Applying and Improving Planning Support Systems for Sustainable Urban Development

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Abstract

Land-use models have become an established tool to help prepare and support spatial planning. This paper described three recent policy-related applications of an operational Dutch land-use model with a focus on sustainable urban development. Subsequently, it discusses ways to further improve land-use modelling in view of ongoing and expected changes in the societal and planning context of the Netherlands.

1. Introduction

Urban development is a complex dynamic process that is characterised by substantial spatiotemporal variation. Growth and decline coexist within neighbouring regions at short distances from each other. In the Netherlands, for example, population and employment are expected to grow in the so-called main-, brain- and greenports, whereas a decline is expected between these regions and, especially, in more peripheral parts of the country (PBL, 2011). This makes steering urban expansion and intensification important policy issues in many regions, while preparing for decline and urban restructuring have become hot topics in others. These processes are driven by various interacting and sometimes even conflicting societal and economic forces that may impact regions differently. Globalisation, for example, is a dominant socioeconomic force that is associated with changes in the production and employment structure of countries and regions. It brings business opportunities and foreign investment to some regions. But at the same time, globalisation is partially responsible for rapid reductions in employment and outflows of high-skilled people in other regions. Both developments lead to increased differences between regions and give rise to the societal and political desire for regionalisation that emphasises 'own' identity and local interests and tries to limit globalisation.

Also on the governing side, we witness opposing forces: societal concerns such as safety, accessibility and economic development call for active and preferably centralised government control, but at the same time central government is increasingly delegating its responsibilities to lower tiers of government (Kuijpers-Linde, 2011). In fact, attention is shifting from government to governance and societal organisations (including businesses and non-governmental organisations) and individual citizens become more important in decision-making processes (Roodbol-Mekkes et al., 2012). This process of change is especially apparent in the renowned Dutch spatial planning system that is currently being stripped from its most prominent features: top-down restrictive zoning polices and urban concentration polices are being abolished (I&M, 2011; Kuiper and Evers, 2011a). Also the underlying principles of distributive justice and solidarity between regions are being removed from spatial planning and the related allocation of funds. This is directly relevant for the management of regional population decline as it implies that classical, costly interventionist urban restructuring policies will not be feasible and calls for the development of other, more innovative strategies. The outcome of the ongoing and partially conflicting societal and economic processes is uncertain and can differ per region. Which processes dominate and prevail in a certain region and how governmental interventions of different governmental levels can help steer these developments is unclear.

This paper explores the extent to which an operational, much applied land-use model can support current planning issues. It starts by briefly introducing the land-use model that is used and then goes on to discuss three recent applications related to sustainable urban development. Based on these applications potential improvements in the application of land-use models are suggested.

2. An operational land-use modeling framework

Land-use change models are useful tools to support the analysis of the consequences of land-use change (Koomen et al., 2008a; Verburg et al., 2004). They have become an established tool to help prepare and support spatial planning in the Netherlands and neighbouring countries (e.g. Hoymann, 2010; Koomen and Borsboom-van Beurden, 2011; Te Linde et al., 2011). Land-use models can, for example, help formulate adequate spatial policies by simulating potential autonomous spatial developments or, perhaps more importantly, by showing the possible consequences of different policy alternatives. Policy makers can thus be confronted with a context of future conditions and an indication of the impact the spatially relevant policies they propose.

The Land Use Scanner we apply here has its roots in economic theory. It simulates the competition between urban, natural and agricultural types of land use and thus offers an integrated view on spatial development. It was developed in 1997 by a group of research institutes and has since been applied in many policy-related research projects in the Netherlands and abroad. The model's basics and recent applications are described in a recent book that also contains numerous references to other publications (Koomen and Borsboom-van Beurden, 2011).

The model is often applied to perform what-if type of applications that visualise potential spatial patterns associated with specific scenario conditions or policy interventions. In that respect it is comparable to well-known rule based simulation models such as the original California Urban Futures (CUF) model and the What If? system (Landis, 1994; Klosterman, 1999). The model proved to be an especially valuable tool to inform policy makers about potential future developments in the context of strategic, scenario-based national planning (Schotten et al., 2001; Borsboom-van Beurden et al., 2007; Dekkers and Koomen, 2007). Other applications include ex-ante evaluations of policy alternatives in both national (Scholten et al., 1999; Van der Hoeven et al., 2009) and regional contexts (Koomen et al., 2011b; Jacobs et al., 2011).

The demand and supply of land are balanced using three main components: 1) regional projections of land-use change (demand); 2) local definition of suitability; and 3) an algorithm that allocates land (cells) to those land-use types that have the highest suitability, taking into account the regional land-use claim. Demands for land are specified for each land-use type and can be derived from, for example, sector-specific models of specialised institutes or policy-based ambitions. The local (cell-based) specification of suitable locations for the different land-use types typically incorporates many different spatial datasets referring to current land use, physical properties, operative policies and market forces generally expressed in distance relations to nearby land-use functions. Two different allocation algorithms are available that allocate land use either as fractions per cell (reflecting probabilities) or in a discrete way (filling each cell completely with one, most optimal type of land use). The latter allocation problem is solved through a form of linear programming (Koomen et al., 2011a).

3. Planning-related applications

To be able to understand the applicability of a land-use model in the current societal and planning context we briefly describe three recent applications that share the following characteristics. First, they deal with sustainability impacts of urban development like, for example, the loss of open space or the increased exposure of urban areas to flooding. Second they relate to contemporary planning issues, addressing questions as: what is the likely impact of decentralising the responsibility for spatial planning on future urbanisation patterns? to which extent is urban intensification possible to limit the ongoing expansion of urban areas? how will flood risk develop in the coming decades following socio-economic and climatic projections? Thirdly they reflect the three different types of applications generally found in planning related studies: what-if type of simulations, trend-based extrapolations and scenario studies (Koomen et al., 2008a).

3.1. Assessing the impacts of a new national spatial policy

As part of the formal Strategic Environmental Assessment of proposed changes in national spatial policy, Land Use Scanner was applied to simulate the possible future urbanisation patterns that might arise from the proposed policy change. This section describes the way these simulations were constructed. For more information about the policy context and expected environmental impacts the reader is referred to the actual assessment report (Elings et al., 2011).

The new national spatial strategy proposes four sets of major changes from current national spatial policy:

1. a new evaluation framework for investments in infrastructure that emphasises economic benefits;
2. less national interference in urban development, abolishing transformation and urban concentration policy;

3. limiting the ambitions for the National Ecological Network, focus on management of current natural areas, limited acquisition of new areas, no development of connection zones;
4. stronger emphasis on internationally unique cultural historic landscape values of, for example, UNESCO world heritage sites, abolishing buffer zones and decentralising national landscapes.

The outcome of these policy changes, however, is uncertain. This is especially true for the impact of decentralising the responsibility for the National Landscapes. Provinces may decide to ease, continue or reinforce the current restrictive planning regime in these areas. To show the uncertainty related to the different possible attitudes of the three provinces involved, it was decided to show two potential, extreme outcomes: one in which current policies are fully maintained (reference alternative) and one in which they are abolished (new policy alternative). Neither outcome is necessarily more likely, but together they show the potential bandwidth of impacts. This scenario-based approach is advocated in strategic planning (Dammers, 2000) and decision making (De Ruijter et al., 2011), but not very common in environmental assessment reports as was previously also recognised by Duinker and Greig (2007).

The table below summarises the main policy objectives and associated extreme spatial implications of the reference situation and the new policy alternative grouped per policy domain. These alternative-specific assumptions were translated in model input and first fed into the TIGRIS-XL land-use transport interaction model (Zondag and Geurs, 2011) to obtain separate sets of regional projections of the demand for new residences and business estates for each alternative in 2040. In a subsequent step these regional demands for additional urban land, together with alternative-specific, spatially explicit assumptions related to, for example, the presence (or absence) of specific policy restrictions, were fed in Land Use Scanner to simulate land-use patterns. These simulations were carried out by PBL Netherlands Environmental Assessment Agency as part of their ex-ante evaluation of the new policy report (Kuiper and Evers, 2011b) and build upon initial work that was done for the ‘Netherlands in the future’ study (PBL, 2010; Kuiper et al., 2011).

The following figure shows the simulated increase in urban area for the reference alternative that follows current policy and the new policy alternative. The figure essentially shows three states: new urban areas according to current policy, new urban areas according to the new policy alternative and new urban areas according to both alternatives. The latter thus show locations that are likely to become urbanised irrespective of any changes in spatial policy. To visualise the uncertainty that is inherent to the simulation outcomes, the very detailed outcomes are not directly shown at their initial 100 metres resolution. Instead, a visualisation technique is chosen that emphasises the presence of similar neighbours in a 500 metres environment. With a moving window filter the 24 cells surrounding a central cell are evaluated; when all cells show the same value as the central cell a colour with a high intensity is selected, when no other neighbour has the same value a low intensity colour is selected.

Obviously the simulations offer indicative, almost caricatural images that do not allow detailed impact assessments with environmental impact models. But these simulations integrate the potential implications of domain-specific policies and help visualising the regional accumulation of the impacts associated with individual policy measures.

Table 1. Overview of the main objectives and expected spatial implications of the reference situation and the new policy alternative grouped per policy domain

Policy domain	Reference situation	New policy alternative
1 mobility and accessibility	- current plans for new infrastructure development carried out	- stronger focus on economic benefits, but spatial implications uncertain: current plans are maintained
2 urbanisation (residences/ commerces)	- bundling zones and transformation zones are maintained, results in ca 30% intensification (share of new residences built in current urban areas) - supply steers location of new residences	- bundling zones and transformation zones abolished: ca. 20% intensification - residential preferences and accessibility (demand) dominate location of new residences
3 nature development	- National Ecological Network realised in 2018 according to initial plan: 100.000 ha nature extra	- limited version of National Ecological Network: 20,000 ha. extra
4 unique landscape values	- Buffer zones and National Landscapes limit urbanisation in specific areas - National Ecological Network and Natura2000 areas limit urbanisation	- Buffer zones abolished, limited impact National Landscapes -only international obligations limit urbanisation (UNESCO, Natura2000)

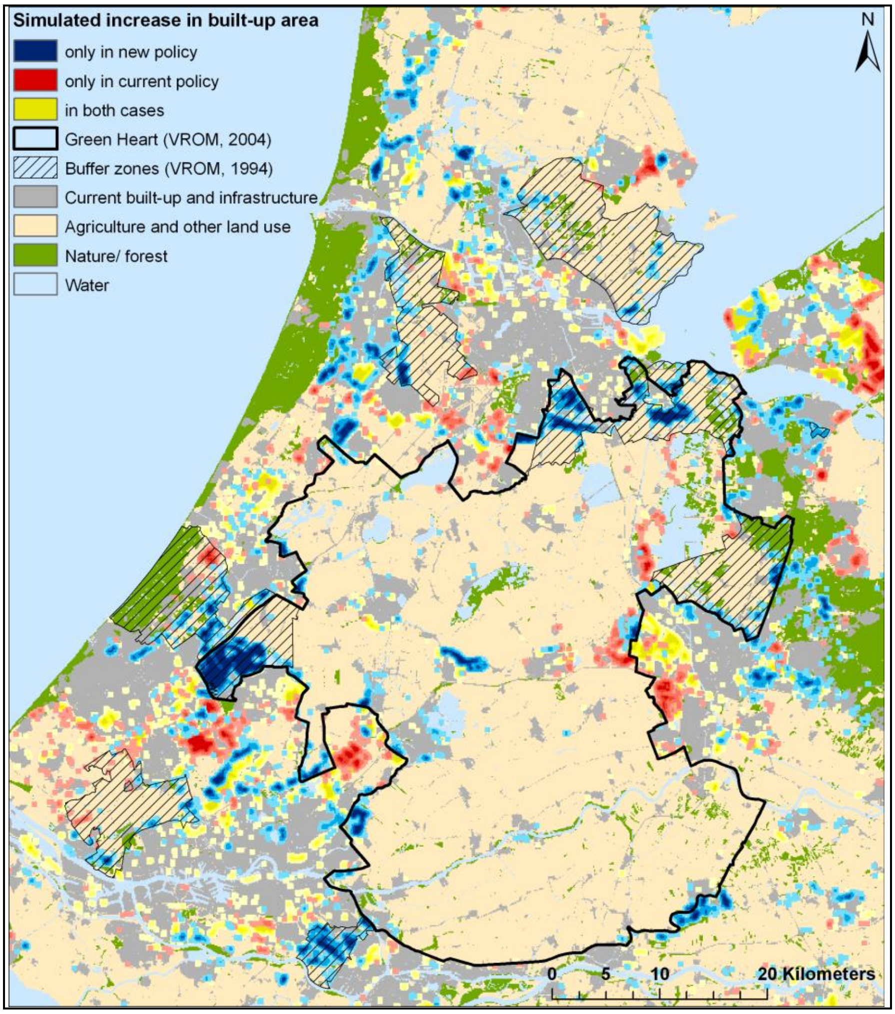

Fig. 1. Simulated changes in built-up area for the new national spatial strategy and current policy (adapted from Kuiper and Evers, 2011a)

3.2. Comparing trends and ambitions in urban intensification

The second example of a land-use model application related to urban development focuses on the difference between policy ambitions and reality with respect to urban densification. Policy ambitions for the containment of urban development are ambitious in the Netherlands as is evident from national and local objectives to concentrate residential development within existing urban areas (VROM et al., 2004; Keers et al., 2011). These ambitions are formulated as target shares of the total net increase in housing stock that should be realised within designated urban area contours. A GIS-based analysis of local changes in housing stock between 2000 and 2008 shows, however, that especially in the already densely-populated western part of country, the realised urban intensification shares are below the specified ambition levels (Koomen et al., 2013).

Using these observations in combination with projections of the regional increase in housing stock we are able to define the land demand for new urban area in 2020. Using Land Use Scanner we then simulate urban development until 2020 according to two policy alternatives. In the first policy alternative, growth in urban area is based on policy ambitions, while in the second this is based on observed trends in the last decade. The urban area demand is calculated in two steps: first the intensification share (based on either the observed values or the policy ambitions) is subtracted from the regional housing demand to account for those houses that are expected to be realised within the urban area that exists in the base year of simulation. The remaining share of houses is expected to form new urban areas. In the second step the size of these areas is determined by dividing the corresponding number of houses by the residential densities observed in the urban extensions formed between 2000 and 2008. To account for uncertainty in the regional increases in number of houses we explore to alternative scenarios: Global Economy (GE) and Regional Communities (RC), provided by the TIGRIS XL model (Significance and Bureau Louter, 2007; Zondag and Geurs, 2011). These projections were made by PBL Netherlands Environmental Assessment Agency for the Delta study (see Rijken et al., 2013 and next subsection). The GE-scenario assumes a higher population growth and stronger decrease in average number of people per household than the RC-scenario and thus shows a higher net demand for new dwellings.

For the (near) future, growth is still expected in many parts of the country, but the projections for individual regions can differ substantially (PBL, 2011). In some peripheral regions in the Netherlands, a population decline is expected; a trend that is already observed in some municipalities in peripheral regions in the northeast, southeast and southwest. The high-growth regions are mainly located in densely-populated and already highly urbanised areas, thereby forcing policy makers to build in higher densities and, if possible, within the existing urban fabric. In the regions with population decline, ambitions regarding urban intensification are high for a completely other reason: more compact urban forms are expected to be better able to maintain current urban facilities levels (i.e. shops, restaurants, public services, et cetera).

The figure below shows the observed growth in urban area between 1977 and 2008 and the simulated demand for 2020 resulting from the aforementioned calculations. Looking at the demand in the four simulations we observe that the difference in intensification shares indeed leads to a difference in demand for urban area between the two GE-alternatives and between the two RC-alternatives. This allows us to analyse and discuss the potential impact of the alternatives under different socio-economic conditions.

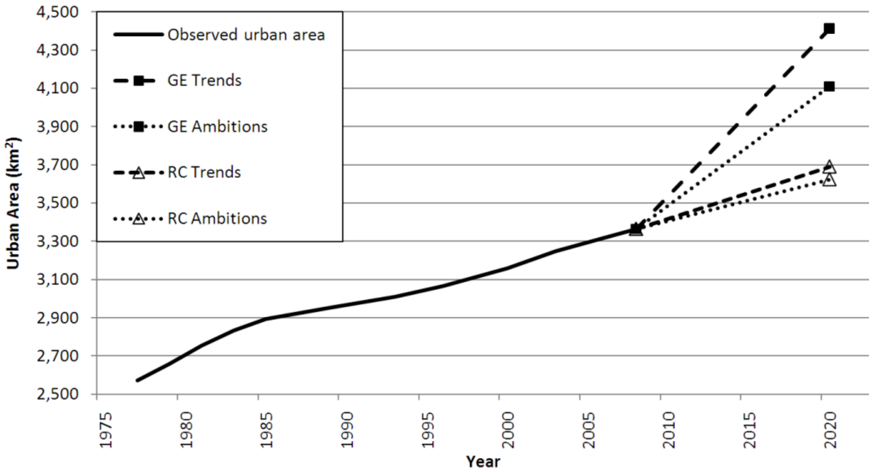

Fig. 2. Observed and projected developments in the amount of urban area (in km^2). Source: Observed urban area adapted from Statistics Netherlands, 2012

The main results of our simulations are shown in Fig. 3. We stress that these simulation exercises are obvious simplifications of reality. For instance, we have only included a limited number of suitability maps and land-use types for these simulations, and no additional land-use demand for land-use types other than urban area and nature. The upper-left map presents the main land uses in the central part of the Netherlands in 2008. The urban footprint of the Randstad cities is displayed clearly.

The simulation result of the GE-Trends alternative is displayed in the upper-right map. This is the most extreme scenario in terms of new urban extensions since it assumes a high population growth rate and a decreasing number of people per household with relatively high shares of new dwellings located outside of existing cities. The differences between the GE-Trends simulation and the 2008 land use map are considerable. We see that urban settlements grow together and an almost-fully urbanized half-moon encompassing the main Randstad cities emerges. In parallel, a large land conversion process takes place in the Green Heart area, where relatively small cities increase their urban footprint by means of additional extensions.

The lower maps show the likely urban extension areas in the Ambitions alternatives (left) and the Trends alternatives (right). The expected increase in urban areas is shown with a colour intensity that reflects the probability of urban development. The maps clearly show that more urban extensification is expected in the GE-scenario than in the RC-scenario. The GE-scenario shows a clear difference between the Ambitions and Trends alternatives. Current ambition levels will greatly help containing the large urban growth that is expected in the GE-scenario. Under the more moderate conditions of the RC-scenario this difference is less clearly visible.

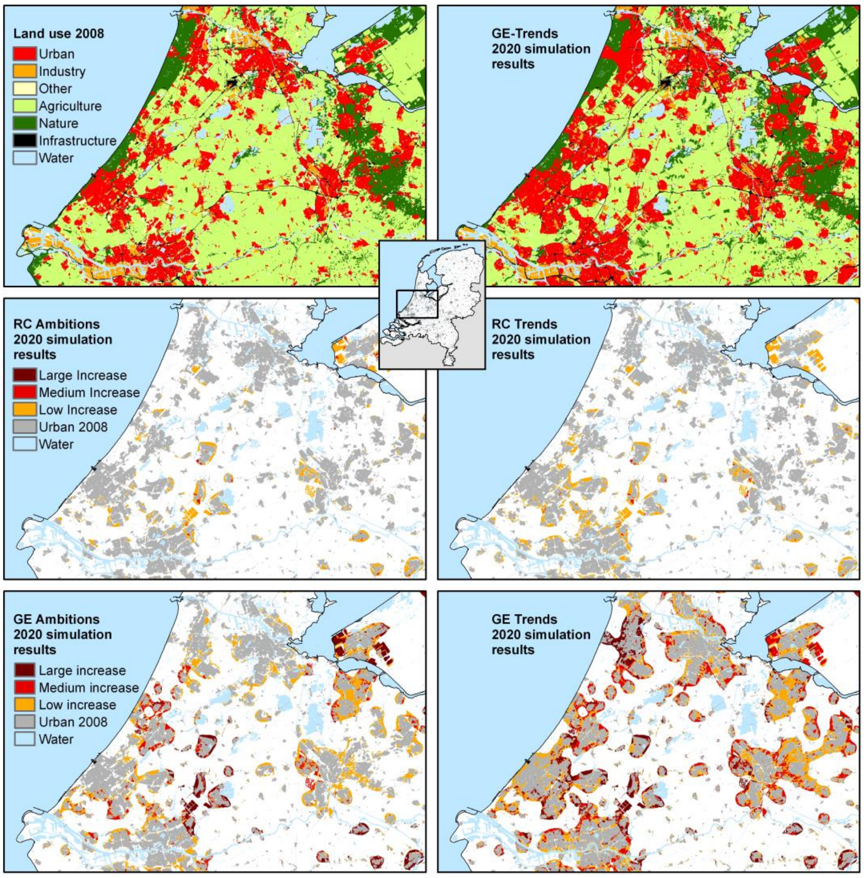

Fig. 3. Current (2008; upper-left) and simulated (2020; upper-right) land use according to the GE-Trends alternative and simulated increase in urban area in 2020 for the RC- & GE-Ambitions and RC- & GE-Trend alternatives

3.3. Scenario-based explorations of climate impacts

About a quarter of the Netherlands is situated below sea level. Current urban areas are concentrated in these areas, leaving the Dutch urban fabric very much exposed in the case of flooding. Most built-up areas are protected by extensive flood defence systems such as storm surge barriers or levies. Building and, especially, maintaining these systems is costly, so investments in these structures are at least partly based on the estimated costs of their failure. These costs are typically expressed in terms of human causalities, damage to physical property etc. Together, these cost factors constitute the so called vulnerability of an area. The higher the vulnerability, the more relevant authorities are willing to invest in flood protection.

Future urbanisation may raise these costs substantially. The question is where, when and to what extent vulnerability and, hence, flood risk, may thus increase. The Dutch national government is currently reappraising existing protection norms. The aim is to come up with a well-informed update in 2014. This reassessment takes place within the broader framework of the so called 'Delta Programme', a multi-departmental, multi-tier government initiative dealing with a wide range of water related issues.

The challenge is to prepare for investment decisions in flood protection (adaptation strategies) that are both efficient and 'robust', i.e., taking into account the likelihood of a wide range of 'probable extremes' regarding future urbanization and climate change effects. Yet both climate change and urbanisation are highly complex processes. This is especially true for urbanisation. As indicated in the previous sections, urban dynamics are driven by the interplay of a wide range of both autonomous (demography, economy) and government-driven processes. The complexity rises with the required detail of the analysis. Yet, detail (up to the scale of 1 hectare) is exactly what is required in this case.

To describe the uncertain context in which the envisaged flood protection measures must be evaluated the Delta Scenarios project was initiated. A consortium of research institutes cooperates in this multi-disciplinary subproject of the Delta Programme, to provide a set of scenarios for the Netherlands in 2050. This is done following the request of the Dutch Ministry of Infrastructure and Environment and the Ministry of Economic Affairs. The scenarios combine both socio economic and climatic components. As for the socio-economic part of the scenarios, two main dimensions of uncertainty are distinguished: 1) high versus low economic and demographic growth, and; 2) liberal versus restrictive spatial policy. 'Steam' and 'Busy' are the high economic and ditto demographic growth scenarios corresponding to the Global Economy scenario discussed in the preceding section. 'Warm' and 'Rest' are the low growth scenarios corresponding to the Regional Communities scenario. On the policy dimension, 'Steam' and 'Warm' are the scenarios in which liberal spatial policy is assumed; restrictive policy is presumed to characterise the scenarios 'Busy' and 'Rest'.

As indicated above, exploring future flood risk requires a high level of spatial detail. A similar level of detail is required for other themes of the Delta Programme such as fresh water supply for agriculture and nature. Therefore, Land Use Scanner is applied to consistently downscale the general story lines composed for the four Delta Scenarios into local level indicators. The resulting land-use simulations provide the input for a wide range of (local) indicators, ranging from fresh water demand, via soil subsidence and soil sealing, to residential vulnerability to flooding. This section goes into the latter issue illustrating the specific use of Land Use Scanner for exploring future flood risk. The focus is on the added risk emanating from residential extensions (green-field development). These developments are especially interesting as they can potentially be relocated by spatial planning measures at relatively little cost.

Fig. 4a and 4b show a preliminary rendering of the two most extreme Delta Scenarios in terms of residential extension between the year 2008 and 2050. The figures show the cells (1 ha) where, according to the scenarios, residential development is most likely to occur. To get insight in the increased flood risk emanating from these extensions, local flood hazard and expected housing densities are incorporated in the analysis. Local flood hazard is shown in Fig. 4c. It is expressed as the probability of flooding multiplied by the potential local damage to the average single family home (given local, physical characteristics such as maximum inundation depth etc.). Flood risk is calculated by simply taking the urban extensions simulated by Land Use Scanner, looking up the correspondent local flood hazard, and multiplying this by the expected residential densities. Fig. 4d and 4e illustrate the results.

The simulations indicate that risk is concentrated in the few areas where residential extension, high housing densities (not shown in this section) and ditto flood hazard coincide. The figures also show that areas characterised by high risk are rather far and in between. Indeed, these small pockets of high risk are dispersed over a number of large flood protection areas (i.e. the areas within the blue lines in Fig. 4c). This is true for both the liberal, high growth scenario 'Steam' as in the opposite 'Rest' scenario – although total risk is evidently higher in Steam.

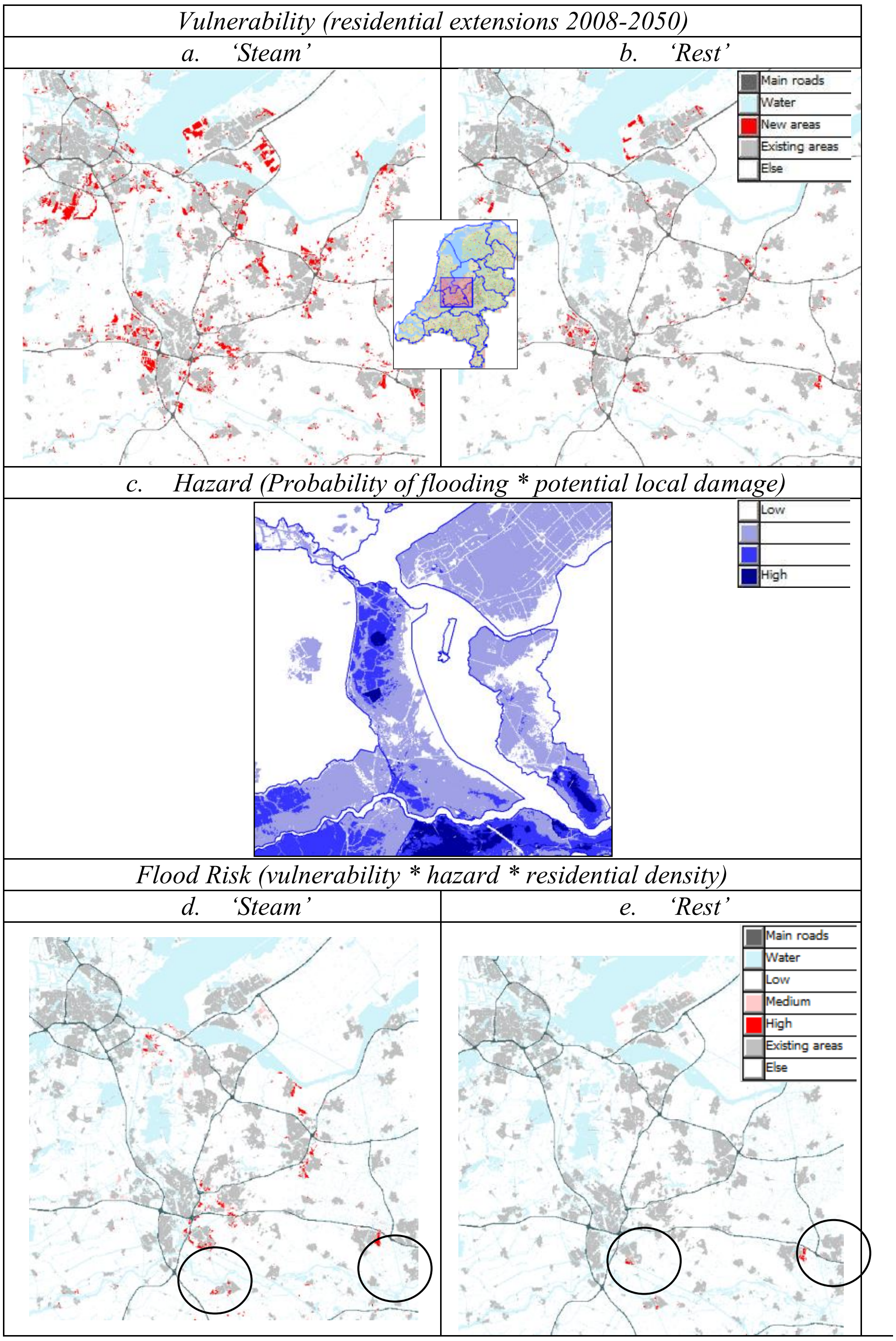

Fig. 4. Exploring Flood Risk in residential extensions 2008-2050 Delta Scenari-

os. Source: Delta Scenarios, 2012

The dispersed patterns shown in the area selected in Fig. 4 can also be observed in other flood-prone parts of the Netherlands. From a flood risk management perspective more concentrated urban development at less risk-prone areas is preferred. Should that prove to impossible, Dutch climate adaptation strategies will have to follow a localised approach that is tailored to the local idiosyncrasies constituting risk in a particular area. This would favour custom adaptation measures like, for instance, elevated or floating housing, spatial zoning or even evacuation plans, over broad, capital intensive measures like further fortification of the flood defence systems surrounding the protection areas shown in Fig. 4c. On account of the efficiency criterion, it would be well advised to focus on the areas in Fig. 4d and 4e showing the highest concentrations of risk. By way of example, these are marked with circles in the figures. The robustness of the required investments would be served if priority would be given to those areas that show high risk in at least two scenarios.

4. Discussion and recommendations

The presented, recent Dutch land-use model applications focussed on simulating future urban expansion patterns. This is for many regions a very real scenario and Land Use Scanner is a powerful instrument to explore the impacts of new urban development in terms of, for example, loss of open space and flood risk. In the near future other spatial policy challenges may become prominent. These may relate to steering urban intensification in regions of urban growth and urban restructuring in regions of population decline (Kuijpers-Linde, 2011). Intensification has the potential to preserve open space, keep down transportation costs, maximise urban economic productivity etc. Effective restructuring, in turn, could minimise the damaging effect shrink may have on the economic health of urban areas.

To allow the simulation of processes such as intensification and restructuring we are currently busy incorporate residential land-use density in Land Use Scanner. Ultimately, this requires a distinction between actors (residents), objects (residences) and land use (residential land) and the addition of information on each of these three layers in the model. Initial attempts to incorporate residential density (as described in the second example Section 3) have treated density change as exogenous model input, based on expert judgement and the extrapolation of past trends. This implies that, while all kinds of assumptions can be made regarding future dynamics on these issues, and numerous local indicators can be derived from the resulting output, the underlying phenomena remain outside the model, preventing them to be simulated in an integrated way that is most probably require. Making these phenomena endogenous model parameters by incorporating the underlying mechanisms into the Land Use Scanner model would at once improve the explanatory power of the model regarding these highly relevant policy issues, and enhance the detail of the relevant model output (i.e., local density). This would greatly enhance the potential for subsequent impacts assessment such as local flood risk assessments discussed in the third example in Section 3.

At a more fundamental, policy-oriented note it should be added that decision making in spatial planning is moving away from a straightforward, linear process (Roodbol-Mekkes et al., 2012). Public debates, storytelling, the generation of new ideas (visioning) and spatial investments are becoming incremental and iterative processes. More and more, the debate about regional development takes place in non-related discourses. Moreover, the consistency between medium and long term relevant policies is becoming weaker or turns out to be absent. Furthermore, many actors are involved that move away from a rational-logical approach to decision making. Traditional tools for evaluation and visualisation may not be fully suitable in this new context, mainly because they lack the flexibility to change spatial scale, time horizon or area selection. They usually are slow in responding to new policy strategies and their output is often difficult to understand or even irrelevant for the various non-expert stakeholders that are involved in today's spatial development processes. An important element that is absent in most spatially-explicit decision support tools is financial information. Especially since the recent financial crises this is a major shortcoming because spatial planning discussions are currently being dominated by financial debates about investment.

A possible way forward is to combine existing land-use models, evaluations frameworks (such as cost benefit analysis or dedicated impact assessment framework) with new visually attractive user interfaces (such as touch tables) to overcome part of the shortcomings of existing evaluation tools. In doing so it may become possible to bring together the values and arguments of different actors in decision-making processes in the built environment that differ in spatial scale, time horizon and focus concerning people, planet and profit aspects. A potentially useful tool for local-level decision making is offered by the Urban Strategy framework that visualizes impacts of spatial developments for different sustainability values related to people, planet and profit (Duijnisveld et al., 2010; Schelling et al., 2010). Currently we are trying to combine this interactive local-level instrument with Land Use Scanner to visualise the coherence between various spatial development issues by linking their different spatial and temporal dimensions.

5. Conclusion

Land-use simulation proves to be a useful tool in the evaluation of policy alternatives and the exploration of future scenarios. The first example shows that a land-use model can successfully be used to depict likely outcomes of policy changes in a Strategic Environmental Assessment report dedicated to the newly proposed national spatial strategy for the Netherlands. This what-if type of simulation typically relies strongly on expert judgement as it has to describe the impact of policies that have not yet been implemented and whose effects cannot be observed. These expert opinions can, to some extent, be tested in GIS-based analyses of the effectiveness of similar policies as described in other studies (Koomen et al., 2008b). A recent, interview-based study by Van Kouwen (2012) into the potential future spatial developments in National Landscapes indicates that most parties involved do not expect sudden changes from the proposed changes in national spatial policy. These expectations, however, seem to be strongly linked to current political and economic conditions. When such conditions change, the current trend towards deregulation and decentralisation may lead to an increase in urban development in currently protected landscapes. Such threats to metropolitan open spaces have, for example, also been described by Van Rij (2009). Therefore, we strongly believe that the type of scenario-based simulations of potential impacts of policy changes described in this chapter offers a powerful approach to incorporate the notion of uncertainty in ex-ante policy evaluation.

The second example shows that current ambition levels are needed to prevent extensive loss of open space. Should urban development (in terms of intensification share and extensions' densities) follow past trends, large-scale urban extensions are likely to occur. This is especially true when future socio-economic conditions resemble the Global Economy scenario.

Finally, the third case study shows that the Land Use Scanner can be a valuable tool in the field of climate adaptation as well. By simulating future residential development at the highly detailed level of 1 hectare grid cells, it demonstrates that adaptation to flood risk emanating from future residential extension can be limited to highly localised strategies like spatial zoning. Cost can be minimised by focusing local adaptation strategies on the areas where risk is most concentrated. Prioritising the places where these concentrations occur in more than one scenario enhances the robustness of adaptation.

Our simulation can easily be expanded to explore other scenarios or strategies, and accommodate additional spatial restrictions or other types of development (e.g. agriculture, industry/commerce, recreation). Such simulations have been performed as part of other studies focusing on, for example, the environmental impacts of a new regional strategic vision (Koomen et al., 2011b) or the potential for new biofuels in the country (Kuhlman et al., 2013).

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