Scenario development for climate change impact

Work package leader : Jaap Kwadijk

Content

1 Description work package

1.1 Problem definition, aim and central research questions

Impact of climate change in the Rhine Meuse delta will be not so much through changes in climate parameters, rainfall, temperature, etc. directly, but more through effects of the changed climate on hydrology, sea level, nature and atmosphere. Adaptation to climate change in the Netherlands means therefore above all adaptation to the effects of these changes on the environmental conditions. The process of designing adaptation strategies requires a supply of climate, hydrological, ecological and socio-economical scenarios. Many scenario studies have been carried out to assess the effect of climate change on natural resources. A problem, however, is that despite the great number of studies, a consistent view on the indirect (i.e. hydrological, hydrodynamical, ecological) effects is lacking. This is caused by the limited scope of the effect studies, mostly they focus on a single natural boundary condition, or are limited to assessments for small areas. The inherent interdisciplinary character of climate change and the need to develop adaptation strategies at local to regional scales requires that climate and climate impact data and models are coupled to determine regional implications of global climate change. For developing spatial planning strategies, this requires coupling between climate scenarios and sectoral climate impact models (water, nature, agriculture and socio-economic models).

A second issue is that we notice that so far scenario building mainly concentrated on generating scenarios where the emphasis was on their sound scientific basis (physically meaningful, consistent, scientifically sound statistics, etc.). Less attention has been paid to explore the effectiveness of the scenarios for decision making. In operational weather and flow forecasting this is often referred to as the difference between the *quality* of the forecast, and the *value* of the forecast (e.g. Zhu et al. 2002). Where (natural) scientists emphasize mainly on the quality, the decision makers are more interested in the value. I.e. their general question is “ Would I take another decision” based on the information provided.

These considerations lead to aims of this :

- To provide quantitative projections including uncertainties for changes in water, agriculture, nature and air quality by means of coupled climate and natural resources models including air pollution.
- To provide scenarios that not only have a sound scientific basis, but that are also valuable for decision making.
- And in this way arrive to best practice to present projections for changes in natural boundary conditions including their uncertainty.

Thus the central research question that will be adressed in this workpackage is:

How to couple climate projections to impact assessment models and how can uncertainty in the impact assessment be incorporated in such a way that it can effectively been used by the adaptation climate community?

1.2 Interdisciplinarity and coherence between the projects

In this workpackage we bring scientists from different environmental sciences (climatology, meteorology, hydrology, agronomy, ecology) together and link them through land use change projections with social and economical scientists.

In broad outlines the role of the different projects is as follows:

- Project 3.1 focuses on the preparation of scenarios for natural resources in different formats. The basis for this is the currently available climate and water projections. These will be produced in the first stage of the project. In a later phase the results are updated using the most recent results from the WP 1 and 2 as well as from the projects WP3.2 to WP 3.6
- Projects 3.2- 3.5 focuses on the coupling of different environmental (water, agriculture, nature) and climate models and the supply of quantitative information required to develop scenarios.
- WP 6 focuses to the evaluation of scenarios in different formats with the climate adaptation community. This work package should result into recommendations on the most suitable format of the scenarios for further use.

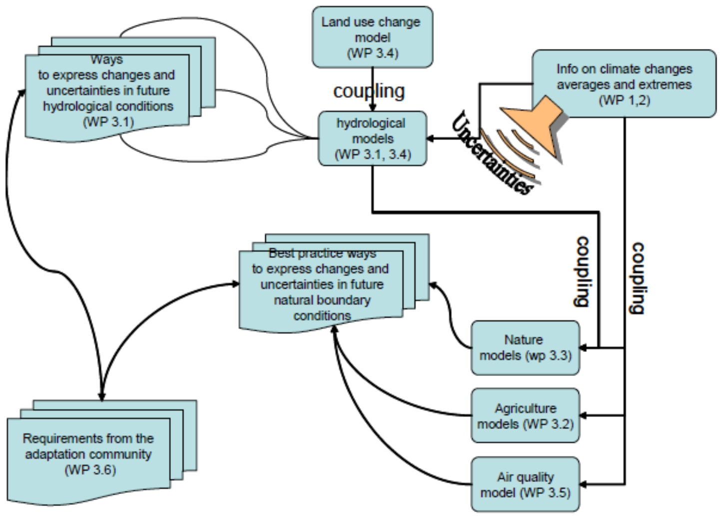

Figure 1 shows the relation between the different projects within this WP3.

As such we will achieve (a) an updated set of climate change and environmental effects scenarios including a more thorough assessment of the associated uncertainties and; (b) include the findings obtained in WP 3.6 on the effectivity of scenarios for adaptation purposes.

1.3 Stakeholders

Apart from providing scenarios for the effects of climate change on water, agriculture, nature and air quality, this project specifically focusses to explore effective ways to provide scenarios for climate change and its effects on natural resources to the community that is responsible to design adaptation measures. We consider the representatives from the KvK Hot Spot projects as well as from the KvK Theme 1 and 2 our main stakeholders

2 Project 3.1 Exploring effective methods to apply information on climate change and its effects for the design of

Project leader: Jaap Kwadijk

2.1 Problem definition, aim and central research questions

Many scenario studies, have been carried out in the last decade. So far four approaches have been applied to generate scenarios for the development of climate adaptation strategies; (1) arbitrary scenarios merely used to assess the sensitivity of environmental systems to a change in climate, (2) expert judgement based scenarios (for the Netherlands, see Konnen, 2001; van de Hurk et al (2006), Vellinga et al, 2009, IVM-VU, 2009). (3) the development of climate scenarios as an ensemble of results from AOGCM-RCM results (IPCC, 1997, 2002, 2007). Where recent approaches focus on including an estimation of their probability (for the UK see UKCIP, 200z, for Germany (http://www.kliwa.de). Approach (1) to (3) can be considered as bottom-up approaches, which is the type commonly applied. Alternatively bottom-up (resilience) based approaches (4) can be used (Dessai and van der Sluis, 2008). These approaches start with an evaluation of the vulnerability of a sector or region to a change in climate. In the Netherlands these were applied with some success in city planning in the Rotterdam City docks (Deltares, 2009; Wardekker et al 2010) and water resources management (Deltares, 2008; Haasnoot et al, 2009). In the UK, also the Thames 2100 project follows this approach (http://www.environmentagency.gov.uk/homeandleisure/floods/104695.aspx)

So far little empirical evidence has been collected which approach can be used most effectively to support the development of adaptation strategies. Different methods have been applied in different studies. However, until recently a comparison between different methods was virtually impossible to carry out due to the lack of sufficient material to develop scenarios in different ways. The production of (1) ensemble series of AOGCM-RCM combinations; (2) the availability of the results of simulations by different environmental models forced with climate model output and (3) the growing experience in dealing with climate change information has changed this picture considerably.

In this project we aim therefore to answer the question which methods of scenario application seems to be most effectively to support the development of climate adaptation strategies in different sectors.

2.2 Approach and methodology

In order to explore the utility of different ways to develop scenarios climate and environmental change for the puropse of climate adaptation strategy design, we follow two phases. Phase 1 in which a rapid assessment is carried out, using currently available information on climate change and its effect on hydrological conditions in the Netherlands.; Phase 2 in which a more complete complete picture is created using the results of other workpackages carried out in this theme and extend the analysis with the findings for nature and agriculture. (1) is done to gain experience with experiments for comparison of the different types of information and to supply the other KvK / Hot Spots themes with the most recently scenario information without delay. We start with water scenarios since these have been developed for application in the water management sector since 2000 and most experience and information is available to generate scenarios in different formats..(2) is done in close cooperation with WP 3.6 to achieve (a) an updated set of climate change and environmental effects scenarios including a more thorough assessment of the associated uncertainties and; (b) include the findings obtained in WP 3.6 on the effectivity of scenarios for adaptation purposes. The finally produced scenarios for the different sectors will be based on the methods that appears most effective.

1. Phase 1
   a. Collect an ensemble of simulations by different GCM-RCM combinations for the Rhine-Meuse and North sea region.. These data are generated by the ENSEMBLES project and can eventually be extended by the results from the earlier ESSENCE project. These data are available through the KNMI/SMHI
   b. Apply these on the Rhine-Meuse-North sea basin modelling system (make use of coupled system developed in KvK 1st tranche KKF-1b) to derive water scenarios.
   c. Generate from the results for climate and water a first set of (a) expert judgement based scenarios comparable with the KNMI 2006 scenarios; (b) a set of ensembles based scenarios including an estimate of their probability; (c) express them for application in a resilience based approach (e.g. using the adaptation tipping point approach (Haasnoot et al, 2009, Kwadijk et al, in press) .
   d. Assess for a selection of the scenarios their effects on agriculture, nature, land cover and air quality using the simulation models described in other projects within this work package. This will be mainly through loosely coupled systems.
   e. Decide together with WP3.6 upon the results the applicability of different approaches effective ways to present the scenario information for adaptation strategies.
   f. Supply information for the web based facility made in WP 4, to store the scenarios for use by third parties.

2. Phase 2:
   a. Collect the climate information from workpackage 1 and 2 from this theme
   b. Derive from WP 3.6 information on how climate information is most effectively used to design climate adaptation strategies where the focus is on the application in practice
   c. Run the coupled hydrological system developed in project WP2-5 with the updated climate scenarios.
   d. Formulate a format for climate and water scenarios based on the findings in WP 3.6 on effective scenarios for adaptation purposes
   e. Carry out the workpackages that link the environmental models to climate input proposed in this workpackage
   f. Generate scenarios for nature and agriculture based according to the principles derived in WP 3.6
   g. Update the web based facility with the most updated information.

2.3 Scientific deliverables and results

- A set of consistent climate and water scenarios based on the currently available information presented in different ways to be evaluated for the use for the development of adaptation strategies
- A set of consistent climate, water, agriculture, nature and air quality scenarios that are evaluated on their use for the development of adaptation strategies.
- We anticipate that both the generation of the environmental scenarios as well as the comparion between scenarios having different formats can be published in form of two or more papers in peer reviewed scientific journals.

2.4 Integration of general research questions with hotspot-specific questions

This project specifically focusses to explore effective ways to provide scenarios for climate change and its effects on natural resources to the community that is responsible to design adaptation measures. We consider the KvK Hot Spot projects as representatives for this.

2.5 Societal deliverables and results

This project will focus on the “value” of scenarios, rather than their “quality”. It is by this approach that we aim to provide scenarios that are better suited to be used for the society to design adaptation strategies upon them.

The results are:

- Guidelines to develop effective climate (effect) scenarios to be used for the design of adaptive measures
- A set of scientifically sound scenarios for climate effects on water, agriculture and nature, using the latest insights in climate change, that provide the decisionmakers valuable information to develop their adaptive design upon.

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3 Project 3.2 Coupling climate data and agronomic models

Project leader: Jan Verhagen, Martin van Ittersum (Wageningen UR PSG)

3.1 Problem definition, aim and central research questions

The vulnerability of agriculture to climate change is related to the impacts of, the preparedness for, and ability to recover from exposures and shocks. The impacts of climate change on crop production have been studied using crop growth models and expert knowledge (Olesen and Bindi, 2002; Ewert et al., 2005). A first step in assessing the vulnerability to climate change at farm level, is to assess how farmers manage current risks. Farmers are adaped to prevailing conditions and gradual changes in temperature and rainfall up to 2050 will most likely not have a large impact (Reidsma et al 2010, Hermans et al 2008), but changes in extreme events (e.g. late frost, heavy rain showers, heat waves) have the potential to alter the future of agriculture (Katz and Brown, 1992, Schaap et al 2009). To increase the preparedness of agriculture to cope with climatic extremes the possible impacts and damages to production and product quality have to be clear. To be able to adapt to these extremes, socio-economic and political conditions should be facilitating.

This research will look at climate risks and address the possible effects of climate change on crop production, product quality and farming systems. Possible adaptation strategies are identified and evaluated in BSIK projects A19, A21 and KvK projects in theme 3.

Central question:

- How can agricultural models be coupled to data and models of climate, land use, hydrology and nature to improve impact assessment of climate change and adaptation strategies in agriculture?

Specific questions

- How to assess and communicate crop damages in relation to extreme events at different scale levels.

- How to model the impact of climate change and variability including shocks on crop production and quality.
- How to link data from agricultural models with land use, hydrology and nature models to improve the assessment of adaptation strategies.

Agriculture is not only dependent on climate, but other, socio-economical, developments are equally, or more, important. Non climate information will be taken into account in the assessments on future developments in agriculture. However, this will not been done in this WP 3.2, but will be addressed in WP 3.4, where a link will be made between climate change, land use changes (driven by socio-economic developments) and hydrological changes. In this WP 3.2 the focus is on the direct effects of climate on agriculture.

3.2 Approach and methodology

This study will primarily look at relevant crops and farming systems in the Netherlands. By using crop simulation models (Donatelli et al., 2002, 2009) and expert knowledge (Schaap et al., 2009) the impacts on production levels, product quality and functioning of farming systems are evaluated. The quantitative projects will have a time horizon of up to 2050, with a special focus on the impacts of extreme events (e.g. late frost, heavy rain showers, heat waves ed.) that may cause crop failure and affect the functioning of farming systems.

Crop simulation: A dynamic model will be used for calculating the biophysical responses of crop production systems in response to weather, soils and agro-management options. The model is able to compute growth rates and yields, both averages and variability across years, as well as the effects on nitrogen leaching, carbon fixation and field water balance. After some initial evaluation one of the following models will be used: APES, LINTUL3, or WOFOST. Although, these models are not designed to assess the impacts of extreme events (e.g. heat waves, waterlogged conditions, heavy rain), these effects could be included using thresholds values.

Expert knowledge: In case experimental data and theory to support the adjustments in crop simulation models are lacking expert knowledge is used to assess the impact of extreme events. Thus expert judgment, both formal and informal, will be used to determine critical threshold values that co-determine crop production and quality levels (Schaap et al 2009). Special attention will be given to the potential for upscaling this knowledge to farm and regional level. This can then be employed in improving the HELP tables currently in use to quantify the relation between water management and farm management in terms of yields and yield reduction (Van Bakel et al. 2005).

Farming systems: Responding to climate change will require the inclusion of the decision making level. In agriculture this is the farming system and the farmer. At this level not only climate change, but also changes in markets and policies have to be taken into account (Hermans et al 2008, Van Ittersum et al 2008). The market and policies may refer to the traditional functions of agriculture but also to the provision of environmental goods and services. This requires a re-evaluation of field and farm management to assess the possible services farming systems can provide (water retention, biodiversity, carbon sequestration, GHG balance) and the potential impacts of agriculture on these services e.g. via leaching and water balance at the landscape level. Agricultural models and expert knowledge must be linked to models and knowledge regarding land use, hydrology and nature to improve impact and assessments of response strategies. In this project we will focus on the delivery of food production and carbon sequestration.

Uncertainty analysis: Information about the uncertainty of results is of importance. Given the complexity of relationships addressed and of the approaches considered various types and sources of uncertainties exist. Uncertainties relate to e.g. underlying model theories and expert knowledge, their implementation and linkage and to input data at different scales. In addition, uncertainty arises due to lack of understanding of relevant physical/economic processes.

Accordingly, a concept will be applied to determine uncertainty for two aims 1. informing users of the results about critical assumptions and parameters and their uncertainties, and 2. providing guidance to the developers in improving the used approaches.

3.3 Scientific deliverables and results

The scientific deliverables are:

- A method and guidelines to couple data and agricultural models to assess impacts of climate change and define appropriate adaptation strategies;
- A method to determine and assess crop damage in relation to extreme events using expert knowledge and agricultural models
- A concept to assess the sensitivity of farming systems to provide environmental services and the impacts of farm management on the provision of environmental services in the multifunctional landscape.

3.4 Integration of general research questions with hotspot-specific questions

The general questions that are addressed in this study:

Hot Spot: Shallow water bodies and the Central Holland peat meadow area.
How can we assess the effects of climate on agriculture, nature and water in the peat meadow area in central Holland. What kind of model coupling is required for this

Hot Spot: Dry rural areas
How can we assess the effects of climate on agriculture, nature and water in the higher sandy areas in the Netherlands. What kind of model coupling is required for this.

3.5 Societal deliverables and results

Climate change will bring more variable weather with changes in frequency and magnitude of extreme events. These extreme events have the potential to destroy entire yields, hamper development of farming systems and the deliverance of environmental services at farm and landscape level. By filling the gap related to the impacts on crop production and quality and the functioning of farming systems this project contributes to the understanding of the potential impacts of extreme events. Moreover by including the impacts on the provisioning of environmental services at the farm and landscape level this study will contribute to a knowledge base for a successful transition to more sustainable and more multifunctional agrarian landscapes.

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4 Project 3.3 Scenario development for nature using ecosystems models

Project leader: dr. Peter van Bodegom and dr. Jana Verboom

4.1 Problem definition, aim and central research questions

Climate change is expected to lead to more extreme rainfall events, increased summer droughts and higher average temperatures. These changes are likely to result in a range of hydrological and soil chemical changes, incl. Changes in nutrient availability and plant productivity which in return will affect flora and fauna. Moreover, climate change might directly affect species distributions due to changes in imposed bioclimatic limits. The quantitative effects of these expected changes on Dutch nature, and in particular on target species (like endangered species) is presently unknown. A key issue for Dutch nature is, therefore, whether climate change will result in irreversible changes in our ecosystems or, in other words, whether our nature is vulnerable to change due to climate change. The aim of this project is to achieve a better insight in the likely ecosystem changes by coupling ecosystems models to climate models such that these coupled models may be applied to a variety of cases.

Central research questions

- What is the impact of climate change on nature in general (and biodiversity in particular)?
- How do uncertainties in climate scenarios affect uncertainties in climate impacts on nature?

4.2 Approach and methodology

Approach

In order to determine whether climate change will impact ecosystems in general and the biodiversity of flora and fauna in particular, we need to consider two issues: 1) Will climate change affect the environmental conditions such that habitat suitability is affected?, and 2) Will climate change negatively affect the connectivity between ecosystems, leading to local extinctions?

Within this project, we will deals with these issues through two sets of complementary methods to assess the impacts of climate change on nature. One set of approaches has been developed by KWR/VU and focuses on the functional responses of vegetation to (changes in) environmental conditions, as affected by climate and nature management. The other set of approaches has been developed by WUR and predominantly focuses on the extent to which species (chosen as representatives of larger groups of species) may experience changes in population viability in correspondence to climate change.

Together, the approaches answer the question of the vulnerability of Dutch nature upon climate change and will yield maps which can be used to determine what ecosystems are under threat and where they are situated within the Netherlands. This includes the opportunities and threats for biodiversity in space and time. If different methods yield similar results, these can be regarded as robust. If differences occur, comparison of the methods can reveal understanding about the relevance of direct vs. indirect mechanisms behind climate change effects as well as indicate uncertainties in climate impacts upon nature.

Methodology:
The approach is to make maximum benefit from projects currently undertaken where links are being made between climate and ecological models (e.g. ENES project (http://www.enes.org/). We will also build upon upon the findings and developments made in earlier studies projects especially the A1 project (hotspots biodiversity) and A2 project (adaptation EHS - National Ecological Network) within the KvR research programme and the KKF-Tailoring project within KvK.

Our methodology consists of three steps:

1. Adapting existing model instruments on Dutch nature to allow direct coupling to output from climate models. In this context, the following conceptual questions need to be answered: what are meaningful ways to couple climate models to nature impact models? What is the impact of climatic extremes and how should those impacts be incorporated into the models, particularly if a sequence of extreme events occurs? And, how can we modify existing modeling tools to be applicable at scales and problems relevant to stakeholders?
2. Developing the subsequent interfaces to initiate models along the chain from climate to impact on nature to allow testing climate scenarios and climate impacts consistently, i.e. 1) focusing on functional and physiological responses and their relative importance in a chain climate-NHI-PROBE and 2) focusing on viability and dispersal limitations in chains climate-NHI-SMART-SUMO-LARCH, climate-NHI-SMART-SUMO-MOVE-DIMO, and climate-NHI-SMART-SUMO-METAPHOR. This allows answering the question which combinations of (changes in) climate variables lead to the biggest responses in nature and to the probability of occurrence of these combinations. Model outcomes will be compared to each other and with field observations.
3. Testing the effects of uncertainties in different climate parameters, both in terms of averages and in terms of extreme values, on assessing climate impacts to nature. By stochastic modeling of climate impacts on nature, the progression of uncertainties will be tested. Given the existing trade-offs between the detail (in temporal, spatial and taxonomic scale) of described impacts and the uncertainties in the descriptions therein, an optimal scale for predictions can be determined.

Cases are all constrained to a limited set of climate scenarios (and combinations with spatial/socioeconomic scenarios) and on one time horizon (2050). Information on impacts will be used by Work package I to construct a basic data set on climate change and its impacts on nature (Figure 1).

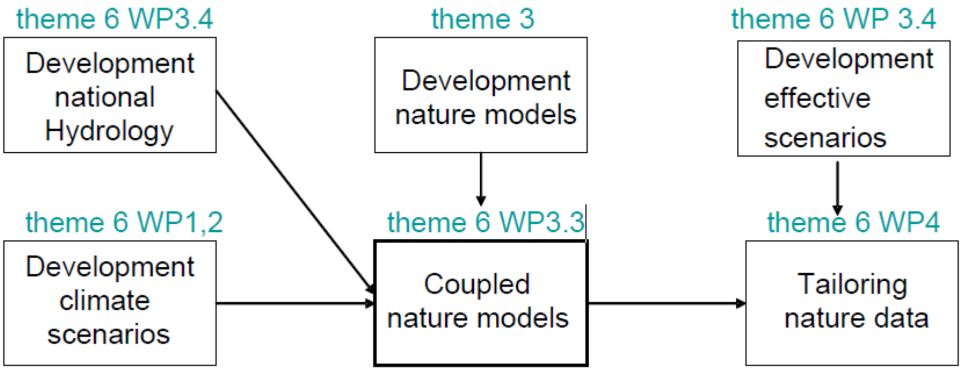

Figure 1: Relations between this work package and other projects within the programme

4.3 Scientific deliverables and results

Current models on climate change impacts on nature are primarily based on correlative relations between climate and the occurrence of particular species. In contrast, by directly coupling the models on flora and fauna occurrences to models on environmental conditions as affected by climate change, the impacts of climate change can be assessed adequately and in a climate-proof fashion. Moreover, by analyzing the complete chain from climate to impact, the importance of carryover effects of changes in climate and environmental conditions to flora and fauna can be assessed. Finally, the coupling proposed in this project allows, for the first time (also internationally), to analyse the effects of uncertainties along abovementioned chain on estimates of occurrences of flora and fauna. The coupling leads to predictions of changes in occurrence of specific flora and fauna groups and will indicate the vulnerability of specific groups of species to climate change within the Netherlands. The predictions will be depicted in regional and national maps of flora and fauna for different climate scenarios, which can be used in concert with maps of e.g. hydrology and land use produced in other projects of this work package to derive a consistent view on climate impacts in the Netherlands.

Moreover, this study will show to which extent temporal and spatial precision can be obtained. The study will also test to which taxonomic or functional level changes in flora and fauna can be predicted. Apart from the scientific merits of such analysis, such information is also essential in relation to questions of various stakeholders; see section D.

The results will cumulate in a joint publication in a peer-reviewed scientific journal by VU, KWR and WUR scientists.

4.4 Integration of general research questions with hotspot-specific questions

Assessment of the vulnerability of our nature has been identified as a key issue by various stakeholders (see e.g. the KKF-tailoring workshop, dated 10-11-’09). Stakeholders have also repeatedly indicated that an important unknown is whether the habitat in the Netherlands will remain suitable for particular flora and fauna groups (also in relation to e.g. the obligations as formulated in the Habitat Directive) and whether the connectivity between ecosystems will remain sufficient. These questions are central to the present project and are therefore of general importance of hotspots that deal with rural areas, in particular the hotspots on dry rural areas, on peatlands and those on the dunes and other coastal vegetation (including salt marshes).

Moreover, by developing generic protocols to couple spatial information on climate and environment to predictions of flora and fauna occurrences, the coupled models can easily be used to run specific cases for different stakeholders. Most of the latter runs will, however, be part of work package 1.

4.5 Societal deliverables and results

There is an urgent need for knowledge about the fate of our nature in the 21st century. Will our ecosystems, as partly protected through e.g. the Habitat Directive, survive? Which ecosystems are endangered and where? What are opportunities for new species, new ecosystems? Will ecosystems be able to reorganize and perhaps shift northwards? Society needs robust, undisputed knowledge about these issues and nature conservation planners andmanagers need tools to base their decisions on and take cost-effective measures for protecting and stimulating biodiversity.

These decisions are partly based on information on climate change. Many existing models that calculate the occurrences of flora and fauna assume that climate is stationary or that responses of nature to climate will remain the same in the future. These assumptions may no longer be valid. By explicitly coupling climate scenarios through changes in environmental conditions on impacts upon nature, this project aims to provide the best information available for decision making instruments and climate change impact models for nature. This information is critical to answer the political and societal questions raised above.

In addition to running the coupled models to produce maps of predicted changes in Dutch ecosystems and its vulnerability, great effort is put in providing the information in a range of formats common to stakeholders work processes and in communication on the data itself and its use. We aim to cover a wide range of fields within the project and invest in generic solutions for interfaces to other fields.

The project will result in a paper in a Dutch journal read by various stakeholders (e.g., Landschap). Results will be disseminated through workshops with stakeholders of KvK.

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5 Project 3.4 Scenario development for water using hydrologic and land use models

Project leader: Scenario development for water using hydrologic and land use models

5.1 Problem definition, aim and central research questions

Climate change will most likely lead to changes in the hydrological system in the Netherlands and the Rhine-Meuse basin due to changes in precipitation and evaporation. In addition socio-economic developments will lead to changes in land use and thus in the local amount of sealed surface and the location of, for example, agricultural and natural areas. These land-use related changes will in turn affect the hydrological system by a.o. changes in groundwater recharge and use and runoff to rivers. Alternatively, changes in the availability and quality of groundwater influence the local potential for spatial development. Also spatial development in flood hazard areas will affect the flood risk in future. A coupling of hydrologic and land use models would allow a more integrated assessment of the feedbacks between climatic and socio-economic changes and could thus assist in a better informed spatial planning.

This project aims to establish a coupling between hydrologic and land-use models to allow a better functioning of the models individually and provide the potential to simulate feedbacks between hydrologic and societal processes. That would us to answer questions such as: will an increase in sealed surface under future climatic conditions lead to a further lowering of the groundwater table of the higher sandy soils in our country (hotspot dry rural areas) and thus worse conditions for nature or agriculture. The coupling will make use of three modelling systems that are standards in their field in the Rhine basin and Netherlands and that are applied extensively in spatial planning issues: The FEWS-GRADE; the NHI hydrologic model and the Land Use Scanner model.

- The FEWS-GRADE system is a modelling system that simulates runoff and river discharge in the Rhine basin. It comprises a hydrological modelling system based on HBV (Bergström, 1976; Lindström et al., 1997, Eberle et al., 2005) and a hydraulic modelling system based on SOBEK (van der Veen, 2007)
- NHI is an integrated hydrological model that uses data on soil conditions and land use to simulate the future state of the water system. Such model simulations take account of anticipated climatic changes, but not future changes in land use. Initial attempts to link future land use patterns with hydrologic models were performed for the Dutch drought study, but experienced a lack of adequate spatial resolution in the land-use data (Dekkers and Koomen, 2007).
- The LUMOS land use scanner simulates future land use based on the demand for space from different economical sectors. On the basis of socio-economic scenarios for the future, the demand for space for every landuse type is generated with help of sectoral models, e.g. The Agricultural Economic Institute (LEI) for agriculture. These demands for space are calculated for each region within the study area. The land use scanner allocates the land use types using these land use claims. For each area the spatial allocation is based on attractivity of the vacant

land. Extensive information on the model can be found in Hilferink, M. and Rietveld, P. (1999). This Land Use Scanner is applied extensively in the Netherlands (Koomen et al., 2008; Loonen and Koomen, 2009; Van der Hoeven et al., 2008) and has a 100 metre resolution that comes closer to the preferred resolution of hydrologic models.

How the NHI system and Land use scanner model can be coupled is one of the results that will be produced in the Knowledge for Climate modelling platform project. In this project WP 3.4 the research questions to be answered are :

1. How can the FEWS-GRADE system and land-use models be coupled such that both the effects of land use changes are taken into account in the runoff production as well as the changes in land use are taken into account in flood safety. ?
2. To which extent does the propagation of errors and uncertainty influence the validity of the simulation outcomes?
3. To what extent is it important for long term decision making in the water sector to incorporate land use change scenarios
4. What are consistent water and land use change scenarios for the Netherlands.

5.2 Approach and methodology

The project is organised in three main tasks, out of which the actual Model coupling (Task 1); Error propagation and uncertainty (Task 2) and Scenario development (Task 3)

1. Task 1 Model coupling land use and hydrological modellling systems.
    a. Specification of input and output characteristics (e.g. spatial, temporal and thematic resolution) of the FEWS-GRADE both models.
    b. Treatment of land-use data to allow incorporation in the land-use model by. This step will involve an analysis of the degree of soil sealing associated with the individual land use types that can be based on the soil sealing data base recently developed by EEA-FTSP.
    c. Technically couple the land use development model to the hydrological modelling systems.

2. Task 2 Error propagation and uncertainty analysis
    a. Qualitative description of the major sources of errors and uncertainties in each model..
    b. Qualitative assessment of the potential feedbacks between the majors sources of errors and uncertainties in each model.
    c. Assessment of the sensitivity of the model to changes in the input data (i.e. climate and land use).
    d. Formulate different formats to prepare scenarios including measures of uncertainties and errors from different sources based on the findings in WP 3.1.

3. Task 3 Scenario development and analysis
    a. Run the coupled system for the current conditons and for different combinations of land use projections and climatic changes
    b. Prepare scenarios in different formats (from task 2d) which includes preparation of infiormation for WP 3.2 and 3.4.
    c. Analyse the scenarios on their applicability for adaptation decision making (together with WP3.6).

Note: This project uses an approach from large scale (global) towards small scale (Regions within The Netherlands. As such this is complematary to the approach followed in Theme 2, WP 2. that aims at an assessment from the very small scale (ditch) to the larger scale (regions within the Netherlands)

5.3 Scientific deliverables and results

A PhD study that comprises a series of papers on the issues: comparison of hydrological response on land use and climate change, a comparison between the sources of uncertainty in hydrological response for water management purposes, a comparison of effectivity of different formats to show hydrological projections for water management purposes.

5.4 Integration of general research questions with hotspot-specific questions

This project aims to assess the future hydrologic conditions in the dry rural areas of the Netherlands. It also will provide boundary conditions for the Hot Spots: Rivers, Dry rural areas, Central Holland peat meadow area as well as for the sectors water safety, and water supply. Information on a further lowering of the groundwater table is crucial to the evaluation of natural and agricultural conditions in this hotspot area. When succesful it will be incorporated into the next generation of the climate change scenarios for the Netherlands. It further contributes to the questions from the Hot Spots, as it aims to find a format of information presentation that is better suits the development of adaptation strategies.

5.5 Societal deliverables and results

A concise report on scenario development for effects of climate change on water of the with special emphasis on Rhine –Meuse delta. The proposed work is of great interest to those working on an integrate assessment of socio-economic and climate-induced hydrologic changes. This makes water managers and, to a lesser extent, spatial planners an obvious target group. The EC-Joint Research Centre (JRC) and Dutch Environmental Assessment Agency (PBL) are very interested in the proposed model coupling as part of their ongoing land-use model development projects. Carlo Lavalle (JRC) and Arno Bouwman (PBL) will therefore act as an advisory group that will be informed about project progress and consulted about potential applications. In addition representatives of the Hotspot case study areas may take part in this advisory group.

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6 Project 3.5 Coupling of climate and air quality models

Project leader: Martijn Schaap (TNO)

6.1 Problem definition, aim and central research questions

Western Europe, most notably the Netherlands, is one of the most densely populated regions of the world and subject to high levels of air pollution. Anthropogenic activities produce a vast amount of atmospheric emissions of pollutants such as particulate matter (EC, OC), nitrogen oxides, ammonia, sulphur dioxide, and volatile organic compounds. In the atmosphere the gaseous constituents also form secondary products, most importantly ozone and particulate matter. The latter are also most harmful for human health as they can cause severe lung diseases, respiratory problems, cancer and immediate death (Ebi and McGregor, 2008). Current air pollution levels indicate a loss of life expectancy of more than a year in the Netherlands (EEA, 2007). In addition, ozone may contribute to crop or vegetation damage in general. Deposition of reduced and oxidized nitrogen as well as oxidised sulphur negatively effect biodiversity, when ecosystem critical loads are exceeded.

Ozone is formed in the lower atmosphere by the oxidation of Volatile Organic Compounds (VOCs) and CO in the presence of NO_x. VOCs are mainly emitted by vegetation and combustion of fuels, whereas NO_x derives mainly from anthropogenic sources. The most important sinks are photochemical breakdown in the presence of water vapor, forming OH radicals, and dry deposition at the surface. Climate change causes an enhanced hydrological cycle, increasing water vapor concentrations in the atmosphere. In remote areas, the photochemical breakdown is the most important factor affected by climate change and the background ozone concentrations will decrease (Jacob and Winner, 2009). Models agree, however, that in polluted areas, the OH radicals formed by the breakdown are regenerated in ozone formation in the presence of NO_x, and therefore, ozone concentrations will increase (Giorgi and Meleux, 2007, Wu et al., 2008, Jacob and Winner, 2009). Furthermore, when temperature increases the biogenic VOC emissions are enhanced (Unger et al., 2006, Wiedinmyer et al., 2006, Jacob and Winner, 2009). Another important aspect of climate change is the increase in stagnant weather conditions and frequency of heat waves in summer. It causes additional build up of ozone in summer periods. In short, peak ozone concentrations are likely to increase in the Netherlands during the summer due to higher temperatures and stagnant weather conditions. The extend is highly uncertain, but recent studies showed that during summertime the mean summer ozone concentration may increase in the range of 1-10 ppb in polluted regions at northern mid-latitudes, including Europe (Wu et al., 2008, Jacob and Winner, 2009).

To date, little is known about the effects of climate change on the concentrations of particulate matter. There are no dedicated modeling studies for Europe documented in literature, yet. Available studies reviewed by Jacob and Winner (2009) do not provide a consistent result, including the sign of the effect. Hence, a dedicated study to assess the first order impact of the predicted climate change on PM in the Europe and the Netherlands is necessary.

We aim to assess the first order impact of the predicted climate change on PM and ozone in the Netherlands.

Central research questions are:

- What is the effect of climate change on PM and ozone levels in the Netherlands?
- What are the main meteorological drivers for the predicted air pollution change?
- How large is the uncertainty in the predicted air quality change?
- Does the air pollution change due to climate change counteract the change due to envisaged mitigation of emissions?

Note that, through the greenhouse gas ozone and through aerosol interactions with radiation and clouds, air pollutants also play a crucial role in the climate system itself. This feedback is currently not considered in this project, though RACMO-LE can be run in a coupled mode.

6.2 Approach and methodology

To investigate the impact of climate change on air quality (in one way) one needs to perform the following steps:

1. Generate a RCM-CTM interface such that the CTM can be driven with meteorology from the RCM.
2. Verify the results of the air quality model driven by a hindcast simulation of the RCM (verification paired in time) with special attention to the derivative to meteorology and emissions.
3. Determine the impact of the bias in the meteorology of the free running RCM on the modelled air quality (verification of air quality PDFs).
4. Perform a number of well defined scenario simulations (current and future) to investigate the impact of climate change on air quality.
5. Perform simulations that account for future developments in important input parameters other then meteorology such as land use and emissions.
6. Evaluate the scenario results to quantify the change with respect to presently observed air quality.

In the Netherlands the CTM LOTOS-EUROS is the community model for air quality. Within the model many processes are dependent on meteorological variables such as vertical mixing, transport, biogenic and other natural emissions, dry deposition, etc. Within BSIK-CS4 a dataflow has been tested and evaluated that enables LOTOSEUROS to be driven by meteorology from the regional climate model RACMO. The air quality results were evaluated against observations and found to be in line with the results using other meteorological sources. The evaluation of the RACMO-LOTOS-EUROS Coupling in climate mode is funded through the first tranche of KvK. Hence, steps 1 and 2 have been performed and step 3 is ongoing. Within this project we propose to perform step 4 to obtain estimates of the air pollution increment due to the change in meteorology due climate change focused on PM, Ozone and nutrient deposition. Furthermore, a first sensitivity study regarding emissions is proposed that would be part of step 5 and 6.

We will perform two pairs of simulations to address the climate change impact on air quality. To span up the uncertainty we will use 2 different GCM's with a considerably different "climate" over Europe to force the boundaries of RACMO. At this moment we envisage ECHAM 5 and Myroc for this purpose as these models have been used for the KNMI'06 climate scenarios. These will be downscaled for a 30 year period in the present and the future. Air pollution emissions will be kept constant to determine the effect of changing meteorology. The emissions are kept constant to be able to provide a stepwise interpretation of the obtained results with a focus on the impact of the meteorological data used. We will perform an analysis of the calculated changes with a focus on the variability in the synoptic situations, which we feel is most important for AQ. We like to stress that it is not the intention to quantify the air pollution in 2050 as that requires accounting for changes in e.g. meteorology, land use, and emissions. The developed framework may be used for such a purpose. However, a future air pollution emission scenario with simple emission reductions will be ran for part of the 30 years in both the past and the present to get a first assessment if the effectiveness of mitigation strategies may change significantly.

6.3 Scientific deliverables and results

- Two thirty year data sets on air quality for present and future climate.
- Quantification of the potential impact of climate change on air quality.
- Peer reviewed publication on the climate effect on air quality in the Netherlands
- Scientific report
- A basis against which future fully coupled simulations can be compared and a basis for performing actual emission scenarios to assess responses in a future climate.

6.4 Integration of general research questions with hotspot-specific questions

The study provides insight in the potential impact of climate change on air quality in the densely populated regions in the Netherlands, such as Roterdam and Haaglanden. The results will be made available in the form of average maps or other statistics to Theme 4. For particulate matter as well as ozone climate change may prove to counteract the downward pollution trends due to mitigation strategies and may force to set higher mitigation targets to reach environmental goals. As such the obtained results can be translated for use in the assessment of the “distance to target”. In case climate change counteracts mitigation strategies additional measures need to be taken to arrive at a given air quality target. The results are therefore very relevant for policy makers.

6.5 Societal deliverables and results

The project will deliver new insights in air pollution and the effect of climate change and meteorology on air pollution in the Netherlands. These are of large societal relevance as air pollution reduces life expectancy and has a negative impact on crop yields and biodiversity.

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7 Project 3.6 Dealing with uncertainty in adaptation application

Project leader: Dr. Rob Swart

7.1 Problem definition, aim and central research questions

This project focuses on the final goal of the overall work package, i.e. “to investigate how the understanding of uncertainties can be used in the development of robust adaptation options and decision making”. The information supplied by scientists should match the demands of policy makers. Climate change adaptation aims at reducing the vulnerability of social and natural systems to impacts of climate change. To base adaptation policies on the best scientific and technical knowledge, it is important to understand both the potential climate impacts, and the capacity of social and natural systems to adapt. Both are characterized by large uncertainties at different geographical scales that range from local to global.

The aim of this project is to (a) assess the main uncertainties that accumulate through the climate change system (coordinated with projects 2.1 and 3.1), (b) to analyze how adaptation policy makers respond to these uncertainties and (c) to develop practical methods to evaluate the robustness of adaptation strategies. In the project, “robustness” will be defined broadly, across a range of socio-economic and climate change scenarios, and taking into account objectives other than avoiding impacts, such as costs and flexibility. The project focuses on water management in river basins, because (a) the special interest expressed for this theme by the Large Rivers hotspots, (b) the vulnerability of several other hotspots and other areas is dependent on river run-off, (c) this choice allows for addressing the important differences between geographic and administrative scales and (d) it allows for inclusion of quantitative information for both climate and (hydrological) impacts. Methodological differences between themes will be explored by adding the analysis of the match between supply and demand of scientific information for a different theme. The main research questions are:

- How does the propagation of uncertainties from global climate models to local impact analysis and the (deterministic or probabilistic) presentation of resulting results affect the usefulness of the information in supporting the evaluation of adaptation strategies,?
- How do uncertainties influence the formulation of adaptation strategies and which gaps can be identified between the supply and demand of scientific knowledge with respect to climate change uncertainties?
- How can the insights derived from the above questions help to improve the evaluation of the robustness of adaptation strategies? What can be learned from other countries?

Because the useable output from scientific analysis for adaptation applications depends on the specific adaptation theme, the above questions can only be meaningfully be addressed through selected case studies.

7.2 Approach and methodology

The project will reach the objectives in three steps (see framework in Figure 1). To focus the analysis and enhance the relevance of the research for society, two main case study areas at different levels will be selected in The Netherlands (e.g., Major Rivers and Rotterdam). To place these in a broader context and learn from methods and practices elsewhere, two case studies in other industrialized countries which face comparable risks, but have different decision-making structures and apply different methodological approaches will be added. The international case studies are the United Kingdom (Thames) and the United States (KvK hotspot California), countries that have already paid attention to the development of robust adaptation options. To explore differences between sectors and ensure that project findings are also useful beyond the water management sector, one case study in another thematic area will be included (e.g., Schiphol).

Step 1: Uncertainty assessment

In step 1, the uncertainties relevant for adaptation planning will be analysed and coordinated with projects 2.1 and 3.1. The emphasis is on uncertainties in the climate and hydrological systems (right-hand side in the Figure) and how they affect the climate resilience of the water management system. Research in this step is conducted by scientific literature review, assessment of available modeling data, expert judgment and, if relevant and feasible in the context of collaboration with partners (notably produced by projects 2.1, 3.1 and 3.4), based on calculations for the Dutch case, applying models for the hydrology of the Rhine basin and the Netherlands water management system. In this step it will first be analyzed how information on climate change and river discharge e.g., from KNMI, ENSEMBLES-Deltares) has been and is being used to sysement systemtematically assess the accumulation of uncertainties through the causal chain.

Questions include: which choices and assumptions are made regarding uncertainties in each step of climate modeling, from emission scenario to local impact? What is the effect of each uncertainty on the climate impact projections? Which uncertainties influence which policy- relevant indicators?

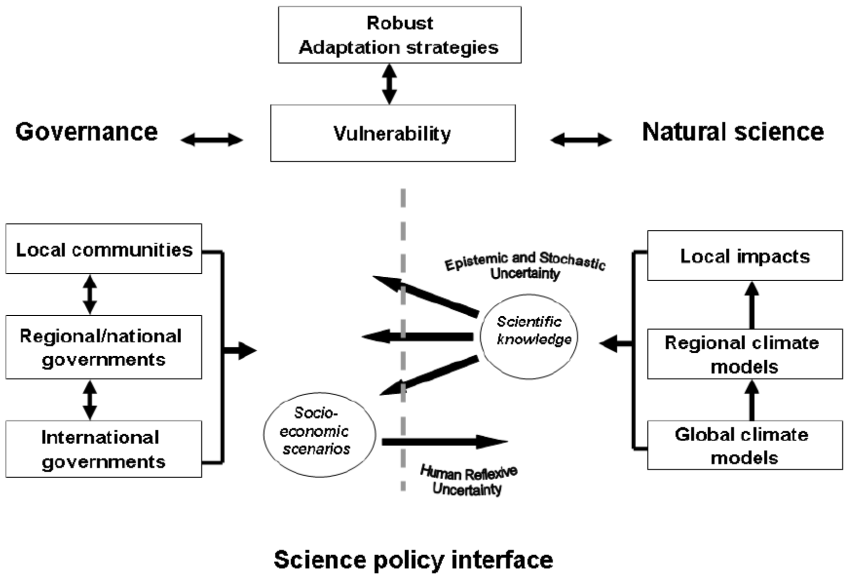

Figure 1: Framework for analyzing uncertainties and developing methods to evaluate robust adaptation strategies

Step 2: Supply-demand side assessment

In step 2, the "supply" of information about climate change impacts is confronted with the "demand" for scientific information of policymakers at different scales (left-hand side in Figure 1). The information required for this confrontation will primarily be collected through review of policy documents and interviews with stakeholders. Step 2 will start during the final stages of step 1. First, the "supply" will be explored: which different types of uncertainty assessment methods and frameworks for decision making under uncertainty are used, taking into account different spatial and temporal scales? This includes the dominant top-down "predict-than-act" approach and the novel bottom-up "assess-risk-of-policy" approach. Next, this information will be used to evaluate the saliency, credibility and legitimacy of the information and to analyse the associated adaptation policy development: how effective is the management and communication of uncertainty [1]?

1 To assess the effectiveness of scientific information about climate change uncertainties, many possible criteria could be used. In this project, three criteria will be applied: saliency, legitimacy and credibility (Cash et al., 2003). *Saliency* deals with the relevance of the information to the needs of decision makers, in our case on climate change uncertainties. Is there a good match between the available information and the demand of decision makers? Does the information provided help decision-makers to develop better strategies? Is the information comprehensible to the user? providers? *Legitimacy* reflects the perception that the production of information and technology has been respectful of stakeholders values and beliefs and is fair in its treatment of opposing views. *Credibility* involves the scientific adequacy of thetechnical evidence and arguments. What is the scientific status of the knowledge providers? *Legitimacy*reflects the perception that the production of information and technology has been respectful of stakeholders values and beliefs and is fair in its treatment of opposing views.

In this step, three questions will be addressed: which information about uncertainties is used (e.g., scenarios)? How is the information interpreted by the users? and How is the information used to develop adaptation (robust?) strategies? In this step, a non-water thematic case (e.g., Schiphol Airport) will be included next to the water-related cases. Collaboration with the theme 7 ("governance") project " Science-policy arrangements at regional scale: how to warrant scientific requests and social robustness?" has been agreed.

Step 3: Robust adaptation - Evaluation

Finally, the results of step 1 and 2 will be used to develop or improve method(s) to evaluate the robustness of an adaptation strategy or for new methodologies. The following questions will be addressed: what are the boundary conditions for the use of these methods? For which cases are they suitable and in which cases are they less suitable? How can the effectiveness of scientific information regarding climate change uncertainties be increased in terms of saliency, credibility, and legitimacy? What capacity does this require from both scientists/technical advisors and policy- and decision-makers?

7.3 Scientific deliverables and results

Output step 1: One or more papers elaborating methods and practices that are used for the analysis and communication of uncertainties in the case study areas. The possibilities of joint publications with projects 2.1 and 3.1 will be explored.

Output step 2: A paper on the use of scientific information on uncertainties supporting climate change adaptation decision-making, with special attention to the choices that are made regarding the analysis and presentation of uncertainties. A second paper could address the differences between the different case study areas, particularly between the Dutch and international case study areas (e.g., the UK, where probabilistic projections are provided). The possibilities of joint publications with theme 7 "governance" will be explored.

Output step 3: Practical methods that enable a decision maker or policy advisor to develop strategies that are robust and have a minimal sensitivity towards uncertainties. One or two scientific paper will be written about these methods.

Final result: A PhD dissertation capturing the results of the three steps based on the papers will be the overall scientific outcome of the project.

7.4 Integration of general research questions with hotspot-specific questions

Theme 6 in general and the results of this project in particular are expected to be relevant across most if not all hotspots, but more specifically for Large Rivers and other hotspots in which river runoff plays a major role, such as Southwest Delta and Rotterdam, as well as Schiphol. While the uncertainties surrounding climate change and impact projections are huge, hotspot teams with their emphasis on practical strategies to climate change adaptation have not spent much attention to them yet. Nevertheless, it is the responsibility of the scientists to include information that adequately reflects the prevailing uncertainties, and is useful for and can be understood by the hotspot teams. From their perspective, it is important to prevent maladaptation, and hence to develop strategies that are robust across a wide range of possible climate and socio-economic scenarios.

7.5 Societal deliverables and results

The project's main societal aim is to provide methods to evaluate the robustness of adaptation options to improve the quality of the decision-making process. However, since the final project's results are expected to become available only towards the end of the project in the dissertation, and management and communication of uncertainties are also relevant for the development of strategies in the various hotspots, during the course of the project opportunities will be generated to provide input to the more hotspot-oriented thematic projects in the themes 1-5. Senior staff at WUR, Deltares and KNMI will take on this role to the extent resources allow. In the final stages of the project, results will also be disseminated through the KvK Knowledge Transfer function and other means available at that time.

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