

climate changes changes spatial planning

Integration

Land use and climate change

E. Koomen

H. de Moel

E.G. Steingröver

S.A.M. van Rooij

M. van Eupen

KvR 062/12

Land use and climate change

Authors

dr. E. Koomen [1]
H. de Moel [2]
dr. E.G. Steingröver [3]
drs. S.A.M. van Rooij [3]
Ir. M. van Eupen [3]

1 Department of Spatial Economics, VU University Amsterdam
2 Institute for Environmental Studies, VU University Amsterdam
3 Alterra, Wageningen UR

KvR report number KvR 062/12
ISBN ISBN/EAN 978-90-8815-053-1

This project (IC3; LANDS: Land use and climate change) was carried out in the framework of the Dutch National Research Programme Climate *changes* Spatial Planning. This research programme is co-financed by the Ministry of Infrastructure and the Environment.

Contents

Summary in Dutch

Klimaat en landgebruik zijn sterk aan elkaar gerelateerd. Landgebruik beïnvloedt het klimaat, bijvoorbeeld doordat vegetatie kooldioxide opneemt, landbouw stikstof vastlegt en industrie diverse broeikasgassen uitstoot. Omgekeerd betekent een veranderend klimaat dat aanpassingen nodig kunnen zijn in bijvoorbeeld: landbouw (overstap op andere gewassen), natuur (veranderingen binnen ecosystemen), de kustzone (door zeespiegelrijzing) en het rivierengebied (meer ruimte voor water). Deze en andere adaptatie- en mitigatie-maatregelen staan centraal in diverse andere projecten van het 'Klimaat voor Ruimte' programma.

Centraal in het LANDS project staan de effecten van klimaatverandering op de inrichting en het gebruik van de ruimte. Het gaat hierbij om vragen als:

- welke mogelijke veranderingen in het Nederlandse landgebruik kunnen we de komende decennia verwachten als gevolg van veranderingen in het klimaat?
- welke adaptatie- en mitigatiemaatregelen zijn denkbaar om op deze veranderingen in te spelen?
- zijn er conflicten tussen de verschillende sectoren te verwachten of ontstaan er kansen voor samenwerking als gevolg van de veranderingen in het landgebruik?

Dit project integreert de ruimtelijke adaptatie- en mitigatie- maatregelen uit diverse andere projecten binnen het 'Klimaat voor Ruimte' programma. Het gaat daarbij om onderzoeken die gericht zijn op specifieke sectoren en gebieden, zoals: landbouw, natuur, rivierengebied en kustzone.

Om de kennis uit de verschillende projecten te integreren en daarmee bovengenoemde onderzoeksvragen te beantwoorden is gewerkt aan de volgende onderwerpen:

- een scenarioraamwerk dat op consistente wijze aannamen betreffende klimaat, bevolking, economie en maatschappij beschrijft als basis voor de diverse adaptatie- en mitigatiestudies;
- een gedetailleerd, gekalibreerd en gevalideerd landgebruiksmodel dat in staat is geïntegreerde simulaties te maken van toekomstig ruimtegebruik;
- een set indicatoren en visualisatietoepassingen behulpzaam bij het opsporen van kansen en conflicten in (combinaties van) landgebruik;
- een onderzoek naar relaties tussen landgebruik, klimaatverandering en waterbeheer, met specifieke aandacht voor overstromingsrisico en gerelateerde adaptatiemaatregelen;
- een beoordeling van potentiële klimaatgerelateerde effecten op huidige natuurnetwerken,en het ontwikkelen van nieuwe strategieën om aan deze veranderde condities aan te passen.

Summary

Climatic changes are expected to have important implications for land-use patterns, especially in coastal areas and river basins. In the Netherlands, the research program 'Climate changes spatial planning' aims to develop an adequate and timely set of policies for mitigation and adaptation to cope with the impacts of climate change. This is done in a series of related research projects dealing with, for example, climate scenarios, water management and adaptations in agriculture, nature and inland navigation. Within the research program the LANDS project identifies climate-change driven land-use developments and integrates these into balanced national visions and regional solutions. The LANDS project produced the following components to integrate the results from the other projects in the research program:

- a scenario framework, that consistently combines assumptions related to climate, population, economy and society, forms the common ground for the various adaptation and mitigation measures;
- a detailed, calibrated land-use model that integrates the sector-specific adaptation measures into simulations of future land use;
- a set of indicators and visualisation applications that supports pinpointing the possible synergies and conflicts in (combinations) of land use;
- an investigation of the interface of land use, climate change and water management, with a focus on effects of land use and climate change on flooding and possible adaptation;
- an assessment of potential climate-related impacts on current nature networks and the development of new strategies to adapt to these changed conditions.

1. Introduction

It is widely believed that climate change and increased climatic variability will impact land use through affecting different economic sectors such as agriculture, housing, nature and ecosystems, and by changing the water resources system (Commissie Waterbeheer 21e eeuw, 2000; IPCC, 2001; Verbeek, 2003). Climate change directly affects, for example, local agricultural and hydrological conditions and consequently influences the economic development potential. Climate change thus modifies the demand for land and its supply, as well as the suitability of space for certain uses (Beinat and Nijkamp, 1997). These processes can be assessed through land-use simulation models that integrate sector-specific demands (for housing, agriculture, etc.) and land suitability for certain uses and provide an indication of the likely use at a specific location in the future under different climate conditions.

Climate change modifies the mechanisms of the demand-supply interplay as well as the boundary conditions and scenarios within which it unfolds. The main processes through which climate change and socio-economic developments may affect the interaction between the demand and supply of land are:

- the physical modification of the suitability of certain areas for some uses of the land;
- the modification of productivity and production processes within sectors such as agriculture, forestry, and nature;
- changes to the primary functioning of economy and society leading to a different set of policies that influence for instance economic development (growth) or the type of development (e.g. free market versus government);
- the extra demand for space as a result of adaptation strategies within various sectors.

In order to accommodate these impacts, pro-active adaptation measures within the area of spatial planning are prerequisite to cope with climate change and will offer new opportunities for rearranging land use (Parry, 2000a; Parry, 2000b). However, such rearrangements will pose challenges and conflicts between the national and regional policy levels, and between sectors. For instance, when problems concerning water storage and flooding are tackled with spatial rather than technical measures, the capital-intensive agricultural or urban functions of these buffering areas will be highly restricted (Borsboom-van Beurden et al., 2005).

Obviously, climate change is not the only factor driving land-use change. Socio-economic developments are another major driving force. In fact, these developments interact with climatic changes (Dale, 1997; Watson et al., 2000). For example, economic and population growth cause increased emission of greenhouse gasses, which influence the global climate. As a result, changes in annual regional rainfall patterns could impact agricultural production or cause the tourist industry to migrate to other regions. Integration of climate-change and socio-economic factors is, in our opinion, thus needed in any long-term study on future land-use configurations and related spatial planning measures.

This report presents an overview of the results of the LANDS project that aims to integrate climate-change induced adaptation and mitigation measures with anticipated socio-economic changes in the Netherlands. This project is part of the Dutch research programme Climate changes Spatial Planning that aims to develop an adequate and timely set of policies for mitigation and adaptation to cope with the impacts of climate change.

1.1 Objectives

Central to the LANDS project is the spatial dimension of climate change. It aims to provide an integrated outlook on a climate-proof future for the Netherlands and involves research questions such as:

- which changes in land use may be expected in the Netherlands over the next few decades as a consequence of climate change?;
- which adaptation and mitigation measures could prepare us for these changes?;
- do the ways different sectors respond to the changes in the climate provoke conflict or open up opportunities?

To answer these questions the LANDS project integrates the results and advancements from a large number of research projects and practice-oriented case studies. More specifically the project consists of the following elements:

- a scenario framework that describes assumptions about the climate, population, economy and society in a consistent manner as a basis for the various adaptation and - to a lesser extent - mitigation studies;
- a detailed, calibrated and validated land use model capable of making integrated simulations of future land use;
- a set of indicators and visualisation tools useful in tracing opportunities and conflicts in (combinations of) land use developments;
- an investigation of the interface of land use, climate change and water management, with a focus on effects of land use and climate change on flooding and possible adaptation;
- an assessment of potential climate-related impacts on current nature networks and the development of new strategies to adapt to these changed conditions.

1.2 Approach

The LANDS project, integrates results from many other projects in the *Climate changes Spatial Planning* research programme. It makes use of the scenarios developed by KNMI and feeds into the projects that analyse and propose possible adaptation and mitigation measures for different societal sectors and geographic regions in the Netherland. The results of these projects are also used to feed into the LANDS project. As the focus of LANDS project is on spatially explicit measures we tend to concentrate on adaptation, rather than mitigation related projects. The layout of the project and its relation with other projects is depicted in Figure 1.1.

The figure shows that the project starts with the development of integrated climate and socio-economic scenarios. These LANDS scenarios incorporate existing climate scenarios provided by KNMI (Van den Hurk et al., 2006) and socio-economic scenarios documented in the 'Prosperity, Well being and Quality of life' study (CPB et al., 2006).

The scenarios are used in the Land Use Scanner model to simulate future land-use patterns. This GIS-based model integrates sector-specific inputs (e.g. regional demand for residential land) from other, dedicated models. It is based on a demand-supply interaction for land, with sectors competing within suitability and policy constraints. Much research effort in the project focussed on the development, calibration and validation of a more detailed model version capable of addressing climate adaptation issues at the regional level. The resulting land-use simulations provide the starting point for different sector and region specific studies. The possible impact of expected climatic and socio-economic changes on water management issues and nature conservation objectives is studied as part of the LANDS project, as well as in several other climate-related projects focussing on flood risk, adaptation measures in the Rhine basin and the spatial distribution of vegetation. Other, subsidiary projects dealing with possible climate-adaptation measures for, amongst others, agriculture (biofuel crops), fen meadows and other regions (province of Groningen, Zuidplaspolder, Veenkoloniën region) to some extent also use the scenario assumptions and simulated land-use patterns as a reference point for their analyses.

In several cases, the adaptation strategies and other results from the sector and region specific are fed into the *Land Use Scanner* to simulate adjusted land-use patterns that take the possible impact of climate change into account. To quantify the differences between the different simulations, indicators are developed that characterise the outcomes at the local, regional and national level. Specific attention will be paid to evaluation measures that identify potential conflicts or synergies between different land-use types.

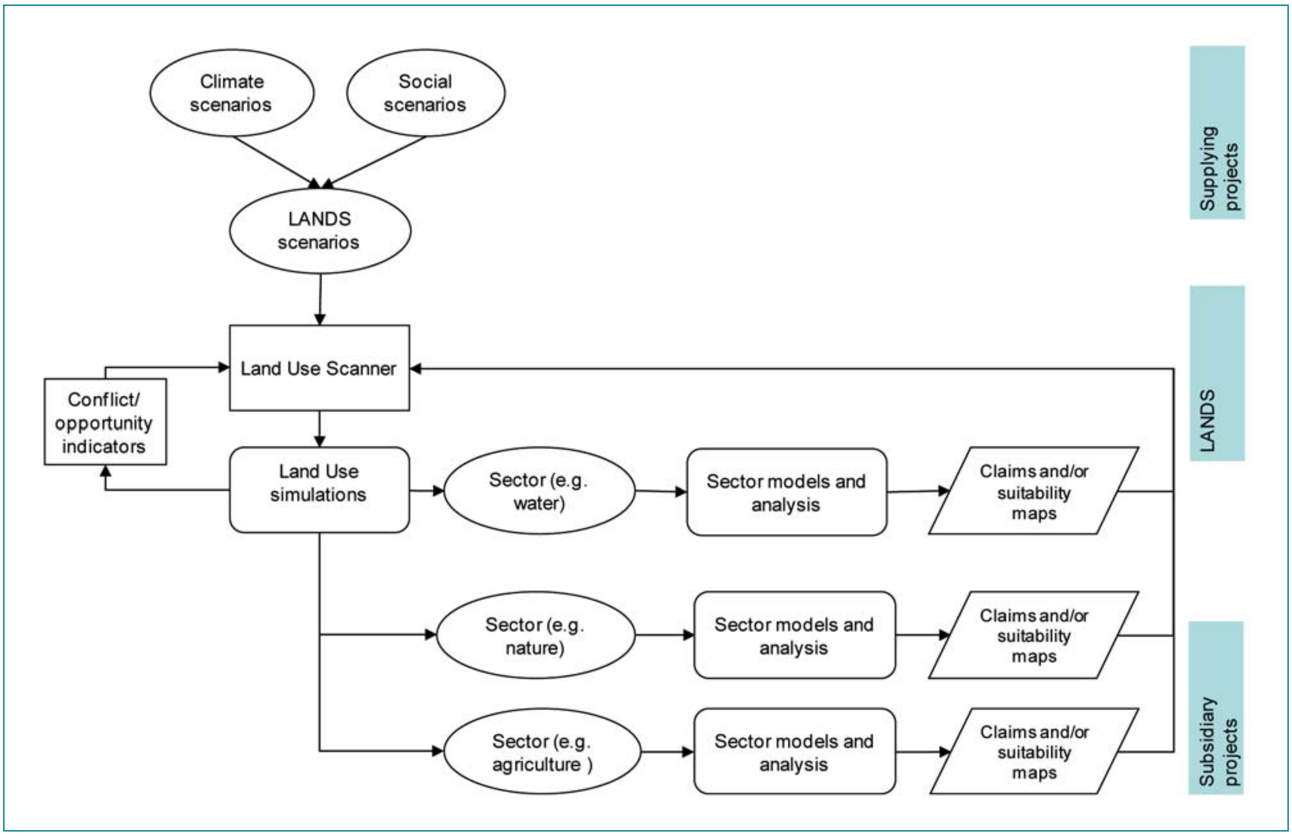

Figure 1.1.
The LANDS framework (source: Koomen et al., 2008).

1.3 Report layout

The main results of the project are highlighted in the following chapters:

- the scenario framework, land-use model development, calibration issues and simulation results are discussed in Chapter 2;
- indicator development and the potential use of visualization tools is the topic of Chapter 3;
- climate-related water management issues and adaptation strategies are presented in Chapter 4;
- climate-related nature conservation issues and adaptation strategies are summarised in Chapter 5;
- the integration of spatially-explicit climate adaptation strategies from other project in the LANDS-framework is addressed in Chapter 6;
- by way of conclusion Chapter 7 discusses the merits of the LANDS project and future plans.

2. Developing scenario-based projections of future land use

2.1 Drafting a scenario framework

Land-use planning is by definition concerned with the future and thus has to deal with uncertainty about future developments in climate, society, demography, economy and technology. A much favoured approach to deal with the uncertainties relating to future spatial developments is the use of scenarios. The aim of the scenario method is to gain strategic insight by means of enlarging knowledge over the future (De Waard, 2005). By describing a set of opposing views on the future as is common in the IPCC reports, we can simulate a broad range of spatial developments, thus offering a full overview on possible land-use alterations. A first step in the LANDS project consisted of the development of a consistent set of future scenarios that could serve as the basis for the development of adaptation and - to a lesser extent - mitigation strategies. These scenarios should describe climatic and socio-economic developments in sufficient detail and represent the most recent insights in these domains. It was, therefore, decided to combine, the two major and authoritative Dutch scenario studies that were published just before the LANDS project started: a socio-economic scenario study performed by three Dutch planning institutes (CPB et al., 2006) and an updated set of climate scenarios by the Netherland Royal Meteorological Institute (Van den Hurk et al., 2006).

To provide a workable set of scenarios it was decided to select only a limited number of scenarios. To simply couple all four available socio-economic scenarios to the four climate scenarios would result in sixteen different combinations. This was an overflow of information for the various adaptation and mitigation projects and, furthermore, contained the risk that each project would select its own specific combination to start from. The latter would imply that the proposed adaptation or mitigation measures cannot be readily integrated into a coherent set of spatial strategies as they all start from different assumptions regarding climate and society. Therefore it was decided to reduce the set of socio-economic scenarios to the two scenarios that describe the broadest range of possible futures. To further reduce the set of scenarios, climate and socio economic scenarios were linked in a logical way.

Based on their common roots in the SRES storylines, the Global Economy (GE) scenario was associated with the SRES A1 scenario family, as were the high temperature rise (W or W+) climate change scenarios. Regional Communities (RC) was related to the SRES B2 family as can be done with the lower rise in temperature (G or G+). The table below summarises the resulting set of scenarios. The advantage of selecting the extremes on both sides of the bandwidth in terms of socio-economic developments is that the full extent of possible changes in land use is preserved, while at the same time the full variability in climate scenarios is preserved.

Table 2.1.
Suggested combination of socio-economic and climatic scenarios in LANDS.

	Regional Communities	Global Economy
Circulation change	Moderate temperature rise (G+)	Strong temperature increase (W+)
No circulation change	Moderate temperature rise (G)	Strong temperature increase (W)

Source: Riedijk et al. (2007).

The proposed combination links the strong economic growth of the Global Economy scenario with the larger climatic changes. This is expected to cause tension between the increased demand in land for various types of urban use (residential, commercial), while at same time providing ample space for coping with the increases in precipitation, river discharge and sea level. How will the government and the market respond to that? In the light of debates around 'shrinking cities' the Regional Communities scenario is highly interesting because another kind of tension related to adaptive measures is expected here: is a shrinking population able to finance the needed adaptation measures? The regional differences in growth in the RC scenario are large; therefore the competition between different regions will be large. Will the transition zone become a competitor of the Randstad, since there is likely to be less inundation risk?

2.2 Developing a revised land-use model

To translate assumptions about future developments into spatial patterns the Land Use Scanner land-use model is used. In order to be able to better address regional adaptation issues a more detailed version of this model was developed in close cooperation with PBL Netherlands Environmental Assessment Agency. This revised model version describes land use with a regular grid of 100x100 metre cells. This resolution comes close to the size of actual building blocks and allows for the use of discrete (homogenous) cells that only describe the dominant land use. The previous version of the model had a 500-metre resolution with heterogeneous cells, providing a continuous description of the fractions of all present land-use types in a cell. The new model and recent applications have been documented extensively in a large number of applied, technical and scientific papers (Koomen et al., 2008; Koomen and Borsboom-van Beurden, 2011; Koomen and Van der Hoeven, 2008; Koomen et al., 2011; Van der Hoeven and Koomen, 2007; Van der Hoeven and Koomen, 2008)

2.3 Calibrating and validating the model

To better understand the possibilities and limitations of the new version of the Land Use Scanner, an extensive calibration and validation analysis was performed in cooperation with PBL Netherlands Environmental Assessment Agency. The main objectives of this analysis were 1) to assess the potential of the new fine resolution in producing sensible land-use patterns, and 2) to compare the performance of the two available allocation algorithms. The sensibility of the simulated land-use patterns is expressed as the degree to which these correspond to the observed land-use patterns. The relative performance of the individual algorithms can be assessed by comparing the degree to which the respective simulation outcomes correspond to the observed land-use patterns (see figure below).

This validation exercise indicated that both model versions provide sensible spatial patterns. In fact, the two different modelling approaches produce very comparable results, given equal starting points. The degree of correspondence (based on a cell-by-cell comparison of simulated and observed land use) of the two approaches typically differs only a few per cent for the most common land-use types. In general, we conclude that the model is well-suited to simulate possible future spatial patterns in the scenario or policy-optimisation studies it is typically applied in. The validation also made clear that the inclusion of more detailed and more specific explanatory variables (related to, for example, spatial planning and accessibility) and a focus on the explanation of recent land-use changes may help to improve the performance of the model in this respect. Following up on these results the importance of accessibility in explaining land-use patterns was analysed in cooperation with the Federico II University of Naples (Borzacchiello et al., 2010). Based on this validation research we were also able to contribute to an international land-use modelling comparison effort (Pontius Jr. et al., 2012).

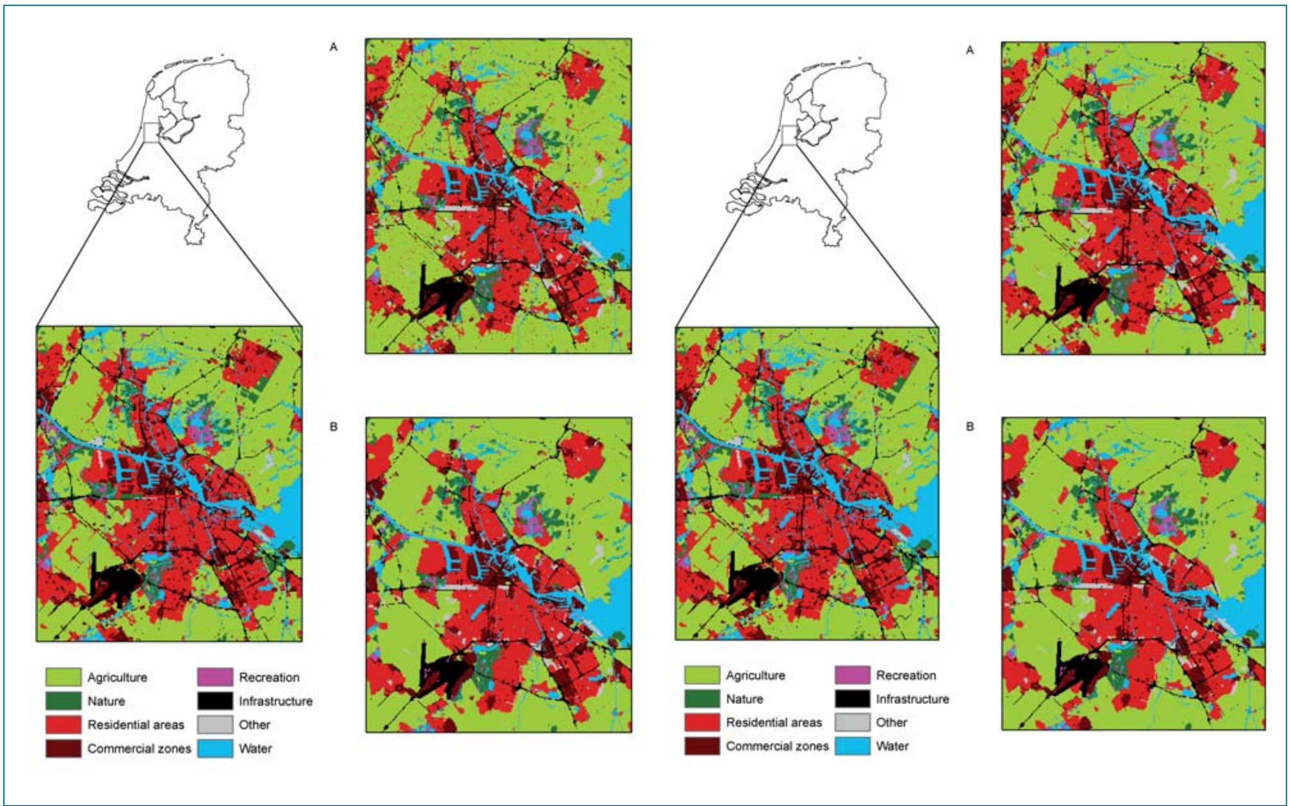

Figure 2.1.
Validating the discrete (left) and continuous (right) version of Land Use Scanner. For each of these model versions simulated 2000 land use according to different specifications of local land use suitability (denoted A and B) are compared with observed 2000 land use (below image of the Netherlands) (source: Loonen and Koomen, 2009).

2.4 Simulating future land use

The revised Land Use Scanner model was used to simulate future land-use patterns according to the scenario framework described above. Figure 2.2 shows the results of these simulations, where we aggregated the initial 17 types of land use to nine major categories. The maps indicate that urban pressure, due to projected differences in population size and prosperity, varies greatly between the two scenarios. The future patterns of nature and forest are similar because they follow from the same policies related to nature conservation and plans for the development of new natural areas. A more extensive discussion on applied model settings and results is provided elsewhere (Koomen et al., 2008; Riedijk et al., 2007). These land-use simulations were input for the development of sector and region-specific climate adaptation measures as will be discussed in Chapters 4, 5 and 6.

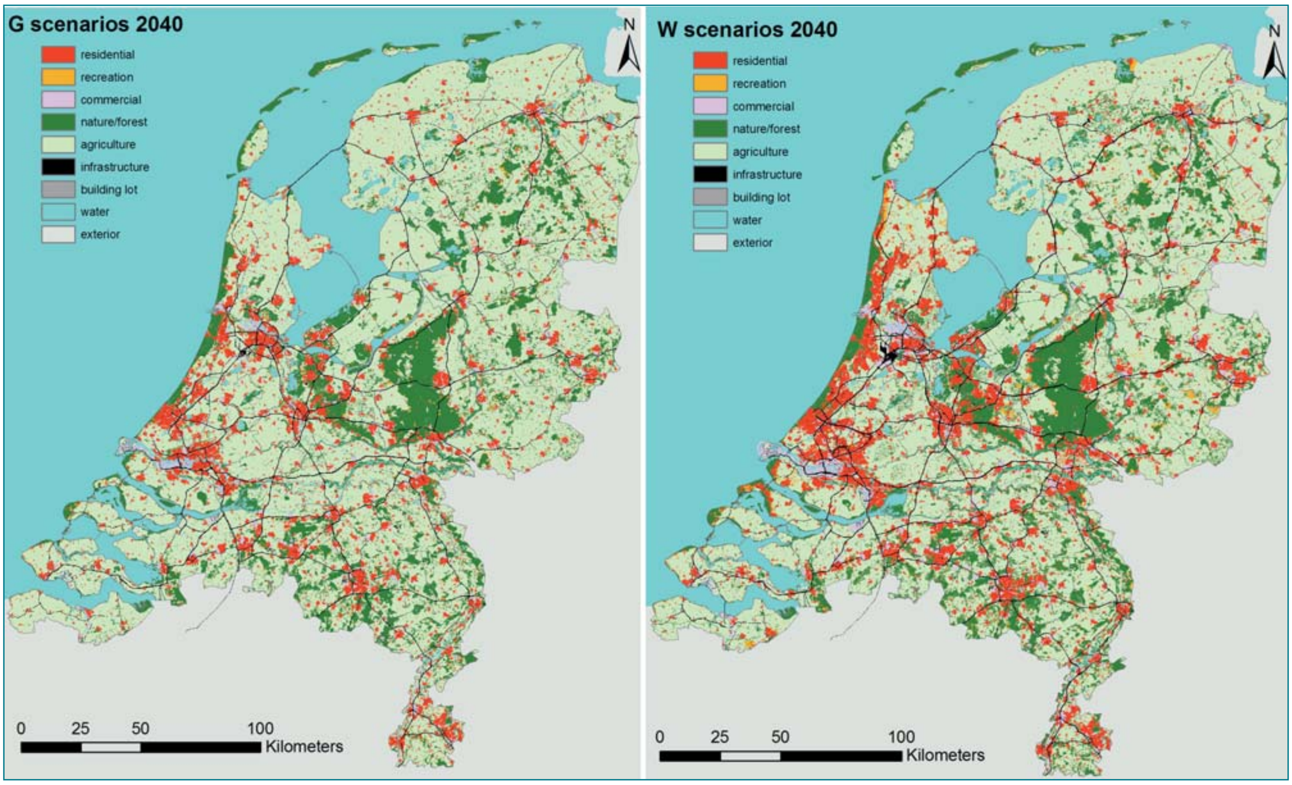

Figure 2.2.
Simulated land use for the G and W scenarios 2040 (source: Riedijk et al., 2007).

3. Interpreting and visualising land-use simulation results

It has been experienced that land-use simulations often result in very detailed, attractive and highly interesting maps. However, it is often difficult to precisely interpret the results, differences and detailed information stored in these maps. As a consequence, on a closer examination, questions emerge such as: where do the maps exactly differ from each other; what do these differences say about the quality of the living environment; what are the effects on a specific land use type in a specific region; which of the scenarios fit best into the current policy guidelines? Quantitative spatial evaluation methods can help to address this issue and to compare and interpret results in a systematic and better way. To enable a more profound evaluation, a number of such quantitative indicators was developed for Land Use Scanner. In addition to generic indicators describing the general composition and spatial configuration of land-use patterns several indicators were developed that quantify land-use change in relation to a number of policy themes. These are discussed below together with efforts to come up with alternative ways to present results using 3D-visualisations and overlay analysis.

3.1 Assessing flood risk

Flood risk is an important climate-change related issue in spatial planning. In fact, spatial planning may be an important instrument in limiting flood risk as it can be used to steer urban development away from potentially risky zones. To be able to evaluate changes in potential economic damage and potential casualties a methodology was developed in close cooperation with PBL Netherlands Environmental Assessment Agency and Deltares. This method combines land-use patterns, potential inundation depths and damage functions. It was tested extensively in the LANDS project (see Section 4.2) and added to the Land Use Scanner model as a new evaluation indicator. Using this approach the flood risk associated with different spatial strategies could be evaluated in the CcSP-project Safety first (A13) that aimed to develop an integrated discussion support system for flood risk management strategies (see, for example, Van der Hoeven et al., 2009). As part of the CcSP-COM30 project the flood-risk assessment module was also applied in the Strategic Environmental Assessment of the new Regional Spatial Strategy of the Province of Overijssel (Province of Overijssel, 2009).

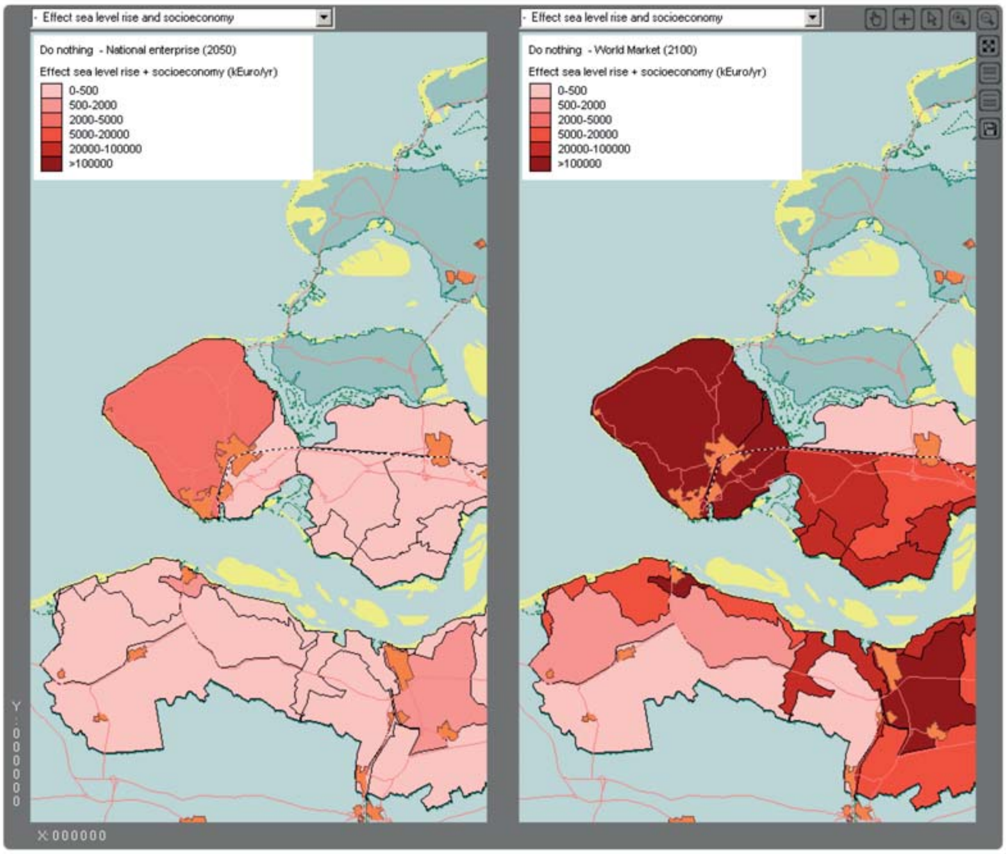

Figure 3.1.
Comparison of economic damage in two future scenarios (source: Van der Hoeven et al., 2009).

3.2 Characterising urban development and landscape impacts

To further assist the ex-ante evaluation of spatial planning policies a set of functional indicators was implemented and tested relate to an important theme in Dutch spatial planning: compact urbanisation. This sets of indicators allows for a critical comparison of scenario-based simulations of future land-use patterns. Single indicators capture individual aspects of urbanisation like magnitude (through general composition indices), spatial pattern (grid cell based urbanisation degree), concentration (patch size distribution) and compactness (average urban area circularity). It is, however, the combined use of composition and configuration indicators at various scale levels that makes it possible to unambiguously interpret the projected spatial developments. The indicators are described in detail elsewhere (Bubeck and Koomen, 2008; Ritsema van Eck and Koomen, 2008). Based on the experience with these indicators we cooperated with EC-JRC in the development of a composite index of urban compactness that can be applied in a land-use modelling applications (Mubareka et al., 2011).

Another important element in the evaluation of spatially explicit planning strategies is the impact on landscape. Research efforts focused on quantifying the impacts of land-use change on land-use diversity (Ritsema van Eck and Koomen, 2008), landscape quality (Koomen, 2008) and the provision of open space (Wagtendonk, 2011; Wagtendonk and Koomen, 2010). For these themes spatially explicit indicators were developed that can be applied on land-use simulation results. These are implemented in the Land Use Scanner model and shared with PBL Netherlands Environmental Assessment Agency to help them interpret simulation results.

Table 3.1.
Examples of land-use based Indicators related to urban development and landscape impacts available in Land Use Scanner.

Composition metrics:
total urbanised area [ha]
urban population density [inhabitants/ha]
urbanisation degree [%]
Spatial configuration metrics:
number of urban areas
average urban area size [ha]
difference maps showing local increase/decrease in specific land-use types (e.g. urban area)
land-use diversity [Simpson's diversity index ranging from 0 to 1]
number of open spaces
average open area size [ha]
urban pressure on high-quality landscapes, national landscapes, natural areas etc.

3.3 Visualising land-use change

Three-dimensional visualisations offer an interesting, alternative method for representing model outcomes. In cooperation with the Universitat de Girona we, therefore, explored a method that combines the flexibility of digital, GIS-based map making with the attractivity of 3D visualisations. The visualisation process is relatively straightforward and its result is appealing, easy to distribute and interactive (see full description in: Lloret et al., 2007; Lloret et al., 2008). This process relies on the creation of 3D elements (in Google SketchUp) in combination with 2D land-use maps and the standard Google Earth interface. The proposed visualisation method can be used in combination with Land Use Scanner results as is demonstrated in Figure 3.2.

Figure 3.2.
Example of a 3D-representation of land-use change in Google Earth (source: Lloret et al., 2007).

3.4 Analysing conflicts and synergies between adaptation measures

Climate adaptation measures for different societal sectors (nature, water storage, agriculture, energy supply etc.) are generally defined in isolation, making it difficult to draft an integrated spatial plan. As part of the development of a spatial strategy for the province of Groningen a methodology was developed and applied to analyse potential conflicts and synergies between sector-specific adaptation measures. The integration was, however, severely constrained by the extremely heterogeneous character of the spatial representations of the adaptation measures. All depictions were presented as maps, but these were ontologically inconsistent and often lacking spatial detail. Some of the maps provided purely conceptual ideas, depicting only schematic system designs. Lastly, the way map elements related to current land use, the environment and each other was not defined comprehensively.

To be able to produce a single map with only spatially explicit, accurately defined and accurately located features with the least overlap possible an integration methodology was applied that started with selecting the spatially relevant features of all sector-specific adaptation measures. Subsequently, these were iteratively further defined, localised and combined. To pinpoint areas with potential spatial conflicts between different adaptation measures, a straightforward raster-based overlay was applied. This analysis showed that most potential conflicts are concentrated in a low-lying area slightly east of the centre of the province. The applied methodology is documented in several papers (Jacobs et al., 2009; Jacobs and Koomen, 2010), while the final suggested climate adaptation strategy was described by Province of Groningen as part of CcSP project A18.

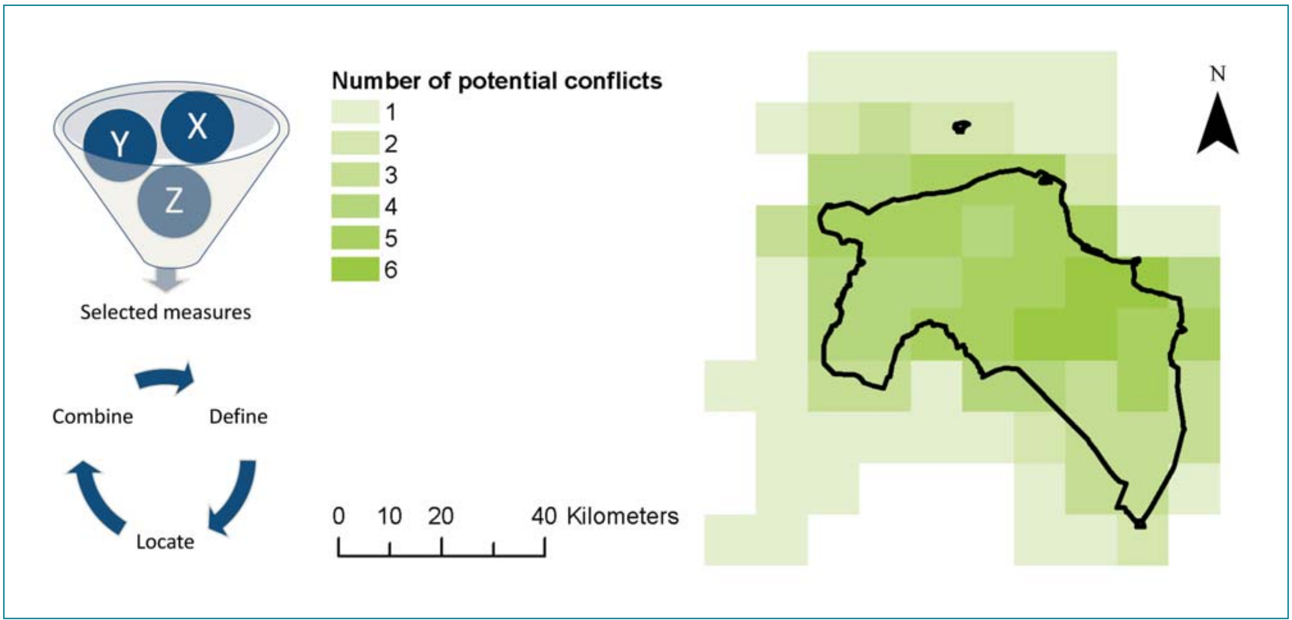

Figure 3.3.
Integration methodology and potential conflict analysis for the development of a climate proof spatial strategy for the province of Groningen (source: Jacobs et al., 2009).

4. Flooding, spatial planning and climate change

Climate change is expected to have an important impact on flooding. This is especially relevant in the Netherlands where 25% of the land is below mean sea level and over 50% of the country is being protected from flooding by embankments. At the same time, the management of flood risk is strongly interlinked with spatial planning and land use. On the one hand, developments in land use affect the exposure to flooding, and thus the magnitude of potential damage and risk. On the other hand, many measures to reduce flood risk are spatial in nature. Examples are the so-called 'room the river projects' that aim to reduce water levels during peak discharges, or zoning measures designed to locate new urban developments in areas with little to no danger of flooding. Within the LANDS project, several aspects of this interface between land use, flooding and climate change have been investigated. These include the spatial mapping of flood risks, assessments of flood risk at various scales, how flood risk changes through time because of land use change and climate change, and strategies to adapt to climate change.

4.1 Mapping flood risk

Spatial information on flood risk can aid flood managers and spatial planners in various ways. In the light of the EU flood directive, every member state is obliged to map flood risk in its territory. The state of flood risk mapping activities was reviewed in order to reveal: 1) the different approaches to map flood risk; and 2) the possible ways such information can be used (De Moel et al., 2009). Different options to conceptually visualise flood risk are shown in Figure 4.1. These representations range from maps depicting historical flood events, through maps displaying specific flood characteristics like inundation depth, to maps depicting estimated damage for a flood event. It was found that many countries had already mapped the flood hazard (i.e. potential danger), but combining this with spatial information on potential consequences was not so common yet. Overall, the flood risk maps were used for a variety of purposes, including emergency planning, spatial planning, raising awareness, and insurance purposes. With respect to spatial planning the status of the flood risk information differs widely. In some countries flood maps serve an advisory purpose in steering spatial developments, but in other countries there is binding legislation related to flood zones (i.e. prohibiting developments in flood zones or demanding certain building measures).

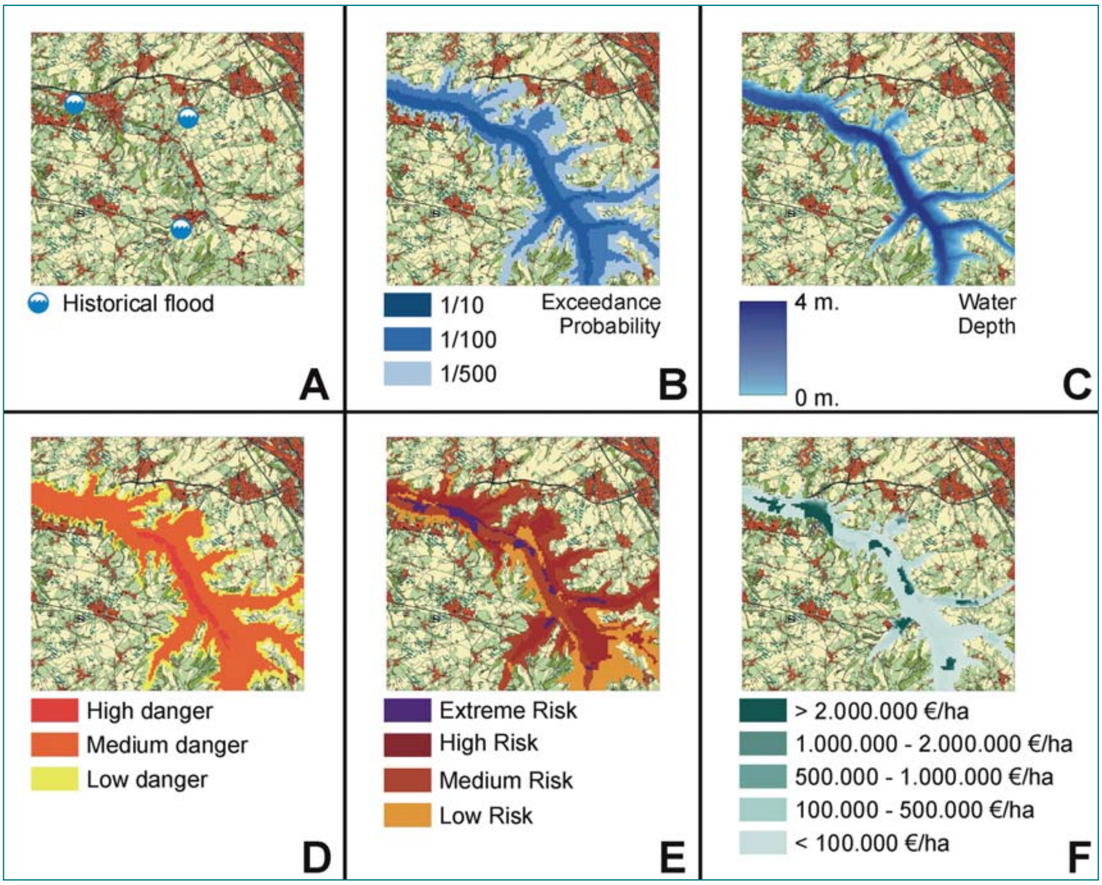

Figure 4.1.
Different ways to visualize flood risk: A) historical flood events; B) flood extent; C) flood depth (single parameter); D) flood danger (combination of parameters); E) qualitative risk; and F) quantitative risk or damage (source: De Moel et al., 2009).

4.2 Assessing flood risk at various scales

To support, amongst others, spatial planning decision making, flood risk assessment plays an important role. This relates not only to the current risk, but also to changes in risk due to certain (flood management) measures or developments (e.g. land-use change, climate change). Flood risk assessments have been performed at various scales to answer a variety of questions. In these flood risk assessments spatial information on exposure (e.g. land use) and the flood hazard (e.g. inundation depth) is combined in a damage model using depth-damage curves to calculate flood damage. These depth-damage curves relate for each cell the inundation depth to the amount of damage that will occur there, based on the land use that is present there. Annual damage estimates, the most common flood risk indicator, are determined by combining the damage results with the probability that they may occur.

4.2.1 Comparing different types of flood risk

In order to gain insight into how risks of different types of flooding compare to each other, flood risk assessments of floods due to extreme precipitation, and from the sea or river have been performed for a small dike ring area in Zeeland (Noord-Beveland). This research shows that flood risk (in terms of annual damage) resulting from extreme precipitation, is actually higher than the flood risk resulting from large-scale flooding from the sea or river (Koks et al., 2011). This implies that policies regulating flood risk (i.e. recent Dutch national norms for extreme precipitation and safety norms for the sea and river) are more stringent for large-scale flooding from the sea or river. This ‘overprotection´ against flooding from the sea or river is probably related to the additional (non-monetary) consequences large-scale flooding from the sea or river can have compared to extreme precipitation. For instance, large-scale flooding may also results in more human casualties and a longer and larger social (and economical) disruption of the area in question compared to extreme precipitation, which would (at least partly) justify such more stringent policies.

4.2.2 Uncertainty in flood risk assessments

As with every model aiming to support decision making, it is important to know how robust the model results are. This can be assessed using uncertainty and sensitivity analyses. To assess the uncertainty of flood risk assessments, various case studies have been performed for large dike ring areas in the Netherlands. For dike ring 14 *(Zuid-Holland)* the flood risk uncertainty related to coastal storm surges has been investigated, and for dike ring 36 *(Land van Heusden/de Maaskant),* uncertainty in fluvial flooding has been studied. The results reveal that the total uncertainty surrounding flood damage estimates is substantial. Though differing between different breach locations, it can be said that the 90% upper and lower estimates are generally about 4.5 times larger or smaller than the median (de Moel et al., under review). Also for estimates of expected annual damage (EAD), the uncertainty was found to be substantial, with the 90% lower estimate 8 times lower, and the 90% upper estimate 4.5 times higher than the median (de Moel et al., in prep). Sensitivity analyses showed that the largest contributor to these differences is the uncertainty in the depth-damage curves used in the damage calculation (De Moel and Aerts, 2011). Also uncertainty in other input factors were of considerable influence, most notably uncertainty in the duration of the storm surge or flood wave on the river and uncertainty in the probability of such conditions happening. Given this large uncertainty, absolute damage and risk estimates should clearly be used with caution. Proportional changes in flood damage (e.g. relative change with respect to a base estimate), on the other hand, were found to be much more robust.

4.2.3 Development of flood risk over time

Flood management measures and changes in land-use are long-term developments, usually lasting at least several decades, but often much longer. It is therefore important to take future developments into consideration in current planning practices. Moreover, analysis of historic developments helps to put current assessments and future projections into perspective. Changes in land use over the 20th and 21st century were related to the flood hazard in the Netherlands to illustrate how flood risk has, and is projected to change over time (De Moel et al., 2011). For the analysis use was made of the risicokaart for the flood hazard (Figure 4.2: top left panel), historical land-use maps (HGN, Figure 4.2: top middle and right panel), and the land-use scenarios developed by the LANDS project (Figure 4.2: lower panels, see also section 2.4). The analysis shows that, contrary to popular believe, urban areas are not concentrated in flood-prone areas in the Netherlands. Through time, urban developments have, however, taken place in areas with increasingly higher potential inundation depths. Overall, potential flood damage has increased sixteen times over the 20th century due to land use change. Future projections show that over the 21st century it may continue to grow exponentially (ten-fold increase) under a high-growth scenario (global economy). Under the low-growth scenario (regional communities) the increase in potential flood damage is much more moderate (two- to threefold increase).

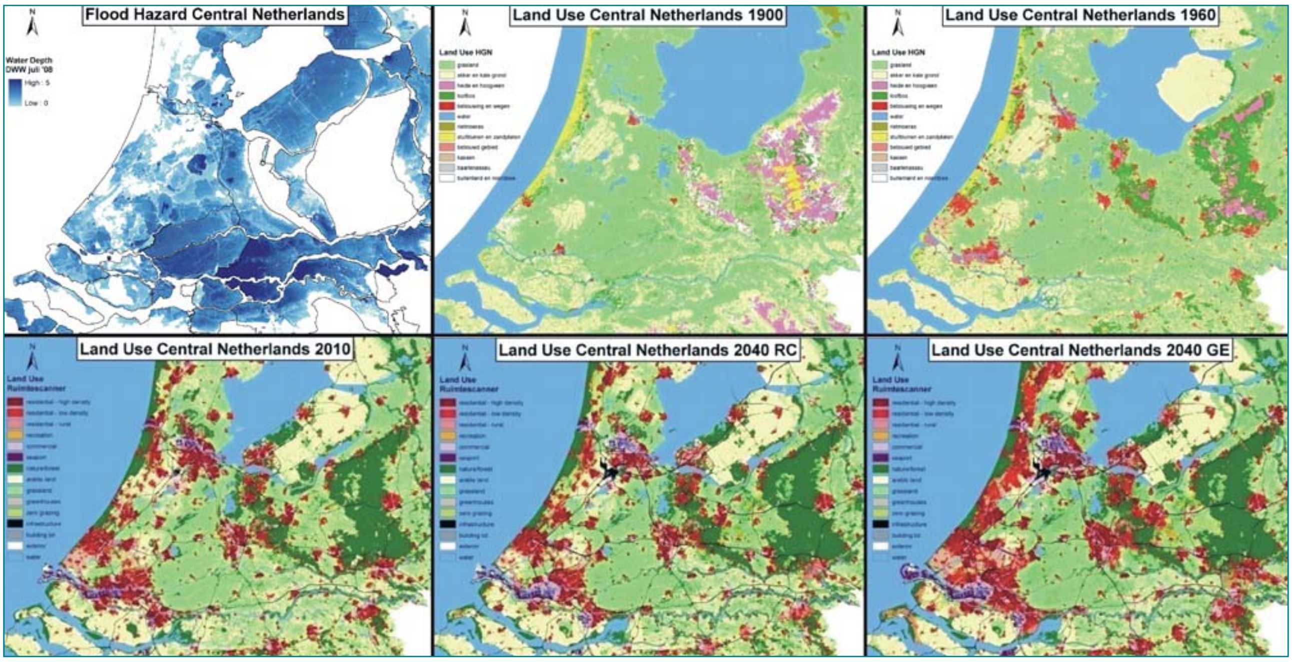

Figure 4.2.
Flood hazard in central Netherlands (top left), historical land-use change (top middle and right) and projected land-use change (lower panels) (source: De Moel et al., 2011).

4.3 Adaptation options

Despite the potential danger from climate change and, more specifically, flooding, there is a need for new urban development in the Netherlands, because of continuing economic and population growth. Timely attention to potential climate impacts offers the opportunity to integrate adaptation measures in the development of spatial plans, thus making them 'climate-proof'. The Zuidplaspolder is an area in The Netherlands where a substantial amount of new houses, industry, greenhouses and nature is planned. In order to do this in a climate-proof way, the 'Hotspot Zuidplaspolder' project tested some of the planned measures and designed several new adaptation measures. With respect to flooding due to extreme precipitation, it was found that the provision of additional open water area that is planned for each hectare of extra development (Figure 4.3, middle panel) will reduce inundation levels due to extreme precipitation enough to meet the current norms in almost every scenario. Only under the most extreme climate change scenario some areas need further measures (De Moel, 2008).

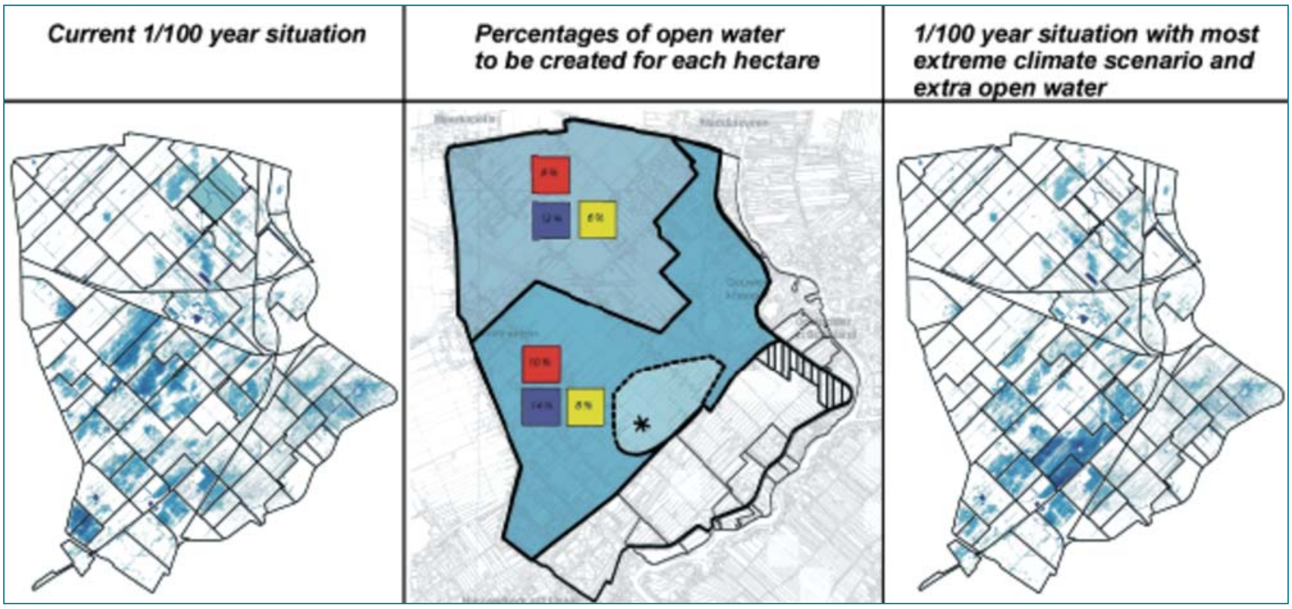

Figure 4.3.
Impact of climate change and provision of additional open water on inundation levels (darker blue is deeper) due to extreme precipitation in the Zuidplaspolder (source: De Moel, 2008).

5. Designing strategies for climate adaptation of nature

Drastic changes are expected in land-use patterns as a result of socio-economic developments and climate change. Biodiversity and other land-use functions require larger areas for adaptation to changes in climate and thus increase competition for available space. This requires a different, more multifunctional type of land-use planning and more efficient management of resources. The LANDS project helped develop adaptation strategies for nature and explored their implementation in both top-down and bottom-up approaches.

5.1 Adaptation strategies for nature

The combination of shifting climate zones, more frequent extreme weather events (e.g. droughts) and current small and highly fragmented nature areas threatens biodiversity in the Netherlands. Additional area is needed to limit these expected negative impacts (Vos et al., 2008; Vos et al., 2010). Research shows that two elements are crucial in adapting biodiversity to climate change: 1) connecting suitable habitats to allow species to follow shifting climate zones and reach their new suitable habitat sites; and 2) maintaining strong key populations that allow species to reproduce and produce enough offspring to colonise new areas, and that are big enough to allow survival of sustainable populations in more extreme weather conditions.

To adapt the current plan for a National Ecological Network (NEN) to climate change, a so-called Climate Adaptation Zone (CAZ) is proposed (MNP, 2008; Vonk et al., 2010). The latter is defined as a national zone of multifunctional land use that is permeable for species, contains a number of fortress populations, and is connected to habitat networks in neighbouring countries. From an international perspective, especially the Climate Adaptation Zone for wetland areas is important for sustaining biodiversity, as the Netherlands have an important portion and thus a special responsibility for wetland habitat and species in Europe. To ensure the Climate Adaptation Zone is functioning as a coherent ecological network, it is important to plan at a national scale, but for its realisation it is equally vital that the actual regional implementation is in harmony with the adaptation strategies for other land-use functions and thus involves local and regional stakeholders.

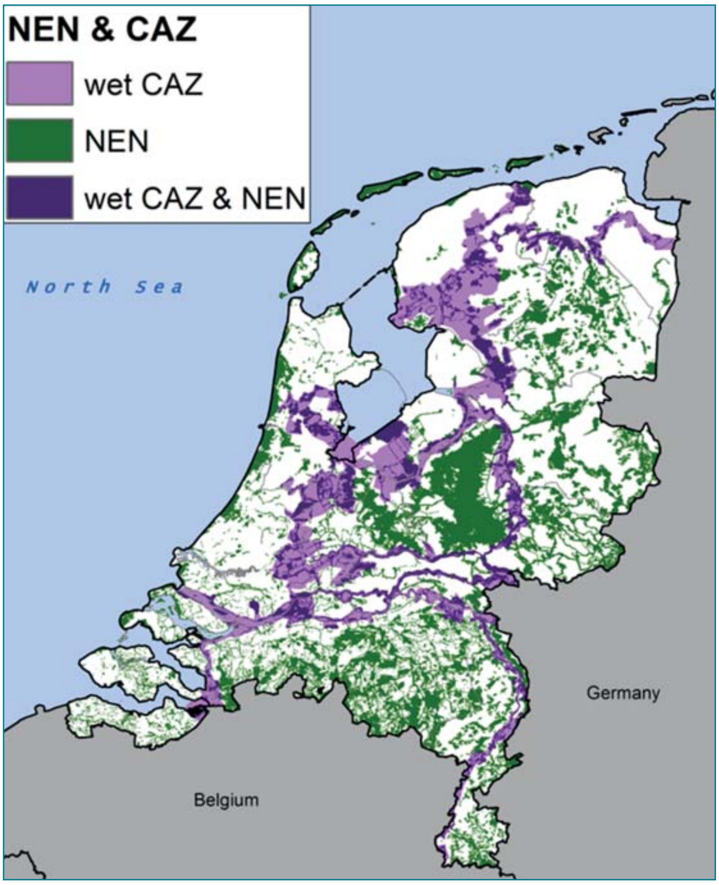

Figure 5.1.
Current plan for a National Ecological Network (NEN) and proposed Climate Adaptation Zone (CAZ).

As the Dutch planning emphasis is currently shifting from national to regional or local governments and stakeholders' preferences play an increasingly important role in landscape planning we compared two different ways to implement adaptation strategies for nature: 1) a top-down approach that explored the effect of different policy strategies on biodiversity at the national scale using the Land Use Scanner model described in Chapter 3; and 2) a bottom-up approach that, together with local and regional stakeholders, explored how adaption strategies for biodiversity can be realised in combination (preferably synergy) with adaptation strategies for other land-use functions.

5.2 Top-down approach: allocating nature with a land-use allocation model

To apply the Land Use Scanner model in the context of nature adaptation the model was adapted by subdividing the initial single-class description of nature into two separate classes related to wet and dry natural areas (Van Eupen 2009; Steingröver et al., in prep.). We then compared three separate, national scenarios that differed in their preferred locations for wet nature types: a) no specified search area (implying that only land will be acquired that is not in demand by other users); b) within the current National Ecological Network; and c) within both the current National Ecological Network and proposed Climate Adaptation Zone. Subsequently, the landscape analysis model LARCH (Pouwels et al., 2002) was used to assess the effect of land-use change on the ecological functioning for two species groups with different spatial characteristics: large wetland birds and butterflies.

Large wetland birds are mobile, need a national network across the Netherlands, and depend on large wetland areas (strongholds) for sustainability. Figure 5.2 shows that when the search area is confined to the current National Ecological Network and proposed Climate Adaptation Zone, both the number of strongholds and the amount of breeding pairs increase compared to the other scenarios. This shows that strongholds in the Climate Adaptation Zone are an effective spatial strategy for adaptation of these wetland species. To study the trade-off between allocating area to strongholds and connectivity we also looked at wetland butterflies, who have a limited dispersal capacity and whose sustainability depends on connectivity between habitat patches. This analysis shows that allocation of nature to the strongholds coincides with an increase in the coherence of wetland habitat. We thus conclude that extending the National Ecological Network with a Climate Adaptation Zone is an effective strategy for adaptation to climate change.

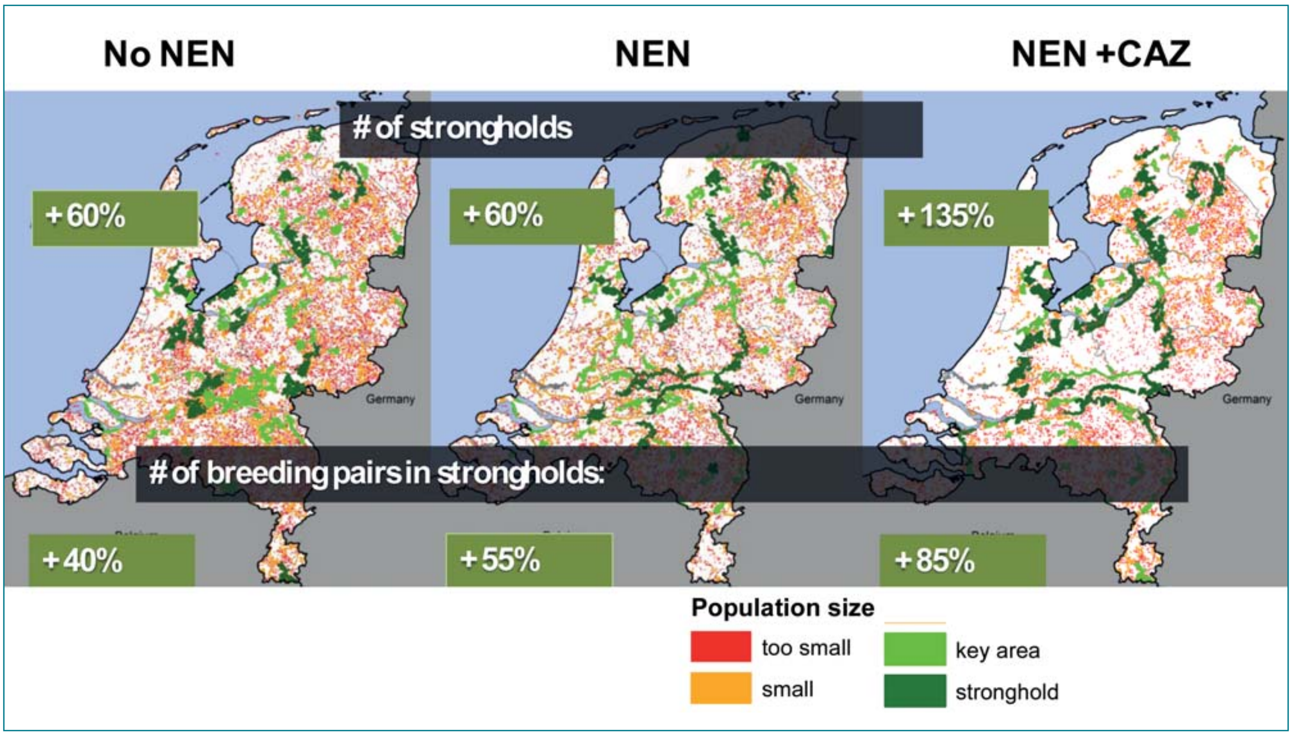

Figure 5.2.
The impact of land-use changes according to three different scenarios on number of strongholds and amount of breeding pairs of large wetlands birds (Steingröver et al., in prep).

5.3 Bottom-up approaches: the Groningen and Salland cases

A part of the wetland Climate Adaptation Zone is projected in the province of Groningen stretching towards the border with Germany. By request of the province we analysed the long-term requirements for adaptation of the nature and water systems. This analysis focused specifically on potential synergies: can adaptation measures for water and nature be combined and, if so, where and how should that be done? Multifunctional adaptation can increase the chances for the actual implementation of adaptation measures. For collaborative planning with stakeholders we developed the PLAN-IT concept (Steingröver and Van Rooij, 2010). Taking possible synergy with necessary water adaptation measures into account, stakeholders identified four possible routes between the brook valleys of Hunze and Westerwoldse Aa for the wetland Climate Adaptation Zone (Figure 5.3). The effectiveness for nature and water adaptation of these routes and their potential synergy was analysed in detail (Van Rooij et al., 2009). The result of applying the PLAN-IT method is a set of options for a multifunctional climate corridor that is effective for nature adaptation and contributes to water adaptation, and that is efficient in the use of (scarce) space and other resources.

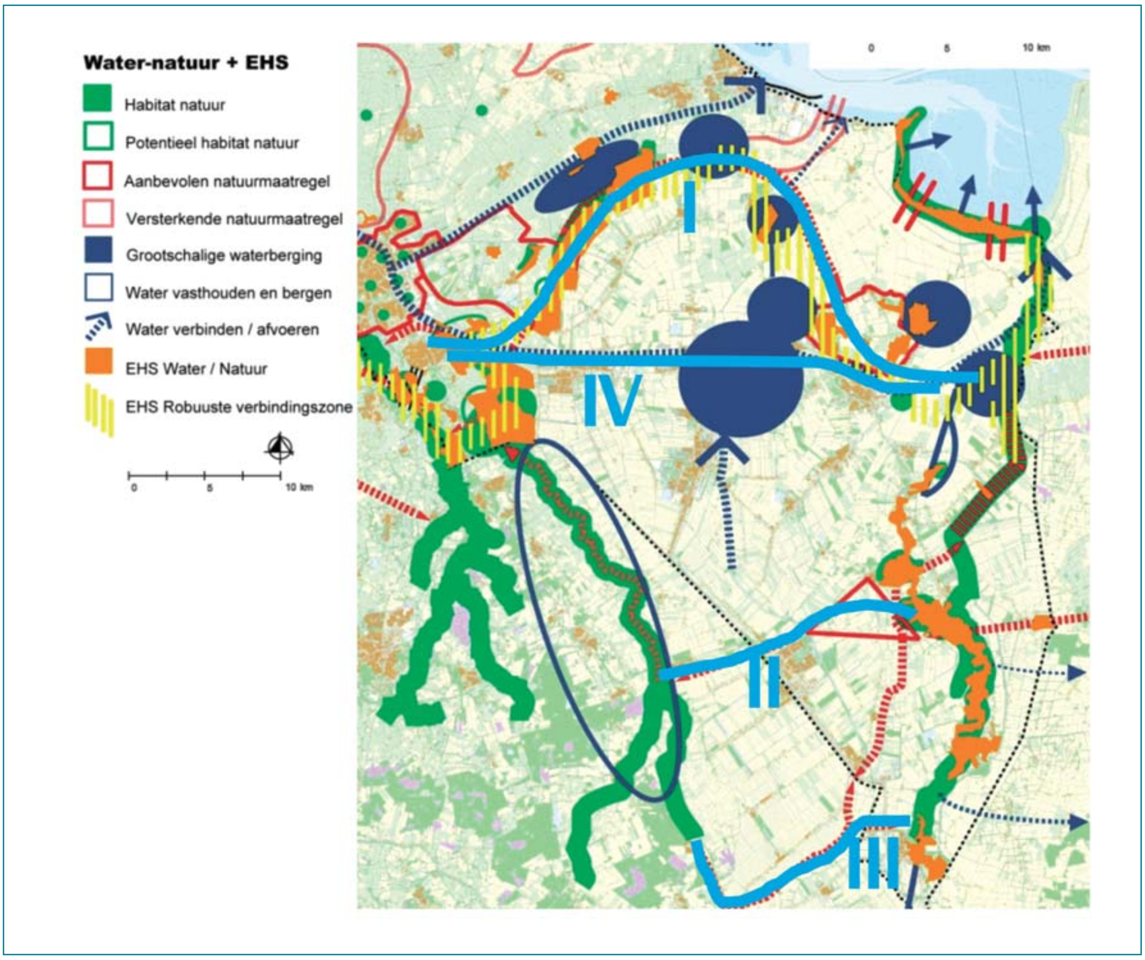

Figure 5.3.
Four potential routes for multifunctional climate corridors in Groningen (marked I through IV) that are effective for both nature and water adaptation (Roggema et al., 2009).

Adaptation to climate change and competition for land use and limited financial resources is not restricted to nature areas inside the National Ecological Network. The green-blue infrastructure outside this Network also helps to adapt biodiversity to climate change by increasing connectivity between larger nature areas. In Salland the province and Landscape Overijssel wanted to apply the PLAN-IT method to find out how and where to invest effectively and efficiently in the regional green-blue network. In addition to biodiversity objectives, goals were set for water, recreation and landscape identity. We developed two tools to help stakeholders identify potential locations with synergy between different objectives: 1) Eco PLAN-IT based on the LARCH model; and 2) a GIS based tool to stack spatial maps (Snepvangers et al., 2010; Snepvangers et al., 2011). The resulting map (Figure 5.4) shows where investing in the green-blue infrastructure most effectively combines nature adaptation with other land use functions.

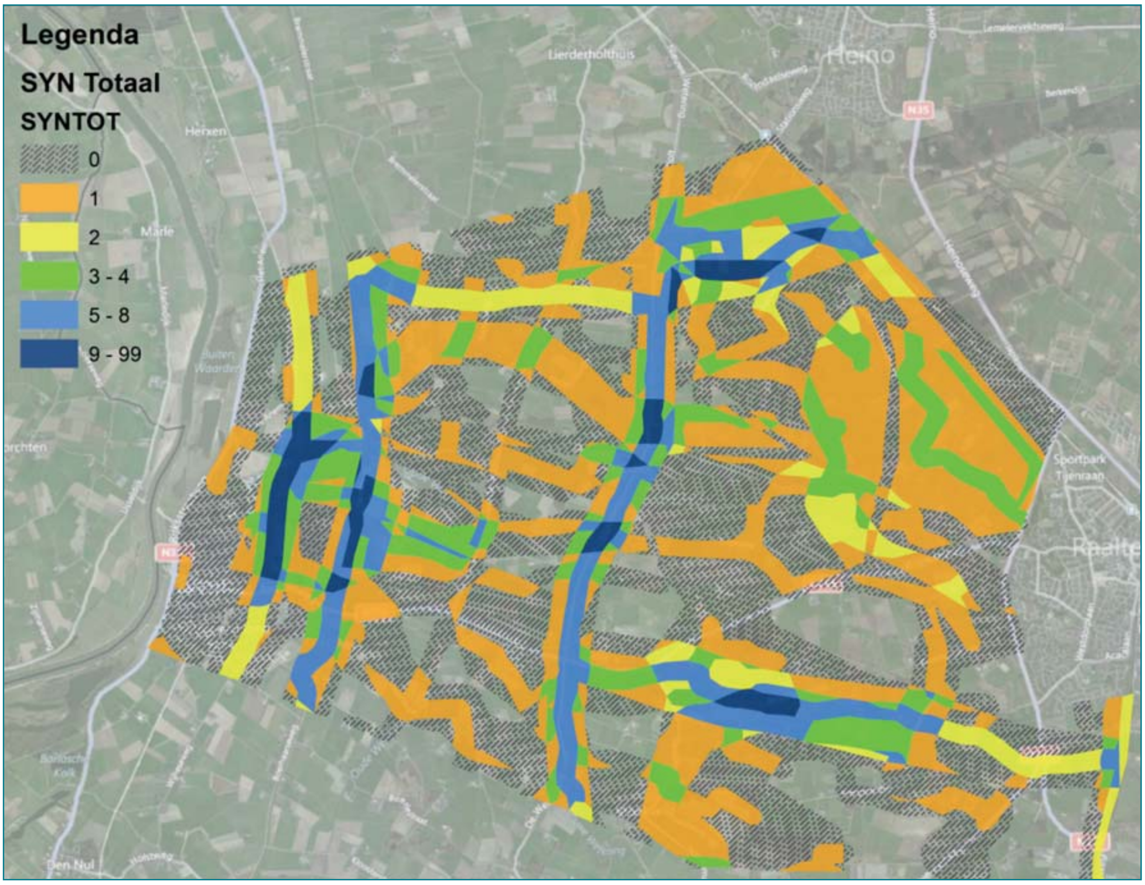

Figure 5.4.
Amount of synergy between different planning objectives of the green-blue infrastructure in Salland (Snepvangers et al., 2011).

5.4 Conclusion

The top-down approach gives insight into the effect of changes in land-use pressure on the planning of nature and the effects of different policy strategies on adaptation. It is best used as an ex ante assessment of possible national policy strategies for climate adaption and gives an answer to questions like: is this the best strategy and will it be effective? The bottom up approach, however, provides a reality check on local abiotic conditions and local support and identifies spatial opportunities, also for multifunctional adaptation. It gives an answer to questions such as: can this national strategy be implemented and thus be effective for adaptation?; and how and where is investing in the regional green blue network most profitable for biodiversity?

6. Integrating spatially-explicit climate adaptation strategies

The scenario framework and land-use simulations developed in the LANDS project have been used in various sector-specific projects to provide the socio-economic conditions for the development of climate adaptation measures. More specifically input was provided to the following CcSP projects: Developing Adaptive Capacity to Extreme events in the Rhine basin (ACER - A07), Safety first (A13/A20), hotspot Groningen (A18), Climate sketchbooks (COM21), Integrating climate change knowledge in regional planning Processes (COM30), hotspot Veenkoloniën (COM32), the modelling of greenhouse budgets at ecosystem level (ME1) and Socio-economic Scenarios in Climate Assessments (IC11). From several of these projects results were fed back into the Land Use Scanner model to develop adaptation strategies while taking into account other spatial developments. These activities are summarised below.

6.1 Developing flood-risk management strategies

As climate change is expected to have a profound effect on flood risk in the Netherlands, the development of flood risk strategies has received ample attention in the CcSP program, most notably the Safety first (A13/A20) project. The land-use modelling framework developed in LANDS played an important role in this project to: 1) indicate potential changes in land use in the long term (50-100 years); 2) help specify and visualise new management strategies; and 3) assess the potential impact of different strategies in limiting flood risk.

In addition to the scenario-based land-use simulations for 2040 discussed in Section 2.4, an attempt was made to simulate land-use patterns for 2100 (Van der Hoeven et al., 2008). These simulations were tailor-made for the Safety first project and indicate potential spatial patterns based on assumptions derived from a limited number of available long term socio-economic future scenarios. New long term flood-risk management strategies were developed within the socio-economic boundary conditions of the new 2100 scenarios and the scenario framework for 2040 described in Section 2.1. these strategies were visualised and implemented in the Land Use Scanner model (see Figure below). By using the indicator described in Section 3.1 the impact on limiting flood risk could be quantified for all different strategies allowing a structured comparison between them.

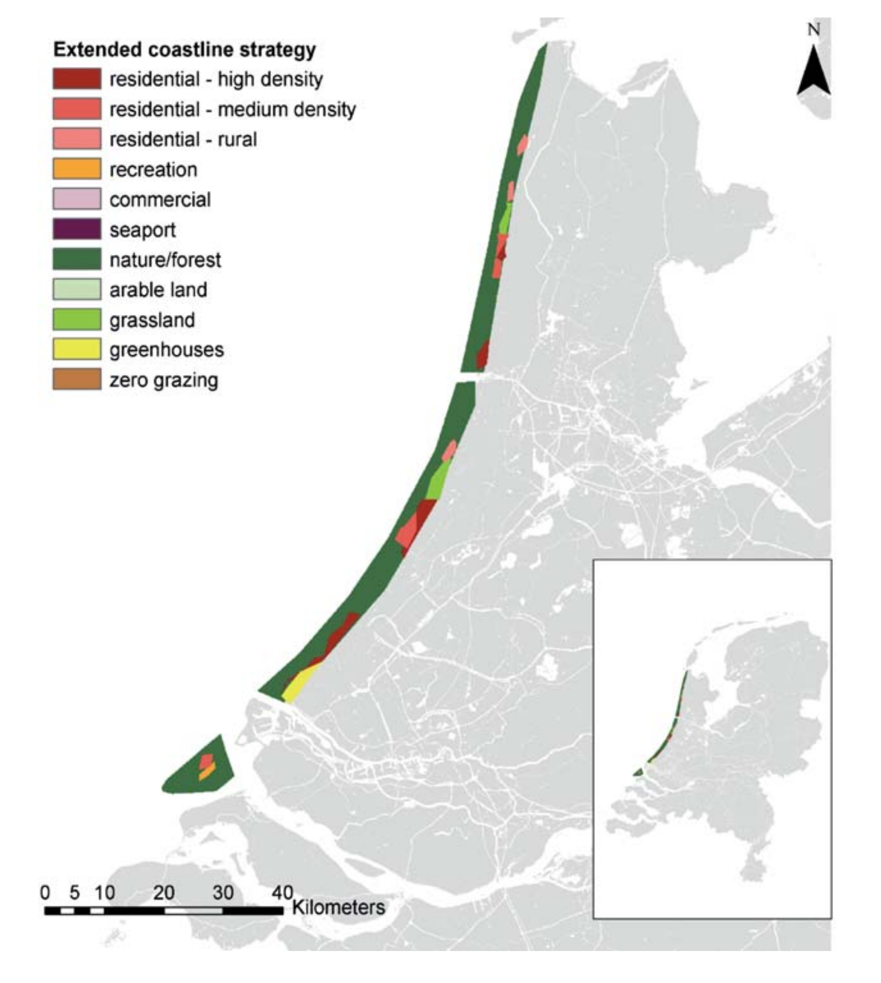

Figure 6.1.
One of the flood risk management strategies developed for the Safety first project (source: Jacobs and Koomen, 2008).

6.2 Analysing the potential for biofuel crops

Biofuel crops receive substantial research and policy attention as they may help mitigate climate change. In the LANDS project we assessed the potential for biofuel crops in the Netherlands. Previous, global analysis shows that first generation biofuel crops have limited value in mitigating climate change. Moreover, they are not likely to be grown in countries and regions that are characterized by a limited amount of land and a capital and knowledge intensive farming sector such as the Netherlands and northern France. We, therefore, chose to analyse the potential of second generation biofuels in The Netherlands, a country with a high pressure on land and an advanced agricultural sector.

In an initial study carried out with the Agricultural Economics Research Institute (LEI) we focussed on two types of wetland crops: reed and willow (Kuhlman et al., 2011). Quantifying only the benefits of energy production and water storage, under currently prevailing conditions these wetland bioenergy crops offer significantly lower benefits than for grassland agriculture. Conditions change, however, if we factor in, on the one hand, the impact of climate change (included here as higher groundwater levels as a consequence of sea-level rise) and, on the other hand, higher energy prices (a consequence of increasing scarcity of fossil fuels). Extrapolating these potential trends until 2050, the viability of grassland use declines and the attractiveness of wetland bioenergy crops increases substantially. At energy prices not much higher than those prevailing in early 2008, assuming modest progress in bioenergy technology, and following a climate scenario where not only higher temperatures prevail but where air circulation patterns have also been affected, reed will outcompete grassland in large areas of the Netherlands.

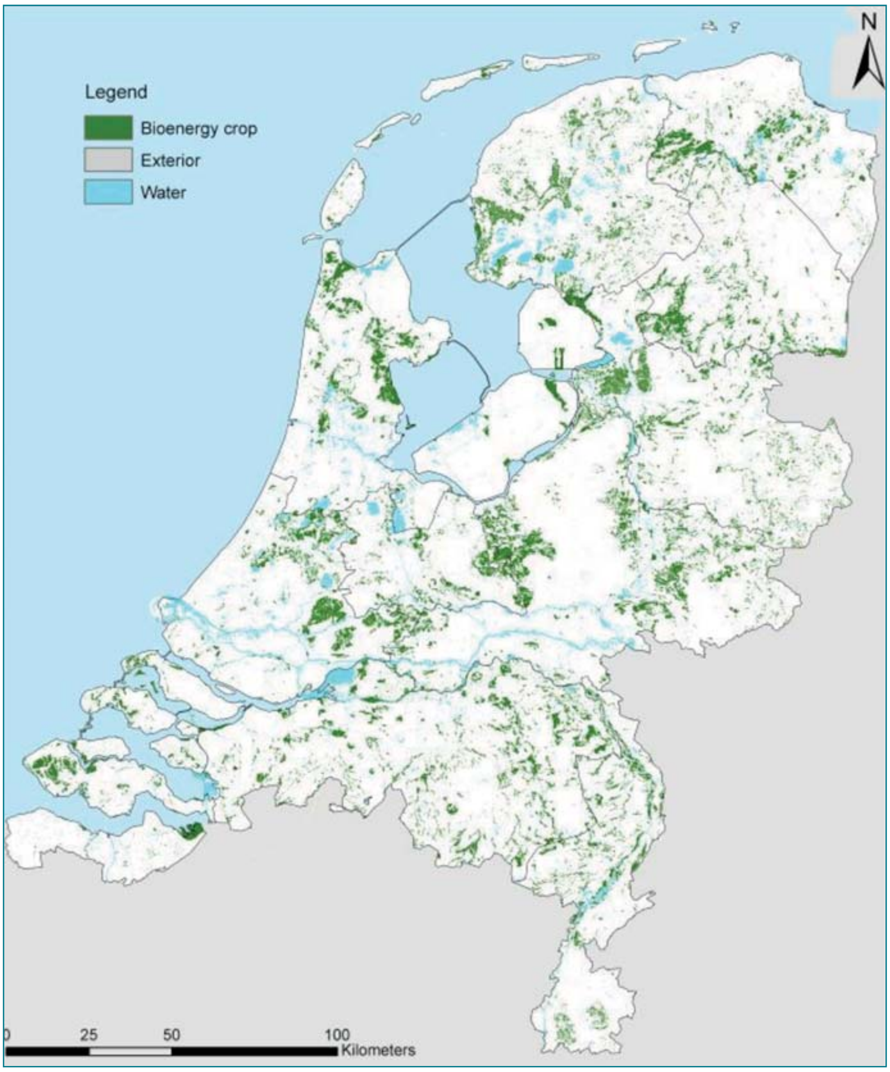

Figure 6.2.
Land use for reed with water storage in the Netherlands assuming a high oil price and higher groundwater table (source: Kuhlman et al., 2011).

A second analysis in cooperation with PBL Netherlands Environmental Assessment Agency and Wageningen University and Research Centre focused on Miscanthus; a promising perennial crop for temperate climates in the medium long term (Van der Hilst et al., 2010). This analysis combined the insights from the CcSP-projects IC2 and ME4 with the land-use modeling framework of LANDS. Starting from a regional-level assessment of the potential of this crop in the Netherlands, a set of location factors is defined that is fed into Land Use Scanner to obtain a national assessment of likely locations where this crop can be grown in 2040 under different scenario conditions. This approach simulates local competition between different crops, while taking account of others demands for land stemming from, for example, urbanisation and nature development. The results indicate that under reference conditions (the Global Economy scenario discussed in Section 2.1) Miscanthus cultivation is not economically viable in the Netherlands (Diogo et al., 2011). In fact, large investment costs and lower yields in the first years turn biofuel cultivation into an unattractive option. However, according to an alternative scenario that assumed current yearly CAP subsidies provided to arable farming to be also allocated to biofuel crops cultivation, Miscanthus could become the most attractive crop in almost 25,000 hectares. When an additional subsidy for the buying of Miscanthus seeds (only in year 1) is included, this rises to almost 70,000 hectares.

7. Discussion

The LANDS project combined methodological development in the field of land-use modelling and the assessment of impacts related, primarily, to flood risk and biodiversity with the drafting and evaluation of adaptation strategies. The methodological advancements in combination with several case study applications have been sketched in the preceding chapters. In this last chapter we discuss how results and methods developed in the project can contribute to actual planning processes. In several cases these contributions have already taken place as is briefly described below.

7.1 Contributing to regional planning strategies

The detailed land-use modelling approach that was developed in cooperation with PBL Netherlands Environmental Assessment Agency has subsequently been used to help prepare and evaluate the regional spatial strategies for the provinces of Overijssel, Zuid-Holland, Drenthe and Utrecht (see, for example, Koomen et al., 2011). In the case of Zuid-Holland and Overijssel land-use based indicators related to flood risk and landscape quality as well as knowledge related to biodiversity impacts of climate change developed in the LANDS project were also applied in the Strategic Environmental Assessments related to the regional strategies. This knowledge transfer was made possible by the CcSP-Com30 project The experiences in these regional model applications are used to steer further development of the Land Use Scanner model (Jacobs et al., 2011; Koomen and Jacobs, 2011).

The PLAN-IT method for planning multifunctional climate corridors appeared to be effective and well applicable. We used the method at the regional and local scale levels. At the level of the province of Groningen we roughly identify climate corridor routes on areas that seem to have good potential for wetland development. Later we assessed three routes in more detail and were able to quantify the required measures and the surplus value for both nature and water adaptation. These results were particularly useful to the local Water Board to see how and where various goals set by the Water framework directive (improving water quality, rehabilitation of brooks) can be met. In this case, it appeared that a significant part of the required nature adaptation measures for wetlands can be carried out by smartly planning water adaptation measures. Also it appeared that the joint research of hydrologist and ecologists, scientists and stakeholders resulted in the identification of new locations and solutions where synergy between water and nature adaptation measures could be obtained. Herewith, it broadened the spectrum of possibilities for the realisation of nature and water adaptation. Furthermore, we conclude that the planning method for climate corridors is well understood by stakeholders. The method facilitates constructive debates between experts and stakeholders on ambitions for nature, required measures, and possible synergy with other land use functions.

7.2 Assessing national planning initiatives

The Land Use Scanner approach was recently also applied at the national level to assess the potential land-use changes resulting from the proposed changes in national spatial planning. Important themes in this new national spatial strategy are: abolishment of the national buffer zones and urban concentration policy, transferring the responsibility for National Landscapes from the national to regional authorities and limiting investment in the National Ecological Network. Especially the latter proposal has a strong relation with climate change as the currently proposed network is considered to be inadequate to maintain biodiversity levels at the required level in view of anticipated climatic changes. Knowledge on the potential impacts of climate change on biodiversity and ecological networks obtained in the Lands and CcSP-A02 project (Strategies for optimising nature conservation) was used to describe these potential impacts in the Strategic Environmental Assessment related to the new national spatial strategy (Elings et al., 2011).

The flood-risk related research of the LANDS project made clear that flood risk management is strongly interlinked with spatial planning. If flood risk is not taken into consideration in new spatial developments, such developments may continue to take place in flood-exposed areas, increasing potential flood risk. There are various adaptation practices possible that can counteract negative effects of climate change and even improve the current situation as was shown in the national Safety first study (Aerts et al., 2008). Our analysis also indicates that flood risk assessments have a considerable uncertainty that should be taken into account in decision making. In fact, the results of our uncertainty analysis were used as input in the Cost Benefit Analysis for the Water safety in the 21st century study of the Ministry of Infrastructure and Environment.

7.3 Supporting international model development

Based on the knowledge gained on land-use model development and the relations between land use and climate change we have been able to participate in various international projects that analyse and model the links between land use and climate change. More specifically we:

- developed a land-use model to analyse water management implications of climate change in the Elbe catchment as part of the German Federal Ministry of Education and Research funded project GLOWA-ELBE (Dekkers and Koomen, 2007; Hoymann, 2010);
- advised the State Government of Victoria (Australia) on the inclusion of a land-use component in their climate adaptation research (Koomen, 2009);
- developed and applied a pan-European land-use model at 1-km resolution for EC DG-Environment as part of larger consortium to study the possible impacts of potential EU biofuel and biodiversity related policies (Perez-Soba et al., 2010; Verburg et al., 2011);
- further refined this pan-European land use model to a 100m resolution for EC-Joint Research Centre to help in more detailed assessments on, for example flood risk (Lavalle et al., 2011);
- developed a land-use model for the Rhine and Meuse catchment areas as part of the CCsP-ACER project to assess potential future flood risk (Te Linde et al., 2011);
- participate in the development of detailed land-use model for Flanders that will be applied in climate adaptation research as part of University of Gent led research project.

7.4 Continuing after LANDS

The research initiated in the LANDS project now continues in many different research projects. The relation between flooding, land use and adaptation measures is being further explored as part of the new Knowledge for Climate research programme. That programme also addresses research questions related to climate adaptation in rural areas, water management and the development of new tools to help define and evaluate adaptation strategies.

In cooperation with PBL Netherlands Environmental Assessment Agency we are now updating the spatial elaboration of the existing socio-economic future scenarios. This development is closely coordinated with the Delta programme to ensure that a consistent set of scenarios is used in the Knowledge for Climate and Delta research programmes. Particular attention is being paid to developments in agriculture that may influence the future demand for water.

The NWO-project Integrating Global and LOcal assessment models (IGLO) now works on the improvement of integrated multi-scale modelling frameworks to assess the interrelationships between land use and climate. The project aims to consistently address the integration of processes operating across different scales and enhance the linkages and feedback between socio-economic processes and biophysical processes within the land change system.

8. References

Aerts, J., Sprong, T., Bannink, B., Bessembinder, J., Koomen, E. Jacobs, Ch., Van der Hoeven, N. Huitema, D., Van 't Klooster, S., Veraart, J., Walraven, A., Jonkman, S.N., Maaskant, B., Bouwer, L.M., De Bruijn, K., Oosterveld, E., Schuurman, H., Peters, K., Ottevanger, W., Immerzeel, W., Droogers, P., Kwadijk, J., Kind, J., Voogt, L., Van der Klis, H., Dellink, R., Affolter, F., Bubeck, Ph., Van der Meulen, M., De Lange, G., Bregman, B., Van den Brink, H., Buiteveld, H., Drijfhout, S., Feijt, A., Hazeleger, W., Van den Hurk, B., Katsman, C., Kattenberg, A., Lenderink, G., Meijgaard, E., Siegmund, P., De Wit, M. & Naples, M. (2008) Aandacht voor Veiligheid, Leven met Water, Klimaat voor Ruimte, DG Water, Rapportnummer: 009/2008.

Beinat, E. and Nijkamp, P. (1997) Land Use Planning and Sustainable Development. Vrije Universiteit, Amsterdam.

Borsboom-van Beurden, J.A.M., Boersma, W.T., Bouwman, A.A., Crommentuijn, L.E.M., Dekkers, J.E.C. and Koomen, E. (2005) Ruimtelijke Beelden; Visualisatie van een veranderd Nederland in 2030. RIVM report 550016003. Milieu- en Natuurplanbureau, Bilthoven.

Borzacchiello, M.T., Nijkamp, P. and Koomen, E. (2010) Accessibility and urban development: a grid-based comparative statistical analysis of Dutch cities. Environment and Planning B 37(1): 148-169.

Bubeck, P. and Koomen, E. (2008) The use of quantitative evaluation measures in land-use change projections; An inventory of indicators available in the Land Use Scanner. Spinlab Research Memorandum SL-07. Vrije Universiteit Amsterdam/ SPINlab, Amsterdam.

Commissie Waterbeheer 21e eeuw (2000) Waterbeleid voor de 21e eeuw. Geef water de ruimte en de aandacht die het verdient. Advies van de Commissie Waterbeheer 21e eeuw. Den Haag.

CPB, MNP and RPB (2006) Welvaart en Leefomgeving. Een scenariostudie voor Nederland in 2040. Centraal Planbureau, Milieu- en Natuurplanbureau en Ruimtelijk Planbureau, Den Haag.

Dale, V.H. (1997) The relationship between land-use change and climate change. Ecological Applications 7(3): 753-769.

De Moel, H. (2008). Wateroverlast, achtergrondstudie voor de Hotspot Zuidplaspolder. Xplorelab Provincie Zuid-Holland, Den Haag, the Netherlands.

De Moel, H. and Aerts, J.C.J.H. (2011) Effect of uncertainty in land use, damage curves and inundation depth on flood damage estimates. Natural Hazards 58(1): 407-425.

De Moel, H., Aerts, J.C.J.H. and Koomen, E. (2011) Development of flood exposure in the Netherlands during the 20th and 21st century. Global Environmental Change 21(2): 620-627.

De Moel, H., Asselman, N.E.M., and Aerts, J.C.J.H. (under review). Uncertainty and sensitivity of coastal flood damage estimates in the west of the Netherlands. Submitted to Water Resources Research.

De Moel, H., Bouwer, L.M., Aerts, J.C.J.H. (in prep.). Uncertainty and sensitivity of fluvial flood risk calculations.

De Moel, H., Van Alphen, J. and Aerts, J.C.J.H. (2009) Flood maps in Europe – methods, availability and use. Natural Hazards and Earth System Sciences 9: 289-301.

De Waard, R. (2005) Simlandscape. Een ontwerp en onderzoek ondersteunend systeem voor planning, gebaseerd op de scenariomethode en kadastraal GIS. Universiteitsdrukkerij Technische Universiteit Twente.

Dekkers, J.E.C. and Koomen, E. (2007) Land-use simulation for water management: application of the Land Use Scanner model in two large-scale scenario-studies. Chapter 20. In: Koomen, E., Stillwell, J., Bakema, A. and Scholten, H.J. (eds.), Modelling land-use change; progress and applications. Springer, Dordrecht, pp. 355-373.

Diogo, V., Koomen, E. and Van der Hilst, F. (2011). Second generation biofuel production in the Netherlands: a spatially-explicit exploration on the economic viability of a perennial biofuel crop. VU University Amsterdam.

Elings, C., Zijlstra, R., Koomen, E. and De Groot, S. (2011) Milieueffectrapport Ontwerp Structuurvisie Infrastructuur en Ruimte in opdracht van Ministerie van Infrastructuur en Milieu. Geodan/Royal Haskoning, Amsterdam/Nijmegen.

Hoymann, J. (2010) Spatial allocation of future residential land use in the Elbe River Basin. Environment and Planning B: Planning and Design 37(5): 911-928.

IPCC (2001) Impacts, Adaptation & Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, UK.

Jacobs, C.G.W. and Koomen, E. (2008) Globale ruimtelijke evaluatie van veiligheidsstrategieën. Achtergrond rapport voor de studie Aandacht voor Veiligheid. Vrije Universiteit, Amsterdam.

Jacobs, C.G.W. and Koomen, E. (2010) A GIS-assisted method for defining an integrated vision of a climate proof Groningen. In: Painho, M., Santos, M.Y. and Pundt, H. (eds.) Geospatial Thinking; Proceedings of AGILE 2010, The 13th AGILE International Conference on Geographic Information Science, Guimarães, Portugal.

Jacobs, C.G.W., Koomen, E. and Roggema, R. (2009) Towards an integrated vision of a climate proof Groningen. Provincie Groningen, Groningen.

Jacobs, C.G.W., Koomen, E., Bouwman, A.A. and Van der Burg, A. (2011) Lessons learned from land-use simulation in regional planning applications. Chapter 8. In: Koomen, E. and Borsboom-van Beurden, J. (eds.), Land-use modelling in planning practice. Springer, Heidelberg.

Koks, E.E., De Moel, H. and Koomen, E. (2011) Comparing extreme rainfall and large-scale flooding induced inundation risk; evidence from a Dutch case-study. In: Kumarasamy, M. (ed.), Water management. Intech, Rijeka, pp. in press.

Koomen, E. (2008) De evaluatie van landschap in ruimtegebruiksimulatie. Vrije Universiteit, Amsterdam. SPINlab Research Memorandum SL-08.

Koomen, E. (2009) Comparing climate change adaption research in Australia and the Netherlands; Review of the VCCAP project. VU University, Amsterdam.

Koomen, E. and Borsboom-van Beurden, J. (2011) Land-use modeling in planning practice. Springer, Heidelberg.

Koomen, E. and Jacobs, C.G.W. (2011) Ruimtegebruiksimulatie in de regionale beleidspraktijk. Rooilijn 44(4): 284-291.

Koomen, E. and Van der Hoeven, N. (2008) The Netherlands climate proof; what will the country look like in 2040? GeoInformatics 11(5): 26-27.

Koomen, E., Koekoek, A. and Dijk, E. (2011) Simulating Land-use Change in a Regional Planning Context. Applied Spatial Analysis and Policy doi:10.1007/s12061-010-9053-5.

Koomen, E., Loonen, W. and Hilferink, M. (2008) Climate-change adaptations in land-use planning; a scenario-based approach. In: Bernard, L., Friis-Christensen, A. and Pundt, H. (eds.), The European Information Society; Taking Geoinformation Science One Step Further. Springer, Berlin, pp. 261-282.

Kuhlman, T., Verburg, R., Van Dijk, J. and Phan-Drost, N. (2011) Biomass on peat soils? Feasibility of bioenergy production under a climate change scenario. Chapter 6. In: Koomen, E. and Borsboom-van Beurden, J. (eds.), Land-use modelling in planning practice. Springer, Heidelberg.

Lavalle, C., Baranzelli, C., Batista e Silva, F., Mubareka, S., Rocha Gomes, C., Koomen, E. and Hilferink, M. (2011) A High Resolution Land use/cover Modelling Framework for Europe: introducing the EU-ClueScanner100 model. In: Murgante, B., Gervasi, O., Iglesias, A., Taniar, D. and Apduhan, B.O. (eds.), Computational Science and Its Applications - ICCSA 2011, Part I, Lecture Notes in Computer Science vol. 6782. Springer-Verlag, Berlin, pp. 60-75.

Lloret, J.R., Omtzigt, N., Koomen, E. and De Blois, F. (2007) 3D visualisations in simulations of future land use: exploring the possibilities of new, standard visualisation tools. Paper for the joint workshop on Visualization and Exploration of Geospatial Data, ISPRS/ICA/DGfK, June 27-29, 2007 Stuttgart, Germany.

Lloret, J.R., Omtzigt, N., Koomen, E. and De Blois, F. (2008) 3D visualisations in simulations of future land use: exploring the possibilities of new, standard visualisation tools. International Journal of Digital Earth 1(1): 148-154.

Loonen, W. and Koomen, E. (2009) Calibration and validation of the Land Use Scanner allocation algorithms. PBL-report. Netherlands Environmental Assessment Agency, Bilthoven.

MNP (2008). Nature Balance 2008; summary. Netherlands Environmental Assessment Agency (MNP), Bilthoven, the Netherlands.

Mubareka, S., Koomen, E., Estreguil, C. and Lavalle, C. (2011) Development of a composite index of urban compactness for land use modelling applications. Landscape and urban planning doi:10.1016/j.landurbplan.2011.08.012.

Parry, M.L. (2000a) Assessment of Potential Effects and Adaptations for Climate Change in Europe: The Europe ACACIA Project. Jackson Environmental Institute, University of East Anglia, Norwich, UK.

Parry, M.L. (2000b) Scenarios for climate impact and adaptation assessment. G.Env.Change 12: 149-153.

Perez-Soba, M., Verburg, P.H., Koomen, E., Hilferink, M., Benito, P., Lesschen, J.P., Banse, M., Woltjer, G., Eickhout, B., Prins, A.-G. and Staritsky, I. (2010) Land use modelling - implementation; Preserving and enhancing the environmental benefits of “land-use services”. Final report to the European Commission, DG Environment. Alterra Wageningen UR/ Geodan Next/ Object Vision/ BIOS/ LEI and PBL, Wageningen.

Pontius Jr., R.G., Castella, J.-C., Clarke, K., De Nijs, T., Duan, Z., Fotsing, E., Goldstein, N., Kok, K., Koomen, E., Lippitt, C.D., McConnell, W., Pijanowski, B.C., Sood, A.M., Veldkamp, T.A. and Verburg, P.H. (2012) Lessons and challenges in land change modelling as revealed by map comparisons. In: Brouwer, F., Goetz, S. and Pontius Jr., R.G. (eds.), The dynamics of land use and ecosystem services; a transatlantic, multidisciplinary and comparative approach. Springer, Berlin.

Pouwels, R., Jochem, R., Reijnen, M.J.S.M., Hensen, S.R. and Van der Greft, J.G.M. (2002). LARCH voor ruimtelijke ecologische beoordelingen van Landschappen. Alterra-rapport 492. Alterra, Wageningen.
Province of Overijssel (2009) Plan-Milieueffectrapport Omgevingsvisie Overijssel. Geodan Next, Amsterdam.

Riedijk, A., Van Wilgenburg, R., Koomen, E. and Borsboom-van Beurden, J. (2007) Integrated scenarios of socio-economic change. SPINlab research memorandum SL-06. Vrije Universiteit Amsterdam, Amsterdam.

Ritsema van Eck, J. and Koomen, E. (2008) Characterising urban concentration and land-use diversity in simulations of future land use. Annals of Regional Science 42(1): 123-140.

Roggema, R., Steingröver, E., Van Rooij, S. and Troost, S. (2009). Naar klimaatbestendige Natuur en Water in Groningen. Hotspot klimaatbestendig omgevingsplan Groningen. Klimaat voor Ruimte.

Snepvangers J, Baake A, Van Rooij S and Steingröver E (2010). Groenblauwe netwerken in Hardenberg. Eindrapportage Fase 1. Alterra, Wageningen.

Snepvangers, J., A. Baake, S. van Rooij, & E. Steingröver (2011). Plannen met multifunctionele groenblauwe netwerken in Salland. Rapportnummer: Landschap Overijssel: LG-2011-01, Alterra rapport nummer 2176.

Steingröver E. & Van Rooij S. (2010). Plan-it: A method enabling regional stakeholders to design a green climate corridor: the Groningen case. In Fábos et al. (eds.) Proceedings of FABOS conference on Landscape and Greenway planning 2010, Budapest, pp: 318-325.

Steingröver, E., Van Eupen, M., Van Rooij, S. and Koomen, E. (in prep.). Climate Change And Nature, Integration Of Spatial Policies With A Land Use Model.

Te Linde, A.H., Bubeck, P., Dekkers, J.E.C., De Moel, H. and Aerts, J.C.J.H. (2011) Future flood risk estimates along the river Rhine. Natural Hazards and Earth System Sciences 11: 459-473.

Van den Hurk, B., Klein Tank, A., Lenderink, G., van Oldenborgh, G.J., Katsman, C., van den Brink, H., Keller, F., Bessembinder, J., Burgers, G., Komen, G., Hazeleger, W., Drijfhout, S. and van Ulden, A. (2006) KNMI Climate Change Scenarios 2006 for the Netherlands. KNMI Scientific Report WR 2006-01. KNMI, De Bilt.

Van der Hilst, F., Dornburg, V., Sanders, J.P.M., Elbersen, B., Van Dam, J.M.C. and Faaij, A.P.C. (2010) Potential, spatial distribution and economic performance of regional biomass chains: The North of the Netherlands as example. Agricultural Systems 103(7): 403-417.

Van der Hoeven, E. and Koomen, E. (2007) Watergestuurd ruimtelijk beleid. H2O 40(22): 14-16.

Van der Hoeven, E. and Koomen, E. (2008) Nederland Klimaatproof; LANDS-scenario's als hulpmiddel. Geografie 17(2): 21-23.

Van der Hoeven, E., Aerts, J., Van der Klis, H. and Koomen, E. (2009) An Integrated Discussion Support System for new Dutch flood risk management strategies. Chapter 8. In: Geertman, S. and Stillwell, J.C.H. (eds.), Planning Support Systems: Best Practices and New Methods. Springer, Berlin, pp. 159-174.

Van der Hoeven, E., Jacobs, C.G.W. and Koomen, E. (2008) Beknopte beschrijving van sociaaleconomische scenario's voor het jaar 2100. Vrije Universiteit, Amsterdam.

Van Eupen, M. (2009). Effect van Klimaatveranderingen op Natuur in de Ruimtescanner. Internal report WUR, Wageningen.

Van Rooij, S., Steingröver, E., Den Besten, J., & Van Hooff, E. (2009). Water en natuur: natuurlijke partners voor klimaatadaptatie. H2O 42 (25/26): 39-42.

Verbeek, K. (2003) De toestand van het klimaat 2003. KNMI.

Verburg, P.H., Lesschen, J.P., Koomen, E. and Perez-Soba, M. (2011) Simulating land use policies targeted to protect biodiversity in Europe with the CLUE-Scanner model. Chapter 6. In: Trisurat, Y., Shrestha, R.P. and Alkemade, R. (eds.), Land use, climate change and biodiversity modeling: perspectives and applications. IGI global, Hershey, PA, pp. 120-132.

Vonk, M., Vos, C.C. and Van der Hoek, D.C.J. (2010). Adaptatiestrategie voor een klimaatbestendige natuur. Planbureau voor de Leefomgeving (PBL), Den Haag/Bilthoven.

Vos, C.C., Berry, P., Opdam, P., Baveco, H., Nijhof, B., O'Hanley, J., Bell, C. and Kuipers, H. (2008). Adapting landscapes to climate change: identifying climate-proof ecosystem networks and priority adaptation zones. Journal of Applied Ecology 45: 1722–1731.

Vos, C.C., Van der Hoek, D.C.J. and Vonk, M. (2010). Spatial planning of a climate adaptation zone for wetland ecosystems. Landscape Ecology 25: 1465–1477.

Wagtendonk, A.J. (2011) Evaluating the loss of open space in land-use change simulation. Spinlab Research Memorandum SL-12. Vrije Universiteit Amsterdam/ SPINlab, Amsterdam.

Wagtendonk, A.J. and Koomen, E. (2010) Evaluating landscape impacts of climate mitigation using land-use simulation. In: Kabat, P. and Vellinga, P. (eds.) International conference Rotterdam, the Netherlands, 29 September-1 October. Abstracts Scientific Programme Deltas in Depth., pp. 210.

Watson, R.T., Noble, I.R., Bolin, B., Ravindranath, N.H.V.D.J. and Dokken, D.J.E. (2000) Land Use, Land-Use Change, and Forestry. A Special Report of the Intergovernmental Panel on Climatic Change. A special report of the IPCC. Cambridge University Press, Cambridge.

Appendix 1 Full overview of project-related publications

This appendix lists all project related publications. Many of them can be downloaded from the publications database on the website devoted to Climate research in the Netherlands, available on: http://climatechangesspatialplanning.climateresearchnetherlands.nl/publications/publication-database
This website also lists additional presentations, lectures and media attention related to this project.

Scientific journal papers

Borzacchiello, M.T., Nijkamp, P. & Koomen, E. (2010) Accessibility and urban development: a grid-based comparative statistical analysis of Dutch cities. Environment and Planning B: Planning and Design 37(1): 148-169.

Bouwer, L.M., Bubeck, P., Wagtendonk, A.J. & Aerts, J.C.J.H. (2009) Inundation scenarios for flood damage evaluation in polder areas. Natural Hazards and Earth System Sciences 9: 1995-2007.

De Moel, H. & J.C.J.H. Aerts (2011) Effect of uncertainty in land use, damage curves and inundation depth on flood damage estimates. Natural Hazards 58(1): 407-425.

De Moel, H., Aerts, J.C.J.H. & Koomen, E. (2011) Development of flood exposure in the Netherlands during the 20th and 21st century. Global Environmental Change 21(2): 620-627.

De Moel, H., Asselman, N.E.M., and Aerts, J.C.J.H. (in review). Uncertainty and sensitivity of coastal flood damage estimates in the west of the Netherlands. Submitted to Water Resources Research.

De Moel, H., Bouwer, L.M., Aerts, J.C.J.H. (in prep.). Uncertainty and sensitivity of fluvial flood risk calculations.

De Moel, H., J. van Alphen & J.C.J.H. Aerts (2009) Flood maps in Europe – methods, availability and use. Natural Hazards and Earth System Sciences 9: 289-301.

Gupta, J., K. van der Leeuw & H. de Moel (2007) Climate Change: A 'glocal' problem requiring 'glocal' action. Environmental Science 4(3): 139-148.

Koomen, E., Koekoek, A. & Dijk, E. (2011) Simulating Land-use Change in a Regional Planning Context. Applied Spatial Analysis and Policy 4 (4): 223-247. doi:10.1007/s12061-010-9053-52011.

Koomen, E., Rietveld, P. & De Nijs, T. (2008) Modelling land-use change for spatial planning support; Editorial. Annals of Regional Science 42 (1): 1-10.

Kuhlman, T., Diogo, V. and Koomen, E. Exploring the potential of reed as a bioenergy crop in the Netherlands. Biomass and Bioenergy (conditionally accepted).

Kummu, M., Ward, P. J., de Moel, H. & Varis, O. (2010) Is physical water scarcity a new phenomenon? Global assessment of water shortage over the last two millennia. Environmental Research Letters 5(3): 034006.

Lloret, J.Rodríguez, Omtzigt, A.Q.A., Koomen, E. & de Blois, F.S. (2008) 3D Visualisations in simulations of future land use: exploring the possibilities of new, standard visualisation tools. International Journal of Digital Earth 1(1): 148-154.

Mubareka, S., Koomen, E, Estreguil, C & Lavalle, C. (2011) Development of a composite index of urban compactness for land use modelling applications. Landscape and Urban Planning 103, 3-4: 303-317. doi:10.1016/j.landurbplan.2011.08.012.

Opdam, P. & Steingröver, E. (2008) Designing metropolitan landscapes for biodiversity: deriving guidelines from metapopulation ecology. Landscape journal 27 (1): 69-80.

Opdam, P. Steingröver, E. & van Rooij, S. (2006) Ecological networks: A spatial concept for multi-actor planning of sustainable landscapes. Landscape and Urban Planning 75 (3-4): 322-332.

Opdam, P., Pouwels, R., van Rooij, S., Steingröver, E. & Vos. C. (2008) Setting biodiversity targets in participatory landscape planning: introducing the ecoprofile approach. Ecology and society 13 (1): 20.

Querner, E.P. & H.M. Mulder (2007) Hydrological analysis for meeting climate change effects and European Water Framework Directive targets. Journal of Water and Land Development 11: 59-69.

Ritsema van Eck, J. & Koomen, E. (2008) Characterising urban concentration and land-use diversity in simulations of future land use, Annals of Regional Science, 42 (1): 123-140.

Steingröver, E., Van Eupen, M., Van Rooij, S. and Koomen, E. (in prep.). Climate Change And Nature, Integration Of Spatial Policies With A Land Use Model.

Te Linde, A.H., Bubeck, P., Dekkers, J.E.C., de Moel, H. & Aerts, J.C.J.H. (2011) Future flood risk estimates along the river Rhine. Natural Hazards and Earth System Sciences 11 (2): 459-473.

Ward, P.J., De Moel, H. and Aerts, J.C.J.H. (2011) How are flood risk estimates affected by the choice of return-periods? Natural Hazards and Earth System Sciences 11(12): 3181-3195.

Books, book chapters, dissertations

De Moel, H. & Aerts, J.C.J.H. (2008) Integration of Spatial Planning and Flood Management in European Research. Chapter 9 in: Timmerman, J.G., Pahl-Wostl, C. & Moltgen, J. (eds.). Adaptiveness of IWRM - analysing European IWRM research. IWA Publishing, Londen, United Kingdom, pp.129-140.

Dekkers, J.E.C. & Koomen, E. (2007) Land-use simulation for water management: application of the Land Use Scanner model in two large-scale scenario-studies. Chapter 20 in: Koomen, E., J. Stillwell, A. Bakema & H. Scholten (eds.), Modelling land-use change; progress and applications, Springer, Dordrecht, pp: 355-373.

Jacobs, C.G.W., Koomen, E., Bouwman, A. & van den Burg, A. (2011) Lessons learned from using land-use simulation in regional planning. Chapter 8 in Koomen, E. & Borsboom-van Beurden, J. (eds.) Land-use modelling in planning practice. GeoJournal Library Vol. 101, Springer, Dordrecht, pp: 131-149.

Koekoek, A., Koomen, E., Loonen, W. & van Dijk, J. (2011) Simulation of future land use for developing a regional spatial strategy; the case of the Province of Overijssel. Chapter 7 in Koomen, E. & Borsboom-van Beurden, J. (eds.) Land-use modelling in planning practice. GeoJournal Library Vol. 101, Springer, Dordrecht, pp: 117-130.

Koomen, E. (2008) Spatial analysis in support of physical planning, dissertation, Vrije Universiteit Amsterdam.

Koomen, E. & Borsboom-van Beurden, J. (2011) Land-use modelling in planning practice, GeoJournal Library Vol. 101, Springer, Dordrecht.

Koomen, E. & Stillwell, J. (2007) Modelling land-use change: theories and methods. Chapter 1 in: Koomen, E., J. Stillwell, A. Bakema & H. Scholten (eds.), Modelling land-use change; progress and applications, Springer, Dordrecht, pp. 1-21.

Koomen, E., Hilferink, M. & Borsboom-van Beurden, J. (2011) Introducing Land Use Scanner. Chapter 1 in Koomen, E. & Borsboom-van Beurden, J. (eds.) Land-use modelling in planning practice. GeoJournal Library Vol. 101, Springer, Dordrecht, pp. 3-21.

Koomen, E., Loonen, W. & Hilferink, M. (2008) Climate-change adaptations in land-use planning; a scenario-based approach. Chapter in: Bernard, L., Friis-Christensen, A., and Pundt, H. (eds.) The European Information Society; Taking Geoinformation Science One Step Further. Springer, Heidelberg: pp.261-282.

Koomen, E., Stillwell, J., Bakema, A. & Scholten, H.J. (2007) Modelling land-use change; progress and applications, GeoJournal Library, Vol. 90, Springer, Berlin.

Kuhlman, T., Verburg, R., van Dijk, J. & Phan-Drost, N. (2011) Biomass on peat soils? Feasibility of bio energy production under a climate change scenario. Chapter 6 in Koomen, E. & Borsboom-van Beurden, J. (eds.) Land-use modelling in planning practice. GeoJournal Library Vol. 101, Springer, Dordrecht, pp: 97-116.

Van der Hoeven, N., Aerts, J., Van der Klis, H. & Koomen, E. (2009) An Integrated Discussion Support System for New Dutch Flood Risk Management Strategies. Chapter 8 in: Geertman, S. & Stillwell, J.C.H. (eds.) Planning Support Systems: Best Practices and New Methods, Springer, Berlin. GeoJournal library vol. 95, pp: 159-174.

Van 't Klooster, S., van Drunen, M. & Koomen, E. (2011) Socio-Economic Scenarios in Climate Adaptation Studies. Chapter 3 in Aerts, J., Botzen, W., Bowman, M.J., Ward, P.J., Dircke, P. (eds.) Climate Adaptation and flood risk in coastal cities, Earthscan, Oxford/New York, pp: 27-51.

Verburg, P.H., Lesschen, J.P., Koomen, E. & Perez-Soba, M. (2011) Simulating land use policies targeted to protect biodiversity in Europe with the CLUE-Scanner model, Chapter in Trisurat, Y., Shrestha, R.P., Alkemade, R. (eds.) Land Use, Climate Change and Biodiversity Modeling: Perspectives and Applications, IGI Global, Hershey, PA, USA., pp: 120-132.

Scientific papers in proceedings

Bubeck, P., te Linde, A., Dekkers, J.E.C. & Ward, P. (2010) Flood risk developments and adaptation strategies in the Rhine-Meuse delta, in: Kabat, P., Vellinga, P. (eds.), Abstracts Scientific Programme Deltas in Depth, International conference Rotterdam, the Netherlands, 29 September-1 October: 261.

De Moel, H. & J.C.J.H. Aerts (2008) Flood maps in Europe: a comparative evaluation of methods, availability and application, 4th International Symposium on Flood Defence: Managing Flood Risk, Reliability and Vulnerability. 6–8 May, Toronto, Canada.

Jacobs, C., Koomen, E. & Roggema, R. (2009) Integratie van sectorale adaptatiemaatregelen voor een klimaatbestendige provincie. In: Abstractbundel RPB Ruimteconferentie 2009.

Jacobs,C. & Koomen,E. (2010) A GIS-assisted method for defining an integrated vision of a climate proof Groningen. In: Painho, M., Santos, M.Y. & Pundt, H. (eds.) Geospatial Thinking; Proceedings of AGILE 2010. The 13th AGILE International Conference on Geographic Information Science, Guimarães, Portugal.

Koomen, E. & Loonen, W. (2007) Exploring integrated scenarios of socio-economic and climate change in the Netherlands, Paper for the TransAtlantic Land Use Conference (TALUC), Washington, DC, September 2007. http://nercrd.psu.edu/taluc/

Koomen, E. & Ritsema van Eck, J. (2007) Measuring urban concentration and land-use diversity in maps of simulated future land use. In: Bunce, R.G.H., Jongman, R.H.G., Hojas, L., Weel, S. (eds.) 25 years Landscape Ecology: Scientific Principles in Practice - Part 2. Proceedings of the 7th IALE World Congress, Wageningen, the Netherlands, 8-12 July.2007. IALE publications series 4: 864-865.

Koomen, E. (2009) Integration of spatially explicit climate-adaptation measures with a land use model, IOP Conf. Series: Earth and Environmental Science 6, 342011.

Koomen, E., Loonen, W. & Kuijpers-Linde, M. (2007) Localising the land-use impact of global climate change; integration of sector-specific adaptation measures with the Land Use Scanner, in: Framing Land Use Dynamics II - abstractbook. International conference, Addink, E., Barendregt, A., Ettema, D., Karssenberg, D., de Nijs, T., FLUD-II, Utrecht University, the Netherlands, 18-20 April.2007.

Kuhlman, T., Koomen, E. & Kram, T. (2010) Exploring the potential for biofuel crops in the Netherlands. In: Kabat, P. & Vellinga, P. (eds.) Abstracts Scientific Programme Deltas in Depth. International conference Rotterdam, the Netherlands, 29 September-1 October: 149-150.

Loonen, W., Koomen, E. & Kuijpers-Linde, M. (2007). Calibrating and validating the Land Use Scanner algorithms. Paper presented at the 15TH European Colloquium on Theoretical and Quantitative Geography, ECTQG 2007, Montreux, Switzerland, 7-11 September 2007.

Rodríguez, J., N. Omtzigt, E. Koomen & F. de Blois (2007) 3D Visualisations: a new tool to decisions making, paper to be presented at the Visualization and Exploration of Geospatial Data session at the ISPRS2007 conference in Stuttgart, Germany, June 27-29, 2007.

Steingröver, E. & Van Rooij S. (2010) Plan-it: A method enabling regional stakeholders to design a green climate corridor: the Groningen case. In Fábos et al. (eds.) Proceedings of FABOS conference on Landscape and Greenway planning 2010, Budapest, pp: 318-325.

Van Eupen, M., Van Rooij, S., Steingrover, E. & Koomen, E. (2010) Climate change and nature, integration of spatial policies with a land use model. In: Kabat, P. & Vellinga, P. (eds.) Abstracts Scientific Programme Deltas in Depth. International conference Rotterdam, the Netherlands, 29 September-1 October: 148-149.

Van Rooij, S. (2009) Bij klimaatverandering zijn waterschappen belangrijk voor flora en fauna, Digitale syllabus van 'De Nationale Waterconferentie', www.watercongres.nl.

Verweij, P.J.F.M., van Eupen, M., Roos-Klein Lankorst, J. & Nieuwenhuizen, W. (2009) Tools for transparent spatial integrated assessments. In: van Ittersum, M.K., Wolf, J., van Laar, H.H. (eds.), AgSAP conference 2009. Wageningen University and Research Centre, The Netherlands, Egmond aan Zee, The Netherlands, pp. 340-341.

Wagtendonk, A. & Koomen, E. (2010) Evaluating landscape impacts of climate mitigation using land-use simulation. In: Kabat, P. & Vellinga, P. (eds.) Abstracts Scientific Programme Deltas in Depth. International conference Rotterdam, the Netherlands, 29 September-1 October: 210.

Posters

De Moel, H. & Aerts, J.C.J.H. (2007) Flood risk mapping in Europe: A comparative evaluation of methods, availability and applications, EGU General Assembly 15-20 april 2007, Vienna.

De Moel, H. & J.C.J.H. Aerts (2007) Flood Risk Mapping in Europe – A comparative analysis of methods, availability and use, Climate changes Spatial Planning Conference, 12-13 September 2007, The Hague.

De Moel, H., Aerts, J.C.J.H. & Asselman, N. (2010). Uncertainty and sensitivity of current and future flood damage assessments. Poster presented at the conference "Deltas in times of climate change", Rotterdam, the Netherlands, 29 September – 1 October 2010.

Kuhlman T., Phan-Drost N., Verburg R., & Van Dijk J.J., (2009) Biomass on peat soils? Feasibility of bioenergy production under a climate change scenario. Poster for the 15th annual conference The International Sustainable Development Research Society (ISDRS); Taking up the Global Challenge: Analysing the implementation of innovations and governance for sustainable development. July 5-8, 2009, Utrecht, The Netherlands.

Van der Hoeven, E. & Koomen, E. (2007) LANDS: Land-use and climate change. Integration of sector-specific climate adaptation measures with the Land Use Scanner. Poster presented at the CCsP conference September 13, 2007, The Hague, the Netherlands.

Reports

Aerts, J., Sprong, T., Bannink, B., Bessembinder, J., Koomen, E. Jacobs, Ch., Van der Hoeven, N. Huitema, D., Van 't Klooster, S., Veraart, J., Walraven, A., Jonkman, S.N., Maaskant, B., Bouwer, L.M., De Bruijn, K., Oosterveld, E., Schuurman, H., Peters, K., Ottevanger, W., Immerzeel, W., Droogers, P., Kwadijk, J., Kind, J., Voogt, L., Van der Klis, H., Dellink, R., Affolter, F., Bubeck, Ph., Van der Meulen, M., De Lange, G., Bregman, B., Van den Brink, H., Buiteveld, H., Drijfhout, S., Feijt, A., Hazeleger, W., Van den Hurk, B., Katsman, C., Kattenberg, A., Lenderink, G., Meijgaard, E., Siegmund, P., De Wit, M. & Naples, M. (2008) Aandacht voor Veiligheid, Leven met Water, Klimaat voor Ruimte, DG Water, Rapportnummer: 009/2008.

Blom-Zandstra, G., H. Goossen, H. Korevaar, E. Steingröver, C. Grashof Bokdam & P. Opdam (2010) Multifunctioneel landgebruik voor klimaatadaptatie in Het Groene Woud. Rapport 335, Plant Research International, Wageningen.

BRANCH partnership (2007). Planning for biodiversity in a changing climate – BRANCH project final report, Natural England, UK.

Bubeck, P. & Koomen, E. (2008) The use of quantitative evaluation measures in land-use change projections; An inventory of indicators available in the Land Use Scanner. Spinlab Research Memorandum SL-07. Vrije Universiteit Amsterdam/ SPINlab, Amsterdam.

De Moel, H. (2008) Wateroverlast, achtergrondstudie voor in Hotspot Zuidplaspolder, Xplorelab Provincie Zuid-Holland, Den Haag, the Netherlands.

De Moel, H., De Haan, E.R. & van Steekelenburg, M.G.N. (2008) Klimaatverandering, achtergrondstudie voor in Hotspot Zuidplaspolder, Xplorelab Provincie Zuid-Holland, Den Haag, the Netherlands.

Diogo, V., Koomen, E. and Van der Hilst, F. (2011). Second generation biofuel production in the Netherlands: a spatially-explicit exploration on the economic viability of a perennial biofuel crop. VU University Amsterdam.

Geertsema, W., R. Bugter, M. van Eupen, S. van Rooij, T. van der Sluis & M. van der Veen (2009) Robuuste Verbindingen en Klimaatverandering. Alterra-rapport. In opdracht van ministerie van LNV.

Hommel, P., S. van Rooij, R. de Waal, F. de Vries & C. Goossen (2005). Bos in Water, Water in Bos. Kansenkaarten voor multifunctionele natte bossen met meerwaarde voor waterbeheer, natuurwaarde en recreatie. Alterra-rapport 1267. Wageningen.

Jacobs, C.G.W., Koomen, E. & Roggema, R. (2009) Towards an integrated vision of a climate proof Groningen. Provincie Groningen, Groningen.

Koomen, E. (2008) De evaluatie van landschap in ruimtegebruiksimulatie. Spinlab Research Memorandum SL-08, Vrije Universiteit, Amsterdam.

Koomen, E. (2009) Comparing climate change adaption research in Australia and the Netherlands; Review of the VCCAP project, Vrije Universiteit Amsterdam.

Koomen, E., Kuhlman, T., Loonen, W. & Ritsema van Eck, J. (2005) De Ruimtescanner in 'Ruimte voor landbouw'; data- en modelaanpassingen.

Loonen, W. & Koomen, E. (2009) Calibration and validation of the Land Use Scanner allocation algorithms, PBL publication number 550026002, Netherlands Environmental Assessment Agency (PBL), Bilthoven.

Mudgal, S., Benito, P. & Koomen, E. (2008) Modelling of EU land-use choices and environmental impacts - Scoping study. Final report and appendices. EC-DG Environment/BIO Intelligence Service, Brussels/Ivry-sur-Seine.

Opdam, P & R. Pouwels (2006). De ecologische hoofdstructuur en klimaatverandering: waar kunnen we het beste investeren in meer ecologische veerkracht? Alterra-rapport 1311. Wageningen.

Riedijk, A., van Wilgenburg, R., Koomen, E. & Borsboom-van Beurden, J.A.M. (2007) Integrated scenarios of socio-economic and climate change; a framework for the 'Climate changes Spatial Planning' program. Spinlab Research Memorandum SL-06, Vrije Universiteit, Amsterdam.

Roggema, R., E. Steingröver, S. van Rooij & S. Troost (2009) Naar klimaatbestendige Natuur en Water in Groningen. Hotspot klimaatbestendig omgevingsplan Groningen. Klimaat voor Ruimte.

Snepvangers J, Baake A, Van Rooij S & Steingröver E (2010) Groenblauwe netwerken in Hardenberg. Eindrapportage Fase 1, Alterra, Wageningen.

Snepvangers, J., A. Baake, S. van Rooij, & E. Steingröver (2011). Plannen met multifunctionele groenblauwe netwerken in Salland. Rapportnummer: Landschap Overijssel: LG-2011-01, Alterra rapport nummer 2176.

Stuijfzand, S. & R. van Ek (eds.) (2007) Onderzoek naar effecten van waterberging in een jong kleibos. Achtergrondrapport Harderbos. RWS Waterdienstrapport nr. 2007.015, Alterra-rapport 1630.

Van den Bergh, D., Berendsen, R., Gerritsen, M., Mes, R., Van Nistelrooij, H., Koomen, E. & Loonen, W. (2009) Ruimtelijke klimaatscan; Methodiek ontwikkeling, case Zuid Holland, Xplorelab, provincie Zuid Holland, Den Haag.

Van der Hoeven, N., Jacobs, C. & Koomen, E. (2008) Beknopte beschrijving van sociaal-economische scenario's voor het jaar 2100. Studie in het kader van het project Aandacht voor veiligheid. Vrije Universiteit Amsterdam.

Van Eupen, M. (2009) Effect van Klimaatveranderingen op Natuur in de Ruimtescanner. Intern rapport WUR, Wageningen.

Van Hussen, K. (2010) Wateroverlast in stedelijk gebied ten gevolge van extreme neerslag; een quickscan voor de intrinsieke gevoeligheid voor wateroverlast . Bachelor thesis Earth and Economics, VU University Amsterdam. Supervised by Eric Koomen and Hans de Moel.

Van Leeuwen, E., Koetse, M., Koomen, E. & Rietveld, P. (2009) Spatial economic research on climate change and adaptation; Literature review for 'Knowledge for Climate', KfC report number KfC 002/09, Vrije Universiteit Amsterdam.

Van Rooij, S., H. Baveco, R. Bugter, M. van Eupen, P. Opdam & E. Steingröver (2007) Adaptation of the landscape for biodiversity to climate change. Terrestrial case studies: Limburg (NL), Kent and Hampshire (UK). Alterra report 1543.

Van Rooij, S.A.M. & Steingröver, E.G. (2010) Winst door combinatie van water- en natuuradaptatie: Groningen. In: Vonk, M., Vos, C.C. & Van der Hoek, D.C.J. (eds.), Adaptatiestrategie voor een klimaatbestendige natuur. Planbureau voor de Leefomgeving (PBL), Den Haag/Bilthoven, pp 83- 87.

Wagtendonk (2011). Evaluating the loss of open space in land-use change simulation. Spinlab Research Memorandum SL-12, Vrije Universiteit, Amsterdam.

Publications in popular magazines

Anonymus (2007) De EHS komt nooit af, Resource Magazine.

Anonymus (2007) Dieren trekken noordoostwaarts door ander klimaat, RO-Magazine.

Anonymus (2007) Dieren trekken noordoostwaarts door ander klimaat, Agri Holland magazine.

Bugter, H., B. van Noorden, H. van Steenwijk & C. Vos (2007) Klimaatverandering en versnippering een slechte combinatie. Bos, Natuur en Landschap 4(8), pp: 24-27.

De Moel, H. (2009) Uncertainties in flood damage assessment. In Heinen, M. (ed.) Climate research Netherlands - Research highlights. Programme office Climate changes Spatial Planning, Amsterdam, p. 37.

Hommel, H., van Rooij, S., Olsthoorn, A. (2007) Ruimte voor Water, kansen voor nieuwe natte bossen. Bos, Natuur en Landschap, pp: 2-6.

Koomen, E. & Van der Hoeven, E (2008) The Netherlands climate proof; what will the country look like in 2040? GeoInformatics 11 (5): 26-27.

Koomen, E. (2005) De toekomst van Noord-Holland; simulatie van veranderend ruimtegebruik met de Ruimtescanner, Agroinformatica, 2, pp: 17-21.

Koomen, E. (2006) De toekomstige inrichting van Nederland, Klimaatmagazine, p.27.

Koomen, E., Jacobs, C.G.W. (2011) Ruimtegebruiksimulatie in de regionale beleidspraktijk. Rooilijn 44 (4): 284-291.

Looman, B. (2009) Ruimtelijke ontwikkelingen in perspectief, praktische studies helpen beleidsmakers bij het maken van beleid. Interview met promovendus Eric Koomen, Bouw+Uitvoering 41 (1): 22-27.

Semeijn, B. (2010) Nederland in 2050: wijnland of woestijnland? Weermagazine 11,4: 16-19.

Van der Hoeven, E & Koomen, E. (2007) Watergestuurd ruimtelijk beleid. H2O, tijdschrift voor watervoorziening en waterbeheer 40 (22): 14-16.

Van der Hoeven, E & Koomen, E. (2008) Nederland Klimaatproof LANDS-scenario's als hulpmiddel, Geografie 17 (2): 21-23.

Van Rooij, S., Steingröver, E., Den Besten, J., & Van Hooff, E. (2009). Water en natuur: natuurlijke partners voor klimaatadaptatie. H2O, tijdschrift voor watervoorziening en waterbeheer 42 (25/26): 39-42.

Climate changes Spatial Planning

Climate change is one of the major environmental issues of this century. The Netherlands are expected to face climate change impacts on all land- and water related sectors. Therefore water management and spatial planning have to take climate change into account. The research programme 'Climate changes Spatial Planning', that ran from 2004 to 2011, aimed to create applied knowledge to support society to take the right decisions and measures to reduce the adverse impacts of climate change. It focused on enhancing joint learning between scientists and practitioners in the fields of spatial planning, nature, agriculture, and water- and flood risk management. Under the programme five themes were developed: climate scenarios; mitigation; adaptation; integration and communication. Of all scientific research projects synthesis reports were produced. This report is part of the Integration series.

Integration

The question is how to increase the 'adaptive capacity' of our society. Analysis of the adaptive capacity is related to the physical component (the feasibility of physical spatial adaptation) and to the existing institutional structures. Areas Climate changes Spatial Planning dealt with are: uncertainties and perceptions of risk; institutional capacity to deal with climate change; the use of policy instruments; and cost benefit analysis. Adaptation strategies must be in line with the current institutional structures of a policy area. For a proper decision process we developed decision support tools, such as socio-economic scenarios, the Climate Effect Atlas and other assessment frameworks.

Programme Office Climate changes Spatial Planning

P.O. Box 1072
3430 BB Nieuwegein
The Netherlands
T +31 30 6069 780

c/o Alterra, Wageningen UR
P.O. Box 47
6700 AA Wageningen
The Netherlands
T +31 317 48 6540
info@klimaatvoorruimte.nl

www.climatechangesspatialplanning.nl