The use of quantitative evaluation measures in land-use change projections

an inventory of indicators available in the *Land Use Scanner*

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Colofon

Title

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Contents

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 and supply for space, as well as the suitability of space for certain uses (Beinat and Nijkamp, 1998). 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 land use 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 demand and supply of space 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); and
- the extra demand for space as a result of adaptation strategies within various sectors.

Obviously, climatic 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., 2006). 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. Prolonged droughts and other extreme weather are other examples of climatic changes that impact the economy.

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).

The research programme '*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 in the Netherlands. The research programme is centered on four main research themes:

- climate scenarios: climate scenarios and climate data management for decision support in spatial planning;
- mitigation: decreasing greenhouse gas emissions in relation to land use and spatial planning;
- adaptation: dealing with the effects of climate change in spatial planning;
- integration: methods for research exchange and integration.

The current Report is written as part of the Integration Project 'Land Use and Climate Change' (LANDS) of the 'Climate Changes Spatial Planning Programme'. The project seeks at identifying climate-change driven spatial changes in land use and land development, and to integrate changes in agriculture, industry, housing and nature sectors into balanced national visions and regional solutions.

After providing a brief description of the model used to simulate land-use change and the set of scenarios underlying these projections the present report will focus on the indicators that are currently used in combination with the *Land Use Scanner* output.

The Land Use Scanner model

The *Land Use Scanner* is a spatial model that aims to simulate future land use. It offers an integrated view of all types of land use including urban, natural and agricultural functions. Since the development of its first version it has been applied in a large number of policy-related research projects focusing on the Netherlands (Dekkers and Koomen, 2007; Koomen et al., 2005a) and several European countries (Hartje et al., 2005; Schotten et al., 2001; Wagtendonk et al., 2001). For an extensive overview of all *Land Use Scanner* related publications the reader is referred to www.lumos.info.

In contrast to most other land-use allocation models, the *Land Use Scanner* uses both different socio-economic scenarios and climate models as an input in various sector specific models. These are subsequently fed into the *Land Use Scanner* model for simulating future land use. The *Land Use Scanner* is a GIS-based model that is based on demand-supply interaction for land, with sectors competing for allocation within suitability and policy constraints. Thus, the *Land Use Scanner* not only addresses proportional changes in land-use patterns but also simulates the locational allocation of land-use change. Land-use simulations are generally scenario driven, with series of coherent assumptions regarding variables such as economic growth or the level of government intervention, determining the way the land demand-supply unfolds (Borsboom-van Beurden et al., 2007; Koomen et al., 2005a). This input is derived from various sector-specific regional models of specialized institutes and consulted experts.

Currently, the *Land Use Scanner* is available in two different calibrated versions, which are referred to as 'continuous' and 'discrete'. The 'continuous' model configuration operates on a 500 metre resolution. It results in a continuous description of land use per cell. The resulting maps describe for each cell the relative proportion of all land-use types within this grid cell. This approach has previously also been described as probabilistic to reflect that the outcomes essentially describe the probability that a certain land use will be allocated to a specific function (Loonen and Koomen, 2008). The 'discrete' model-configuration applies a 100-metre grid, covering the terrestrial Netherlands in about 3.3 million cells, thus offering a very detailed view on possible spatial patterns in the future. The high resolution, which comes close to the size of actual building blocks allows for the use of homogenous grid cells that only describe the dominant land use. Therefore, the new model-configuration is referred to as 'discrete' model, as it uses a discrete description of land use per cell. The amount and kind of land-use classes can generally be customized depending on the area of interest or level of detail required. Momentarily, both versions distinguish 17 land-use types, out of which the model allocates 11. The remaining six land-use types, mainly related to infrastructure and water, have a pre-defined location that is not influenced by model-simulation. Their location is either a continuation of current land use or consists of pre-defined, approved plans, as is the case with, for example, long-planned railway links.

For a more detailed description of the most recent model version and its calibration and validation the reader is referred to other publications (Loonen and Koomen, 2008).

The LANDS Scenarios

The two integrated scenarios that are used in the LANDS projection are referred to as *G-* and *W-Scenario*. The main characteristics of these scenarios are described below. A detailed description of both scenarios also explaining the derivation of the specific scenario assumptions is provided elsewhere (Koomen et al., 2008a; Riedijk et al., 2007).

The *W-Scenario* combines the socio-economic *Global Economy* scenario from the prosperity and habitat study (CPB et al., 2006) and the warm climate scenario of KNMI (Van den Hurk et al., 2006). The scenario assumes a high population growth in combination with a high economic growth. The EU will expand to the east. Trade will flow freely without political integration. No initiatives are taken on the international level to come to environmental agreements. Infrastructure such as rail- and motorways are extended.

The *G-Scenario* combines the *Regional Communities* scenario from the prosperity and habitat study (CPB et al., 2006) and the moderate climate scenario of KNMI (Van den Hurk et al., 2006). The scenario assumes a moderate population growth until 2010 and a slight decline thereafter in combination with a modest economic growth. Unemployment is considered high. Trade between countries is restricted and the government collects environmental taxes. An emphasis is put on national environmental policies and public awareness for environmental concerns increases. Infrastructure such as rail- and motorways is extended.

Based on these assumptions, the *Land Use Scanner* calculates land-use change projections for both scenarios for the year 2040. The results of the simulation process are shown in Figure 1. (Fore more detail also refer to Riedijk et al., 2007).

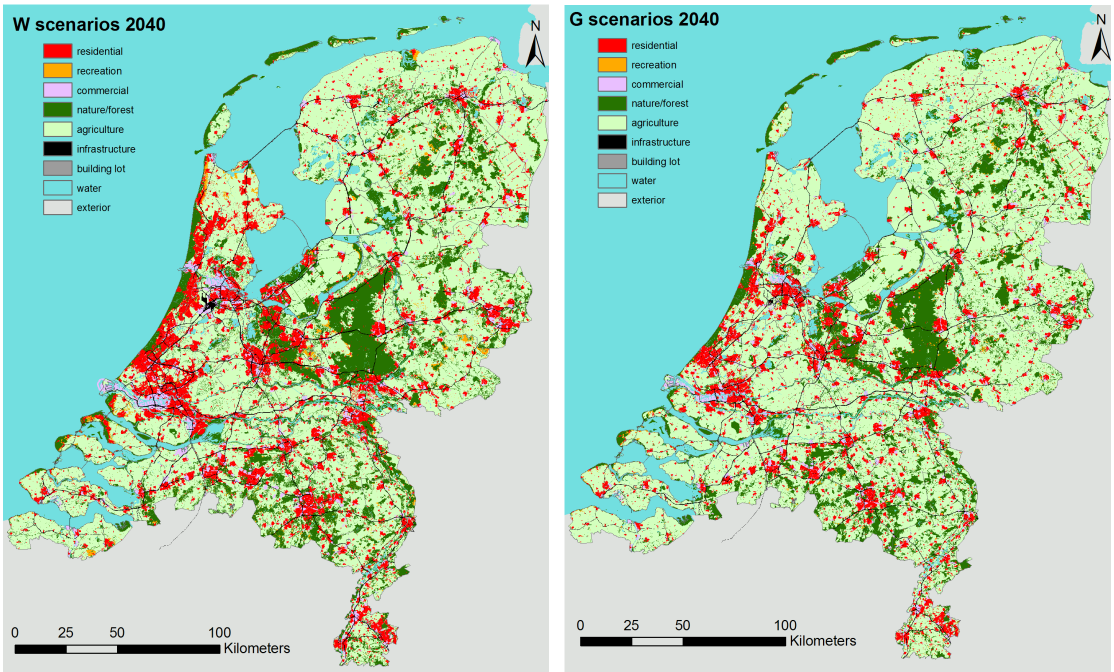

Figure 1: Simulated land use for the *G-* and *W-* Scenarios for the year 2040.

Evaluating land-use change simulations

It has been experienced that these land-use simulations often result in attractive and very detailed maps, indicating possible future land use. This also holds true for the projections of the *Land Use Scanner*, as can be seen in Figure 1. At first, these maps are highly interesting. However, it is often difficult to precisely interpret the results, differences and detailed information stored in these maps. This is also the case for the maps produced by the *Land use Scanner*, which operates on such a high resolution of a 100 metre grid and distinguishes 17 different land-use types. 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, the *Land Use Scanner* possesses a number of such quantitative indicators, which can provide insights about the way the allocation of future land use takes place.

The aim of this report is to provide a description of the indicators available in the *Land Use Scanner* and to demonstrate which information can be derived from these indicators. Where applicable, the results obtained for the *W- and G-Scenarios* will be discussed for each of the indicators.

Currently, several indicators are available for three different scale levels in the *Land Use Scanner*: 'Global', 'Regional' and 'Local'. The resulting output consists either of tables or map layers. The content of the tables can easily be exported to an excel sheet. Maps can be easily exported as bitmaps or ASCII grids and thus imported in a Geographical Information System (GIS). An overview of existing indicators is given below. After a short description is provided for each of the indicators, special attention is paid to how the indicators could be possibly used for evaluating the land-use projections. The results of the allocation process according to the specific indicators are discussed for both the *G-Scenario* and the *W-Scen*ario.

Furthermore, the report also presents an additional indicator, which, among other input parameters, makes use of the land-use change projections to assess damages from potential floods under different socio-economic and climate change scenarios. Finally, a separate set of sustainability indicators is discussed that has been applied in a recent study by the Netherlands Environmental Assessment Agency (MNP) in a study called 'Nederland Later' (MNP, 2007).

2 Global Indicators

The indicators listed under *Global* refer to the entire *Land Use Scann*er grid and are all represented as tables. The extent of this grid is larger than the territory of the Netherlands and also comprises parts of neighbouring countries. The global indicators are described in the following section. A summary of these indicators is provided in Appendix 1.

2.1 *Current Land Use*

This table shows the amount of the changeable land-use types for the present situation in hectares. The base year is 2010 since land use patterns can be well predicted for this period. Explicit land-use plans, mainly taken from the new map of the Netherlands survey (NIROV, 2005) are included in the simulation to represent autonomous developments. Thus, the advantage of choosing 2010 as the base year is that existing spatial plans, for example concerning urban development, are already incorporated.

2.2 *Allocated Land Use*

The indicator 'Allocated Land Use' shows the total amount of hectares assigned to the respective land-use types according to both scenarios for the year 2040. These tables allow a proportional comparison of the simulation results between the *G*- and the *W-Scenario* as well as a comparison to the base year (2010). By comparing these tables it can be seen, for example, that the *W-Scenario* shows a much larger increase in residential areas. While the land-use type 'Residential – high density' increases by 1,290 hectares in the *G-Scenario,* the *W-Scenario* shows an increase of 34,337 hectares compared to the present situation. The same development can be observed regarding economic development. While the land use type 'Commercial' shows a decline in the *G-Scenario* by 12,413 hectare, it increases by 14,353 hectare in the *W-Scenario* (Appendix 1). These differences follow the scenario assumptions which assume a much larger demand for commercial and residential land use in the *W-Scenario* due to the high economic and population growth (Riedijk et al., 2007).

2.3 *Weighted Mean Suitability*

The suitability is a crucial component in the allocation of future land use. The suitability of a grid cell can be interpreted as the net benefits (benefits minus costs) that a land-use function derives from that specific location and are expressed in Euros per square metre. The higher the suitability for a specific land-use type, the higher the probability that the cell will be used for the respective type. For every location the suitability or attractiveness for different land-use types is described, based on a number of site specific characteristics. The factors, influencing this suitability can be divided into three groups:

- present land use;
- policy maps; and
- thematic groups.

The value of a grid cell in a suitability map can also be negative indicating that the cell is highly unsuitable for a certain land use. This could e.g. be the case for a grid cell in a national park for the land-use type 'Commercial'.

The 'WeightedMeanSuitability' indicator shows the average suitability value of all allocated grid cells of a specific land-use type. It reveals to what extent the demand of a particular land-use function could be allocated to grid cells, which are considered suitable for the respective land-use type. The indicator can thus be used to optimize the suitability maps and to make sure, that enough suitable locations for a specific land-use type are defined.

The present configuration for example shows for the land-use type 'Residential - High Density' an average suitability value of 11.9 for the *W-Scenario* and 4.2 for the *G-Scenario* (Appendix 1). In comparison to other land-use types, these numbers seem to be too low considering the high economic power of this specific land-use type. Due to the high economic power, the mean suitability value should be higher in this case. The low value indicates that not enough locations (grid cells) have been defined as suitable for 'Residential – High Density' in the current suitability maps.

By contrast, the land-use function 'Commercial' shows much higher mean suitability values with 25.9 for the *W-* and 18.1 for the *G-Scenario*. This reveals that the demand for commercial land-use functions could be matched with a larger amount of suitable grid cells in the course of the allocation process than it was the case for 'Residential-High Density'.

2.4 Weighted Standard Deviation Suitability

This indicator provides information about the variance of the suitability values of allocated grid cells for a particular land-use type. It explains how widely all the suitability values are spread around the mean in the respective data set. The indicator thus helps to closer examine the mean suitability value and to assess the (relative) expressiveness of these values. The expressiveness of a suitability map indicates the purchasing power of the related land use type. Appendix 1 shows that land-use functions with a high economic power show a larger standard deviation than those with a lower one.

2.5 Minimum Claims

This indicator shows the minimum amount of hectares that must be allocated per land-use type by the *Land Use Scanner* model. In this respect, it defines a lower boundary of hectares to be allocated for each land-use type. The tables for the *G-scenario* and the *W-Scenario* show that all land-use types have a minimum claim except for 'Agriculture – arable land', 'Agriculture-Grassland' and 'Construction Grounds'. This reflects the assumption that agricultural functions will face continuing demand for space especially from residential and commercial functions. Competition will be high since the market values for these sectors are much higher than for agriculture. It can also be seen that minimum claims for the land-use type 'Commercial' is larger in the *W-Scenario*, reflecting the scenario assumptions of a higher economic and population growth (Riedijk et al., 2007).

2.6 Maximum Claims

This table represents the maximum amount of hectares that can be allocated per land-use type by the *Land Use Scanner* model. In contrast to the previous indicator, it thus defines the upper boundary of hectares to be allocated for each land use type. By combining the information of the Minimum- and the Maximum Claims indicators the range in which the allocation process takes place can be derived for each land-use type. For 'Greenhouses' the amount of land to be allocated must be in the range between 22,270 hectares and 22,279 hectare in the *W-Scenario*.

A comparison of the tables shows for some land-use types identical values for the minimum claim and the maximum claim. In this case a detailed estimation was available from one of the sector specific models. It is assumed that the space 'consumed' by a certain land-use type in 2040 can be well predicted. This does not mean, however, that no simulation process takes place. In fact, only the amount of hectares assigned to this land-use type is fixed. Not restricted is the simulation process regarding the locational allocation of the land-use claim.

2.7 Minimum Claim Realisation

Minimum Claim Realisation lists to what extent the minimum claims (in per cent) for each changeable land-use type have been realised in the course of the simulation process. This table can be used to check the correctness of the allocation process. Since all minimum claims must be realised, the changeable land-use types having a minimum claim should show a realisation of 100%, indicating that the allocated hectares are not below the target value (Minimum Claim). This was achieved for the *W*-and the *G-Scenario* (Appendix 1).

2.8 Maximum Claim Realisation

This indicator provides information to what extent the maximum claims for each changeable land-use type could be realised (in per cent). Thus, by looking at the table it gets immediately obvious if a shortage of available space occurred for the respective land-use type for a specific scenario. For the *G-Scenario* all maximum claims are realised (~ 100%) except for the land-use type 'Agriculture – arable land' (93.5%).For the *W-Scenario* all maximum claims are realised (~ 100%) except for land-use type 'Agriculture – Arable Land (74.9%) and 'Agriculture - Grassland' (93.6%). These outcomes are again reflecting the assumption that agricultural land will face continuing demand for space from other land-use functions.

3 Regional Indicators

The land-use claims used by the *Land Use Scanner* are defined on a regional level. The regional indicators refer to those regions for which the land-use claims are valid. They are mainly related to the COROP-, or LEI14- areas. The regional indicators are represented as map layers and tables per land use type (since claims for different land use types can be partially overlapping) and are described in following section.

3.1 *Current Land Use*

This indicator provides a map layer for each changeable land-use type, showing the current amount of hectares for each of the different claim regions. These maps thus allow a more detailed assessment of the present land use than the indicator 'Current Land Use' listed under *Global*. It provides, for example, information about the distribution and density of the different land-use categories over the regions. An example is provided in Figure 2. The same information can also be accessed in a table.

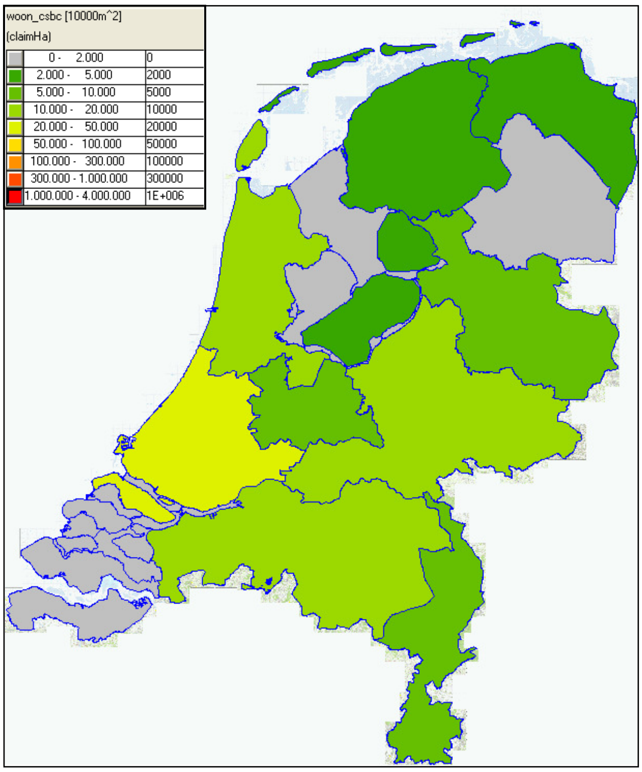

Figure 2: Regional claim distribution of land-use type 'Residential – High Density' (in hectares) for the current situation.

3.2 *Allocated Land Use*

The indicator *'Allocated Land Use'* consist again of a number of map layers that show for each changeable land-use type the allocated amount of hectares for all claim regions. These map layers in combination with the previous indicator can be used to evaluate de- or increases of certain land-use types on a regional level. By comparing the map layers from the *G-Scenario* and the *W-Scenario*, regional differences in the amount of hectares allocated to a specific land-use type can be assessed. An example is given in Figure 3.

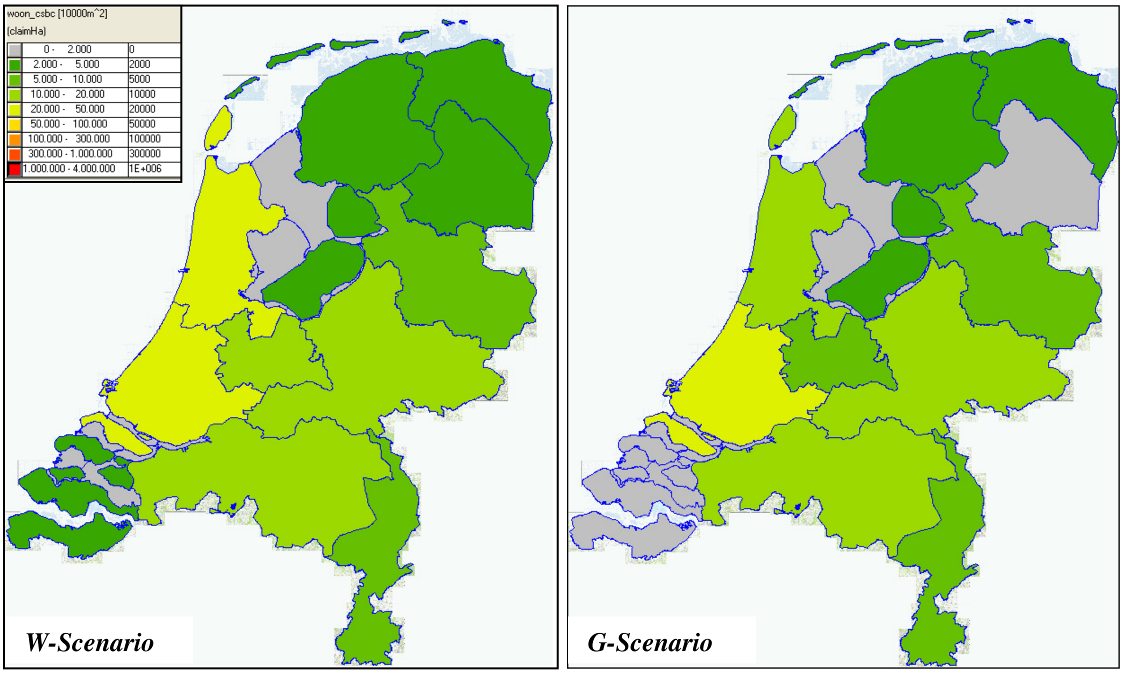

Figure 3: Regional claim distribution of land-use type 'Residential – High Density' (in hectares) for both scenarios.

Again, a table providing an overview of the total amount of allocated land for each land-use type per claim region is accessible as well.

3.3 Minimum Claims

'Minimum Claims' contains map layers for each land-use category that show the minimum claims on a regional level. Since the claims of different land-use types are specified and calculated on a regional level, these maps provide important information about regional differences in claims. By comparing the map layers for the *G-* and the *W-Scenario*, potential differences in land-use claims for a respective land-use type can be evaluated. As discussed under > Global > Minimum Claim, this indicator provides the lower boundary of land that must be allocated for each land use type: this time on a regional level. Additionally, a table provides an overview of the minimum claims per land-use types for the different regions.

3.4 Maximum Claims

This indicator also contains a map layer for each land-use category that shows the maximum claims on a regional level. The maps provide important information about regional differences in claims. Similar to the indicator > Global > Maximum Claim, it provides the upper boundary of land that can be allocated for each land use type. By combining the information of the regional 'Minimum'- and the 'Maximum Claim' indicator the corridor in which the allocation process takes place can be derived for each *land*-use type. In contrast to the global indicator, this can be done individually for each claim region. An overview of the minimum claims per land-use type for the different regions is also accessible.

3.5 Minimum Claim Realisation

These map layers show for each land-use category to what extent the minimum claims (in per cent) were realised in the course of the simulation. This indicator is useful to control, if the minimum claims could be realised for all regions. The regional perspective is of importance, since a complete realisation for the whole of The Netherlands does not necessarily mean that the claims could be realised for all regions. Looking at the maps for the both scenarios, it shows that all minimum claims defined have been realised for all regions (= 100%). Again, a table is accessible providing a quick overview to what extent the minimum claims have been realised for each land-use type per claim region.

3.6 Maximum Claim Realisation

The map layers listed under this indicator show for each land-use type to what extent the maximum claims (in per cent) were realised on a regional level in the course of the simulation. These maps are useful to assess, in which regions the maximum claims could not be realised. As said before, the regional perspective is of importance, since a complete realisation for the whole of the Netherlands does not necessarily mean that the claims could be realised for all regions.

Looking at the map layers for both scenarios, a first observation is that maximum claims for all land-use types were realised in all regions except for 'Agriculture – arable land', 'Agriculture – grassland' and intensive husbandry. In addition to the information provided by the global indicator 'Maximum Claim Realisation' it is now possible to assess regional differentiations in the realisation of maximum claims for the respective land-use types. By comparing the maps from the *G-scenario* and the *W-Scenario* differences in the maximum claim realisation can be evaluated. A comparison for the province Zuid-Holland shows, for example, that in the *G-Scenario* 95% of the maximum claims from agricultural land could be realised, while in the *W-Scenario* only 57% could be realised. While 100% of the maximum claim from agricultural land could be realised in Friesland in the *G-Scenario*, this was the case for only 94% in the *W-Scenario.*

4 Local Indicators

The indicators represented under 'Local' are calculated on the level of single grid cells, thus allowing a very detailed comparison. While the global and regional indicators allowed assessing the change in the total amount of certain land-use types as well as their regional distribution, the local indicators provide detailed information e.g. about the exact locational changes in land use.

4.1 *Changed Land Use*

These two map layers provide information about where land use has been changed according to the projections. The indicator 'New Land Use' ("bij") represents all grid cells that were assigned a new land-use class and indicates which land-use type this is. In reverse, the indicator 'Disappeared Land Use" ("af") provides a map that also shows where land use has changed but indicates which land-use type was lost.

4.2 *Land Use Prices*

As already mentioned before, suitability plays a crucial role in the allocation of future land use. It can be interpreted as the net benefits a particular land-use type derives from a particular cell and is expressed in Euros per square metre. The higher the suitability for a certain land-use type, the higher the probability that the cell will be used for that type. Suitability is assessed for potential users and can be related to a bid price in the discrete allocation. After all, the user deriving the highest benefit from a location will offer the highest price. During the allocation, the different land-use types compete for the most suitable location. This procedure yields a shadow price for meeting the regional demands and restrictions as a side product. The bid price is defined as the suitability plus the shadow price. More information is provided in (Koomen and Buurman, 2002) and (Dekkers and Koomen, 2007). The container 'Land-Use Prices' holds a number of indicators that provide detailed information about this crucial component of the allocation procedure.

Highest Price
This indicator shows for each grid cell the highest benefit a particular user derives from that particular cell. Accordingly, it also represents the highest or 'winning' bid for that specific cell. Thus, this map allows assessing the value of each cell.

Highest Bidder
This map layer shows for each grid cell the user (land-use type) that derives the highest benefit and thus is 'willing to pay' the highest price as presented by the previous indicator. By definition, it equals the land use map that resulted from the allocation model since exogenously imposed land users are also considered as highest bidders.

Shadow Prices
This indicator, which is calculated on a regional level, provides information about the difference (in Euros) between the suitability of allocated grid cells and the actual price paid by each user to reach their regional claims. It thus can also be viewed as an indicator on the scarcity or abundance of suitable grid cells for a respective land-use type. A positive shadow price indicates what the highest bidder had to pay on top of the suitability in order to get the regional minimum demand allocated. In reverse, a negative value shows that a lower price than the suitability had to be paid in order to stay below the regional maximum restriction.

Bid Prices
This indicator contains a map layer that represents for all allocatable land-use classes the maximum bid (suitability plus shadow price) for a particular cell before this cell gets assigned a

land-use function. Accordingly, it provides information about the 'willingness to pay' of a particular land-use type for a specific grid cell. This map also indicates bid prices on locations that were exogenously imposed and thus were not available for endogenous allocation.

Second Price
This indicator represents for every grid cell the value of the second highest bid and thus provides information about the opportunity costs. Opportunity costs are of interest since they represent the costs (possible but lost utility) caused by choosing one option over an alternative one. Opportunity costs are an economic concept in order to quantify alternatives that have not been chosen. They always arise when scarce resources can be used only once as it is the case of land use. Since the second price is defined as the highest price of an allocatable land-use class that wasn't allocated, the second price becomes the highest price for cells where exogenous land-use classes were imposed.

Second Bidder
As an addition to the previous indicator, this map layer reveals for each grid cell which user (land-use type) makes the second highest bid. Hence, it indicates which land-use type would be assigned if the highest bidder would not occupy this cell. Where an exogenous land-use class is imposed, the second bidder is the first bidder that would have been allocated if the cell would have been available for endogenous allocation.

Price Difference
As a last indicator in this group this map layer provides the difference between the highest and the second highest bid. It reveals to what extent the chosen alternative represents a more optimal solution compared to the second highest bid (best alternative). This can be useful to assess the robustness of the allocation process.

4.3 Difference Maps Endogenous

This indicator provides a map for each allocatable land-use type that shows the changes resulting from the allocation process on a grid cell level. Thus, these maps allow a very detailed assessment of land-use change resulting from the simulation process. The base year used to derive the difference maps is 2010.

W-Scenario
The global and regional indicators have shown an increase in commercial land-use functions for the *W-Scenario* as a result of a significant population and economic growth. The map of the present indicator now allows assessing where this increase occurs according to the *Land Use Scanner* projection. It can, for example, be seen that large commercial developments take place in the neighbourhood of Amsterdam, Haarlem and the airport Schiphol (Figure 4).

A comparison with other difference maps indicators reveals that in both projections residential land use in city centres is converted into commercial land-use types. In contrast, residential land-use functions are shifted from the central parts of the cities to the suburbs and outside of the cities. It can be questioned, to what extent this development is realistic. It could be argued that current land-use patterns will show a greater resilience in reality. The indicator thus signals that current land use should be more strongly incorporated into the suitability map definition.

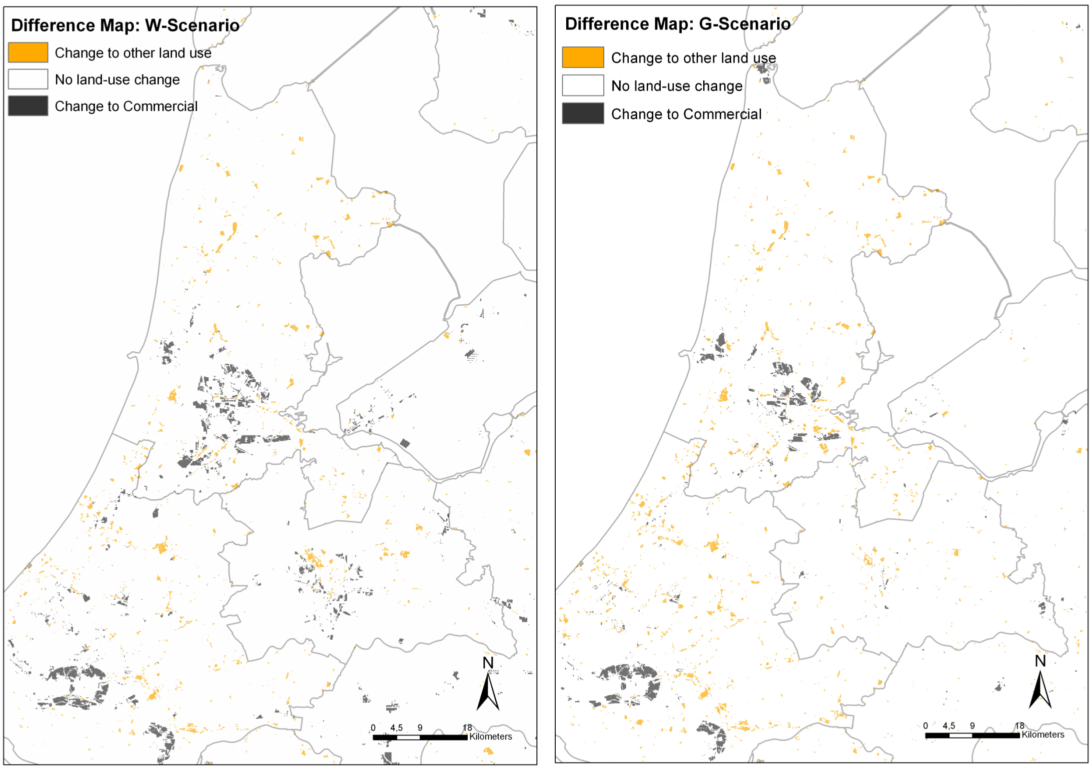

Figure 4: Difference map for the land-use type 'Commercial' for the G- and the W-Scenario.

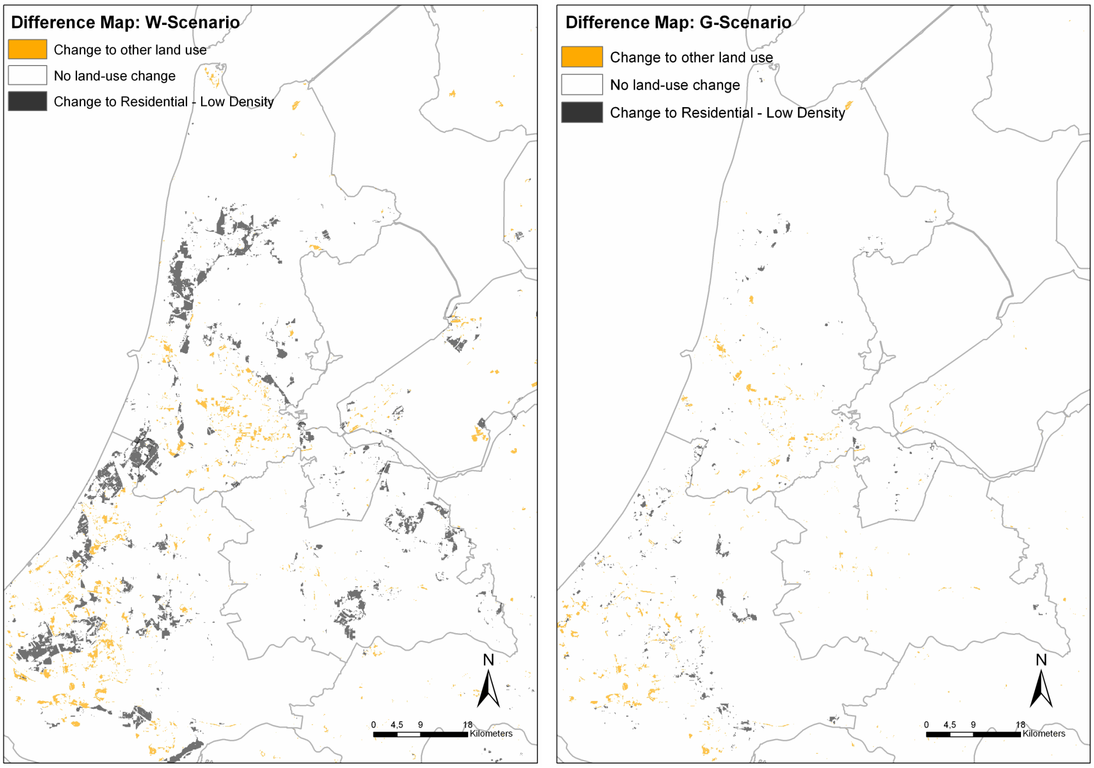

Figure 5: Difference Maps for the land-use type 'Residential –Low Density' for the *G-* and the *W-Scenario*.

The difference map 'Residential-low density' for the *W-scenario* shows a large increase, mainly in the Randstad area (Figure 5). It can be also observed that substantial urban development takes place along the coast, an environmentally sensitive area. This development is in line with the scenario assumptions that there are little environmental regulations which would restrict new urban development in such areas as it is the case in the *G-Scenario* (Riedijk et al., 2007).

The difference map of agricultural land shows again a great variation. While large agricultural areas change to other land use types, new agricultural land is allocated in different regions at the same time. A crosscheck with other maps of the same indicator reveals that this change occurs within the agricultural land-use functions, mainly within 'Agriculture – arable land' and 'Agriculture - Grassland'. Similar to the discussion earlier regarding the projections of commercial land-use functions it can be questioned, to what extent these variations are realistic. Again it can be argued that the current land-use patterns should have a stronger influence on the allocation of land.

G-Scenario
For the G-Scenario, the global and regional indicators have shown a slight decrease in commercial land-use functions. This is due to the scenario assumptions that population will slightly decrease after 2010 and that the economy will only grow modestly (Riedijk et al., 2007). As it is the case for the *W-Scenario*, commercial land-use functions develop in the neighbourhood of Amsterdam, Haarlem and Schiphol (Figure 4). By comparing the maps of both scenarios it can be observed that the *G-Scenario* shows a smaller amount of commercial development in that area (Figure 4).

Looking at the difference map for land-use type 'Residential-Low Density', the *G - scenario* shows a modest increase, especially in the Randstad area (See Figure 5). Development of new residential areas is mainly centered around existing urban infrastructure. In contrast to the *W-Scenario,* no development takes place in the coastal areas, reflecting the stricter environmental policies assumed for the *G-Scenario.*

The difference map of agricultural land also shows variations. However, the change from agricultural land to other (agricultural) land-use functions is less pronounced than in the *W-Scenario.*

4.4 Difference Maps Exogenous

This indicator consists of a number of maps that show for each land-use type that is not considered by the simulation process, if changes occur due to other reasons. These changes mainly refer to existing infrastructure projects, such as the Zuider-Zeeline. This railway extension, which was planned to be built between Groningen and Amsterdam, can be seen in the difference map 'infrastructure railway'. This plan is still represented in the Land Use Scanner model, even though the project was cancelled lately by the Dutch government.

4.5 Difference Maps for nine land-use types

This indicator contains difference maps for nine important land-use categories:

1. residential;
2. recreation;
3. commercial;
4. nature;
5. agriculture;
6. infrastructure (roads, railways, airports);
7. other;
8. exterior (Germany and Belgium);
9. water (including sea and waterways).

The first five are aggregates of allocatable land use types; the last four represent exogenously imposed land use types.

These maps show a more aggregated level of land-use categories, such as 'Residential', which summarizes the results for the three residential land-use types 'Residential-high density', 'Residential- low density', 'Residential – rural'. This indicator map thus can provide a quick overview on the process of urban sprawl. The advantage of this indicator is that changes within the three urban classes are no longer represented. Comparing the results for both scenarios for the aggregated land-use category 'Residential', the difference in the amount of hectares allocated and their location gets obvious (Figure 6).

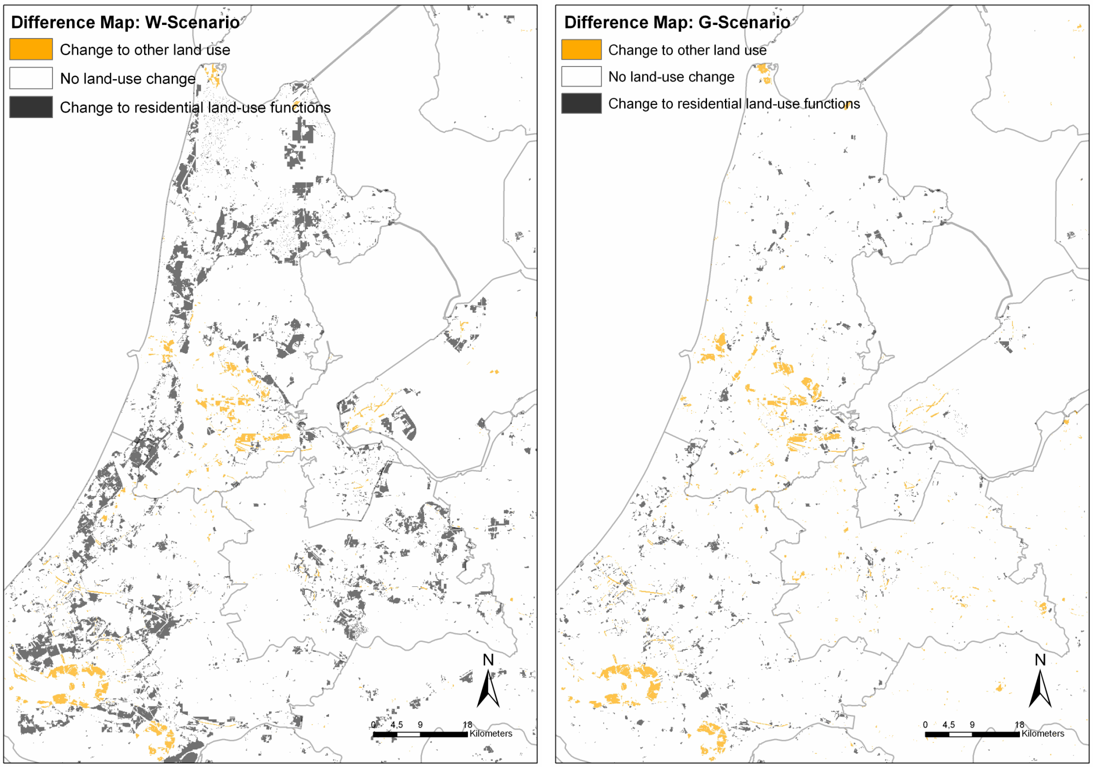

Figure 6: Difference Maps for the aggregated land-use function 'Residential' for the *G*- and the *W-Scenario*.

The different agricultural land-use types have also been aggregated to one category and are represented in a single map 'Agricultural land-use functions'. The difference to the indicator > *Local* > *Difference Map Endogenous* > *Agriculture –Arable Land* (Figure 7) is, that changes which occur within the agricultural land-use functions are no longer shown. The map of the present indicator (Figure 8) solely shows where agricultural land has been transformed to a different land-use category. Thus, it provides a better insight into where and how much agricultural land disappears according to the projections. Figure 8 clearly shows, that a large amount of agricultural land is demanded by other categories in the W-Scenario, as already discussed before.

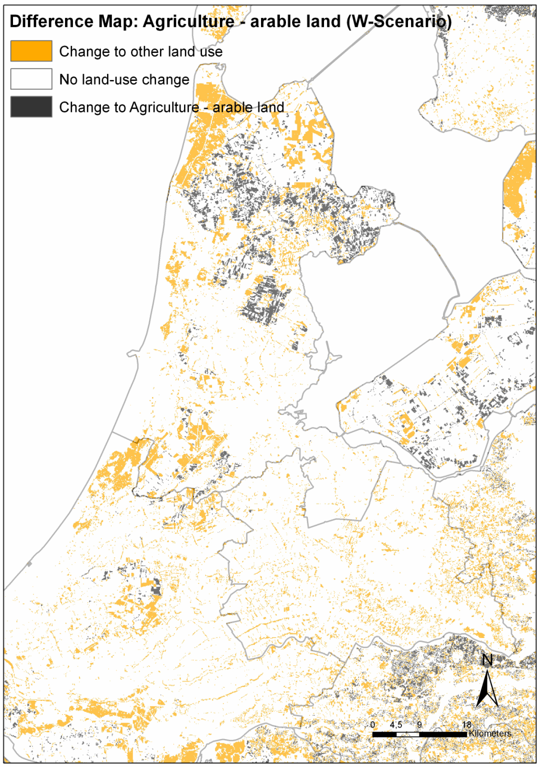

Figure 7: Difference Map for the land-use type 'Agriculture – Arable Land' for the *W-Scenario*. This map also shows changes that occur from one agricultural land use to another.

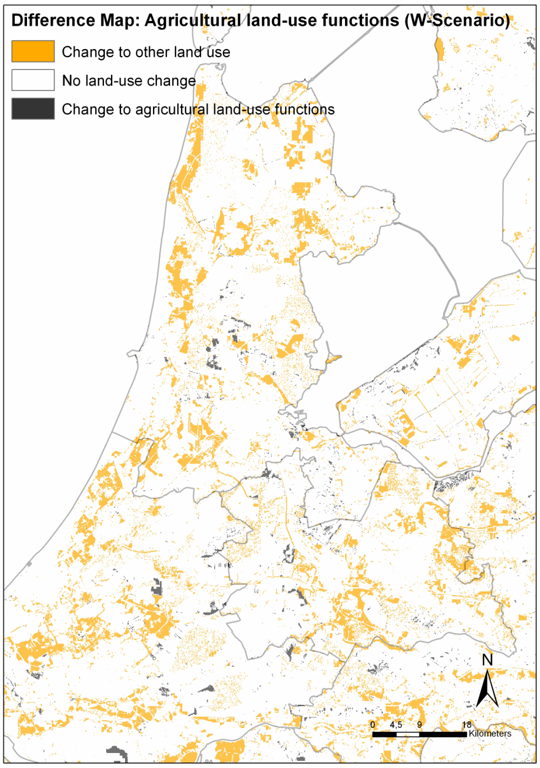

Figure 8: Difference Map for the land-use category 'Agricultural land-use functions'. This map solely shows changes from agricultural to other land-use functions.

4.6 Difference Maps Urban

The folder *Difference Maps Urban* contains four map layers which provide information about the process of urbanisation. Containing the large-scale, land-consuming urbanisation processes, often referred to as 'urban sprawl', is a key issue in spatial planning and has also been a constant in Dutch spatial planning (Ritsema van Eck and Koomen, 2008). The container *'Difference Maps Urban'* thus provides important tools to evaluate the effects of future land-use allocation in this respect. Four different map layers can be accessed.

Difference Map Built-up area
This map shows the difference in urbanisation between the current situation and the future projection. For each grid cell it is indicated if it was assigned an urban land-use type in the course of the projection, if it changed from an urban into a non-urban land-use type or if there was no change between these two categories. All cells that are one of the three residential or commercial land-use functions, greenhouses, intensive husbandry or infrastructure are considered as built-up areas.

As indicated by the regional and global indicators, the *W-Scenario* shows a strong increase in urban land use, resulting from the much larger claim for these functions. With the help of the present indicator it can now be assessed where this process of urban sprawl occurs. Several larger clusters of newly allocated built-up areas can be observed especially in the Randstad area and North Holland. Examples can be seen between Zoetermeer and Gouda, around the airport Schipol or north-east of Hoorn. Additionally, several other areas are assigned as newly built-up. These are e.g west of Enschede as well as around many smaller villages in rural areas. A striking development is the appearance of new built-up areas along the coast line, e.g. north of Bergen, south of Egmond or south of Zandvoort. This result follows the before mentioned scenario assumptions of high economic and population growth and at the same time a diminishing governmental interference regarding environmental policies (Riedijk et al., 2007). Due to these factors urbanisation also takes places in the designated national landscapes.

For the *G-Scenario*, the regional and global indicators have indicated a much smaller urban sprawl compared to the *W-Scenario*. Still, several large clusters of newly allocated built-up areas can be observed, which coincide with the ones of the *W-Scenario* but show a much smaller extent. Examples can also be seen between Zoetermeer and Gouda, around the airport Schipol or north east of Hoorn. A significant difference with the *W-Scenario* is that no urban development can be observed along the coastline, reflecting the scenario assumption of stringent national environmental policies (Riedijk et al., 2007). It can also be observed that current urban areas disappear according to the projection. In how far it is realistic that a substantial amount of urban areas is actually build back into natural land-use types is open for discussion.

Pressure for urban development
This map layer shows which areas (grid cells) face a high pressure for urban development according to the projection. Basis for this indicator is the *'Difference Map Built-up area'* described above. This map layer now only shows the grid cells that were newly assigned 'urban'. This reflects their suitability for urban development and thus the likelihood that there will be a great demand for these grid cells for urban land-use functions.

Height level (NAP) of New built-up areas
In the Netherlands, large parts of the country are well below sea level. Since these areas can be considered as potentially risk prone to flooding. Therefore, the NAP level of the areas where new urban development is projected is of interest. This information is provided by the present

indicator. The indicator shows that new built-up areas below NAP can be mainly found in North and South Holland.

4.7 Urbanisation

This indicator provides a number of maps which represent the extent of urbanisation. Grid cells that are considered as urban are the three residential and commercial land-use functions, greenhouses, intensive husbandry and infrastructure.

Built-up Areas

In contrast to the difference maps (4.6.) the indicator *Built-up Areas* provides information about the total extent of urbanisation for the present situation and according to both scenarios. The difference in the total amount of urbanized spaces in 2040 is represented in Figure 9.

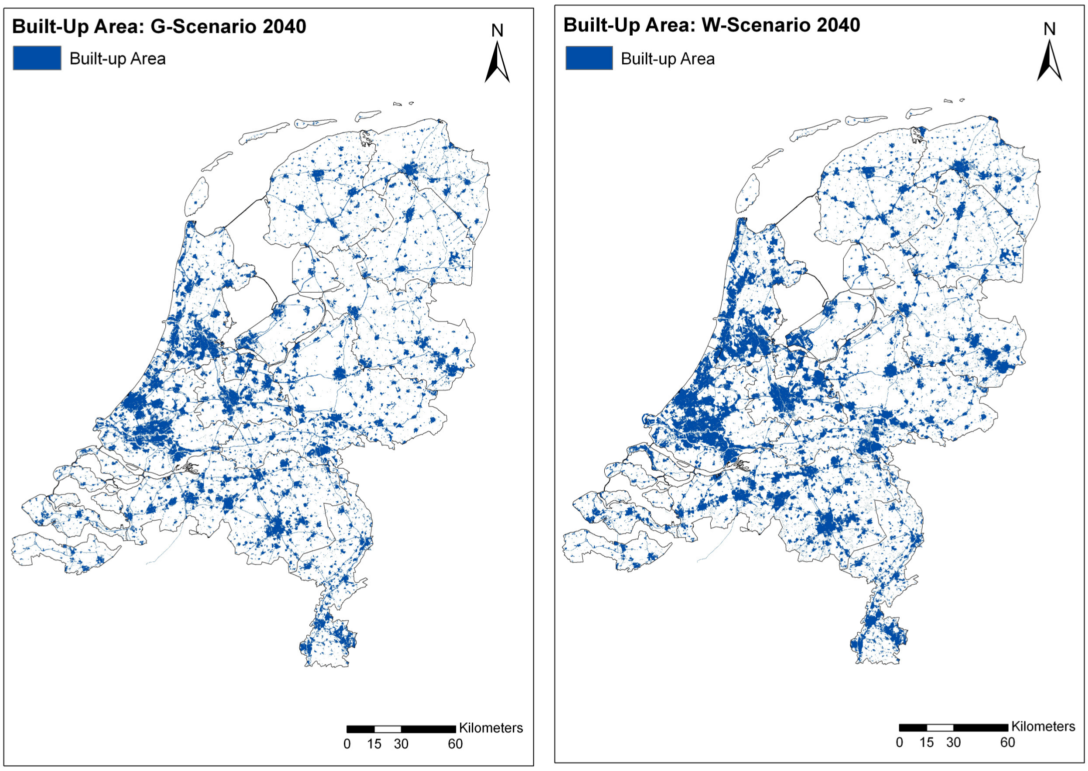

Figure 9: Built-up area according to both projections.

Connected Areas

The map layer of this indicator shows clusters of either built-up or non-built-up grid cells. All built-up or non-built-up grid cells that are adjacent to each other are assigned a unique identifier and considered as a connected area. Thus, the indicator provides an index of connected areas of a similar land use (urban or non-urban). In the current configuration infrastructure such as roads are also considered as urban areas. This leads to result that all urban areas that are continuously connected through a road are considered as one connected area. The connected area with the unique identifier number 23 e.g. reached from Zeeland to Groningen, including nearly all major cities. This seems to be a relic from the initial application of this indicator at a coarser (500 metre) resolution.

Size of connected areas

This indicator assesses the size of all connected areas identified by the previous indicator and groups them into the three classes 'Small Core' (up to 100 hectares), 'Medium Cores' (up to 250 hectares) and 'Large Cores' (above 250 hectares).

Size of connected urban areas
In contrast to the previous indicator this one only assesses the size of connected urban areas. These are again grouped into the three size classes: small, medium and large cores.

4.8 Effects of Urbanisation

These eight maps indicate the increase in built-up area (in hectares) in respect to various spatial policies. The first map shows those grid cells within the *Belvedere* areas which are considered as built-up after the simulation. This is another option of showing the effect of urbanisation. Other maps show the effect of urbanisation on *UNESCO World Heritages* or *National Landscapes*.

4.9 Open Spaces

As a consequence of the growing demand for houses in the Netherlands in past decades, total surface area used for residential purposes has expanded rapidly. In a densely populated country such as the Netherlands, with a limited amount of open spaces and natural areas, the fragmentation of open space is of particular concern. The issue of open space is closely related to the density of settlements. Low-density urban development, usually associated with urban sprawl, is considered as inefficient, even though it may be in accordance with the desires of households to live in a spacious environment. It increases transportation costs, consumes excessive amounts of land, and adds to the costs of providing and operating public utilities and public services (Rietveld and Wagtendonk, 2004). Therefore, it is interesting to evaluate the current situation and the projected land-use change against an indicator providing information about open spaces. Landscapes, which are considered as potentially 'open', are 'Recreation', 'Nature', 'Agriculture' – Arable Land', 'Agriculture - Grassland' and 'Water'.

Open_Landscape_types (2040)
This indicator contains a map that shows an aggregation of all land-use types listed above for 2040 according to both scenarios.

Current_ Open_Landscapes_types
This map shows an aggregation of all land-use types listed above for the current situation (2010).

Open_areas
While the indicators above provide information about individual grid cells which can be considered as an 'open' land-use types, it cannot provide information about open spaces as such. To be considered as an open space, a cluster of grid cells of these land-use types is necessary. Only if a number of those grid cells are adjacent to each other, this cluster can be regarded as an open space. The present indicator identifies where such clusters are present and defines these groups of cells as an 'open space'.

Three different classes of open areas are distinguished: 'Small areas' (up to 100 hectares), 'medium scale areas' (up to 250 hectares) and 'large areas' (more than 250 hectares).

4.10 Urban pressure on high quality landscapes

The map layer 'Urban pressure on high quality landscapes' distinguishes three different types of grid cells: 'High and low pressure on low quality landscapes', 'Low pressure on high quality landscapes' and 'High pressure on high quality landscapes'. As said before, a constant of Dutch spatial planning policies is the containing of urban sprawl. This is especially the case when it comes to landscapes with a high quality. Thus, the grid cells showing 'High pressure on high quality landscapes' are of special interest, since these grid cells show the most undesirable effects of urbanisation. This indicator is based on a grid map of the Netherlands that shows the existence of landscapes with natural or cultural qualities, which is taken from the 'Monitor Nota Ruimte'. It is based on the existence of landscape elements and patterns that are characteristic for the evolutionary history of the respective landscape. This can be about ecological, geographical and cultural phenomena. The data are taken from the data portals 'Kennis Infrastructuur Cultuur Historie' (KICH), a Geographical Information System (AKIS) and a land-use map of the Netherlands (LKN).

Areas with a high natural or cultural value can be found especially in North of Drenthe, the IJsselmeerpolders, the 'Green Heart', the Veluwe and Southern Limburg. With the present indicators it can then be assessed to what extent valuable landscapes face pressure from urban development according to the different scenarios. Many high quality grid cells facing high pressure can also be found along the highways. Examples are the A6 in the Noordoostpolder or the A7 west of Groningen. This allocation result seems to be questionable since it assigns grid cells adjacent to highways a high landscape quality, whereas the scenic quality and natural conditions will obviously suffer from the present highway.

W-Scenario:
With 90,543 hectares the pressure on high quality landscapes is significantly higher in the *W-Scenario* than the other scenario. Many of these grid cells can be found especially along the coast line as well as in the Randstad area (Figure 10). This observation follows the scenario assumptions, which expect less governmental interference in respect to environmental policies (Riedijk et al., 2007).

G-Scenario:
In the *G-scenario*, 15,528 hectares of high quality landscapes face high pressure from urban demand. Clusters of these areas are e.g. west of Gouda, east of Leeuwarden and around the airport Schiphol (Figure 10).

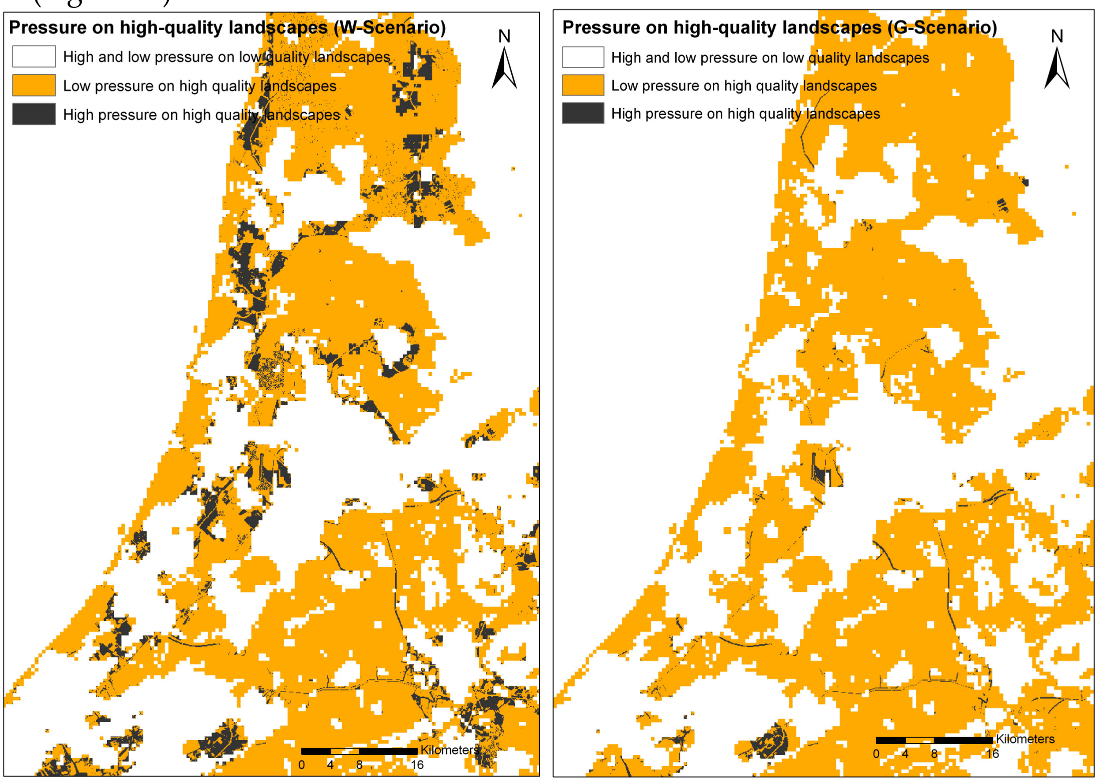

Figure 10: Urban pressure on high quality landscapes for the *W-* and the *G-Scenario.*

4.11 Land-use diversity

Within previous applications *of the Land Use Scanner* model a land-use diversity indicator was applied. This measure for diversity of land use in a raster cell was derived from equivalent indices in ecology that for example measure biodiversity. In our case we applied distributional measures, which indicate the number of species (land-use types) and the distribution of individuals (amount of hectares) over those species. *Figure 11* present an example of the application of this indicator on a different *Land Use Scanner* application (described in: Koomen et al., 2005b; Ritsema van Eck and Koomen, 2008).

Striking features on the map (at left) are a number of areas with very little mixed land use: large nature areas such as the glacial ridges in the central/east part of the country, large-scale agricultural meadows in the Green Heart (indicated with number 1) and extensive tracts of arable land in the IJsselmeerpolders (indicated with a 2). In these areas, we find some more mixed land use along the main transport infrastructure. Other areas with moderately mixed land use (diversity indices around 0.50) are found in the small scale agricultural areas (in the southern and eastern parts of the country) and in urban areas. High diversity index values (around 0.75) are found along the rivers and motorways, in villages and, not surprisingly, on the edges of urban areas, as transition zones are by definition areas of diversity.

Specific for the Cooperating Region scenario (in middle) are areas with very high diversity along the edges of nature areas, particularly prominent around the glacial ridges of the Veluwe and Utrechtse Heuvelrug (indicated with number 3). These areas are at present predominantly agricultural and characterized by livestock keeping (mainly fowl). The Cooperating Region scenario, however, pinpoints these areas as relatively attractive for a multitude of functions that are not allowed in the nearby nature areas. Especially low-density residential land use rises sharply but also recreation, agriculture and some industry and services find their place here. It is not quite clear that these functions can be combined on this scale; the model does not contain checks on improbable combinations of land uses. In any case, it is clear that these areas do have a certain potential for a wide variety of different land uses. The model thus pinpoints at potential 'hot-spots' for mixed land use that can be of great interest to policymakers.

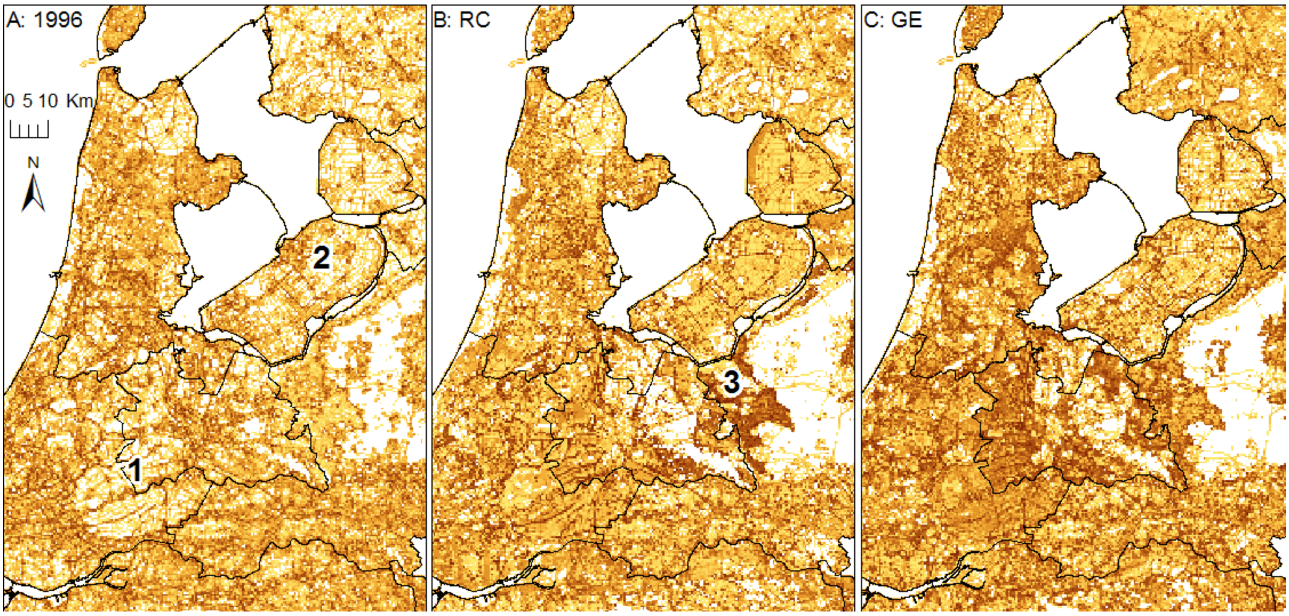

Figure 11: Land-use diversity index for current, 1996, land use (a), the Individualistic World (b) and Cooperating Region (c) scenario; dark colours denote a higher diversity, numbers are referred to in the text.

As the application of this indicator was developed for coarser grained (500 metre) land-use maps it is not any longer operational in the current 100 metre grid version. The indicator, furthermore, requires heterogeneous land-use data describing the presence of different types of land use per cell. It is thus not suitable for application on many newer *Land Use Scanner* applications that use homogenous land-use that only describe one type of land use per cell. The available methodology can, however, be applied to aggregated 100 metre grid cells to distinguish spatial diversity.

5 Flood Risk Assessment

Water management in the low-lying and deltaic Netherlands is a precarious planning issue that continuously needs adjustment because of ever-changing conditions of the water system and the society that inhabits this risk-prone area. The protection against large scale flooding events is of crucial importance and is today provided by Dutch national law and defined per dike ring. The different dike rings and their safety standards can be seen in Figure 12.

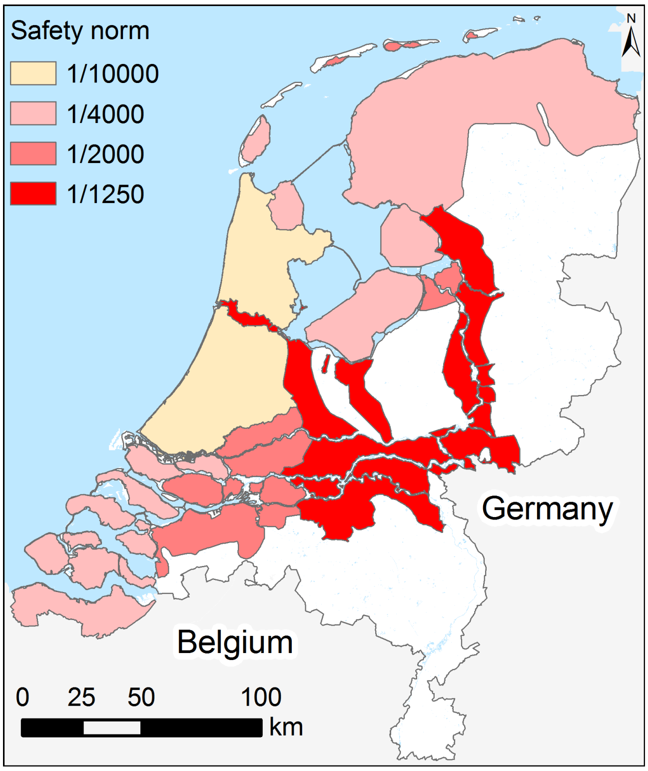

Figure 12: Safety standards per dike ring in the Netherlands.

To be able to evaluate changes in the damage potential and flood risk in the future, the latest configuration of the Land Use Scanner contains an indicator that is referred to as the *Damage Scanner*. It represents a simplified damage module that assesses potential flood damages based on the input parameters land use and inundation depth. Additionally, an estimate of the potential number of casualties is provided. The assessment of potential economic damage and number of casualties are based on relatively simple depth-impact functions are used that quantify the relationship between inundation depth and damage or casualties for different land-use types.

Methodological Approach

The following section describes the main elements of the *Damage Scanner*. It does so by explaining the damage calculations. The calculation of the number of casualties is done in a similar way and not explicitly described here. A graphical overview of the methodological approach is provided in Figure 13. The required land-use maps are produced by the land-use model itself, each reflecting the scenario specific assumptions. Additionally, the current LANDS configuration also contains several inundation maps reflecting different sea-level rise scenarios (25cm, 60cm, 80cm, 150cm and 300cm) in combination with two adaptation strategies.

The different adaptation strategies are referred to as 'Do Nothing Strategy' and 'Business as Usual Strategy' and describe two contrary alternatives how to react to a rising sea level. The assumption behind the 'Do Nothing Strategy' is that dikes heights remain unchanged. This leaves the water level in the dike rings unchanged but leads to increasing flooding probabilities. In contrast, the 'Business as Usual Strategy' assumes that dikes are raised in line with the sea level rise what results in higher water tables within the dike rings and thus to higher damage potentials. The probability of a flood event remains unchanged following this adaptation strategy.

The inundation map representing the initial situation is a collection of available inundation simulations that were collected and integrated by the provinces. Based on this initial situation a set of inundation scenarios reflecting sea-level rise scenarios in combination with an adaptation strategy were developed at the Department for Spatial Analysis and Decision Support at the Institute of Environmental Studies (IVM) in Amsterdam.

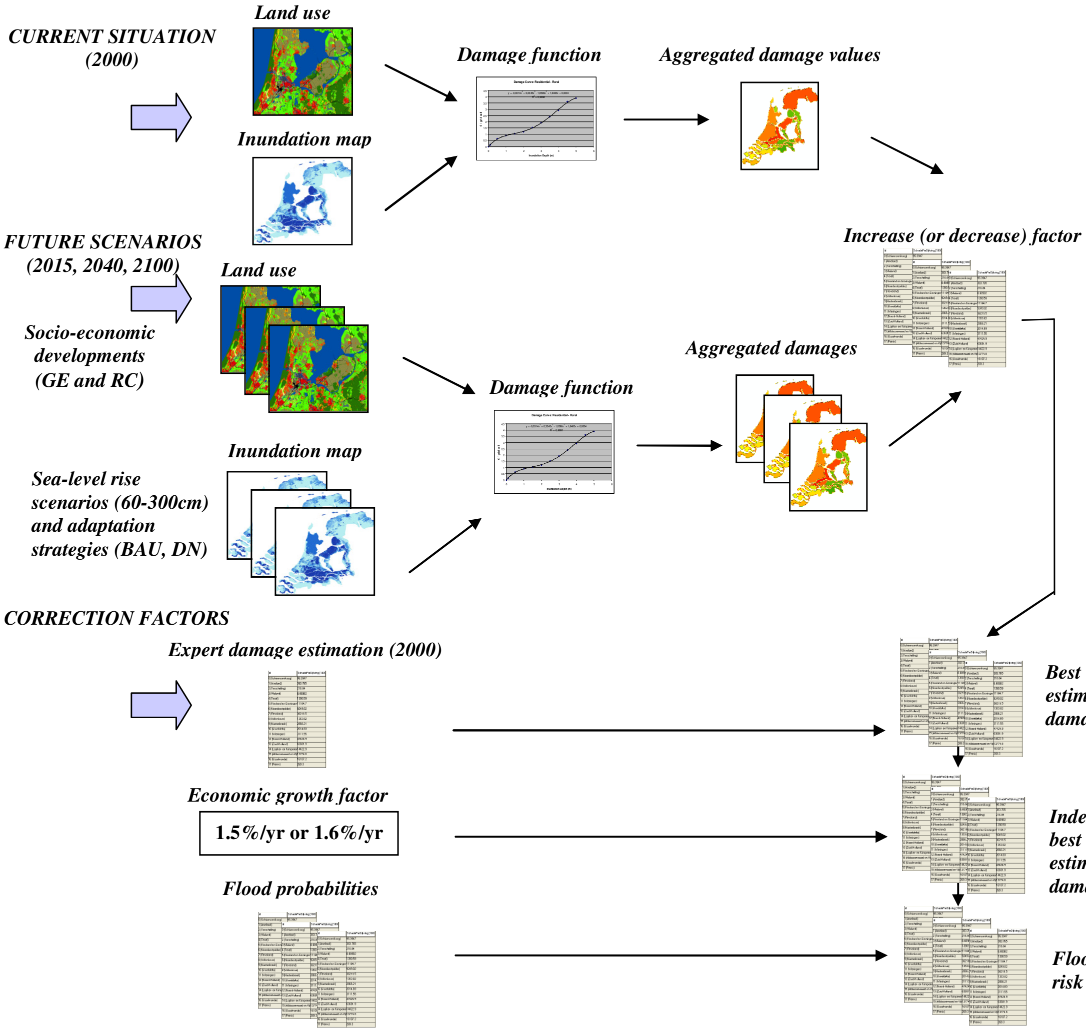

Figure 13: Flowchart of the flood risk assessment with the *Damage Scanner* approach.

To assess potential flood damages the information of the land-use maps and the inundation maps are combined by using simple depth-damage functions. These provide the maximum damage values (total loss) for 14 different land-use classes and the respective growth of the function, which quantifies the relationship between inundation depth and damage. These functions are derived from the Hoogwater Informatie Systeem (HIS), which is the standard software tool in the Netherlands to evaluate flood damages. For more details on the HIS damage module and the procedure deriving the damage functions for the *Damage Scanner*, the reader is referred to other sources (Huizinga et al., 2004; Klijn et al., 2007; Van der Hoeven et al., 2009). Figure 14 provides an example of the damage function for the land-use class 'Residential – Low Density', which has a maximum damage value of 4 Million €/hectare.

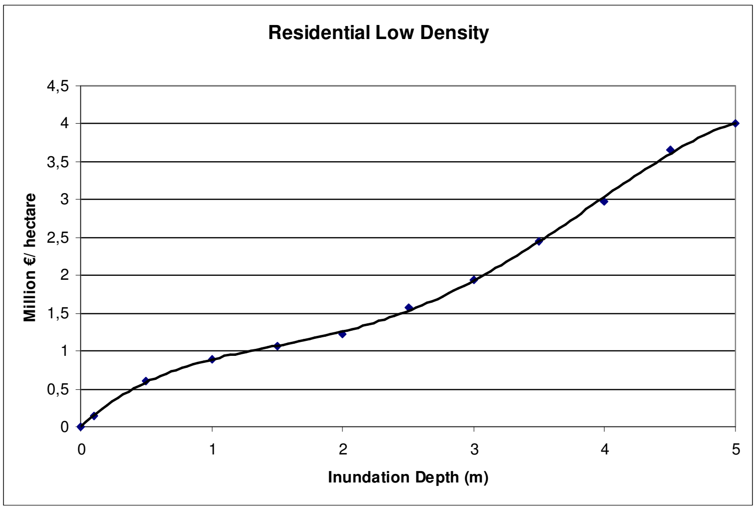

Figure 14: Damage function: 'Residential-High Density'.

Since the *Damage Scanner* gives a rough overview only, it is used to calculate the increase in damages according to a certain scenario compared to the calculated damage potential for the year 2000. The thus derived increase factor (or decrease) is subsequently multiplied with the best estimate currently available for each dike ring. These figures were initially derived by Klijn et al., 2004 (see also Klijn et al., 2007**)** and shall represent the most realistic estimation of potential flood damages for each dike ring. By multiplying the increase factor with the best estimate, possible over- or underestimations in the damage calculation resulting from unrealistic inundation maps can be corrected. The resulting damage figures are subsequently multiplied with an economic factor to represent growth in wealth (Figure 15) according to the *G-Scenario* and the *W-Scenario*.

Results
The results of this indicator are presented in a number of different maps. A first map layer contains the land-use map that forms the basis for the damage calculation. A second map layer shows on the level of individual grid cells the occurring damage in that specific location. A third map layer shows the aggregated damages on the level of dike rings. An additional container provides for each dike ring the increase in damage in per cent, compared to the base line of 2000.

Accordingly, it is possible to evaluate how damages develop according to the *W-scenario* and the *G-scenario* respectively. A crucial dike ring in the Netherlands is Number 14 (Zuid-Holland), which protects the Randstad and cities like Amsterdam, Rotterdam and The Hague and thus the economic heart of the Netherlands. This dike ring also shows substantial differences in the increase of urban development in the W-Scenario and the *G-Scenario*; the land-use type with the highest values at risk. This increase in urban development is also reflected in the damages. While the *W-scenario* shows a damage of 370 billion Euros for dike ring 14, this number is with 270 billion Euros substantially lower for the *G-Scenario*. A map representing the potential damage for the *G-Scenario* under a 60cm sea-level rise scenario in combination with the 'Do Nothing' Strategy can be seen in Figure 14.

Risk of flooding
The results of the damage calculations can be subsequently used to evaluate the risk of flooding under the different socio-economic and sea-level rise scenarios. Risk in this case is defined as the product of probability and damage and thus reflects the expected average damage per year.

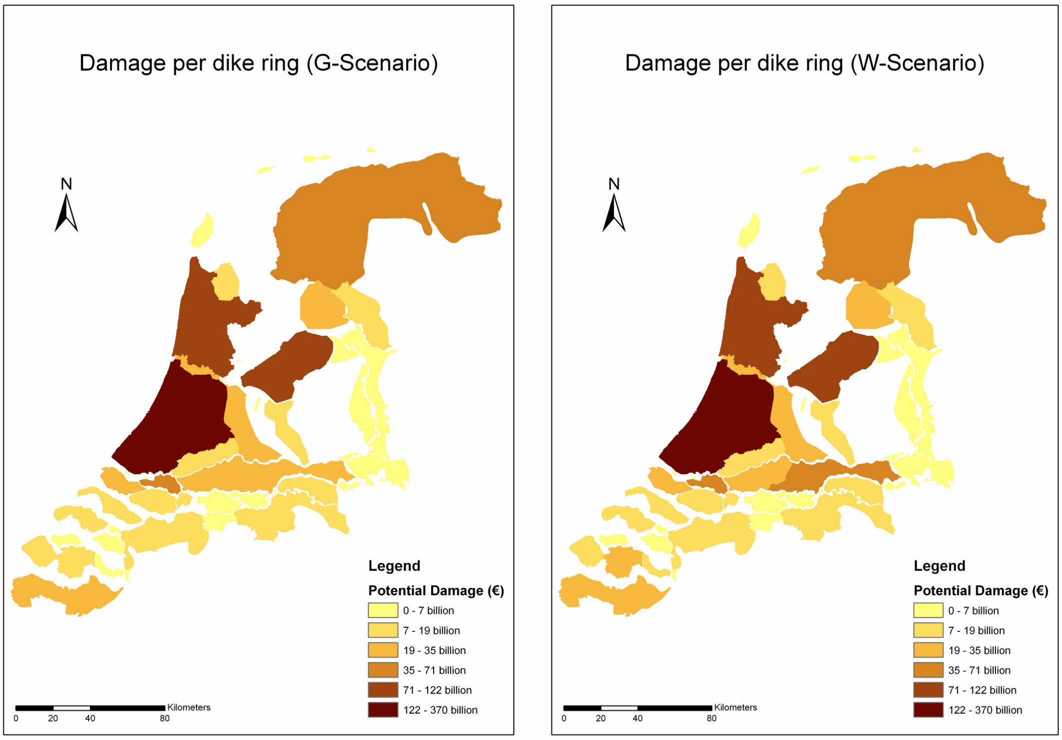

Figure 15: Potential damages aggregated on dike ring level; reflecting the 'Do Nothing Strategy' for a sea level rise scenario of 60 cm.

The current probabilities are defined by national law for each dike and are reflected in the safety standards (see Figure 12). For future scenarios the development of the probabilities depends on the chosen adaptation strategy. For the 'Business as Usual Strategy' probabilities remain the same, assuming that dikes are raised in line with sea level rise to guarantee current safety standards. The risk of flooding changes in this scenario due to the increase in the damage potential. For the 'Do Nothing Strategy' probabilities decreases with rising sea-level rise, reflecting the scenario assumption that dikes are kept at the existing height. According to this scenario the risk of flooding increases both due to the increasing damage potential and the more frequent occurrence of floods.

6 Further applications: sustainability indicators

The second sustainability outlook *'The Netherlands in the Future'* (MNP, 2007), published by the *Netherlands Environmental Assessment Agency (MNP)*, provides an interesting example of how land-use change projections of the *Land Use Scanner* can be used to assess their sustainability. By means of a set of indicators land-use maps are evaluated in terms of the three sustainability dimensions people, planet and profit.

The following topics have been identified as important for a sustainable spatial development of the Netherlands:

- safety against flooding;
- adaptation to climate change;
- biodiversity;
- accessibility;
- quality of the physical living environment;
- spacious and green living;
- international investing climate;
- landscape quality; and
- maintenance cost/ transformation costs.

The set of quantitative indicators, evaluating land-use change projections against these sustainability topics are described in the following paragraphs.

Safety against flooding
With the help of this indicator, the development of potential flood damages is evaluated as it was described in the previous section on flood risk.

Adaptation to climate change
This indicator provides information about the amount of newly-built up areas that are projected in flood prone areas. All areas that are below the National datum level (NAP) are considered as flood prone. This indicator reveals to what extent the economic value and the percentage of people at 'at risk' increase until 2040. According to the present indicator, the potential damage in the flood prone areas increases by a factor of two. The new built-up areas account for about 25-30% of this damage.

Biodiversity
This indicator looks at several characteristics of natural areas. At first, it is assessed if the amount of hectares representing natural areas in- or decreases according to the land-use change projection. Secondly, the size of connected nature areas is assessed, which are grouped into several classes and compared to the base line of 2000. This comparison reveals that the size of natural areas slightly increases until 2040.

Furthermore, the degree of fragmentation of these areas is evaluated. The connectivity of natural areas is an important factor in respect to biodiversity. To assess the effects of the fragmentation of natural areas on biodiversity the spatial model 'Landscape ecological Analysis and Rules for the Configuration of Habitat' (LARCH) was applied. It is used to determine the suitability of ecological networks. This model is based upon empirical analyses on a number of species that were used to set up a standard for a sustainable network size. For more detailed information on the LARCH model the reader is referred to Verboom et al., 2001. The results of the model on the sustainability of species is subsequently indexed into the three classes 'sustainable', 'potentially sustainable' and 'not sustainable'. It is revealed that due to the remaining fragmentation of natural areas in 2040 the conditions for preserving biodiversity are hardly improved.

Accessibility
In the 'Nederland Later' study, accessibility is defined and assessed in three different ways trying to reflect its different aspects. Following an economic perspective, accessibility is expressed as the hours lost in traffic jams. This is calculated by means of a traffic flow model that takes into account the capacity of the road system and the number of cars commuting. For more detailed information the reader is referred to (Geurs, 2006).

Following a spatial perspective, accessibility is expressed by the number of jobs that can be reached within one hour by car or within 90 min by public transport. A second indicator with a spatial perspective looks at other facilities such as recreational areas, sports facilities or e.g. cultural facilities that can be reached within a certain period of time.

According to the results of this model, the amount of traffic and the numbers of 'hours lost' in traffic jams increases significantly until 2010. After 2010, a scheduled investment package of 14,5 billion Euros leads to a stabilisation or decrease of 'hours lost' between 2010 and 2020, even though commuting traffic increases. For the time after 2020 the model predicts a steep increase in 'hours lost' if no further investments are taken. In total, the number of 'hours' lost in traffic jams increases by 70% between 2000 and 2040 for the *trend scenario*. For a second scenario which assumes a higher economic and population growth, the number of 'hours lost' even triples.

The results for the spatial accessibility indicators show a different picture. The accessibility of jobs markedly improves in the period between 2010 and 2020 both due to the investments in roads and the increase in existing jobs. If no further investments are taken, this trend reverses after 2020 due to congestion and a decrease in available jobs.

Quality of the physical living environment
This indicator looks at the impact of noise on residential areas. To assess the impact of noise the model 'Environmental Model for Population Annoyances and Risk Analysis' (EMPARA) was applied, which considers mainly the impact of traffic noise (road-, rail- and air) and industry. It is assumed that noise protections will be installed along highways for built-up areas that are exposed to 65 DB L_{den} or more. For more information on the EMPARA model the reader is referred to http://www.mnp.nl/nl/dossiers/leefomgeving/modellen/index.html.

According to this indicator, an additional 0.5 million houses will be exposed to noise higher than 55dB L_{den} by the year 2040 in the trend scenario. This increase is due to the growing traffic flows in residential areas, especially in the 'Randstad'. At the same time, the number of houses exposed to less than 48 dB L_{den} decreases. Looking at the number of people exposed to more than 55dB L_{den}, figures are similar for 2010 and 2040. This is due to the decreasing number of inhabitants per household, which is supposed to decrease from 2.3. towards 2 inhabitants per household.

Spacious and green living
In The Netherlands, there is a large demand for living in a green and spacious environment. This leads to pressure on attractive landscapes and leads to a partial use of National Landscapes for urban land-use functions.

In the configuration of the *Land Use Scanner*, three different types of residential areas are distinguished. The present and simplistic indicator groups the two classes 'Residential – Low Density' and Residential – Rural' into a new category representing a green and spacious living environment. It subsequently evaluates how this land use types develops according to the projection. This indicator was referred to as being mainly qualitative and there are no detailed results provided in the report.

Landscape Quality
This indicator assesses the effects of land-use change on the quality of the landscape and takes several aspects into consideration. At first, it takes into account how much urban development takes place in National Landscapes. Secondly, the so-called KELK model (Model for the evaluation of the effects of land-use changes on land-use quality) was applied. With the current version of the KELK model land-use change can be evaluated against the three indicators 'historic value, 'experience value' and 'recreational utility value'. Accordingly, it consists of three parts referred to as 'landscape module', 'experience module' and 'recreation module'. All three are knowledge-based models that do not simulate processes but make use of simple rules based on expert judgement. (Roos-Klein Lankhorst et al., 2004). Each module works with two types of sources referred to as *data* and *knowledge*. As the name implies, *data* can be e.g. accessible in the form of a GIS data base. Examples are data bases of historical landscapes, archaeological landscapes, present nature areas, present length of bicycle lanes, soil statistics or ground water tables(Farjon et al., 2004). *Knowledge* describes the relationship between the different sources, thus between the data and other knowledge sources. These *knowledge sources* can have the form of knowledge tables (kennistabellen), rules of thumb or simple process models. By coupling future scenarios as data sources, the effects of land-use change can be evaluated. For more detailed information on the KELK model and its application on land-use simulations the reader is referred to other publications (Farjon et al., 2004; Koomen et al., 2008b; Roos-Klein Lankhorst et al., 2004).

According to this indicator, landscape quality decreases until 2040. One reason is that agricultural land is partly replaced by urban land-use functions. Since many agricultural areas have an 'open' character the landscape quality declines. Besides, urban development is more profound in National Landscapes than in the Netherlands as a whole, what will also have a negative effect. The worst effects can be observed for the areas with the highest pressure for urbanisation. These are for example the 'Green Heart' and historic defence lines.

Maintenance Cost / Transformation Costs
The last indicator applied to assess the sustainability of land-use change looks at the costs related to maintaining a certain land-use type compared to the costs of transforming the land-use function into another. The maintenance costs to preserve a land use function are estimated on the basis of specific historic regional and land-use type specific figures. The transformation costs reflect estimations of the costs to change one land-use type into another. The results of this indicator are not further described.

7 Conclusion and discussion

The *Land Use Scanner* model comes equipped with an extensive set of land-use based indicators that are directly calculated and mapped in the model. The existing indicators are available for three different scale levels: global, regional and local. The global indicators refer to the full extent of the study area; the regional indicators relate to specified regions (e.g. demand region) and the local indicators are calculated on the level of single grid cells, thus allowing a very detailed assessment of the simulation results.

Part of the indicator set summarises the results per land-use type or aggregated category, for example, the total amount of a specific land-use type or the increase of all urban types of land use. Through analysing these results at the three available scale levels analysis information be obtained on issues such as: which types of land use increase (or decrease) the most, in which regions is this phenomenon most pronounced and exactly which locations are affected by this development. Besides these indicators that solely look at the simulated land use, additional indicators are available at all three scale levels that relate to the simulation process describing, for example, average or local transition potential values or the shadow prices that result from simulation. The latter type of information indicates the 'pressure' on space.

Through combining the resulting land-use maps with additional information on, for example, landscape or natural quality additional impact assessment indicators are calculated indicating, for example, those areas were landscape or natural values are declining because of increased urbanisation.

More elaborate spatial analysis methods are also directly applied within the model to allow for the construction of more complex indicators. A currently available example of this type of impact assessment relates to the issue of urban sprawl. This assessment is implemented through an analysis of the compactness of urbanisation and the loss of open space. Another example relates to the analysis of flood risk and relies on additional non-land use information. This indicator describes the potential future economic damage and number of casualties resulting from a possible flooding. This analysis takes future spatial patterns into account and can assess the potential benefits of specific safety measures

Even more elaborate impact assessments can be obtained through a coupling of DMS modelling framework with additional spatial models as is shown by the Dutch Environmental Assessment Agency and others to calculate, for example, biodiversity and accessibility impacts (MNP, 2007) and possible water shortages (Dekkers and Koomen, 2007). Such impact assessments can also be established in the framework of the LANDS project, should the need arise.

Further development

Quantitative indicators thus substantially increase the amount and quality of information that can be derived from land-use change projections, thus improving the communicative power of the *Land Use Scanner*. Based on the application of the available indicators in the *Land Use Scanner* we can also pinpoint several issues for future model and indicator development.

Some of the results of the indicators showed that the land-use projections partially represent illogic and inconsistent spatial developments. The large swap within agricultural land-use types as discussed in Section 4.3 is an example for this. Here, the current land use should be more strongly considered in the definition of the suitability maps. Another example is the fact that the planned Zuiderzeeline railway is included in the land-use change projection even though it was cancelled by the Dutch government. This needs to be corrected. It is also questionable, whether substantial amount of urban areas would really be built back into natural land-use types, as it is projected by the G-Scenario (see 4.6).

Other results led to the conclusion that the indicator itself needs further improvement. An example is that grid cells along highways are considered as areas with a high landscape quality. This seems to be questionable as discussed in Section 4.10. Also the indicator 'Connected areas' and the ones derived from it need further adjustments. Roads should no longer be considered for the connectivity of areas to avoid the undesirable effect described in Section 4.7.

The chapter on the sustainability indicators (Section 6.) describes a set of indicators that can be possibly incorporated in the *Land Use Scanner*. Here, the integration of land-use change projections and transport models seems to produce innovative and policy relevant insights.

Moreover, the development of new indicators can help to further improve the evaluation of land-use change projections and to evaluate policy objectives. Initial work in this direction is currently underway in several research projects. For the Glowa-Elbe project a sealed surface indicator is being developed to assess potential changes in the hydrological system. For other projects commissioned by the EC-DG Environment and Joint Research Centre additional more complex indicators will be developed in cooperation with Wageningen University Centre. These will relate to specific aspects of climate change, biodiversity and soil protection, such as: carbon sequestration; soil sealing; landscape indicator; biodiversity index (Mean species abundance index, based on the GLOBIO approach); connectivity of habitats based on the LARCH approach; and erosion (based on the USLE approach).

Appendix 1: Global land-use statistics

	Unit	Residential - High Density	Residential Low Density	Residential - Rural	Recreation	Commercial	Commercial-Seaport	Nature / Forest	Agriculture - Arable Land	Agriculture - Grassland	Agriculture - Greenhouses	Agriculture - Zero Grasing
Current Land Use (2010)	ha	99721	208166	36729	34808	87830	10658	585306	1.078E+10	1.117E+11	15657	14301
Allocated Land Use												
W-Scenario	ha	134058	242290	94840	48878	102183	14898	622207	807887	1.175E+11	22278	15249
G-Scenario	ha	101011	203352	42010	48878	75417	8847	630207	1.009E+11	1.131E+11	7999	9189
WeightedMeanSuitability												
W-Scenario	Euro*m²	11.9	12.6	17.1	7.4	25.9	13.2	3.6	1.5	1.3	12.6	11.2
G-Scenario	Euro*m²	4.2	8.3	12.7	5.2	18.1	12.5	6.2	2.0	1.5	5.9	6.6
WeightedStdDevSuitability												
W-Scenario	Euro*m²	8.0	6.4	5.4	5.3	7.9	1.1	2.3	2.0	1.8	1.7	2.3
G-Scenario	Euro*m²	7.7	7.3	6.2	4.4	7.4	5.3	3.7	9.1	2.2	3.4	2.6
Minimum Claims												
W-Scenario	ha	134054	242283	94835	48878	102177	14892	622207	0	0	22270	15189
G-Scenario	ha	101006	203349	42001	48878	75413	8844	630207	0	0	7993	9172
Maximum Claims												
W-Scenario	ha	134060	242290	94840	48878	102183	14897	622207	1.08E+10	1.26E+11	22279	15203
G-Scenario	ha	101011	203352	42010	48878	75417	8847	630207	1.08E+10	1.13E+11	8002	9186
Minimum Claim Realisation												
W-Scenario	%	100	100	100	100	100	100	100	0	0	100	100
G-Scenario	%	100	100	100	100	100	100	100	0	0	100	100
Maximum Claim Realisation												
W-Scenario	%	100	100	100	100	100	100	100	74. 9	93.6	100	100
G-Scenario	%	100	100	100	100	100	100	100	93.5	100	100	100

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