the first cities with an adaptation strategy approved by the city council. Cities such as Amsterdam, Arnhem, Tilburg and Utrecht have incorporated adaptation to climate change as an element of various municipal projects. Policies have constantly been influenced by knowledge generated by CPC, such as identifying the vulnerability of a city, the results of measurements of heat in the city and the effects on the elderly, and the effectiveness of various measures for dwellings.

As a result, the CPC consortium is regarded by stakeholders in the Netherlands as a leader in research into urban adaptation policy. By regularly bringing together parts of the network at our consortium meetings, by regularly publishing overviews of the results of our research and through our close contacts with other actors in this field, such as the Delta Programme sub-programme 'New Construction and Restructuring', STOWA, CROW and the various pioneering municipalities and water boards, CPC has played a role in ensuring the subject is on the agendas of cities and water boards.

2. Reflection on the initial objectives of the consortium

The principal question formulated by the Climate-Proof Cities programme when it started was as follows: how can Dutch cities prepare for the consequences of climate change? This main question was broken down into five separate questions corresponding with the steps in the cause-effect-reaction-implementation chain:

1. How does the urban climate system in the Netherlands work? The objective of the research was to improve methods of simulating the microclimate in Dutch cities by means of measurements and modelling (and by improving the models) in order to understand the impact of climate change and the effect of adaptation measures.
2. What are the sensitivities of Dutch cities to the consequences of climate change and how can we characterise parts of cities according to their sensitivity? The question of sensitivity was broken down into different levels: humans (with research into the impact of heat on vulnerable groups and the ensuing health effects); the scale immediately above humans, the building, and the scale above that again, the neighbourhood. CPC confined itself to studying the effects of warming (heat waves) and changes in precipitation (extreme storms). Flooding (in urban areas outside the dikes, for example) is covered in Theme 1.
3. How can we best take account of the future climate in the design of buildings and cities? The aim here was to find an answer to this question again at different scale levels (building, street, district, city, region) and, where relevant, to establish links between solutions at different levels. Besides devoting specific attention to 'green space' and other measures, the research extended to urban water systems as a whole and the relationship between mitigation and adaptation.
4. How can climate adaptation be integrated into existing urban planning processes? The aim of the research was to analyse the urban planning process at the municipal level for the restructuring and renovation of buildings, districts and business parks. In view of the role of residents, a separate objective was to investigate how self-organisation by citizens can be encouraged in the interests of climate adaptation.
5. As integration of the above: what are the consequences of the global and regional climate scenarios for Dutch cities (in other words, how much will it cost if we do nothing), and what strategies would be suitable for the various scenarios and how much would they cost.

In addition, CPC set itself the goal of collaborating closely with the cities (the KfC hotspots of Rotterdam and Haaglanden, as well as Amsterdam, Utrecht, Arnhem-Nijmegen and the cities in Brabant) and their local authorities, water boards and other stakeholders. In recognition of the fact that policy development in the cities is also progressing rapidly, another objective was to provide stakeholders with regular updates of the findings from the research.

The structure with five main questions/objectives proved extremely useful. The CPC programme's steering group reaffirmed this in 2013 by recommending that the five main questions should be followed in the reporting on the programme. Many new insights were gained on each of the five questions: about the energy balance in the city and the role of evaporation, about methods of surveying vulnerability from the level of humans to that of the city as a whole, about the effectiveness of individual adaptation measures and combinations of measures, about the

governance process and, finally, about the integration of knowledge for the purposes of policy-making.

The goal of regularly communicating interim results was also well chosen. It was accomplished by publishing three interim reports and a final report in Dutch that covered the entire field of research and by organising eleven meetings for the consortium's stakeholders and researchers, as well as various smaller meetings where the results could be discussed.

However, the formulation of the last research question (the combination of consequences and damage under different new climate scenarios and the costs of various adaptation strategies) was too ambitious, however. We waited too long for the new climate scenarios to become available, but above all, collecting data about the costs of damage and of measures proved to be very labour-intensive, also because of the local variation in vulnerability and the associated variation in small-scale measures.

3. Most important scientific and societal results

The CPC programme has shown that every city in the Netherlands, large and small, is vulnerable to the impact of climate change. This is an important message, which also underlies the broadly formulated National Manifesto on the Climate-Proof City, which opens with the words, 'Cities and villages ...'.

CPC has shown that the degree of exposure to and the effects of climate change vary greatly within a city. This finding laid the basis for a shift in political attention from broad instruments (such as a subsidy for green roofs 'to cool the city') to an approach targeted at districts, and sometimes even streets or buildings.

The programme contributed to the insight that urban adaptation measures are about (a) reducing exposure to climate threats and (b) containing the damage if an extreme event does occur. This finding dovetails seamlessly with the public discussion about the acceptance of a certain degree of nuisance (from the occasional flooding of the street, for example) if it does not cause any significant damage.

The inventories of adaptation measures demonstrated that there are many measures that can be taken locally, but which will often require cooperation between public and private partners. This conclusion was taken to heart in the WATERgraafsmeer programme in Amsterdam, for example, in which cooperation and the role of residents and companies was a central feature.

CPC also helped to make terms such as 'coupling' (with other developments) and 'mainstreaming' (in other policies) commonplace. Climate change is a slow process, which means it is possible to defer implementing measures and to piggyback on activities such as maintenance, renovation, new building, restructuring and urban development at little additional expense. Since extreme weather conditions can already occur with the existing climate, however, it is important to increase the city's resilience to climate change whenever the opportunity arises.

It would be an exaggeration to say that CPC research alone led to the aforementioned insights or policy changes, but it did play a role in the discussion by keeping policy-makers regularly informed.

The most important scientific findings underlying these societal results were as follows:

The mechanics of the urban climate: measurements and satellite images show that every city in the Netherlands has a heat island effect (particularly in the summer, but also in the winter). The effect can be significant (up to nine degrees difference at ground level compared with the surrounding rural area in the evening in the summer months) and is similar to that in other European cities. The urban heat island (UHI) effect appears to follow a daily pattern according to a predictable curve, which means that the average UHI effect can be predicted with measurements of the temperature in the countryside by the KNMI. Since the strength of the UHI effect is highly localised, it is advisable to assess the vulnerability to heat waves at district/neighbourhood level, even in smaller cities.

Micro-model: in the CPC programme, a micro-model was developed to simulate the urban climate, which combines and refines CFD, radiation transport and the surface-energy balance so that fewer assumptions have to be made about important processes. The model is therefore highly suitable for gaining insight into the effect of individual mechanisms and how they influence each other. It can also be used, if the computing time allows it, to explore the possible effects of location-dependent adaptation measures. The results show that correctly calculating heat transport through radiation is essential. This applies not only for radiation from the sun (shadow, reflections from buildings) but also for the radiation emissions from buildings. The so-called long-wave trapping effect is particularly important in urban areas and can even greatly exceed the other components of long-wave radiation. Ventilation, or heat transport by convection, is also very important. For a street canyon with a height-width (H/W) ratio of up to 1.0 (the building is as high as the street is wide), there is mixing throughout the entire street canyon. This effect is greatly reduced with higher buildings, however, where mixing occurs mainly in the upper part of the street canyon and a very stable air situation is created in the bottom part of the canyon, where very low wind speeds and scarcely any mixing of the air was found. The variations in wind speed and air temperature are also extremely localised, which makes them very difficult to capture in a generic model. Besides information about air temperature, the CFD model also shows the link between surface temperature and air temperature, something that is very difficult to parameterise on the scale of individual buildings, due to the wide local variation.

Meso-model: a lot of work was also performed in the CPC project to improve the representation of urban areas in the meso-scale model WRF. Using the Corine land-use map (CLC2006), it is possible to identify different urban types within WRF. At a more detailed level, a map with a cell size of 550 x 550m was used for the input parameters in WRF for different districts in Rotterdam. These are the average height of the buildings, the standard deviation of the building height, the average width of the buildings, the average width of the canyon, and the fraction of green space. For the district Bergpolder-Zuid, the value of the conduction coefficient, the albedo and the thickness of walls and roofs was surveyed in detail, which made it possible to perform simulations with WRF in which the conduction coefficients and the thickness of the walls and roofs differ from the standard values. WRF was adapted to run with locally measured water temperatures that deviate from the surface temperature of the neighbouring sea and, finally, it was adapted to allow detailed inventories of the

anthropogenic heat acquired using the LUCY model to be used in WRF. On an urban scale, the emission of anthropogenic heat was found not to be a negligible factor. These modifications also facilitate better weather forecasts for urban areas.

The vulnerability of the elderly to heat waves: older people generally display sub-optimal behaviour during heat waves. Measurements have shown that during warm periods the skin temperature and the body temperature rise to very high values (normally associated with a fever). Healthy young people can adapt well to heat because they acclimatise and they are able to increase their cooling capacity. Older people do not seem to be physiologically capable of acclimatising, at least not within a period of three days. These findings are important for drafting plans for coping with heat.

Urban climate characteristics and their causes: by means of satellite image analyses and remote sensing, CPC research provided insight into the characteristics of a city's thermal climate and their causes (materialisation, water, green space, (de)concentration, street pattern, urban functions, etc.). The use of space has a measureable influence on the surface temperature. Surface hardening, surface water and green space are particularly important factors. Using information from satellite images, 'hotspots' can be identified for effectively tackling local climate problems.

Vulnerability maps for the urban heat island effect: on the basis of a detailed spatial analysis, we can determine which neighbourhoods will be more vulnerable than average during heat waves because of their physical features, social quality and the composition of the population. With this information, adaptation measures and spatial investments can be focused and prioritised.

Vulnerability functions: impact functions have been defined for flooding due to extreme rain and for heat waves, which show on a general level the relationship between a climate effect and the ensuing damage (in monetary units). The results are important for the communication about the seriousness of climate change and for rationally weighing the costs and benefits of adaptive measures in the city.

The role of green space and water in preventing heat in the city: green spaces in the city lower outside temperatures more than water bodies, provided that there is sufficient (ground)water. The cooling effect of vegetation comes from the creation of shade and evapotranspiration. Shallow and small surface water bodies retain heat and can therefore actually have an opposite effect, for example at night and during longer periods of heat. Large bodies of water can have a cooling effect due to wind.

The role of trees, green roofs and green walls in preventing heat in the city: the influence on the air temperature of planting a row of trees and constructing green roofs and walls was investigated in the Van Muijlwijkstraat in Arnhem. Planting rows of trees in a single street can have a significant impact on the air temperature in that street, but constructing green roofs and walls in a single street has only a very minor impact on air temperature in that street. Green roofs and walls also have a very limited effect on the indoor temperature, even negligible for new (well isolated) buildings. Constructing green roofs and walls on a very large scale (in other words, throughout an entire district/city) might be effective in achieving a significant decline in air temperature.

Perception: 91% of urban residents regard large green structures, such as parks, as pleasant, while 70% believe that parks are important. People feel comfortable in streets with a lot of green and feel that vegetation improves the look of the street. Furthermore, measurements showed that parks are on average one degree cooler during the day than their built-up surroundings.

The effectiveness of climate adaptation measures at building level: for the Dutch climate, and for climates in the same Köppen climate classifications as the Netherlands, on the basis of detailed numerical simulations for three types of dwellings (detached house, terraced house and apartment) it was shown, among other things, that the problems with heat are greater in new dwellings than in old ones. This apparently illogical conclusion can be explained by the fact that a better insulated house retains heat longer once it has entered the dwelling, for example from the sun shining through the windows. The insulation and draft-proofing of new houses has steadily improved in the last few decades. These measures significantly reduce energy consumption in the winter, but also mean that home will be warmer in the summer and also remain warm for longer.
Two of the most effective climate adaptation measures for dwellings are (1) the installation of adjustable sun shades for windows on the east, west and south and (2) the use of additional natural ventilation by opening windows above a particular temperature, and only when the outdoor temperature is lower than the indoor temperature. With these measures, the number of hours when the temperature in a house is above the threshold value for thermal comfort can be reduced to practically zero. Although these two measures are the most promising for both old and new houses, a degree of uncertainty exists about the practical efficiency of the measures, because they depend very much on the behaviour of the residents. A certain level of awareness and knowledge is needed to implement these measures effectively. The operation of the sunshades could perhaps be automated to allow them to be used as efficiently as possible. It is also noteworthy that the majority of dwellings in the Netherlands have few, if any, sunshades, even though they could prevent many problems.
Increasing the albedo values (reflection factor of short-wave solar radiation) of the building skin results in a better indoor climate. However, the size of the effect depends greatly on the thermal resilience of the building skin and the type of house: the lower the thermal resilience, the greater the effect of this measure. The effect is therefore relatively small for very well insulated homes. A green roof had only a very limited effect on the indoor climate.

The effectiveness of climate adaptation measures at neighbourhood level: using the Couperus neighbourhood in Amsterdam-West as a case study, it was found that the paving planned by the municipality where there is now green space would have a major impact on the local temperature. Adaptation measures (e.g., open pavement, trees, alternative finishing and colours on façades) produce different effects, up to two degrees of cooling, but sometimes also warming. In particular the effect of painting the façades white (increasing the albedo) is not uniform: the higher the reflection value of the façade, the higher the outdoor temperature. Combined measures seldom produce cumulative cooling effects, and are sometimes counter-productive (for example, the combination of a lighter façade and trees in front of it).

The effectiveness of climate adaptation measures at regional level: the large-scale increase of albedo on the roofs in densely built-up areas of the city proved an effective approach for countering the heat island effect. Special attention should be paid to the conversion of countryside/natural

areas to suburban areas. This transformation has a greater negative impact than increasing the density of an existing urban area.

Integration of climate adaptation in municipal policy: climate adaptation measures can in theory be incorporated in municipal policy in two ways: via a 'dedicated approach' and via 'mainstreaming'. Research in the municipalities of Amsterdam and Rotterdam, with Philadelphia as the reference case study, showed that there are pros and cons to both methods, but that a combination of the two seems to be the best route to successfully implementing climate adaptation measures in municipalities in the longer term.

The significance of self-organisation by residents for more climate-proof building: theoretically, there are various possibilities for more effectively matching the policy objective of building more sustainably (and more climate resilient) to the wishes of individuals. Nevertheless, there is almost always friction between the two sides, most of it stemming from the traditional working methods, the routines on the work floor, and local institutions. This is also apparent in the Dutch context of climate-adaptive cities. Although self-organisation is an increasingly common phenomenon in relation to greening of the city, for example, it is still very difficult to integrate these initiatives into urban policy by means of co-evolution. The research shows how important it is to first determine the municipality's actual objectives for climate adaptation and then to review what is already being done in the municipality and which parties are already engaged with initiatives, and only then to adopt the policy and the vision.

Promoting climate adaptation measures by housing associations: many housing corporations regard the implementation of climate measures as not feasible up to now, the reasons being the absence of a policy and a lack of financial resources. To encourage the innovation needed to realise climate resilient dwellings the parties in the study said that 'instruments' such as demonstration projects, corporate social responsibility and covenants (with municipalities, for example) are needed. The parties are also sensitive to their position within the stakeholder network and would like to strengthen it. Other public instruments, such as regulations and subsidies, were felt to be less necessary.

Climate adaptation in urban regeneration processes: at least theoretically, the implementation of climate adaptation measures in urban regeneration processes is not complex solely because of the many parties involved, but also because of the range of interests, instruments and objectives with which this type of process is confronted. Research showed that incremental successes can be achieved in this cooperation, but that maintaining control of the process is extremely difficult.

Financial instruments to facilitate climate adaptation measures: as the various studies have shown, the practical feasibility of climate adaptation measures is a problem. An innovative financial construction, based on the property tax system, could potentially solve the problems in relation to financial resources. The 'tax increment finance' (TIF) system is already used in countries such as the US and Canada. Research shows that this financial construction could also be used for Dutch urban development in combination with other planning instruments. Yet, practitioners think that TIF has a limited application in relation to financing climate adaptation The reluctance to use tax increment

financing is related to issues associated with climate adaptation in general, such as values uncertainty, planning horizon and indirect benefits.

4. Reflection on value creation[1]

I) scientific and social value in terms of high-quality and climate-proof spatial investments

II) contribution to strengthening the knowledge infrastructure

III) valorisation of knowledge

I. The CPC programme has provided insight into the relative effectiveness of measures, which will contribute to a far more effective use of resources, particularly in relation to measures at the building and street/district level.
For example, increasing the thickness of insulation in dwellings with little direct sunshine has little effect in terms of preventing overheating, while in houses that admit a lot of sunshine (top-floor apartments, for example), the overheating actually increases. This finding shows the greater need for sun shades and adequate ventilation in new dwellings. In the last few years, greater attention has been devoted to reducing the energy consumption for heating in winter than to preventing dwellings from becoming warmer in summer. A lot of discomfort and damage can be prevented in the future by consciously designing homes with both energy consumption and thermal comfort in summer in mind.
Green roofs and façades also have little effect on overheating in buildings, and green roofs have little effect on the ambient temperature at street level. For buffering water, a blue roof with controlled drainage is an alternative with equivalent value to a green roof.
There are various lessons along these lines that would prevent maladaptation (and poor investments as a consequence) in the area of cooling and surface water and the recovery capacity of rainwater buffers, for example.

The insight generated by CPC that the local vulnerability in a city varies greatly facilitates a far more targeted approach (compare the vulnerability map of Amsterdam with the far rougher climatopes maps produced by the University of Kassel, for example).

The emphasis in the CPC programme's governance research on the practice of urban planning yielded insight into 'mainstreaming' and 'coupling'. This focus leads to more efficient interventions because use is made of existing processes rather than top-down policy.

II. The knowledge infrastructure in the Netherlands has been enormously strengthened with the work on the theme of climate adaptation in the city. Not only by delivering nine PhDs and many dedicated Master's students, but more especially by introducing the subject of climate adaptation in the urban environment in university faculties that would not have conducted any research into the subject without this programme and by creating cores of specific expertise in research institutes. The CPC consortium has evolved into a close alliance between the most important universities and research institutes in this field, as is apparent from the various partnerships that have been formed

[1] Knowledge for Climate Final Report, chapter 5

outside CPC (for example, partnerships formed for collaboration between universities of technology, for FP7 calls and for follow-up assignments/research).
Although consultancy and engineering firms were not involved in the second tranche, a lot of knowledge was transferred to them through individual contacts of TNO, Deltares and the KWR (apart from the fact that they could follow the research though our reports).
At the ICLEI conference 'Resilient Cities 2014', the cities greatly emphasised the need to initiate the science-policy dialogue and to ensure that the results of research are tailored for use by cities. CPC has gained a lot of experience in this regard and has ensured that there is now a group of policy-makers and a group of researchers with practical experience. This experience can be built on in a succeeding phase, in which a larger group of cities start developing adaptation policy and when an expanding range of stakeholders become involved in this process.

III. A special report was published in the third tranche about the valorisation of CPC knowledge (de Vos, S.E., V. Kamphuis, 2013. Valorisation of knowledge for creating climate-proof cities. TNO report R12022. Knowledge for Climate report number 111/2013). An important conclusion in this report is that steps still need to be taken to raise awareness and create room for experiment for some disciplines before a market for urban climate adaptation can be created. Having said that, the research by the CPC consortium contributed to raising awareness and generating knowledge among companies operating in this market, primarily with consultancy and engineering firms. It is more difficult to substantiate the contribution to raising awareness among other market parties, but the impression is that knowledge generated by CPC has also found its way to the green sector. Securing greater involvement by the business sector remains a challenge for the coming period.

It is impossible to compare the costs of the research (€ 7.5 million) to the monetary benefits arising from more efficient use of adaptation measures - it would be a totally hypothetical exercise since there are scarcely any adaptation measures being adopted by cities. However, the example of Copenhagen and the CPC's estimates of flooding and heat stress show that the costs of the research are modest if at least part of the damage from extreme weather conditions can be prevented by timely measures. Copenhagen suffered damage amounting to almost a billion euros (in insurance claims alone) from the flooding in July 2011, while in 2014, the city council has to adopt a package of roughly 300 measures requiring an investment of roughly € 850 million.

5. Most important social and scientific developments relevant for future research priorities

In the Netherlands, the outcome of the discussions about the Manifesto for the Climate-Proof City, the details of the priority actions relating to stress tests, strategy and roll-out and, ultimately, the specific recommendations in the Delta Decision Spatial Adaptation are important. The trend in front-runner cities seems to be that, rather than developing an urban adaptation strategy, they are endeavouring to incorporate climate adaptation in local processes (the municipality no longer acting as a planner, but as director). The Delta Decision Spatial Adaptation specifically mentions the need for monitoring and evaluation, an area in which knowledge is scarce.

In Europe, cities are mentioned separately in the Adaptation Strategy and plans are being made for separate financial instruments for large urban adaptation projects. Ensuing from the requirement in the directive that 20% of the spending must be climate-related, the structural funds, the regional

development funds, instruments like LIFE+ and the investment banks are devoting attention to adaptation projects in the city. Notwithstanding, or perhaps in connection with, the possible EU contributions, the subject of financing remains a hot topic. Also connected with funding, there are calls for standardisation of vulnerability analyses (for determining the priority of projects) and of the methods used to establish the effectiveness of measures (so that projects can be compared better with each other). The worldwide discussion concerns resilience in general, with a lot of attention being devoted to coupling widely diverging initiatives that all contribute to increasing urban resilience, such as disaster risk reduction, urban agriculture, climate mitigation, etc.

New research questions:

- No vertical profiles (temperature, wind, humidity, CO_2, air pollution) in cities were measured in the CPC research. Consequently, little is known about the interaction of fluxes (heat, latent heat, CO_2, and air pollution) between the urban canopy layer (UCL) and urban boundary layer (UBL);
- The coupling between a meso-scale and micro-scale model. This was planned within CPC, but proved to be a difficult process.
- The thermal comfort indices PET and UTCI sometimes do not seem to behave in accordance with reality. For example, PET scarcely rises with the humidity, which contradicts reality. An explanation for this is that these indices were developed in Germany, which has a continental climate. Additional measurements of the behaviour of thermal comfort indices under Dutch weather conditions are needed. Additional measurements are also needed to find a better correlation between thermal comfort calculated according to indices and the thermal comfort actually experienced (thermal perception) by Dutch citizens;
- Evapotranspiration in cities is still an important gap in the knowledge about the water balance in cities. Systematic measurements with a higher spatial resolution are needed for a comprehensive urban water balance (Eddy correlation, scintillometry, sap flow measurements for trees);
- Humans spend most of the day (80-90%) in buildings and indoors. Although indoor and outdoor measurements were compared (Arnhem) in CPC, our knowledge of the relationship between indoor and outdoor climate is still limited considering the variation in building types and the complex relation between building climate and urban climate.
- Climate change and drought in the city is still an immature area of research. A methodology is needed for carrying out vulnerability studies, which would involve increasing the detail of groundwater models and adapting them for use, verifying the models, linking them to KNMI14 scenarios, the role of water supply for green space and evapotranspiration and, finally, the organisation of a city's water supply.
- Costs and benefits of climate change in the city. A first step has been made in the CPC programme, but it is still an open field of research, particularly in terms of the link to multi-criteria analysis and decision-making processes.
- Effectiveness of measures according to standard protocols. There is a need for practical tests (and demonstrations) of measures against flooding, which are properly measured. Although CPC delivered a multitude of data about the effectiveness of measures against heat, there is a need for more data about the effectiveness of different measures in various urban situations and under different conditions (including future climates) and the effectiveness of integrated/combined measures against heat, water shortages and surpluses and air pollution in urban areas.
- Possibilities for cooling the city by generating air flows.

- Insight into the relationship between tipping points ('the necessary amount of adaptation' – can we establish it?) and the dynamic of the city ('windows of opportunity').
- Integration between the analysis and adaptation solutions for vulnerable infrastructure in a city and adaptation of the public space and buildings.
- Monitoring and evaluation of the implementation of adaptation in the city is still in its infancy. Both the methods and the indicators to be used still have to be developed.

6. Reflection on the cooperation between the consortium partners in order to stimulate substantive cohesion

- Two meetings were held each year (and even three in 2012) for all the researchers and stakeholders in the consortium. Consortium meetings provided a platform for researchers to inform one another about the progress with the individual studies; at almost every meeting there was a discussion of the cohesion between the work packages or between the various case studies. In addition, there were meetings of the teams engaged in a work package, at which internal cohesion within the work package was central.
- International spring school in 2011 and summer school in 2012 for the PhD students and other researchers. The summer school in Manchester in 2012 made a particularly important contribution to the creation of a close-knit team of PhD students.
- Internal two-day meeting for the PhD students in September 2013.
- Joint production of annual progress reports. The annual substantive progress reports provided an overview of progress in each area of research and their production provided an opportunity to discuss any problems in the coordination between them.
- Bergpolderzuid case study in work package 5. In this case study, a number of researchers collaborated in exploring the vulnerability of the district and investigating adaptation measures that could be included in a Master Plan+ for the district. The project ended with a design session with the stakeholders.

Climate adaptation in urban areas is a new field of scientific research. Consequently, there are no conventions yet about how to perform measurements, what variables to measure, where to measure and sometimes not even about what to measure. In the course of the CPC programme, attempts were made to reach internal agreements on these issues, but these efforts were not ultimately sufficient to produce an overview of similar adaptation measures or to integrate a vulnerability map and a packages of measures. That is another fertile field of research. The same applies for the costs and benefits of adaptation measures.

7. Reflection on the cooperation with foreign research partner(s)

- Attendance and lectures at various meetings of the consortium.
- Spring school in Utrecht, March 2011, organised by the University of Manchester, with input from the University of Kassel.
- Summer school in Manchester, April 2012, with input from the University of Freiburg.
- Comparative study of the buffer zone Manchester-Liverpool/Rotterdam-The Hague (only with the University of Manchester). This resulted in a joint paper.

The cooperation with international partners was important for the CPC programme because, at the beginning of the programme, it provided an easy opportunity to learn about the research being done by our partners. In the course of the programme, this was replaced by individual contacts between our researchers/study groups and their foreign counterparts. Carrying out joint studies with international partners is very demanding for a programme like this: PhD students are too inexperienced to handle it and it requires intensive commitment and supervision on both sides.

Theme 5 – Infrastructure and Networks, Climate Adaptation and Hotspots (INCAH)

Consortium leader: Prof. Lori Tavasszy (TNO)

1. Reflection on the consortium's position in the international research arena and the contribution to the (inter)national scientific and public debate

Climate change can have major consequences for infrastructure and networks. Weather extremes, such as periods of severe drought and high temperatures, flooding, other water-related problems caused by heavy rainfall and extreme storms with strong gusts of wind will probably occur more often. The National Adaptation Strategy (NAS) in 2007 referred to a number of risks for the transport and energy sectors in particular, the most important being the impediments to aviation and inland shipping and a lack of cooling water for power stations (NAS, 2007). At the same time, the infrastructure is the backbone of society. Citizens, businesses and the government rely on it and expect uninterrupted service from these networks.

Theme 5, 'Infrastructure and Networks, Climate Adaptation and Hotspots' (INCAH), focuses on two aspects of this issue: (a) identifying the effects of climate change on the infrastructure and networks via modelling and (b) designing an integrated approach to adaptation to climate change. As regards the first element, a study in 2009 confirmed that research into how the infrastructure could be adapted to cope with climate change was lagging behind (Koetse and Rietveld, 2009, Rietveld, 2013). A later survey of the literature (Chappin and Van der Lei, 2014) shows that research had focused mainly on the impact of changing and extreme weather conditions on technical elements of the infrastructure and that there had been practically no research addressing the long-term effects at a systems level. In addition, the modelling of adaptation of the infrastructure is still in its infancy, which confirms the view that INCAH is also doing pioneering work in relation to the second element mentioned above.

Recent extreme weather conditions (the Balkans in May 2014, the south of England in January 2014 and New York in November 2012) have served as a wake-up call for a number of actors in the domain of infrastructures and networks in the Netherlands. Since the start of the INCAH project, a growing number of network managers have come to realise that the infrastructure is vulnerable to climate change and associated extremes in weather conditions. Workshops and meetings with contributions from members of the INCAH team have clearly demonstrated the growing interest in the subject. With the workshop 'What can we learn from Sandy' (in June 2013), we succeeded in launching a dialogue between representatives from the domains of vital infrastructure and climate adaptation. Workshops organised by INCAH for the Foundation for Applied Water Research (STOWA), the Delta Programme Knowledge Conference and a conference on updating the climate risks for the next National Adaptation Strategy further confirmed that the subject is receiving greater attention. Nevertheless, a lot of work still needs to be done to make adaptation to climate change a 'mainstream' element of investment decisions. This is partly attributable to uncertainty. One of the earliest reports on the effects of the climate on transport stated that climate change would present decision-makers with a serious challenge (TRB, 2008).

It is becoming increasingly evident that the connections between the networks are very important and that infrastructures are too interdependent for network managers to take measures in isolation. The energy network is particularly important, since without it, a great many social functions could not be performed. We have taken the first step on the path to creating an integrated multi-infrastructure framework. The INCAH programme's integrative paper in Regional Environmental Change (Bollinger et al. 2013) provided an important basis for that and was used as one of the points of departure in the FP7 projects INTACT and PREDICT. During the Deltas II Conference in Rotterdam, we organised a focus session with an international dialogue on frameworks that are currently being developed in Sweden, the UK and Australia, which also demonstrated the growing international and academic interest in an integrated approach to adapting networks to the climate. In the context of practical applications, INCAH has worked on a case study in the Rotterdam-Noord region, where the combination of research and practice and the cooperation between networks on the basis of questions raised by stakeholders and the outcomes of models was, according to INCAH researchers, unique. The interdisciplinary approach adopted in the case study identified the failure mechanisms in the infrastructure if flooding occurs as a result of heavy rainfall, a number of tipping points, and options for adaptation strategies – integrated knowledge that was previously lacking. INCAH is now editing a special issue of European Journal of Transport and Infrastructures Research (EJTIR, the only free, open-access journal in the transportation field with an impact factor) on the latest research on climate adaptation of infrastructures.

In 'The Climate Agenda: Resilient, Prosperous and Green' (Ministry of Infrastructure and the Environment, 2013), the Dutch government announced its intention to draft a National Adaptation Strategy by 2017 at the latest. The proposal came in response to a critical report from the Netherlands Court of Audit, which found that vital sectors such as transport and energy (the most important networks covered in INCAH) had received scarcely any attention in the Netherlands' adaptation policy. As it had been in INCAH's mid-term review, ICT was mentioned as an important missing link in that report. The point of departure for the National Adaptation Strategy will be to update the climate risks for these three networks (transport, energy and ICT), along with others. The results generated by INCAH will be used as input for that process.

The partners in the INCAH consortium have a strong international position, because of the strength of their research, knowledge and expertise in the relevant domains, as well as their current programmes and projects, and because they complement each other. At the national level, TNO, the leader of the consortium, has been asked to perform three of the studies designed to update the climate risks related to infrastructure. Researchers from INCAH were consulted or asked to take part in coalitions involved in the 'Vital and Vulnerable Functions' and the 'Climate-proof City' projects in the New Construction and Restructuring sub-programme of the Delta Programme. They were also asked to join the analyst network for the Ministry of Security and Justice's national risk assessment. The individual partners and INCAH as a whole have been prominently involved in international activities. Through webinars and conferences, INCAH shares information with the United States about the climate programmes of the Federal Highway Administration and the Directorate-General for Public Works and Water Management. The Adaptation and Resilience to a Changing Climate (ARCC) programme in the United Kingdom invited INCAH to give a briefing on the case study for the Rotterdam-Noord area and to take part in working sessions for infrastructure managers, designed to

highlight mutual dependencies. In addition, INCAH was the keynote speaker at the Climate Adaptation Engineering Symposium in Australia in 2013 and is invited to speak at the 2015 US Transportation Research Board Annual Meeting in Washington.

2. Reflection on the initial objectives of the consortium

INCAH's main objective is to generate and substantiate knowledge about the relationships between climate change, infrastructure networks and governance, in order to help stakeholders to formulate adaptation strategies. There are a number of facets to the research: establishing the effects of climate change on infrastructures, specifically the physical effects on the behaviour of the subsoil, on civil constructions and on networks; modelling the effects on the operation of infrastructures; and exploring these elements from a network perspective. There are four central characteristics that are essential to the integrated approach, namely integral modelling, a system perspective, adaptive policy and the practice-science interface.

The researchers have produced models that make it possible to deliver substantiated knowledge about the effects of climate on infrastructure, which also reveal failure mechanisms in the infrastructure systems relating to the components described above. These models were also used in combination in an area study and help stakeholders to develop strategies for adaptation. We have focused mainly on transport, water and electricity networks and, in so doing, have provided substantiated information about the effects of climate change on infrastructures and networks.

Because this is a new field of research, where far more literature is available at the macro and micro level than at the level of networks and interactions between networks (the meso level), INCAH had to perform a great deal of ground-breaking work. The models provide insight into the effects of the climate on the infrastructure and help in developing adaptation strategies.

Although the ICT network is important for the functioning of many other vital sectors, we found that very little is known about the impact of climate change on this specific network and that the funds were lacking to add ICT to the scope of the programme.

Of the four characteristics mentioned above, the system perspective (see the integrative INCAH paper by Bollinger et al. 2013) and the practice-science interface (see the evaluation of the area study by researchers and stakeholders, for example) emerged clearly. The idea behind adaptive policy (in which short- and long-term cycles are linked and can be incorporated with uncertainty in collaborative planning) was also included (Schenk, Bogmans).

The integrated modelling, where we wanted to combine in-depth knowledge with integrated knowledge, proved more difficult, for a number of reasons. For example, in the work package relating to the physical infrastructure, the effects of climate change were identified from different perspectives (climate change, physical elements) using mind maps and checklists, but the findings proved difficult to apply in practice. It was also difficult for the researchers, who worked in different technical areas, scientific disciplines and geographical locations, to work together on the same case study early in the process, although it was later possible in the area study. For example, it has not yet been possible to make the necessary translation of climate change uncertainties to the micro scale

for dimensioning of flood protection systems, despite its importance for e.g. making a translation to benchmark storms and actual evaporation in order to calculate peat dike stability.

3. Most important scientific and societal results

With all the connections between infrastructures and between the technical, social and environmental systems, a local event can cause a wave of effects through systems at various levels. An analysis of the literature on the adaptation of infrastructures to climate change showed that earlier research had focused mainly on the consequences of changing and extreme weather conditions on the technical elements of the infrastructure; practically no research was found that dealt with the long-term effects at a system level. The modelling of infrastructure adaptation is still in its infancy (Chapin and Van der Lei, 2014).

Because of the great uncertainty that still surrounds climate change, the Delta Programme is focusing on adaptive management. In view of all the connections, the aim in relation to infrastructure should be collaborative adaptive management, which we define here as 'formulating (together with stakeholders) policies and plans and devising and carrying out projects that remain flexible during their lifetime so that new information can be incorporated'. Adaptive management is a structured, iterative process of decision making about a system in a context that is highly uncertain (Holling, 1978). Over time, the uncertainty will diminish as more becomes known about the system. In the process, a balance always has to be found between collecting information so that better decisions can be made in the future and securing the best short-term outcome on the basis of the knowledge available at that moment.

Adaptive management of infrastructures demands the involvement of many stakeholders in the process – policy-makers and scientists – with different information, values and interests. A collaborative approach through Joint Fact Finding overcomes governance barriers (Schenk, 2014 forthcoming). This means that efforts have to be made to establish links between substantive disciplines and to foster cooperation between scientists and policy-makers. The model of the infrastructure as a socio-technological system is useful as an instrument for structuring the dialogue between the stakeholders and researchers (Maas, 2012).

Adaptation strategies cannot be designed to address a single event, because numerous events could lead to a similarly disproportionate series of consequences. There are five elements to making the network more robust: prevention, redundancy, compartmentalisation, resilience and flexibility (Bollinger et al., 2013).

One of those elements, the resilience of the infrastructure, calls for knowledge about design value: what is the design value (the maximum intensity of precipitation at which an infrastructure remains safe and available, for example) and when and how often would this design value be exceeded? In other words, when will the scale of the change be so great that the infrastructure will not be able to function properly? We have developed a method by which the consequences of climate change can be quantified and the tipping points and measures required can be defined. This method was tested for the flooding of a national tunnel as a result of precipitation (Huibregtse, 2014).

Research into the impact of changing weather conditions shows that human experts are not really capable of properly estimating the effects of relatively small changes in the weather. For example, statistical research into the performance of the railway system and train delays shows that the rail service fails to operate properly due to weather conditions far more often than experts estimate (Xia et al., 2013). Approximately 4% of all disruptions on the railways are caused by weather conditions. Transport by rail is particularly sensitive to temperature (high and low) and wind (gusts and falling leaves); trains are often delayed in temperatures that are not extremely high (at 26°C compared with 22°C, for example), the number of number of disruptions is 30% higher than average when it is warmer than 30°C. While snow, rain and fog lead to longer journey times with the bus or trams and the metro, journeys by train are less sensitive to these conditions. Journey times by road are also influenced by the weather. The decline in capacity (5.7% in light rain, 8.1% in heavy rain) combined with a different flow of transport in rain (an increase of 2.3% in light rain and a decline of 2.3% in heavy rain) leads to an average increase in the risk of congestion in a bottleneck from 50% to almost 87% in light rain and about 77% in heavy rain. The variation between bottlenecks calls for a specific analysis by location. (Calvert and Snelder, 2013)

INCAH has also produced models for determining specific technical characteristics, such as the effect of flooding on hollow pipes (expansion, distortion), the influence of temperatures on water pipes (Wols and Thienen, 2014), and the effect of flooding, long-term drought and moisture on road surfaces (Esch and Sman, 2012). Among other things, we have learned that roads are particularly vulnerable when the water recedes again after flooding, which is precisely the time a road will be used as an escape route. We have also improved the library of failure mechanisms that is used for dike analyses in the modelling instrument DAM. Using this model, the dehydration of peat dikes can be calculated far more accurately, which makes it a useful tool for STOWA.

We have also seen that water pipes can shift and bend and, ultimately, crack or break as a result of uneven settling of the subsoil. Extremely high temperatures, in particular, can cause damage.

The vulnerability of conventional power stations in Europe to climate change was also analysed, mainly in the context of the reliance on water for production and the effect of high temperatures on the efficiency of production. The economic analysis of this question focused on the role of the individual producer and shed new light on the seriousness and nature of the problem (Bogmans, 2012; Bogmans et al., 2012).

It appears from the literature (Bollinger, 2012) that vulnerability to climate change is limited at the moment. However, climate change not only forms a direct threat to the integrity of the physical infrastructure (from flooding, for example), it will also lead to changes in the generation and use of electricity.

A new type of model has been developed that allows the growth of a network and its vulnerability to be investigated simultaneously as a function of various scenarios. Building these models and creating simulations that are sufficiently close to reality require detailed and sufficiently accurate data regarding the structure of our networks, only some of which are publicly available. Some data were provided by the network managers.

With a load-flow model, it is then not only possible to analyse vulnerabilities but also to visualise whether and, if so, where a wave of failures could occur in the networks (Bhamidipati et al, 2014). Finally, by linking the load-flow model to an agent-based model, the influence of changes in production and the location of production and consumption (central generation versus local generation) can be investigated in combination with scenarios where, for example, important components of the network, such as transformer stations, either shut down or are switched off due to flooding or a threat of flooding. This research showed that a shift from central to local could, in time, lead to the creation of entirely different network structures: there could be more 'networking' at both national and continental levels, as well as at the local and regional levels.

It will ultimately be possible to use the new models to provide as underpinning for investments in network capacity, in particular by answering the question of whether a new link in a network, or an increase in capacity, will make the network more robust and more resilient and reduce its vulnerability to cascades of disruptions.

During the modelling process, indicators of network performance were developed on the basis of the literature and consultations with network managers and other stakeholders.

Management plans for infrastructures (asset management) include procedures for dealing with disasters. But due to climate change, rare events that could now be regarded as disasters might occur more frequently. They must then become part of the regular business, management and maintenance processes. The management of an infrastructure is based on maintaining a balance between maximising value and minimising risk. Adaptation is therefore not only a technical issue, but also has an institutional aspect: managers must know the risks ensuing from climate change, the actions that can be taken and how to find the resources to carry out those measures. The management approach, the instruments that are available for it and how the infrastructure's performance is measured and evaluated will change in order to address the new risks arising from climate change (Bhamidipathi, 2012). Agent-based models could help to deal with the uncertainties surrounding climate change in the management of infrastructure.

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4. Reflection on value creation[1]

I) scientific and social value in terms of high-quality and climate-proof spatial investments

II) contribution to strengthening the knowledge infrastructure

III) valorisation of knowledge

The results correspond with INCAH's objectives. Accordingly, the social and scientific returns are in line with the consortium's costs. From an economic perspective, the results show that waiting to

[1] Knowledge for Climate Final Report, chapter 5

invest in adaptation to climate change could be a good strategy. The modelling for electricity networks shows that network managers could opt to invest in resilient networks, but that, over the longer term, networks will emerge in response to the function of the location and the method of production and use of electricity. The 'area study' also revealed very specific vulnerabilities and mutual dependencies in local infrastructures, about which stakeholders were immediately informed.

The knowledge infrastructure has been strengthened, at both the national and international level, by the many presentations, workshops and invitations to international events, and by the connection with the domain of vital infrastructure and the field of research into flood risk. With the knowledge that has been developed in the INCAH programme and the associated pioneering work, we have established a robust research position which we can build on further in the forthcoming EU FP8 H2020 programme. Consortia are currently being formed and research proposals drafted for this programme.

The lack of awareness among private parties about the effects of climate change on their infrastructure and the 'gap' between long-term climate change and the shorter-term issues around asset management mean that network managers do not yet 'own' this issue in relation to their tasks, statutory or otherwise. Apart from a few small assignments, we have therefore not yet succeeded in securing a steady stream of orders from private parties. Furthermore, this is a multi-client issue, which further complicates the problem of ownership. We therefore plan to establish a platform where network managers can raise these issues jointly. The Ministry of Infrastructure and the Environment is also aware of the essential contribution the network managers can make to the National Adaptation Strategy, which could create opportunities.

An important conclusion is that co-ownership of adaptation strategies is important, but will not arise automatically and must be fostered by creating new structures. Although we have identified the need to do so, designing these structures was not one of INCAH's objectives. We have observed that social attitudes towards this issue are changing. Although awareness at the national level has increased, the Delta Programme is concentrating heavily on decentralisation for the establishment and implementation of an adaptation strategy. Consequently, the question of co-ownership has not really been addressed in our view. The conclusion that a sense of co-ownership is still lacking therefore implies a social risk for the implementation of the National Adaptation Agenda.

5. Most important social and scientific developments relevant for future research priorities

As previously mentioned, the increasing occurrence of extreme weather conditions is making the actors in this domain more aware of the risks to their networks. In a recent survey by PriceWaterhouseCoopers, climate change ranked highly as a prospective business risk. At the same time, it is still a question of dealing with uncertain, natural threats. People (including decision-makers) are masters at denying that anything is wrong, believing that it will mainly be others who will be affected, and that if they are affected, the effects will be minimal. In addition to this under-estimation of risks, people are inclined to defer decisions under great uncertainty, preferring short-term options over investments that may only pay for themselves years later. There is also the difficulty of determining the costs and benefits of adaptation measures.

For future research, this means that a number of social features are and will remain important, in relation to which we have made some minor steps in INCAH:

- Approach the issue from a system perspective, on the basis of dependencies between networks and cascade effects as well as technical, governance and climate issues. Frameworks for adaptation should combine process-oriented innovations (e.g. targeted joint fact finding approaches) and substantive research (e.g. models for impact analysis).
- Integrate disciplines and encourage (and develop!) multi-disciplinary approaches.
- Adopt adaptive management as the guiding principle for adaptation strategies, and therefore for policy development, with a focus on monitoring and learning. Design and create the necessary governance structures and economic business models for this.
- Bring researchers, policy-makers and practice/entrepreneurs together and communally produce new research results.

More substantive research questions and challenges include the following:

- Greater insight is needed about the effectiveness of government measures for the road, rail and energy networks.
- Climate change will create a number of extreme weather patterns, such as wind gusts, heavier rain, longer periods of drought and high summer temperatures. Research up to now has concentrated on these extreme circumstances. The effects of more gradual climate change on supply and demand for the traffic and energy networks needs to be further investigated.
- The translation of macro-level climate change information to the micro scale of infrastructure objects: what is occurring where?
- The actions that network managers could take: what are they allowed to do? What are they required to do? For what are they accountable? And how do the various responsibilities affect one another?
- What are the effects of measures on vital infrastructures in relation to climate change? What measures make networks more robust, also in relation to climate change?
- What might a resilience approach and strategy to complex networks look like?
- What insight can be gained into network effects that could influence the effectiveness and efficiency of investments in infrastructure adaptation (from individual network components to a network approach to a multi-infrastructure approach)?
- What details can be learned about the effect of disruptions in ICT networks on other infrastructures and of necessary measures to increase their robustness?

6. Reflection on the cooperation between the consortium partners in order to stimulate substantive cohesion

Substantive cooperation in the project was organised during the annual integration workshops, which were intended to foster coordination within the project and to involve the stakeholders and keep them informed of developments, but most especially to jointly define relevant issues and types of outcomes. The first workshop presented an opportunity for the researchers to learn about each other's work. The second workshop, intended as a condensation point with a case study, came too early in the project – the distance between the researchers was still too wide. The third workshop

was divided into two components: a workshop for the municipality of Rotterdam and a workshop for the Directorate-General for Public Works and Water Management. A larger delegation from both organisations clearly illustrated how INCAH's studies could contribute to answering stakeholders' questions, but also helped to improve the liaison between the researchers themselves.

We also held regular meetings of project managers with the leaders of the four work packages to promote the sharing of information and the cohesion of the programme. The executive leader of the INCAH consortium acted as a sort of broker in establishing contacts between the researchers. The results were also integrated in the joint article that was written for Regional Environmental Change, which contained contributions from many INCAH researchers under the direction of Andrew Bollinger.

The condensation point with a case study finally went ahead in 2013, in the form of an integrated area study, at which time the connections between the different components of the INCAH programme were made even more explicit. This exercise was very illuminating for both the stakeholders and the researchers. The subject was an area study covering the Rotterdam-Noord area, with the stakeholders asking questions and the models developed in INCAH being applied in the study, during which questions from (30!) stakeholders were focused and researchers used information from the area for their models and coordinated and produced a cohesive report.

In addition to an assessment of the capacity of the networks in the area to withstand a number of extreme weather types, the study produced a process by which the approach could also be adopted in other areas, as well as valorising the knowledge for stakeholders. In terms of the integration of knowledge, the case study provided a clear picture of the dependencies between the networks and how the outcomes for one infrastructure (via model, calculation, visualisation) could, in turn, provide input for others, and what type of information is needed. The outcomes of these calculations mainly showed the sensitivity of the infrastructure networks to extreme weather conditions.

7. Reflection on the cooperation with foreign research partner(s)

The purpose of these activities was to share knowledge, identify opportunities and create possibilities for closer cooperation with foreign partners. The main activities included the following:

- Participation at the WEATHER workshop in April 2011
- Presentation at Planet under Pressure, London, March 2012
- Presentation at ICLEI Resilient Cities conference, May 2012
- Cooperation with MUSIC (MIT-USGS at Science Impact Collaborative) via joint PhD research.
- Organisation by INCAH of two special sessions during CESUN symposium in Delft, June 2012
- Participation in the European Cooperation in Science and Technology (COST) programme concerning the stability of earth systems, June 2012
- Participation at the ROADapt workshops in January 2013
- Organisation of workshop with MIT and AECOM during ECCA Hamburg, March 2013
- Papers, posters and presentations during ECCA Hamburg, March 2013
- Research visit by postdoc Christian Bogmans to University of British Columbia, March-May 2013.

- Research visit by PhD student Andrew Bollinger to York Centre for Complex Systems Analysis (YCCSA), 2011.
- Cooperation with the School of Mines in Colorado on the subject of the stability of earth systems, April 2013
- Participation in EEA panel of experts, May 2013 for Report “Adaptation of Transport to Climate Change in Europe”
- Keynote presentation by invitation of CSIRO at Climate Change Adaptation Engineering Congress 2013 in Melbourne, October 2013 (following participation at ECCA)
- Joint writing of proposals with international partners (including FP7 INTACT, Roadapt, RESIN)
- Participation with research results at various conferences on roads and incidents (NECTAR, ARSC, IEB: 1st Meeting on Transport Economics and Infrastructure)
- Participation at the first ‘Dialogue on infrastructure dependencies and interdependencies’ in collaboration with the EA’s Infrastructure Operators Adaptation Forum, March 2014
- Organisation of a focussed session and a practitioners’ session during the 2nd Deltas in Times of Climate Change Conference in Rotterdam.
- Invited presentation at 2015 Transportation Research Board Annual Meeting

Theme 6 – High-quality Climate Projections for Adaptation in the Netherlands

Consortium leader: Dr. Arnout Feijt (KNMI)

1. Reflection on the consortium's position in the international research arena and the contribution to the (inter)national scientific and public debate

Theme 6, 'High Quality Climate Projections for Adaptation in the Netherlands', is closely connected with the KNMI project 'KNMI-next', the aim of which is to produce new climate scenarios for the Netherlands on the basis of the global climate simulations for IPCC Assessment Report 5, which was published in 2013. The new climate scenarios, referred to as 'KNMI'14', play a central role in the Dutch government's policy on climate adaptation.

The information in KNMI'14 is general in nature, so one of the aims of Theme 6 is to produce specific meteorological information of particular relevance to the adaptation issues facing the Netherlands. The point of departure is the Netherlands' vulnerability to long-term drought, heavy precipitation, higher temperatures, sea level rise and the flooding of rivers. The programme has also translated general information about the climate to the social areas of agriculture, ecology, air quality and hydrology. Being the target group, stakeholders were involved as closely as possible from the outset to ensure that the information would be of practical use for the Delta Programme, Schiphol airport, water boards, agriculture, etc. Considerable attention was also devoted to sharing the knowledge with other research institutes that can use the general climate information in their own specific domains.

Accordingly, the consortium plays a crucial role in translating international scientific research on the climate (as embodied in the IPCC) for users in the Netherlands. A number of examples are given below.

The drought in 2003 caused major social problems and substantial costs. Many people died from the heat, a dike shifted as a result of drying out, farmers' harvests were small, ecologically vulnerable areas had to be saved with water imported from other areas, there was too little cooling water for electricity production, etc. This consortium has devoted a lot of attention to developing methods for studying extreme situations in the future, for example on the basis of a PhD study in which a climate model was 'pushed' into a particular meteorological situation. By forcing a meteorological blockade in the climate model, future periods of drought, similar to the 2010 drought in Eastern Europe, were simulated and studied. The research with these so-called Singular Forcing Vectors (SFV) has provided important information for adaptation.

Heavy showers, also known as deep convection, will become even heavier in future, and they will be accompanied by hail and lightning. To find a cost-effective way of anticipating this in the design of drainage systems such as sewers, more information is needed about the spatial distribution involved and the distribution of the extremes in terms of severity. An estimate of the future frequency of hail and lightning could also be relevant for decisions about investments. A PhD student conducted

research for the consortium into the processes of deep convection and the impact of land use and building on those processes. The study also investigated the influence of the distance from the North Sea, which will be important if a larger area of the coastal region is built up in the future.

A breakthrough development is the advances made in high-resolution modelling, with which spatial and time patterns of meteorological events can be determined in far greater detail. During this project, the development of the KNMI's high-resolution model 'Harmonie' proceeded more rapidly than expected. The model calculates events on an unprecedentedly fine-meshed grid and small time intervals. As a result, the meteorological information for weather applications has greatly improved, for example for our hotspot Schiphol. This also strengthens confidence in the application of Harmonie for our research.

With the rapid development of Harmonie, this line of research has accomplished even more than anticipated. The intention was to use it to produce more detail in climate projections, but has also been possible to create realistic simulations of instances of weather situations that might be relevant in the future, such as extreme precipitation in a specific area. This concept, known as 'Future Weather', closely meets the needs of water managers, in particular, to have an idea of how weather conditions of specific relevance to them might look and so gain a clear impression of their impact and consequences and of the actions and adaptation measures that might have to be adopted. Many parties involved in water management, including the Delta Programme, the Major Rivers hotspot and the water boards, are keen on using the Future Weather concept to study specific areas of vulnerability, for example in the context of situations such as the flooding in the Noorderzijlvest in January 2012, the problems due to coincidence around the Maeslantkering, the flooding in Hupsel in the province of Gelderland in August 2010, etc.

The interest of stakeholders is often connected with a recent event that has caused (serious) problems and the ensuing concerns as to whether the existing infrastructure will be able to withstand a similar situation in the future.

2. Reflection on the initial objectives of the consortium

In a nutshell, the consortium's objectives were to develop methods of forming a clear impression of the potential impacts of climate change to support various sectors of society in formulating adaptation measures. In that context, a lot of attention was devoted to better methods of interpreting extreme meteorological situations, including the studies into heavy precipitation systems, high-resolution modelling, the generation of statistics on extremes in a changing climate and the 'SFV method'.

An important choice in this regard was to adapt the evolving Harmonie weather model for climate applications. The model is used as a research tool and as an integrator of new knowledge about small-scale meteorological phenomena. High resolution modelling was described as promising and highly ambitious in the scientific review prior to the project.

The realistic simulations with the weather model were made possible by a coherent cluster of studies specifically designed to produce realistic, high-resolution simulations of relevant future (extreme)

weather phenomena. They are based, among other things, on knowledge about land-atmosphere interactions in urban and rural areas and land-sea transitions, as well as knowledge of deep convection and soil processes in the event of drought. A great deal of effort was also devoted to developing the interface of this model with the climate models RACMO and EC-EARTH. This cascade of models has proved to be the right choice.

The sub-projects relating to impacts have also proved to be well chosen. In addition to the mutual cohesion created by the fact that researchers from diverse social disciplines had to produce a common vision, it is in precisely these sub-projects that the connections with other themes arise. For example, some ecology sub-projects are connected with Theme 3 (Climate Adaptation for Rural Areas) and the sub-projects relating to hydrology are connected with the various water safety themes via the National Hydrological Instrument (NHI). The link with the Delta scenarios was also made explicitly for the Delta Programme.

These sub-projects suffered more from timing aspects than the other projects because the results for different social domains had to be produced at different times and the source data were also released at irregular intervals. For example, NHI results already had to be produced in the summer of 2013 for the Delta scenarios and the KNMI-next scenario data were released six months later than anticipated. All in all, our impression is that solid progress has been made and that, with more time and a larger budget, the consistency of the projections would have been even greater.

In terms of outreach, major advances have been made in the communication with stakeholders. Various sessions were organised at which a range of stakeholders in the domains of policy making and academia exchanged views about the substance and form of climate information, which made a major contribution to the accessibility and usability of the knowledge and data generated by this consortium.

The timing was good with respect to international developments, of which there have been a number in recent years. Under the auspices of the EU, among others, steps have been taken to produce international Climate Services, for example the JPI, Climate KIC, Copernicus and the Global Framework for Climate Services (GFCS). The priority has been to make an inventory of the needs and wishes of users, while at the same time, the different international approaches are being compared and harmonised. The international component in Theme 6 meshed perfectly with this movement by virtue of the cooperation with German, Swedish and British partners. Consequently, the consortium has acquired a strong position among international suppliers, and optimal use can be made of the knowledge it has generated in this area.

3. Most important scientific and societal results

In this project, the consortium has turned to high-resolution modelling of meteorological processes for climate research. In many respects, this has led to scientific progress with social added value.

The consortium's work has produced greater insight into the influence of land-sea transitions on meteorology (the so-called coastal effect). More is now known about the impact the warming of the North Sea will have on the weather, particularly on precipitation, in coastal areas in the future.

The influence of urban areas on meteorology and vice versa has also been studied. This research concerned relatively small-scale meteorological phenomena of significant relevance for the human environment. In some projections for spatial planning, the coastal area will have become entirely urbanised by 2050. The meteorology of land-sea transitions and of urban areas will obviously then converge. With the consortium's work, more is now known about the future weather in such built-up areas.

Significantly more has been learned about the behaviour of storm complexes. Based on observations and various forms of modelling, estimates have been made about the relationship between the volume of precipitation and temperature, a relationship that can be difficult to determine from first principles because of its complexity. On the basis of these studies, estimates have been made of the future development of phenomena associated with storms, such as updrafts, hail formation and lightning. This is very important information for society, particularly for transport networks, and the new estimates have been incorporated into the KNMI'14 scenarios.

Thanks to the increased understanding and better modelling of local processes due to the work of the consortium, it is also possible to make a clearer distinction in climate projections between effects caused by local processes and effects due to changes in the large-scale circulation. The Dutch climate is very sensitive to changes of wind direction as a result of changes in large-scale circulation, since on a warm winter day the wind comes from the south-west over the relatively warm sea surface, while on a warm summer day, the wind blows from the east over the heated land. A change in the large-scale circulation would alter the climate in the Netherlands significantly. In the KNMI'14 scenarios, therefore, a distinction is made between projections based on a substantial change in the circulation and those based on a less severe change. Because local processes are described more clearly, the impact of a change in circulation can also be better understood and quantified.

The behaviour of global models was evaluated during this project, and it was found that, for a number of important parameters, including (heavy) precipitation, deviations from measured variables were greater than expected. With the systematic studies in this PhD programme, the deviations were quantified and a so-called bias correction can now be carried out for them.

In the last few years, a global scientific effort has been made to identify the various mechanisms that lead to a local rise in sea level more clearly. This consortium has made an important contribution to that effort, including the publication of an article in *Nature,* and many of the team's findings found their way into the IPCC Assessment Report 5, which was published in September 2013. Consequently, the estimates of the sea level for the Netherlands in 2050 and beyond, as presented in KNMI'14, reflect the scientific state of the art, with evident added value for society.

The frequency of extreme conditions is very important information for the infrastructure. Dikes are designed to withstand extreme water levels that occur once every 1,000 or even 10,000 years, and most of the commonly used statistical methods do not take climate change into account. In this project, major progress has been made in developing methods to produce statistics for extremes in a changing climate, although the PhD research has also clearly shown that a lot of work is still required to produce reliable estimates for all the key meteorological figures. Of an entirely different order is

the technical progress made in research into the use of scintillometers to determine crosswinds at our airports. This entirely new technology is developed in order to make take-offs and landings safer and enable runways to be used more efficiently.

During this project, various knowledge chains were created to develop scenarios for the consequences of climate change for specific social sectors in the Netherlands. One chain, for example, is translating meteorological climate scenarios into hydrological scenarios using the NHI and then using that information in impact studies relating to land use, nature and agricultural production.

Hydrological projections have also been incorporated in the Delta scenarios for the Delta Programme. The same applies for land-use projections, which were produced in close collaboration with the Agricultural Economics Research Institute (LEI) and the Netherlands Environmental Assessment Agency (PBL).

The Agro Climate Calendar was developed for agricultural applications. It is a relatively simple tool that enables farmers to estimate the consequences of changing meteorological conditions for the agricultural sector.

The consortium has spent roughly 20% of its budget on interactions with stakeholders, which has great added value, since it means that the research programme is closely geared to social issues and that the new knowledge and data are used effectively for the benefit of society. The interactions with stakeholders have significantly shortened the route from scientific progress to social added value.

4. Reflection on value creation[1]

I) scientific and social value in terms of high-quality and climate-proof spatial investments

II) contribution to strengthening the knowledge infrastructure

III) valorisation of knowledge

With the coherence described above between Theme 6 and KNMI'14, the balance between the costs of the project and the social benefits is very positive. The new KNMI'14 scenarios are used to provide information to underpin many adaptation measures, including the Delta Programme.

The work of the consortium has made a substantial contribution to the creation of new knowledge about meteorological phenomena to which the Netherlands is vulnerable. In particular, the KNMI'14 brochure refers to sea level rise, heavy precipitation (and the associated hail and lightning), spatial diversification of trends and the interpretation of trends in extremes.

The aviation sector benefits from the unexpectedly rapid development of the high-resolution model Harmonie, which is already operational and can be used to study meteorological situations that will be critical to the sector's operations in the future.

[1] Knowledge for Climate Final Report, chapter 5

The social added value of the new climate scenarios has been greatly enhanced by the fact that the connection with various social sectors has been increased by means of the coherent impact studies and through the extensive consultation with stakeholders.

For a number of social sectors, ready-made projections have been produced for relevant parameters. In addition, tools have been developed that will enable scenarios to be used as input for impact analyses.

A major accomplishment was the further development of the 'transformation program', with which series of meteorological observations can be converted into future series. In this way, water boards and other parties can enter their own series of measurements and transform them to the W_h scenario in 2070. The transformation program is already widely used.

Various engineering firms are also using (or plan to use) the tools in providing their own services. A concern in that regard is that a lot of detailed knowledge about the scenarios is required to use them correctly. It is therefore advisable to consult a scenario expert.

The project has also introduced a number of new methods to improve communication between scientists and policy makers. As part of a PhD programme, experiments were conducted with the concept of 'simulation gaming', where policy-makers and scientists used simulations of future climates to discuss the impact of climate change on the catchment area of the Rhine and the implications for the management of the area. This proved to be a very valuable and informative exercise for everyone concerned.

An unexpected success is the Future Weather concept, which can not only be used for research purposes, but has also proved helpful in providing policy-makers and other authorities with an insight into and a sense of the consequences of meteorological events that might be caused by climate change in the future. This method therefore influences the manner of thinking about risks, but it is such a recent development that we cannot yet properly gauge its impact on water safety and related policies.

5. Most important social and scientific developments relevant for future research priorities

There is a growing need to understand the relationship between the occurrence of rare (extreme) meteorological events and climate change, the so-called attribution issue. Every rare occurrence raises the following questions: Is it exceptional? How often has it occurred in the past? Will it occur more often in the future? Is it a sign of climate change? Examples are situations that cause a lot of damage, such as heavy precipitation, the flooding of rivers, lengthy periods of drought, etc. In this project, as part of a PhD programme, an entirely new approach to studying this type of situation was explored, namely 'forcing' the climate model to simulate such a rare occurrence under current or future climatological conditions. This new method will have to be further developed in the coming years.

Advances in very high-resolution, meso-scale modelling of the climate(with Harmonie) in order to simulate phenomena on the scale of tens of kilometers are still in their infancy, particularly compared to the status of the rougher global climate modelling. The Future Weather cases of extreme storms developed in Theme 6 are the first examples of the use of this type of model. To gain more confidence in the quantitative use of these models for climate applications, comparison studies with observations and with other models will be required, among other things. For example, the fact that the system has only been tested to a very limited extent is reflected in the great uncertainty regarding changes in extreme precipitation in the new climate scenarios.

The urban climate of the future is on many agendas. In project WP3.5, a study was conducted into coupling an air-quality model to a climate model. Although it was only a first step, this line of research is certain to be continued because of the high political priority given to the subject.

It should be borne in mind, however, that the most important thing is also to continue developing mainstream climate knowledge: representing more geophysical phenomena in models, assimilating a steadily expanding set of observations (e.g., from satellites) and making optimal use of new technologies, such as parallel processing with grids of graphic processing units (GPU).

The endeavours in WP3 to produce coherent scenarios for the impact of climate change also create new possibilities. For example, by analogy with the Future Weather concept, time series could be selected from climate model simulations as input for the NHI or for impact models. This would naturally require intensive cooperation between scientists in the fields of climate modelling and impacts, for which networks like those used for the Delta Programme, which produced climate series for the NHI which are, in turn, used for land use, could serve as an example. Similar networks have been formed to address the impact on nature.

An important external development is the establishment of European Centres for Climate Services. Through the activities carried out with our foreign partners (SMHI, the University of Exeter and DWD) and participation in the JPI and Climate KIC, this research group is well positioned to play a part in these international activities.

6. Reflection on the cooperation between the consortium partners in order to stimulate substantive cohesion

Substantive cohesion is guaranteed by the organisational structure and the relationship with the KNMI-next project.

Theme 6 has four work packages, which naturally have considerable internal cohesion because the activities and interests are very closely related. The participants work in roughly the same field of science and also meet at other times outside the project. WP meetings are held regularly to monitor progress.

Coordination of the activities in the various work packages takes place mainly during regular meetings of the WP leaders with the consortium leader, where progress is discussed on the basis of

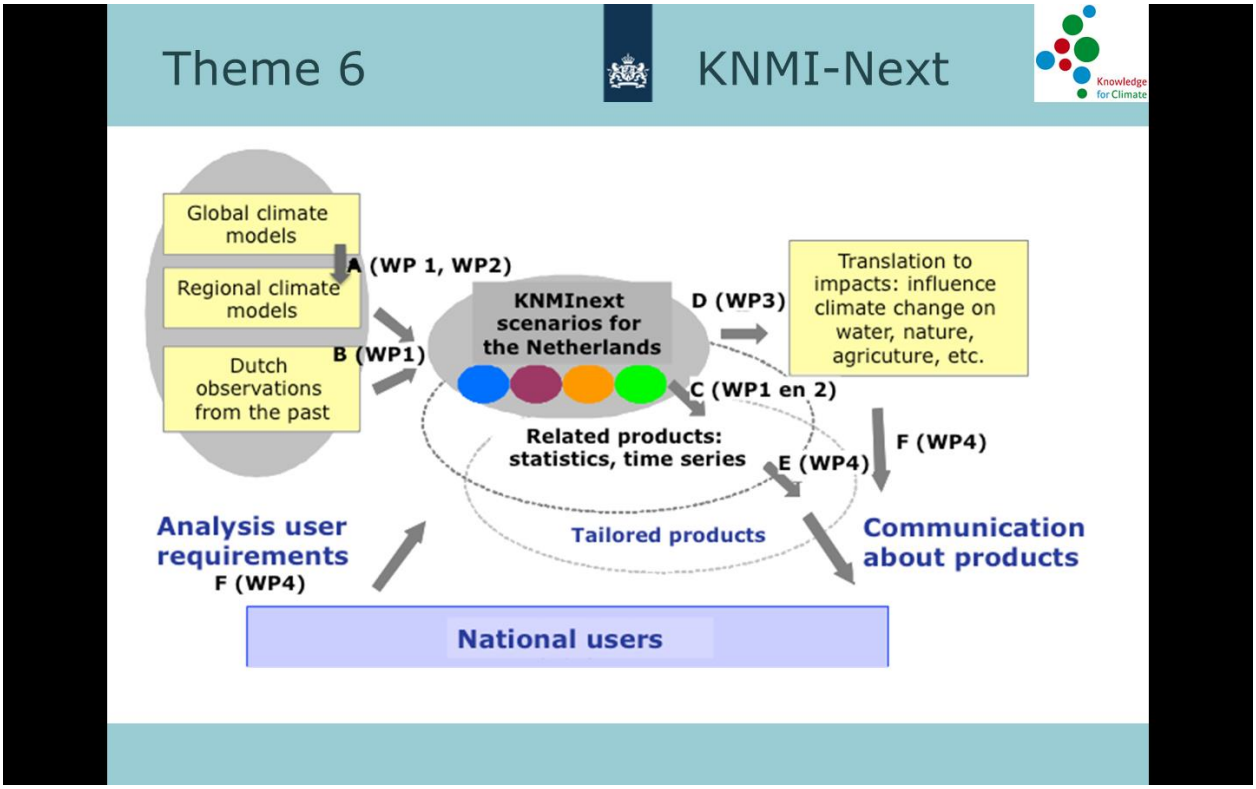
the project matrix. This matrix describes the status of all the sub-projects and indicates the dependencies between them, which quickly pinpoints any delay in a sub-project that could have consequences for other sub-projects.

The project matrix is also an important management tool for the Steering Group, which meets every six months to discuss progress and where the members have an opportunity to warn of any inconsistencies that, from their perspective and in light of their interests, may be arising. We are fortunate to have a number of very active members in the steering group who are generous with their positive criticism.

Every year a plenary meeting is held, which is attended by researchers, WP leaders, steering group members and representatives of the hotspots and the programme office. These meetings are devoted to identifying cross-links between the work packages at an operational level. For example, every researcher is asked to consider how his or her work can contribute to Hotspot Schiphol and Hotspot Major Rivers. Unexpected cross-links sometimes come to the fore during presentations on work in progress.

The mid-term review provided a good opportunity to review the cohesion of the programme again and present it to the steering group.

In addition, the activities in Theme 6 are closely related because they are part of a cluster of projects connected with the new climate scenarios for the Netherlands, KNMI-next. The figure below presents a diagram of the internal and external cohesion.



The cohesion within Theme 6 is also safeguarded by the need to align the activities with those of the KNMI-next project, and this is reflected in the composition of the team and the organisational structure, among other things. The project is divided into four work packages. The leaders of three of the four work packages work at the KNMI (Janette Bessembinder, Wilco Hazeleger and Geert Lenderink), which facilitates communication even on minor issues and fosters intense commitment. The leader of WP3 is Deltares. This connection required more care, partly because of regular changes in the occupant of the position of project manager. Since the Dutch consortium partners for WP3 and WP4 are largely the same and because the activities of these WPs are closely linked, the project teams always held joint meetings, which proved very useful and efficient in terms of the substantive coordination of the WPs.

7. Reflection on the cooperation with foreign research partner(s)

The activities are deeply embedded in the international scientific community. The studies for IPCC AR5 form the basis for the high-quality climate projections for adaptation in the Netherlands, and the consortium has worked intensively on the analyses of the CMIP5 modelling data set in international projects, so the latest scientific insights have been incorporated in this project.

There has been a concrete working relationship with SMHI, DWD and the University of Exeter in the project. There was also frequent contact with SMHI in its capacity as a partner in the EU FP7 projects IMPACT2 and CORDEX, as well as regular communication by e-mail to discuss substantive and organisational issues. There was also frequent e-mail correspondence with DWD, as well as regular contact at meetings of the JPI. In addition, DWD, Deltares and KNMI all have responsibilities with regard to the management of the Rhine. The University of Exeter's role has been mainly advisory, which is appropriate to the very limited budget.
All of the foreign partners have attended consortium meetings. Some were represented at the annual plenary meetings, while others participated at the summer school on uncertainty.

During the project, there has also been close cooperation with the European Commission's Joint Research Centre, with whom two scenarios were defined and then translated into changing land-use patterns for the Rhine flood plain using EU-ClueScanner.

Theme 7 – Governance of Adaptation to Climate Change

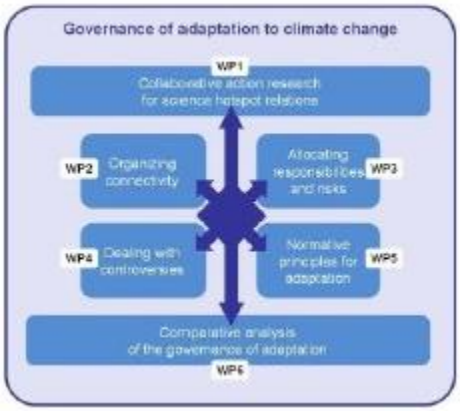
Consortium leader: Prof. Katrien Termeer (Wageningen University)

1. Reflection on the consortium's position in the international research arena and the contribution to the (inter)national scientific and public debate

General

When the consortium began its work, the aspect of governance in relation to climate adaptation was still receiving relatively little attention. There is now a far greater realisation that, in addition to the need to find technical solutions, adaptation to climate change also involves complex governance issues. Research into governance has become an important element of the national and international research agenda, and the consortium has certainly contributed to that. Governance research is not only concerned with developing smart ideas for producing technical solutions, but also contributes to the development of better solutions through concepts such as agenda-forming, joint fact finding, co-creation and mainstreaming.

We defined 'governance' as the interactions between public and/or private actors aimed at achieving social objectives, in this case climate adaptation. The governance arrangement is the composite of actors, rules, processes, discourses and instruments that provides a structure for these interactions. Governance is therefore more than government policy, more than financial incentives and more than laws and regulations. The issue of governance therefore has to be investigated from the perspective of various disciplines.



The consortium clearly positioned itself as a broadly oriented, multidisciplinary group of lawyers, public administration specialists, political scientists, economists, environmental policy experts, planning experts and psychologists. The point of departure was a joint conceptual framework, which was used to analyse, evaluate and design new governance arrangements. The framework embraces various important aspects of a governance arrangement: the links (connectivity) between parties and sectors, the allocation (or reallocation) of risks and responsibilities, dealing with controversies and researching, developing or adjusting normative principles. Governance arrangements were assessed for their effectiveness, legitimacy and resilience. The consortium developed an ambitious action research approach, designed to increase the connection with practitioners and to reveal a lot of

empirical material, an approach that was based on recent ideas from the field of transdisciplinary research. In this way, the consortium was able to make a contribution to both the scientific and social discussions concerning climate adaptation.

Contribution to the scientific discussion
An important contribution we made to the scientific discussion is that the findings from our research do not always accord with the dominant international literature about governance (in relation to climate adaptation). The mainstream literature focuses heavily on the major, long-term challenges of climate change, the many controversies, the need for a participative approach, etc. The insights yielded by our project also present a different picture, however: Emphasising the major challenges of climate change can also lead to procrastination, participation is not always effective and the focus on controversies can lead to deadlocks. Besides trying to operate across boundaries (between public and private, for example), it is also sometimes necessary to draw boundaries in order to realise effective cooperation. Setting clear goals and preconditions can also help in achieving a consensus regarding objectives and instruments and for operating across the public-private boundary. Sometimes it is better to tighten the focus in order to achieve actual results rather than concentrating on the process of integrating and mainstreaming everything.

Our research also shows how the scientific community involved in 'the governance of climate adaptation' is dominated by a 'system assessment approach' (Vink, et al. 2013). This approach defines climate adaptation as a static, technical and institutional challenge, but largely ignores the dynamic interactions between knowledge, interests, social learning and political negotiation. The research by our consortium involved concepts such as boundary work, framing and 'puzzling and powering'. Whereas the literature on climate adaptation is often concerned with (scientific) knowledge or the political play of interests, we also endeavoured with our contribution to gain an understanding of the complex dynamics between knowledge and interests in the governance of climate adaptation.

Adaptation to climate change was scarcely developed in the legal discipline, and concepts such as resilience and adaptive capacity have been concretised in the legal context, in a manner that allows them to be used in both a monodisciplinary and an interdisciplinary fashion. The attention to the normative aspects of adaptation was fleshed out for various policy sectors and embedded in existing principles.

These conclusions and other insights were presented at various international conferences by keynote speeches, participation in expert panels, presentations and posters. Highlights were our own international conference on climate governance in Amsterdam (2012) and the section with seven separate panels during the conference of the European Consortium for Political Research in Bordeaux (2013). Our experience with active research also enabled us to make a useful contribution to the discussion concerning methods of action research and resulted in a book on action research in the field of governance of climate research. The book will be published by Routledge at the end of 2014.

We made a clear contribution to the scientific debate with a large number of publications. We also produced special issues for four scientific journals: Climate Law (2011), Ecology & Society

(2013/2014), Utrecht Law Review (2014) and the Journal of Water and Climate Change (in production).

Contribution to the social debate

The consortium focused heavily on action research in order to make the greatest possible contribution to the social discussion. Unfortunately, such intensive cooperation with hotspots (and the related co-financing) proved difficult in some cases. Nevertheless, there was ultimately a lot of cooperation with a great many actors, including some outside the hotspots. For example, major contributions were made to policy formulation and the social debate through the collaboration with almost all of the sub-programmes in the Delta Programme.

Governance in general, and our governance research in particular, has received growing attention recently, as evidenced, for example, by the interest in the co-creation project, in which perspectives for action were formulated for urgent governance issues in consultation with leading policy-makers. In addition, members of the consortium were regularly asked to share their views on governance issues at expert forums and at other meetings. For example, a number of professors took part in expert forums for Delta Programme sub-programmes, the highlight being the conference for practitioners 'Governance of climate adaptation: Perspectives for action' on 13 March 2014 in Rotterdam, which was attended by practitioners (more than half of the participants), which further underlined the growing interest in governance. The participants were very enthusiastic.

Stakeholders at the Conference for Practitioners on Governance of Climate Adaptation: Perspectives for Action, and the closing speech by Stefan Kuks and Gerlach Cerfontaine

The impact of the research is also reflected in actual policies. For example, normative elements are more explicitly visible in the recently published EU adaptation strategy following interaction with members of the consortium. In the Delta Programme Freshwater, insights about normative elements (referred to as 'values' there) and the discussion about the scope of the public task (and hence the division of tasks between public and private parties) are clearly presented, partly as a result of a number of expert forums and the co-creation process. Via action research, a direct contribution was made to the IJsselmeer sub-programme of the Delta Programme, the participative process in Noordzijlvest's 'Droge Voeten 2050' project and the Delta Programme sub-programme High Sandy

Areas. In addition, one of the PhD candidates worked with the South-West Delta Programme, which had clear added value for the impact of the research in practice. A lot of research was also carried out in various case studies, with the findings often being directly disseminated in workshops, for example in the municipality of Rotterdam (green roofs, heat policy, roof park and flooding, for example), the Delta Plan for Dry Sandy Areas (leadership, normative principles and participation), the Delta Programme Freshwater (including normative aspects) and the Delta Programme Coast (cross-border decision-making processes). Other activities included expert forums, guest lectures (for secondary schools and universities), presentations at numerous meetings, contributions to a climate-change project by fifth-year students of the Maas-Waal secondary school and articles for popular science magazines. The involvement of different disciplines in these activities of the various work packages indicates the multidisciplinary approach that has been developed by the consortium.

2. Reflection on the initial objectives of the consortium

The consortium's scientific objective was to learn about governance arrangements for climate adaptation and to use the insights gained to develop and test new arrangements that could contribute to the realisation of adaptation strategies and to increasing the adaptive capacity of society. The social objectives were to make these insights relevant for the social actors who are engaged in the governance of climate adaptation. This two-pronged objective was largely accomplished within the period of the research on this theme. Due to various circumstances (start-up problems with action research, tensions with existing institutions, reluctance to start using new arrangements), we did not progress as far as we had hoped with testing new arrangements. This objective was perhaps too optimistic. It is, however, clear to us that policy-makers have taken up recommendations that were made in our programme. Unfortunately, due to the fact that our research programme has come to an end, we are no longer able to systematically analyse these result in practice.

We will discuss these circumstances in more detail. To achieve our objectives, an ambitious action research programme was set up at the start of the programme. Despite the structure of the programme, the involvement of the stakeholders at various stages in the early days of the programme, the enthusiasm shown beforehand, and the time that was invested by researchers and stakeholders, it still proved very difficult to organise action research. Successfully organised action research only really came into its own in the peat meadows hotspot and in the South-West Delta, where a PhD candidate carried out very intensive longitudinal, participative action research. In two hotspots (Rotterdam and Dry Rural areas), projects were started in which the cooperation between the stakeholders and researchers was less intensive than envisaged. Ultimately, no projects were started in the Haaglanden and Wadden Region hotspots, both of which had originally staked a lot on the governance research.

With other stakeholders, the consortium also explored possibilities for action research, which led, among other things, to an action study for the Delta Programme sub-programme IJsselmeer and intensive involvement in the Rivers and Freshwater sub-programmes. Ultimately, a large part of our research was performed in association with stakeholders and will therefore contribute directly to increasing adaptive capacity. Furthermore, our experiences with action research prompted a number of researchers to reflect on tensions between action research and existing institutions and how to

deal with them, and their insights were presented at conferences and published in papers and a book.

We actually far exceeded our scientific ambitions. If everything that we have set in motion succeeds, the consortium's output will comprise four special issues, a book, an international conference, a practical conference, a practical guide, many articles and presentations and participation in panels.

One objective was to reflect on action research. This took the shape of authorship of a number of papers and the organisation of a number of action research workshops for and with the PhD students. Furthermore, a book about methods of action research is currently being finished, with an overview of case studies from the Netherlands and other countries. The book will be published by Routledge towards the end of November 2014.

The objective of cross-border integration was achieved by organising meetings with the foreign partners and a large international symposium on 'The Governance of Adaptation' in Amsterdam (March 2012), sending large delegations to the first European Climate Change Adaptation Meeting in Hamburg (March 2013) and, with six panels, the ECPR conference in Bordeaux (September 2013). In addition, the closing special issue will be devoted entirely to international comparative research that has been carried out within our consortium.

In addition to these major objectives, the consortium also had a number of underlying targets related to the four aspects of the conceptual framework: increasing connectivity, (re)allocation of risks and responsibilities, dealing with controversies and reflecting on normative values.

Increasing connectivity
The objective was to search for possibilities of increasing the connectivity in the fragmented field of governance of climate adaptation. The relevant research focused on four sets of strategies. The first related to experiments (WP2.1). By investigating a set of 18 policy experiments, the following questions were answered: 'What is a policy experiment and what are the dynamics of experiments?', and 'How can you design experiments and what design features are most successful in enhancing the learning effects of experiments?' The most important results from the research are: (1) experiments, as tests of innovative solutions, are less common than expected; (2) in principle, there are three types of experiments: technocratic, advocacy and boundary experiments. These types differ from each other in the degree to which non-governmental parties participate, the degree to which the communication between participants and outsiders is open, and the degree to which policy-makers or experts determine the agenda and the problem at hand; (3) experiments create cognitive and relational learning effects, but do not enable participants to alter their perspective.

The second type of strategy is aimed at the integration of land-use functions: multiple land use (WP2.2). In association with a number of hotspots, this research analysed how different strategies for dealing with boundaries promote or hamper the effective integration of functions. This research has made a conceptual contribution to the literature on (organisational) boundaries and integral work by not studying strategies for dealing with boundaries as a static subject, but as a set of boundary actions that take place during the process of making and implementing decisions. The purpose of boundary actions can be to traverse boundaries, to coordinate joint actions, for example, but also to

preserve or reconstruct boundaries, for example to carry out a functional task properly or to defend particular interests. Among other things, the research yielded the insight that bridging boundaries is important for achieving integration, but that achieving effective integration is also a matter of reconstructing and respecting boundaries, since those boundaries help to create a sense of structure and transparency regarding responsibilities, which accelerates implementation.

The third set of strategies are leadership strategies (WP2.3). The use of leadership strategies was investigated in four case studies: the Delta Plan for High Sandy Areas, the Waalweelde project, the Manhood Peninsula partnership (UK) and Nordhessen (Germany). The most important results are that (1) leadership is an important factor for the success of adaptation projects, (2) forms of leadership other than hierarchical leadership, such as enabling and binding leadership, are also required, (3) leadership is usually fragmented; a number of organisations and individuals can display leadership and it is precisely the combination of different forms of leadership that determines the progress of adaptation projects, and (4) the challenges of leadership in projects that are initiated from the bottom up are different to those in projects initiated top-down. The model of leadership functions that was developed proved very useful for reflecting with policy-makers on the role of leadership in adaptation projects and identifying possibilities for improvement. See, for example, the results of the co-creation project with the province of Noord-Brabant in the practical manual.

The aim of the fourth and final set of strategies is to synchronise processes on different scales (WP2.4), where actors at different levels and in different sectors are trying to formulate and implement adaptation strategies. These actors depend on each other. Because of this dependency, adaptation strategies can only be implemented when the processes of the actors are synchronised. This synchronisation process was studied in collaboration with the Major Rivers and South-West Delta hotspots, among others, and the research showed that synchronisation is indeed essential for the successful implementation of adaptation strategies. It was also shown that the synchronisation in these processes arises from creating a structure, giving significance to the process and making use of the opportunities that arise. The objectives of the projects provided sufficient guidance and proved useful and feasible.

(Re)allocation of risks and responsibilities

The aim was to develop an evaluation framework that could serve as a basis for making properly underpinned choices for governance arrangements with respect to (1) the division of responsibilities and (2) the choice of policy instruments, and to investigate how the range of climate adaptation services supplied by private parties can be optimised and whether it can be designed in a manner that is flexible and resilient.

The framework for evaluating the division of responsibilities was developed (WP3.1) and applied to three empirical themes: water storage (including the use of green roofs), water safety in areas outside the dikes and heat stress. A method was also developed for selecting policy instruments, taking the specific features of the climate adaptation issue into account, and it was also applied to the three aforementioned empirical themes. The objectives were met in time.

Optimising the supply of climate adaptation services by private parties was studied by research on reflexive monitoring, auctions and ‘smart subsidies’ (WP3.2). Auctions of water storage contracts, for

example, and smart subsidies are instruments for ensuring that water storage can be provided at the lowest possible cost. These instruments were investigated in experiments, some with students (as is usual with this sort of economic research) and some with experts and policy-makers from Deltares, the Aa and Maas Water Board and the province of Noord-Brabant. For reflexive monitoring, we specifically analysed the relationship between the governance concepts of 'trust' and 'control'. If the government is not willing or able to impose concrete measures, reflexive monitoring was found to be effective in increasing the supply of climate services by private parties. Providing information about the need for and usefulness of the services increases the supply, and in that situation, additional regulation does not lead to an even higher supply - unless the regulation turns out to be very high after all. The provision of Information and (imperfect) regulation are therefore substitutes in terms of acquiring climate services rather than complementing one another.

Dealing with controversies

The broad research question about how to deal with controversies was expressed in three separate - questions: (1) looking back at the work of the second Delta Commission, how have the ideas and knowledge about climate change been processed, substantiated and presented?, (2) how can 'puzzling and powering' be used to deal with the varying perspectives and interests relating to climate change? (studied in association with the Delta Programme IJsselmeer and Noorderzijlvest Water Board); and (3) how do existing knowledge arrangements of policy sectors influence the production of relevant climate knowledge?

The subject was studied with (action) research in the Delta Programme IJsselmeer and in the project Droge Voeten 2050 (Noorderzijlvest). An important finding is that, due in part to the financial crisis and the controversy about the science of climate and climate change in 2009-2010, climate change is a lot less prominent on the social and political agenda than it used to be. The current challenge for climate adaptation policy therefore lies less in dealing with controversies and more in making it an issue – and that is being done by referring back to classical water safety frames. In that context, climate knowledge is often included as an "extra margin of safety" in existing knowledge-policy arrangements, without a thorough reconsideration of the knowledge base. Inherent to these developments is the risk that decision-making on climate adaptation will only consider long-term challenges and uncertainties to a limited extent.

Normative principles

The aim of the research was to identify the normative principles that (often implicitly) underlie adaptation policy and to analyse and assess them against the requirements of resilience, legitimacy and effectiveness. In this way, the influence of these principles on the governance of adaptation was studied thoroughly. Adaptation has a normative dimension, but there is scarcely any discussion of that dimension in the literature and in policy.

The political-legal question of the scope of the public task is relevant for a proper understanding of the significance of the normative principles, because it partially determines the course of the government's policy and the normative principles on which it (often implicitly) bases its policy. The underlying principles behind the policy then influence the choice of instruments. Examples of this are the tensions between centralisation and decentralisation, private versus public or collective responsibility, or profit versus solidarity (in the context of financing and liability). In the course of the

research, it was found that different disciplines give different interpretations (sometimes overlapping, sometimes supplementary) to the chosen concepts in the framework of assessment, such as adaptation, resilience, legitimacy and effectiveness. All of the disciplines in our consortium therefore jointly endeavoured to formulate a better and more detailed definition of these terms and so make them more useful as a framework of assessment for a range of disciplines and adaptation issues. For example, the influence of the criteria was investigated in the European context of adaptation to climate change in a general sense, with respect to the Water Framework Directive and other water-related legislation, the relationship between water and spatial planning and water and adaptation policy at the international, EU and national levels. At the international level (as part of a UN programme), we considered ways in which a transition could take place from disaster risk management to a more preventive approach, with a stronger role for normative and legal instruments. At the European level (in association with DG CLIMA), we participated in discussions about the European adaptation strategy, and at national level in discussions about participation and allocation of responsibilities between public and private parties. At the level of the flood plain, research was carried out into the importance of and the way in which cooperation can be organised in relation to transnational rivers. Research was also conducted on adaptation strategies in border areas in order to discover what specific principles apply to 'transboundary governance for climate adaptation'. This research suffered a few setbacks because, despite its importance, stakeholders showed little interest in this aspect of climate adaptation and because of changes that occurred in the team of researchers. In the last year of the research programme, a lot of progress was made and the objectives will still be met.

3. Most important scientific and societal results

The most important social result is the greater attention for governance of climate adaptation. It has become clear to many actors that technical solutions alone are not enough. More thought has to be given to how promising strategies can be put in place, how technical solutions can be implemented and which measures and solutions are the most appropriate depending on different normative assumptions.

We disseminated our scientific knowledge to the policy-making world by writing fact sheets and drawing up perspectives for action (WTC7), thus expanding the social impact of our research and ensuring our research was clearly translated into practice. The aim was to reach a wide group of practitioners. In this way, we were able to contribute even more to increasing adaptive capacity. The social results are largely connected to the contribution to the social discussion (see 1a).

In scientific terms, apart from the large number of publications (more than 200, including around 50 papers in journals such as Regional Environmental Change, Environmental Politics, Policy Sciences and Water Resources Management, three special issues in Climate Law, Ecology & Society and Journal of Water and Climate Change and 15 chapters in books), an important result is that much of our highly empirical research led to conclusions that sometimes differed to some extent from what has been written in the mainstream literature up to now (see table 1). In that context, it should be noted that the insights from the dominant literature were also observed by us and that our insights are supplementary to them. What is needed above all are more 'smart governance' solutions, which combine the insights of our consortium with the existing insights in a smart manner. In other words,

stressing a major challenge can help to spark action, but also contains the risk that people will simply sit back because the challenge is too great or they no longer feel responsible for it. Aim for connection, but also indicate boundaries. Action is often iterative, with regular adjustment, partly on the basis of (non-explicit) normative principles. There are plans for another integrative paper, which will incorporate the conclusions concerning 'smart governance'. Work is also continuing on critical reflection on the current Dutch climate adaptation arrangements and the role of path-dependence and 'lock-ins' in governance arrangements.

Table 1: Difference of insights in the dominant literature and our consortium

Dominant literature	**Our Consortium**
Emphasising enormous challenge	Risk of leaning backwards
Mainstreaming	Cherry-picking, smart connections
Public private partnerships	Importance of clear boundaries
Bottom-up/top-down dichotomy	Mixtures
Respecting normative principles	Addressing tensions
Bridging the science policy gap	Risk of collusion
Regional problem	Synchronizing between various scales
Strong leadership	Fragmented leadership
Learning by accident	Learning by experimentation

'The Governance of Adaptation' is still a fairly novel scientific theme and there is still no question of a specialist scientific community in the field, but the conference in Amsterdam has contributed to the creation of one. The conference on 'The Governance of Adaptation' in March 2012 attracted a lot of international attention and the special issue that was produced following it was widely read. The consortium was also very well represented at the ECCA conference in Hamburg in 2013.

An important result from the action research is the book 'Action Research for Climate Change Adaptation: Developing and Applying Knowledge for Governance', which will be published in the Routledge series 'Routledge Advances in Climate Change Research'.

Increasing connectivity

From the perspective of connectivity, important scientific results are greater insight into policy experiments and how they should be applied. For example, it has become clear that, for every envisaged learning effect, a different structure is required for an experiment. In integrating different policy areas, which is often necessary for successful climate adaptation, it is important that an attempt is not only made to transcend boundaries: reconstructing and respecting boundaries is also important for the process of effective integration. Successful adaptation also calls for collective leadership, whereby various parties, including non-government parties, can fulfil important leadership functions. For effective cooperation between these parties, also at different levels of government, it is important for actions to be synchronised. In other words, actions in one process

must fit in with the entire set of processes. This synchronicity is created by structures, giving significance and exploiting opportunities.

(Re)Allocation of risks and responsibilities

Adaptation to climate change usually calls for a reallocation of risks and responsibilities, whereby private parties will also be assigned a greater role. The research into this subject showed that climate adaptation at the local urban level is being addressed mainly by public authorities, but the choice of a particular division of responsibilities is often selective, routine and not carefully considered. It was also found that hierarchical management arrangements are significantly more effective for implementing measures and often lead to greater innovation and more creative solutions. Without some form of government direction, many adaptation measures do not take off (on a large scale), or only very slowly. But market actors are needed to ensure greater efficiency (cost reduction and innovation). We also see this reflected in research into auctions and smart subsidies. Smart subsidies often prove more efficient than is usually assumed in the literature. Particularly repeated auctions produce more efficient results. It seems better to repeat auctions for green/blue services on agricultural land every few years, rather than concluding contracts for decades. Repeated auctions do have the disadvantage that they can lead to more coordination between suppliers, which can in fact drive up prices again.

The shift of responsibilities from public to private also alters the way in which legitimacy is acquired. Network arrangements use different sources of legitimacy, but do not necessarily have greater public support. Official ratification of important decisions by elected public representatives remains important for legitimacy, regardless of the governance arrangement and even if there is mutual trust. In many cases, it is also not possible to leave everything to the market, since by doing so, vulnerable groups might be compromised. The protection of vulnerable groups is primarily a question of individual versus collective responsibility, and secondarily (with collective responsibility) of public versus private responsibilities. Protection of vulnerable groups at the local level benefits most from the existence of multiple tailored network arrangements, geared to the different types of vulnerability and the public and private actors that could play a role in addressing them. These arrangements could be dormant and only activated in a crisis, such as a heat wave.

Public responsibility for the protection of the weaker in society is necessary in terms of policy-making and initiating and facilitating the network arrangements. Another important public responsibility lies in communicating risks to the public.

Dealing with controversies

The translation of knowledge into policy processes is important for dealing with controversies, since there is regular discussion of the significance and influence of knowledge during the policy development process. In contrast to a more linear relationship between scientific knowledge and policy practice, a model in which the knowledge itself, via translation and reframing, gradually changes was found to give a better representation of reality. This led, among other things, to an amendment to the literature on knowledge arrangements in so-called ‘boundary organisations’, in which the positioning of newly negotiated knowledge claims plays an important role, in addition to the more usual internal activities of knowledge translation.

In terms of social semantics in climate adaptation governance processes, we also showed that framing is more than static communication. Contrary to much of the literature that approaches framing in relation to climate change purely as a media issue, we have shown that framing is an interactive process in governance processes, in which frame interactions are the conceptual link between processes of learning and processes of power organisation. We also show that the character of these frame interactions, and hence the policy outcomes, change when a process is institutionalised or organised in a network context.

Normative principles
The choice of adaptation measures is a political and social choice and is not value-free. Whether collective or individual measures are preferred, and to what extent adaptation is the task of the government or the citizen, depends on whether one takes a liberal, libertarian, communitarian or collectivist perspective. The choice of policy instruments is also determined by this perspective and, because this is not always realised, this can lead to the wrong choice of instruments. A further elaboration of our ideas at the level of normative principles was made for a transnational, Dutch/German context. We worked on a contribution on shifts in thinking about the public interest and, in association with PhD candidates from other work packages, an article (in English and Dutch) is being written about the role of the solidarity principle in Dutch adaptation strategies.

In addition, we made a comparison from a normative perspective of the Dutch and English methods of dealing with flood risk and of the Dutch and Flemish approach, framing and organisation of adaptation policy. For this study, we analysed how the freshwater supply for agriculture is arranged in an area that faces structural water scarcity (Tholen and Zuid-Beveland), when the law is not designed for that situation. Although the law on water in the Netherlands does not meet all the requirements for adaptive law specified in the literature, it did provide sufficient discretion for local authorities and businesses to improve the local water supply and to create two different measures and arrangements –public and public-private, respectively. It is also noteworthy that the public arrangement has a more adaptive design than the private arrangement.

4. Reflection on value creation[1]

I) scientific and social value in terms of high-quality and climate-proof spatial investments

II) contribution to strengthening the knowledge infrastructure

III) valorisation of knowledge

The Governance of Climate Adaptation consortium delivered some evident benefits, as described above. The knowledge developed can be used at the European (further development of the EU's adaptation policy), national (in the continuing Delta Programme, for example) and local level (stimulating green roofs, for example). By organising workshops, using action research and organising the co-creation project, including a conference for practitioners and handbook, this knowledge was actively disseminated to policy-makers. Knowledge generated by our research was also used to provide advice about the future of the Delta Programme.

[1] Knowledge for Climate Final Report, chapter 5

Many of the insights generated were shared and are already being used in practice. The research into policy experiments has proved useful for parties that are experimenting with new approaches on Dry Rural Sandy Areas, for example. The research into synchronisation in a multi-level governance system made a major contribution to the programme management of the South-West Delta programme via participative action research. With reflections, input was provided for the programme management of the Delta Programme as a whole and for the Delta Decision Rhine-Meuse Delta. The research into green roofs, heat stress and adaptive development of areas outside the dikes (WP3) was repeatedly shared with the municipality of Rotterdam. In WP4, there was also intensive collaboration with various parties (particularly the Delta Programme IJsselmeer and the Noorderzijlvest Water Board). The results of research were fed back directly to the stakeholders via an action research structure, so that the knowledge could be immediately valorised. The knowledge from WP5 (normative principles) was also shared with various organisations, including, at the request of the Ministry of Foreign Affairs, with the UN ISDR in Geneva, for the development of the European climate adaptation strategy, and with various sub-programmes of the Delta Programme and for the development of more integrated environmental legislation.

There were more than 25 scientists, including nine PhD students and two post-docs involved in Theme 7, who will be able to use the knowledge they have gained in future projects and jobs. The active cooperation with stakeholders has also made a further contribution to strengthening the knowledge infrastructure and valorisation of the knowledge. Researchers in WPs 2, 3 and 5 have used results of the research in a project in the 3rd tranche of KfC (HSDR3.5). The research into leadership, for example, strengthened the knowledge infrastructure through the cooperation between research institutes in the Netherlands and other European countries. WP6 (international exchange) helped to establish those international contacts. Accordingly, there was a lot of cooperation with various foreign partners and those contacts have already generated publications in highly respected scientific journals.

5. Most important social and scientific developments relevant for future research priorities

An important recent development is the completion of the Delta Programme and the climate adaptation strategies for regions such as Rotterdam. As a result, attention is shifting from agenda setting and policy development to the actual implementation of adaptation measures. Up to now, the research into climate adaptation has focused mainly on the start of the policy cycle. Although the consortium devoted a lot of attention to implementation (for example in WP2.2, where an analysis of the decision-making and implementation process was made for three case studies), we anticipate that the research will shift even more in that direction. There are now many ideas and plans, but there is still little experience with actually carrying them out. How can obstacles to successful implementation be removed and how can the implementation be accelerated and designed in a manner that is both adaptive and legitimate, for example with a good mix of policy instruments that allows for adjustments? Government budgets are still under pressure and that is not likely to change in the coming years. How is it then possible to secure the necessary financial resources to implement adaptive measures?

Another important social trend is the government's withdrawal in combination with the government's changing attitude towards individuals ('pleasant contact with the government'). More knowledge is therefore needed about forms of self-governance by the market and civil society. With a strong emphasis on new forms of participation, for example, there is a risk that vulnerable groups will be left behind. There is also a risk that the possibilities for critical opposition in every phase of the policy process (policy-implementation-enforcement-legal protection), which is essential for legitimate government action, could disappear from the regular institutional framework.

There has been relatively little research into the involvement of citizens. The research should also concentrate more than it has done up to now on the business perspective. In this respect, the work of WP3.2 has already yielded important insights that can be built on. What can the market contribute and what is the position of companies in this regard? This relates to aspects such as the further development of corporate social responsibility, issues of liability, duties of care that are being created for individuals and the government (the Planning and Environment Act, the Drinking Water Act), insurance against damage caused by the climate and the 'commercialisation' of sewers by offering space to energy and telecom companies for their cables. What influence will all these things have on the division of responsibilities and what powers and instruments are the most appropriate in that context? How can synchronicity be created between the relevant actors? The latter is not only important for planning and implementing policies, but above all for crisis management if a disaster occurs. With decentralisation and austerity measures, there is actually growing pressure on line organisations to focus more on their core tasks, which means that the issue of synchronisation will remain important.

Another important point is the mainstreaming of climate with other policy fields. How can we expand the climate agenda to other policy areas beyond the currently dominant domain of water? This point is also reflected in the proposed expansion in the climate agenda and the National Adaptation Strategy in 2017. The plan to perform a risk analysis of social issues such as energy, infrastructure, nature, agriculture, health and tourism is particularly interesting, since this can be seen as recognition of the dysfunctioning of the science-policy arrangement in the Netherlands and an attempt to correct it. The research could focus on the link between climate, energy, agriculture, food, health, infrastructure and water, and combinations of these areas. In this way, the water chain would acquire a steadily greater role in energy generation, for example by modifying sewage treatment plants so that they can generate energy instead of using it. This raises questions about the status of this type of organisation if it also has a commercial division.

In scientific terms, that raises questions about factors behind the narrowing and broadening of knowledge arrangements and the role of the framing of climate adaptation in that process. On the other hand, it raises questions about the institutionalisation of this proposed expansion in relation to cognitive path dependency. The question is to what extent the proposed expansion of climate adaptation will endure and how it can be integrated, applied and financed on the basis of existing institutions. After all, financial resources are made available, but that is not accompanied by institutional anchoring in broader policy objectives, new tasks for organisations or changes in the area of regulation of risk assessments.

Another interesting field of research is the connection between law, policy, innovation and sustainability. How can we use law and policy to stimulate innovation and how do we ensure that the innovation enhances sustainability/climate adaptation? In that context, the law and policy must not focus solely on the development of new technologies, but should also create room for implementation and social innovation. For example, what is the consequence of innovations in policy arrangements, technology and instruments on institutional design? To actually implement innovations, these uncertainties, which create obstacles in the use of innovations, have to be resolved. The question of how mitigation and adaptation measures can be better combined also deserves further research. It is noteworthy in this context that the bill for an integrated Planning and Environment Act, which was submitted to the Lower House of Parliament on 17 June 2014, envisages integral solutions for climate mitigation, but devotes no attention to an integrated approach to the question of adaptation.

Finally, it is noticeable that the phases of preparation for, action during and recovery after a disaster as a result of climate change have scarcely been researched and seem to be taboo. There are also major governance challenges in this area.

6. Reflection on the cooperation between the consortium partners in order to stimulate substantive cohesion

A number of activities have been undertaken to promote cooperation and substantive cohesion. For example, WP1 organised a number of workshops on action research for PhD students. Every year, the consortium also organised an open day, when the partners could meet and discuss the research and the consortium. There were also annual meetings with international partners in the Netherlands, which were also attended by researchers from the other work packages. The integrative case study highlighted the cohesion between the different theoretical perspectives. The expert forums and conferences were always attended by different researchers from the consortium who tried to find joint answers to practical questions. Because the researchers steadily grew to know and understand one another better, the added value of these activities increased steadily. The cooperation on products was complicated, however, by the highly individual objectives of the universities, particularly for PhD candidates. Despite these difficulties, it was still possible to write numerous joint articles.

Researchers from different work packages also collaborated in the co-creation process, the book on action research and the production of the special issues.

Deliverable 3.2.1. (a publication in *Ecology and Society*) is a joint project of WP3 and WP5, for example, and a joint paper by WP3 and WP5 was also published in *Climate Law*. A joint paper by project 3.1 and WP5, describing responsibilities for areas outside dikes from an administrative and legal perspective and using Heijplaat in Rotterdam as a case study, is still planned. WP 2, 3 and 5 also wrote a joint paper (for *Regional Environmental Change*), in which legal, network and planning perspectives were combined to increase the insight into legitimate governance strategies for climate adaptation.

Andrea Keessen, Mark Wiering and Wouter Ernst organised a workshop for PhD students in January 2013 to discuss the normative dimension of their research and, in particular, the principles that play a role in it. A joint paper on the solidarity principle based on that workshop is currently being written.

In WP4, the two PhD researchers (Wageningen and Nijmegen) worked closely together, both on case studies (for example, in the Noorderzijlvest water board's project Droge Voeten 2050) and on publications, which yielded considerable synergy and substantive cohesion in WP4.

7. Reflection on the cooperation with foreign research partner(s)

One of the consortium's work packages (WP6) was specifically aimed at improving the collaboration with the partners and other parties in other countries. Among the highlights were the successful climate adaptation governance conference in Amsterdam, the ensuing special issue, the international writing workshop, joint publications and joint panels at other conferences. For the EPCR conference in Bordeaux in September 2013, the consortium organised various sessions in association with international partners. The international partners also made a contribution to the practical conference in the form of two workshops. Annual meetings were also organised with the international partners in the Netherlands, which were also attended by the researchers from other work packages. Preparations were also made for an exchange programme with other countries for three PhD students from the consortium: one exchange has already taken place and two are still in the planning stage.

The book on action research also included contributions from international authors, including Patrick Driscoll and Martin Lehmann (both from Aalborg University) and Todd Schenk and Lawrence Susskind (both from MIT). There was also participation in a workshop on 'Societal Transformations in the Face of Climate Change' organised by JPI Climate. Important contacts were established with the JPI research community during the workshop, the purpose of which was to develop a research agenda for the coming decade.

From project 2.1, there was cooperation with the British partners in organising a panel at the ECPR conference in September 2013, and later, in analysing several English case studies that might be suitable for international comparison in the second half of 2013.

For the case study for research into leadership (project 2.3) in climate adaptation on the Manhood Peninsula, there was intensive cooperation with Carina Keskitalo of the University of Umeå (Sweden), with whom a panel was also organised on the role of leadership in climate adaptation at the ECPR conference in Bordeaux in 2013.
A number of studies were carried out in the other countries in project 3.1, which helped to establish relationships with the universities in other countries, including HafenCity University in Hamburg and Aalto University in Helsinki.
Deliverable 3.2.2 was written in association with Carmen Arguedas (Universidad Autónoma de Madrid).
Martijn Vink and Daan Boezeman (WP4) are working with researchers at the University of Exeter in the UK on an international comparison of processes of institutionalisation and framing, in which they are trying to link the outcomes to different state traditions and social contract theory.

There was collaboration from WP5 with a number of international partners and groups, which generated various papers and presentations at conferences. WP 5.1 produced a joint publication with researchers and staff of US EPA (Green et al. 2013); with Helle Tegner Anker of the University of Copenhagen about the role of monitoring in an adaptive approach (Beijen et al, 2014); and with Alexandra Aragão about the significance of compensation (Aragão and Rijswick, 2014). An article for the concluding special issue is being written in association with Colin Green (Professor of Water Economics) and Sally Priest (both from the Flood Hazard Research Centre, Middlesex University). In addition, as part of project 5.2, a paper was submitted with a comparison of adaptation policy in the Netherlands and Flanders, which was written by Mark Wiering in association with Anne Crabbé (University of Antwerp) and Duncan Liefferink (University of Nijmegen). WP5.2 is now also conducting participative research into cross-border cooperation for climate adaptation at the International Rhine Commission.

Theme 8 – Decision Support Tools

Consortium leader: Prof. Ekko van Ierland (Wageningen University)

1. Reflection on the consortium's position in the international research arena and the contribution to the (inter)national scientific and public debate

Climate change is one of the most important global issues of our time. The analyses by the IPCC and the underlying studies show that substantial changes can be expected in atmospheric temperature, patterns of precipitation, discharge in rivers and sea levels. Practically every sector of the economy and society will feel the effects of these changes. It is therefore crucial to find the right combination of measures to mitigate greenhouse gas emissions and adapt to climate change.

Theme 8 of the Knowledge for Climate (KfC) research programme focuses in particular on innovative methods and models that could help to identify and assess possibilities for adapting to climate change, with the objective of ensuring that decisions about adaptation to climate change are properly prepared and are sound.

The consortium consists of researchers in a range of disciplines. From that perspective, the consortium has been successful: the solutions and the methods from various disciplines have been shared and have led to innovative and successful approaches. The themes and objectives of the consortium were selected in close consultation with stakeholders, including representatives of the various tiers of government, NGOs and the businesses sector. Consequently, theme 8 is a broad theme, in which important gaps in our knowledge were explored in the work packages of the programme.

The research programme is based on an analysis of knowledge gaps in the various stages of the adaptation cycle, as shown in Figure 1 below. Using this cycle as a foundation has led to the development of a coherent programme and illustrates how the various elements of the programme contribute to improving and modernising the methods that are used for adaptation. The work packages (WPs) in the programme have all made important and innovative contributions, and because they are mutually coherent, they have strengthened the entire knowledge chain for adaptation.

The consortium has contributed in numerous ways to the national and international scientific and public discussion about adaptation to climate change, particularly in relation to the knowledge gaps identified in the programme. Research in the Netherlands has been conducted in close collaboration with various stakeholders in different regions, including the hotspots of the Haaglanden region, the shallow-water areas of Friesland and peat meadow areas. There have also been interactions with Rotterdam and with the Delfland Water Board on various occasions. The consortium's findings have been passed on directly to agencies responsible for preparing policies via the Netherlands Environmental Assessment Agency (PBL) and the Delta Programme Commissioner and through consultation with the Netherlands Bureau for Economic Policy Analysis (CPB) and the Ministry of Infrastructure and the Environment.

Within the international community, the consortium has contributed to the body of knowledge about many aspects of adaptation and decision-making under uncertainty, in particular by publishing the results of its research in the international literature and by giving presentations at international conferences. The findings have also been incorporated into the MEDIATION Adaptation Platform via the EU-funded project MEDIATION. As part of the wider presentation for the KfC programme, the results were presented at the 'Deltas in Times of Change 1' conference, and the most recent findings will be presented at 'Deltas in Times of Change II'.

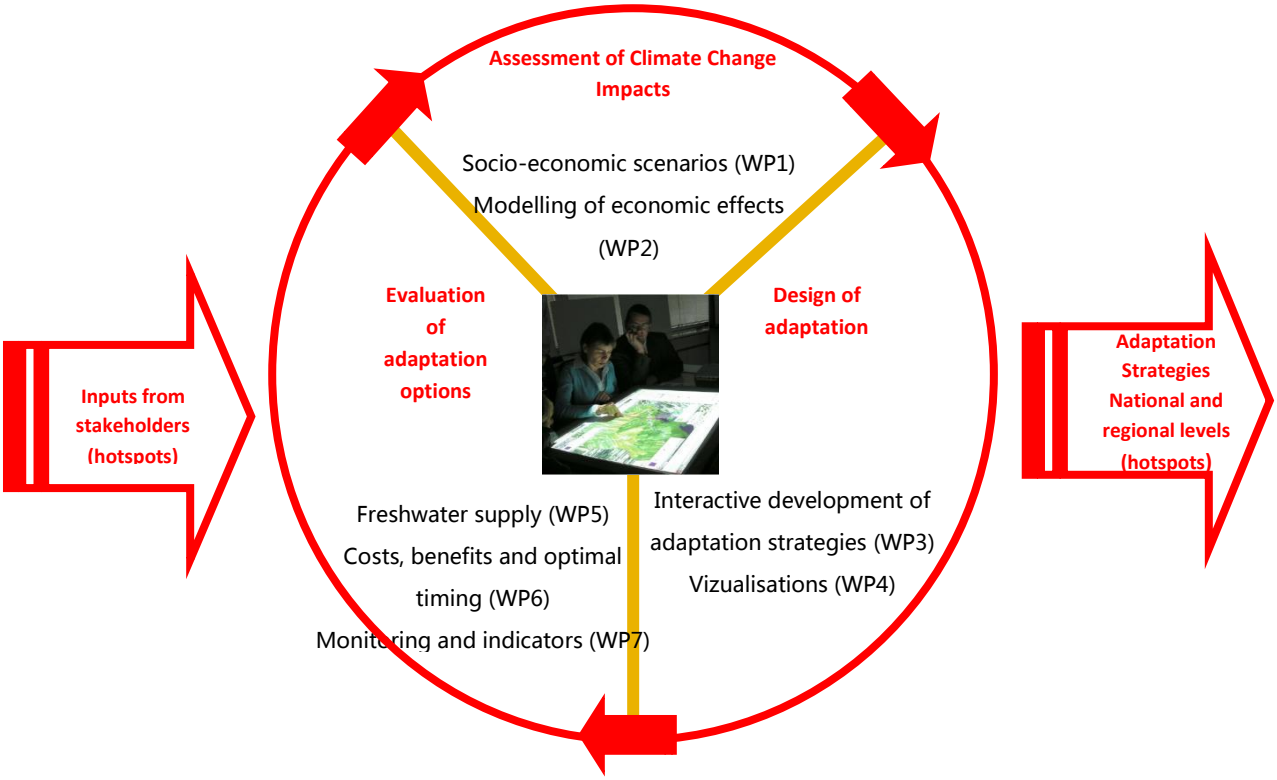


Figure 1 Structure of the programme and cohesion of the work packages in the adaptation cycle.

The consortium has made important contributions in the following areas:

- The development of detailed spatial scenarios for the Netherlands with very fine resolution: such scenarios will allow stakeholders (including municipalities, provinces, water boards, individuals and NGOs) to consider the issue of adaptation in the context of the future spatial development of the Netherlands.
- Economic analysis of the effects of natural disasters: existing models lack a number of properties that are needed to study the dynamics in the recovery phase after a natural disaster. In particular, existing models not equipped to analyse the behaviour of households under risk and uncertainty. The consortium focused on the question, *How can the response of households after the occurrence of a disaster be incorporated realistically in macroeconomic models?* This research has made an important contribution to the international literature on macroeconomic modelling of natural disasters. With the development of a methodology for integrating Agent-Based Models (ABM) with Computable

General Equilibrium (CGE) models, the consortium is also helping to expand the literature in the broader field of economic modelling.

- Improving the use of geo-information in formulating adaptation strategies by applying the 'touch table' approach, in which the best adaptation measures can be selected in interactive sessions with stakeholders: the project has established a reputation in the relatively new field of geodesign. Presentations have been given at several conferences, including the Geodesign Summit Europe in 2013 and the Digital Landscape Architecture Conference in Zurich in May 2014.
- Visualising the impact of climate change and the possibilities for adaptation, in both two- and three-dimensional real-time representations: the three-dimensional representation is based on cutting-edge technology developed within the 3Di framework, which has also been moulded into a new commercial organisation that will continue to conduct research to find product-ready software solutions in this domain. The long-term objective is to develop open-source software that will have an impact on research institutes, consultants and policy-makers throughout the world.
- Analysis of the economic aspects of the availability and allocation of freshwater resources: there were significant gaps in the knowledge in this area but methods have now been created to allocate water in times of scarcity, partly on the basis of economic insights into the costs and benefits as calculated with a general equilibrium model. This marks an important step forward in the preparation of policies for allocating freshwater.
- Economic analysis of decisions made under uncertainty with regard to raising dikes and creating water-storage systems to curtail flooding: analyses were previously based on a deterministic setting (where the degree of climate change is a given), but now the analysis can be performed in a stochastic setting, which makes it possible to make more accurate and better-documented decisions that are explicitly based on more detailed information about the likely extent of climate change. These results have also been published in international journals and are therefore available to the international scientific community and policy-makers.
- Monitoring of adaptation and the development of the necessary indicators: this is a new subject on which a small group of pioneering countries are working. The UK is the absolute frontrunner as a result of the Climate Act, which explicitly provides for monitoring and evaluation. Finland and Germany are also prominent in this movement. The European Commission and the European Environmental Agency are preparing a scoreboard for adaptation, but no consensus has been reached on it yet. With the Dutch consortium's approach, it will also be possible to incorporate an effective method of monitoring based on clearly defined indicators in national adaptation strategies.

A final observation is that practically all of the objectives for the theme as a whole and for the individual work packages have been achieved, although some activities originally assigned to PhD candidates were taken over by more experienced researchers in close consultation with the KfC programme. The work of the consortium has strengthened the Netherlands' position in this domain and produced concrete results in areas that are among the key concerns of national and international climate policy. The systematic structure of the programme and the cohesion that was created by using the adaptation cycle proved very significant in the course of the programme. The

results have been communicated in many ways, for example with articles in leading international scientific journals, presentations and contributions to the professional literature, as well as on websites, and by delivering models and tools for visualisation and interactive decision-making. Participants in the programme also played an active role in the public debate through their contacts with stakeholders and their attendance at conferences and workshops.

2. Reflection on the initial objectives of the consortium

Practically all of the objectives of the full proposal have been achieved, or will be achieved when the various theses have been completed. In the original proposal, the objectives were described as follows:

> '*It is an important challenge to define a coherent adaptation strategy and to develop adaptation measures that are well-designed and flexible, and that meet various criteria such as efficiency (in spatial and temporal perspective), coherence (e.g. in integrating cross-sectoral aspects), innovativeness (in terms of exploiting new technological options and new options provided by climate change) and effectiveness.*
>
> *The problem definition of the programme is to improve the tools for defining the adaptation challenges for the various sectors and areas in the Netherlands and to develop, to improve and apply tools for the development of a coherent strategy for adaptation and implementation of practical adaptation measures, and to improve the evaluation tools to further optimize the options and to select the best packages of adaptation options.*
>
> *This results in the following research questions:*
>
> 1. *How can - in a dynamic context and given the uncertainties related to climate change - the targets be identified for adaptation in the various sectors and the various regions of the Netherlands and what will be the desired timing?*
> 2. *How can a consistent adaptation strategy and alternative and innovative adaptation options be generated, both in terms of changes in infrastructure and changes in behaviour and society, in order to cope with climate change and to make the Netherlands climate-proof?*
> 3. *How can assessment and evaluation tools be developed and applied for adaptation in the various regions in the Netherlands and for the various sectors and hotspots, including crosscutting issues?*
>
> *For research question 1, this requires new scientific methods to consider uncertainty issues and climate change impacts and issues, such as the optimal timing of the various targets for adaptation (how much needs to be done and when?)*
>
> *For research question 2, we want to identify, in close collaboration with the stakeholders in the various hotspots of KfC, what alternative options are available, ranging from technical to behavioural and institutional options and what are the most promising ones and how can this be integrated in a consistent adaptation strategy?*

Under research question 3, we will focus on the urgent and remaining issues related to the costs and benefits of the options, in particular the optimal timing of the implementation, the cross-sectoral issues, discounting and the flexibility in the timing of the various steps in the implementation of the strategy and the relevant adaptation options.'

These objectives proved extremely apt, since there are growing calls, in the Netherlands, Europe and the rest of the world, for the scientific and social underpinning of policies on adaptation to climate change. When the proposal for Theme 8 in the KfC programme was being written, we quickly identified the relevant gaps in knowledge in close consultation with stakeholders, and thanks to the KfC funding, we have made significant progress in understanding the issue of adaptation and developing economically sound methods for making decisions, based on detailed insights into the costs and benefits of different adaptation options, again in close consultation with stakeholders. This has been accomplished in a coherent programme, which clearly identified the phase of the adaptation cycle to which each work package contributed and the mutual relationships between the different work packages. The coherence between this theme and the other themes in the KfC programme is also highlighted by the policy adaptation cycle, whereby the methods that have been developed in Theme 8 will benefit preparations for decision-making on subjects in Themes 1 to 7 of the programme.

3. Most important scientific and societal results

The most important scientific and social results and conclusions are as follows:

- The consortium has played a prominent role in developing methods for producing detailed spatial scenarios that are of great importance for analysing climate change in a changing social context. These methods are then applied in the Spatial Outlook reports for the Netherlands, which are very important to the stakeholders.
- The consortium has made an important breakthrough by analysing the secondary effects of flooding, using three related approaches. The first was designed to gain a better understanding of the economic effects of flooding at a regional level and modelling them in the framework of a CGE model, the so-called RAEM model. This part of the research focused on the dynamics of economic recovery and development in the flooded area. The second comprised a study of the adaptive behaviour of households in response to actual flooding and the risk of flooding. This behavioural adaptation was implemented in a multi-agent modelling framework. The third approach combined the first two parts in an integrated framework based on the computable equilibrium modelling approach and agent-based modelling. The study showed that the flood disaster in 1953 and the subsequent construction of the Delta Works have had an impact on the distribution of the population in the Netherlands, and revealed, on the basis of a general equilibrium analysis, how natural disasters and spatial differences in protection have an impact on the economy.
- The consortium has made important innovative contributions to the development, testing and application of a map-based interactive working environment for designing, testing and applying spatial adaptation strategies. Maps are central to this method, and interactions between humans and a map have been facilitated by the touch table, a large interactive

computer screen on which participants at the workshops could design or modify plans. The touch table stimulates discussion and enhances learning. Loosely translated, the research question being investigated was, 'How do you make the smartest possible use of existing knowledge in order to produce good plans?' The most interesting aspect is the interaction between humans and design technologies, which is also the key to innovation. A relatively large number of people are engaged with these types of technology, but few researchers use them in practice. Among the questions we addressed were, 'Do people understand the presentations we give?' 'What are the dynamics in the group and how can technologies alter them?' and 'How does a person absorb information?' The touch table is a fantastic instrument for interactive planning for provinces and water boards and offers more possibilities than the transparent maps laid on top of each other that designers previously used.

- The research has demonstrated in an innovative manner how visualisation of climate information can help in transferring knowledge between scientists and policy-makers. The project was linked to the further development of the Atlas of Climate Change Impact, which made it possible to test new visualisation methods immediately in various policy contexts. It also led to the upgrading of the Atlas of Climate Change Impact to an operational instrument for policy-makers, which will be integrated into the Spatial Adaptation Guidelines that are being drafted in the Delta Programme. Many stakeholders have used the climate atlas to develop fact-based adaptation strategies.
- The research achieved the objective of gaining an insight into the economic aspects of freshwater allocation in times of water scarcity on the basis of a sound economic analysis. This was an important breakthrough and the method is perfectly suited to further detailing and application, not only for the Netherlands but also for international case studies in many regions.
- Decision-making under uncertainty is an important factor in designing measures to contain the risk of flooding. With the findings from the research, it is possible to consciously weigh the costs and benefits of potential measures while taking account of the uncertainties and the possibilities of learning more. The choice of this subject has proved extremely relevant, particularly in relation to substantial, long-term investments. Dutch research is playing a prominent role in this field, which is being addressed by institutions in the Netherlands and other countries, including the CPB and IIASA, to name just two.
- There is growing demand for monitoring mechanisms in response to the implementation of adaptation policies. Although policy implementation does not always proceed in an orderly fashion, it is possible to learn from current projects on adaptation and monitoring remains a useful element of the policy process. The EU is launching an adaptation policy and the lessons learned by the consortium will be extremely useful and important for shaping that policy and its monitoring. Ideally, concrete objectives or quality requirements for monitoring should be in place from the outset, which is not usually the case for adaptation. Initiating research into monitoring and indicators at an early stage has had its advantages and we can now say that the Netherlands has a lead over other countries in terms of the formulation and monitoring of adaptation strategies.

From a scientific perspective, the consortium has helped to develop spatial scenarios for the Netherlands that provide greater insight than before into the land use that can be expected in the coming decades. These findings form the point of departure for analysis of potential adaptation measures in the Netherlands, in terms of trends in land use and urban development and with respect to water management and land use in the context of nature development and infrastructure.

These scenarios can help in mapping the effects of any future flooding in more detail, which is relevant since the degree of economic damage depends in part on the spatial allocation of built-up areas and economic activity. The research has shown that where families choose to live can also be influenced by the risk of flooding and that people with the financial and other resources to do so are more likely to leave vulnerable and risky areas.

The most important scientific contribution in terms of establishing the secondary effects of flooding has been the integration of two methodological approaches, agent-based models (ABM) and computable general equilibrium models (CGE). This integrated framework retains the advantages of a consistent, structured economic model that can be used for policy analysis, while at the same time allowing the behaviour of households in response to risk and uncertainty to be factored in. It increases the reliability of predictions about the indirect and long-term effects of flooding and other natural disasters, which could help in the development of a future strategy for climate adaptation, not only for the Netherlands, but for the entire European Union. The approach will help policy-makers to take more realistic account of the responses of households to flooding and the perceived risk of flooding in determining the effectiveness of climate adaptation measures.

By outlining the anticipated spatial development without the effects of climate change, it is possible to study the possible adaptations with stakeholders. Most of the scientific results generated by the consortium relate to the development, testing and application of geodesign instruments for designing spatial adaptation strategies. These results can be found in Eikelboom, T. & Janssen, R. (2013); Stewart, T. J. and R. Janssen (2014); Eikelboom, T. and R. Janssen (in press); Eikelboom, T. & R. Janssen (in press); Janssen, R., et al. (in press); Brouns, K. et al. (2014).

Visualisation plays an important role in developing and weighing options for adaptation measures. The most important scientific insights relate to the following:

- the development of Climate Adaptation Services as a concept for ensuring that information about the climate is assimilated in policy- and decision-making processes at the local level;
- the development of an information enrichment chain that combines complex information and relationships in a straightforward indicator and maps that are relevant for policy;
- the development of a participative bottom-up approach to assessing vulnerability, for which a manual has been developed and used in a number of national and international case studies;
- the development of an information visualisation framework that facilitates various approaches to adaptation.

The scientific results of the 3Di project have been published in various scientific journals and to articles in prominent ‘graphics’ magazines and were awarded prizes at the ISC Supercomputing

Conference. The work has also had a social impact. With the 3D visualisation method, policy-makers can understand, simulate and control the process of flooding more easily, and it improves the planning of evacuation scenarios. One of the most relevant aspects of our work is the bridge it builds between scientific experts and policy-makers. It is equally useful for the general public, for whom it explains the complex subject of flooding by means of realistic representations and allows people to form an opinion about the decisions that are made. The 3D visualisation and simulation application can be seen in various public spaces, including museums (e.g., the Science Museum in Delft, the Noodwater Museum in Zeeland and the Municipal Centre in Delft).

In scientific terms, the most important result relating to freshwater allocation is that it is now possible to perform an integrated analysis of economic issues. Whereas, previously, pragmatic considerations played a role in the allocation of freshwater in times of scarcity, it is now possible to assess the options for adaptation and how the available water can be allocated on the basis of economic considerations.

The principal results in relation to analysis of the risk of flooding are the possibilities of explicitly incorporating the risks and uncertainties surrounding climate scenarios in the analysis. This could lead to a situation where it might be better to defer raising a dike if better information is expected to become available soon, but if the expectation is that no better information will become available, or only much later, adaptive measures should commence immediately.

When it comes to enforcing explicit targets for containing flood risks, it is important to be as clear as possible about what the risks are on the basis of a combination of monitoring and scenarios and to constantly monitor compliance with the standards. If that is not the case, additional measures will have to be taken. In that context, it is best to anticipate future developments in order to avoid having to quickly adopt further measures again. In this way, the fixed costs of measures will not be incurred too often.

In terms of monitoring and indicators, the most important result was the development, on the basis of a literature study, of a framework consisting of general elements of monitoring and evaluation. The framework is designed to help in assessing existing monitoring systems and to support the development of new monitoring programmes. The framework has five buildings blocks:

1. general requirements;
2. requirements for the monitoring organisation;
3. a method for defining the system;
4. a method for selecting indicators;
5. monitoring and evaluation procedures.

Most of the attention in the literature has previously been devoted to indicators, which are divided into three categories: process, output and outcome. Process indicators concern the process of policy and decision-making, output indicators are concerned with the methods that are adopted for adaptation and outcome indicators relate to the actual measured reduction of a climate impact. Far less is known about the other building blocks. One important aspect that still requires attention is how monitoring can be used as an instrument for learning, since adaptation will usually be addressed according to the principles of ‘adaptive management’.

The framework was used to evaluate three national monitoring programmes and was found to provide a useful structure for comparing monitoring programmes. It was also found that monitoring can either be more for *learning* purposes or more for *accountability* purposes, and that in the latter case, a clear legal framework is needed.

The social results have been the many contributions made by the members of the consortium to spatial planning in relation to adaptation. These contributions are reflected in the application of the results of the spatial analysis in the foresight studies in almost every domain of decision-making regarding future spatial developments in the Netherlands and climate-proofing Dutch society.

In addition, many workshops have been organised for stakeholders (see, for example, F. Hellmann et al. 2010, Eikelboom et al. 2011; Brouns et al. 2013; Eikelboom and Janssen 2012). Input was provided for planning processes such as the setting of regional water levels (*Peilbesluit Smilde*), regional water plans for the Friesland Water Board, a vision document for the peat moors in Friesland and the policy on peat moors of the Province of Utrecht.

The 3Di project has been used in many important social applications to simulate the risks and process of flooding and to understand what additional measures are needed to contain the risk of flooding. It has therefore proved to be of great social significance in that it was possible to make the correct visualisations to enable policy-making agencies to arrive at well-founded decisions.

Case studies were carried out to apply the monitoring method at a regional level. The case study in the Haaglanden region showed that planning a monitoring mechanism at an early stage helps in refining strategies. In the Rotterdam region, the case study showed that the definition of the system and the lack of understanding of how the system works formed the major obstacle to formulating a strategy, and that monitoring can help in gathering further knowledge about the system. The consortium's insights will also demonstrate their value for society in the drafting of the adaptation strategy for the Netherlands.

4. Reflection on value creation[1]

I) scientific and social value in terms of high-quality and climate-proof spatial investments

II) contribution to strengthening the knowledge infrastructure

III) valorisation of knowledge

In general, the costs of the programme were low in relation to the results achieved. The programme has played an important role in capacity building, in developing directly applicable methods for effectively planning investment projects involving many billions of euros. The Netherlands has established a significant lead over other countries and Dutch expertise is sought by many international agencies in such domains as water management and flood risk (Katrina and other extreme weather conditions in the US and many other countries). The social contribution and the

[1] Knowledge for Climate Final Report, chapter 5

role played in strengthening the knowledge infrastructure are commensurate with the costs, and a cohort of a new generation of top analysts and researchers has been trained, who will be able to help in ensuring that the best possible decisions continue to be made in the future.

Special mention should be made of the climate atlas and the 3Di project, the results of which will be exploited commercially or in a non-profit business. The climate atlas has been assigned to a foundation for non-profit exploitation, and the company Nelen & Schuurmans is building a business model around the software for the 3Di project and has already secured its first clients. As part of *Enlighten Your Research 3*, a Surfnet Sara initiative, a new method has been developed to support the remote representation of flooding, which allows complex software (such as our simulation and visualisation applications) to be used on standard devices through server-side calculations. The results of the KfC project have been integrated into the 3Di project, which will generate income that will be used to improve solutions and expand the activities. The long-term objective is to make the product software-ready and, in time, offer it as open-source software.

The costs of the work package on monitoring and indicators were modest and the future benefits will be substantial for the following reasons:

I. The insights into monitoring have already led to sections on monitoring in the regional adaptation strategy for the Haaglanden region and in an advisory report for municipalities in the Rotterdam region. The knowledge is also being used in a follow-up project to develop monitoring on a national scale under the leadership of the Netherlands Environmental Assessment Agency.
II. The project has generated more knowledge about monitoring of adaptation and led to the creation of a network of international researchers in this field, so the results will have an effect in both the Netherlands and abroad.

5. Most important social and scientific developments relevant for future research priorities

There are important questions concerning how future economic and spatial development can be geared to climate change, and noteworthy trends include the desire for sustainable and selective growth in times of global population growth, with regional contraction here and there. The EU's ambition of reducing greenhouse gas emissions by 80% by 2050 and making the transition to a sustainable low-carbon economy is also important in the context of addressing the climate issue. There is also a growing realisation that, over the longer term, the climate problem will be far greater than is now anticipated, in particular the long-term rise in the sea level. Accordingly, it is not only adaptation that is important, but also a greater level of mitigation.

The climate issue is taking place in a world of intense and growing competition for land and water, in part due to climate change. The use of the oceans is also playing an increasingly important role at the international level, and the acidification of the oceans deserves special attention, also from an economic perspective.

A number of recent studies have explored the issue of how greater environment-related risks could lead to the migration of households. The scientific literature on adaptive behaviour by households as a result of environment-related risks is still in its infancy. Given the increasing pressure on the

environment as a result of climate change and the growing importance of adaptation on the political agenda, this area of research will probably grow in scale and importance. A particularly important subject that needs to be researched is how to isolate the effect of the environmental burden as a driver of migration from other contributing factors.

Changes in flood risks mean that the role and responsibility of the public sector in managing flood risk will receive more attention, in both research and policy. There is an idea that allocating the risk to the private sector could reduce the consequences of a disaster because of the incentive for private agents to adopt appropriate measures themselves. This is based on the assumption that risk is a relevant factor for private agents in making decisions. Further analysis of individual behavioural responses to risk and the knock-on effect on the entire economic system is an important topic for future research.

Important research questions relate to further improvement of geodesign instruments in both 2D and 3D. The current prototype solution in 3Di already works well enough and can be used by semi-experts. Our aim is to make the software even more user-friendly and accessible to everyone.

As far as economic analysis is concerned, there is still a need for simpler methods that consultancy firms and policy institutions can use to deal correctly with the uncertainties in adapting to climate change. The advanced methods are often too complex and the standard methods do not always produce the right solutions, creating the risk of incorrect investment decisions.

There are still a lot of questions surrounding the monitoring of policies on climate adaptation. For example, how can the correct indicators be selected that can then be used in a similar manner in the monitoring of the national adaptation programmes of the various EU member states and how can the costs of monitoring be kept within acceptable limits.

6. Reflection on the cooperation between the consortium partners in order to stimulate substantive cohesion

The research plan was drafted and submitted jointly and the use of the adaptation policy cycle gives it a logical cohesion (see figure 1 at the beginning of this report).
Subsequently, regular meetings were organised with the stakeholders (e.g., the Haaglanden region) to coordinate the activities. Coordination and cohesion were then discussed in detail with the steering group of Theme 8, where the content, progress and results of the work packages and the programme as a whole were discussed and commented on. Where necessary, this led to adjustments in the activities and intensification of the communication with the stakeholders with a view to knowledge co-creation.

The results of the spatial analyses were used, in combination with visualisation techniques, for an analysis of the heat-island effect in Haaglanden and Amsterdam, among other things.

The parties in the consortium that were involved in the analysis of the secondary effects of flooding met roughly every two months. The research into the effects of heterogeneity in risk perception was

carried out in association with Tatiana Filatova (TU Twente, Deltares) and Henri de Groot (FEWEB, VU Amsterdam).

Visualisation methods developed within the consortium were tested in experimental workshops with approaches targeted at the stakeholders with the help of touch tables. Case studies took place in rural areas.

The economic analysis of the freshwater supply was carried out in close collaboration with Deltares, thus promoting trans-disciplinarity and also creating cohesion with the other research relating to the supply of freshwater.

Integration with other themes was realised through cooperation with Haaglanden, where many other themes also made a contribution, and with the Delfland Water Board. There was close cooperation between Alterra, Wageningen University's Department of Environmental Sciences and the Netherlands Environmental Assessment Bureau (PBL) throughout the duration of the programme.

7. Reflection on the cooperation with foreign research partner(s)

Research was launched in collaboration with our Australian partner into the effects of climate change on the agricultural sector in Australia. This study is intended to deepen the methodological knowledge that we have acquired in Theme 8 with insights from our colleagues on the other side of the world. During a two-month visit to our partner in Melbourne, researcher Vasco Diogo gave a number of presentations for Australian researchers and practitioners and took part in a study into climate adaptation in the Gippsland region. With our other foreign partner (EC-JRC), we discussed the implementation of scenarios and improvements to the model framework. On that basis, an additional proposal was drafted for a project in which that cooperation will be fleshed out.

One of the PhD students attended the Young Scientist Summer Programme at the International Institute for Applied Systems Analysis (IIASA) in Laxenburg in Austria.

There was intensive cooperation with Professor T.J. Stewart of the University of Cape Town, which culminated in the development of software and a joint publication. A second joint publication is planned.

The research also led to presentations at events that were also attended by international researchers. They included the following:

- A presentation on the guiding model approach at IALE UK Conference, Edinburgh, September 2012;
- A presentation on the concept framework at ECCA Conference, Hamburg, March 2013;
- A presentation on the Climate Adaptation Services approach at CIRCLE3, Lisbon, March 2014;
- A presentation on the Information Enrichment Chain and Climate Agenda Map approach to Deltas II, September 2014;
- Application of handbook for Vietnam as part of an education module;

- Application of handbook for Ireland in association with the Irish Environmental Protection Agency and Coastal and Marine Research Centre;
- Application of handbook and framework for Bangladesh as part of Delta Plan Bangladesh;
- Application of handbook and framework for Himalayas ((HiAware).

Recent work on the 3Di project focused on compression techniques for the external presentation of data that were developed in association with new international partners, such as NVIDIA and the Max Planck Institute.

A close association was formed with Dr. Alvaro Calzadilla of the Institute for World Science in Kiel, Germany, and Dr. Richard Tol, a professor at the University of Sussex in England.

On the economic side, there was close collaboration in the EU's MEDIATION project with the most important research institutes in the field of climate adaptation in Europe, e.g., PIK (Jochen Hinkel), IIASA (Reinhard Mechler), JRC, REC and Alterra (Rob Swart).

During the ECCA conference, there was cooperation with speakers from the UK, Germany and Australia, including Mike Harley (Climate Resilience Limited, UK), Jean Palutikof (Griffith University, Australia), Hans-Martin Füssel (EEA, Denmark), Sebastian Catovsky (UK Committee on Climate Change, UK), and Manfred Born (Metropolitan Region Bremen-Oldenburg, Germany).