Assessment of the Greater Dublin Region's Development Using the MOLAND Model

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Abstract

Management strategies and tools are needed to mitigate the environmental impacts of urban areas. In the past few decades, researchers have made considerable progress in improving the capabilities and usefulness of GIS for urban management and policy evaluation. However, there is a lack of tools available to compare and contrast policy scenarios, particularly tools which integrate land use, transport and socio-economic variables. MOLAND is one such tool which has been developed to support decision-makers working within policy and planning development. It is a Cellular Automata based model sponsored by the European Commission's Joint Research Centre. MOLAND uses layers created by ArcGIS and runs on a modelling framework, Geonamica© which allows dynamic integration of a variety of spatial models. The model has already been applied in over 20 territories in Europe and is currently being applied in Ireland by the Urban Environment Project funded by the Environmental Protection Agency Ireland.

Introduction

Understanding the link between development-space-environment is increasingly important given the environmental pressures associated with urbanisation and the fact that global trends point to ever increasing levels of urbanisation. The rapid urbanisation of the world's population over the 20th and 21st centuries is presented in the 2007 Revision Population Database of the UN World Urbanization Prospects report (UN, 2008). The global proportion of urban population rose dramatically from 29.1% (737 million) in 1950, to 48.6% (3.2 billion) in 2005. The same report projected that the figure is likely to rise to 57.2% (4.6 billion) by 2025 and the world urban population is expected nearly to double by 2050, increasing from 3.3 billion in 2007 to 6.4 billion in 2050. More than 80% of US population (UN, 2008) and 75% of all Europeans (EEA, 2006) now live in urban areas and based on current trends this could rise to 85% in US and 80% in Europe by 2020. In Ireland approximately 2.3 million are now living in urban areas. Unprecedented economic growth in the 'Celtic tiger' years has been coupled with an increase in population which is concentrated in the Greater Dublin Region (GDR) highlighted in Figure 1. Urbanisation has many impacts which are well documented. These include waste management, air quality, noise and water pollution, traffic congestion, the loss of open spaces and the degradation of the urban landscape (EPA, 2008).

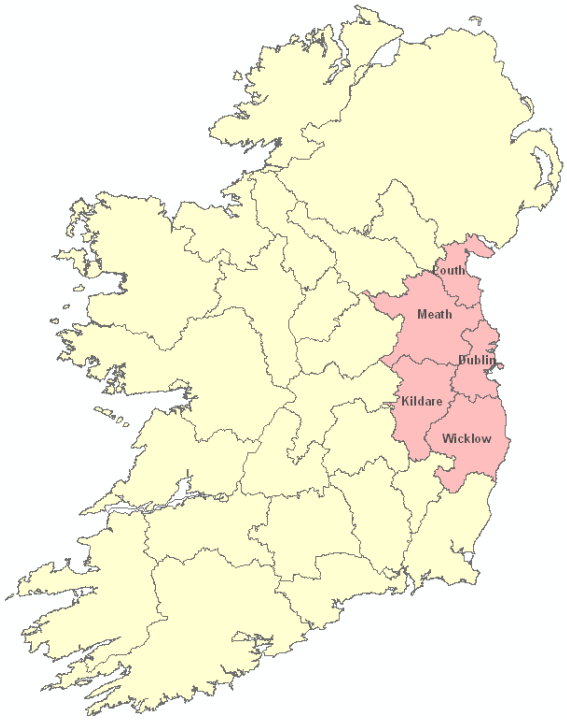

Figure 1: Greater Dublin Area (GDR)

With the progress in computer engineering and new technologies urban geographers and IT scientists have developed new ways to simulate, model and experiment with complex geographic systems. Benenson & Torrens (2004) describe the use of automata as a basis for modelling geographical systems. Two broad categories of models are described. The first group relies on cellular automata (CA), the second on multi-agent systems. The key

differences in the two approaches can be understood with regard to their treatment of space. In the CA approach each cell has a specific location and remains stationary over time, but the cell state changes. In the agent based approach individual agents are free to change position and their behaviour is programmed to include for e.g. way-finding and spatial cognition. The cellular automata approach is particularly suited to the complex and dynamic nature of urban systems. One of many advantages is that it can be used in conjunction with GIS technologies which are used in the preparation of data for input to the model and the results can be analysed using spatial analysis techniques which have matured in recent years (Longley, 2003).

This paper focuses on an application of the MOLAND model which is a CA based model. The area of implementation incorporates the four Dublin local authority areas i.e. Fingal, South Dublin, Dublin City and Dun Laoghaire-Rathdown—modelled as one region, as well as the counties of Kildare, Meath, Wicklow and Louth (**Error! Reference source not found.**1).

MOLAND Model

The MOLAND model was developed as part of an initiative of the European Commission's Joint Research Centre as a response to the challenge of providing a means for assessing and analysing urban and regional development trends across European member states (Engelen et al, 2007; EEA 2006).

The MOLAND model comprises two sub-models working at different scales. At the macro scale, the model takes as input the population and the economic activity (number of jobs) in a region, this population and activity is then split between the sub regions encapsulated in the model area. In the Dublin Region application, the sub-regions are the administrative counties within the region. At the micro scale the provision for population and economic activities is translated into a number of land uses; for example, the population will be provided for within residential land use types and the economic activity will be provided for within commercial, industrial and service land uses. The micro model is based on the cellular automaton. The land use type assigned to any given cell is determined by an algorithm which aims to satisfy the demands for land use in each time step. The result is a spatially explicit output which places particular land uses in specific cells, each of which corresponds to a parcel of land. It provides a means of representing the various social, economic and environmental interactions which occur. The micro model takes four factors as input, namely, current land use, accessibility, suitability and zoning. These are described below.

Land Use

A GIS layer describes the land use characteristics of the Greater Dublin Region. Satellite imagery, aerial photography and high resolution Quickbird data is used to produce a vector layer of polygons which are classified according to a number of land uses. The classification is based on the European CORINE system (EEA, 2007), but has additional classifications for land uses which are particular to urban areas e.g. residential discontinuous sparse. The vector files were converted to ASCII raster format with 200m cell size using ArcGIS software.

Accessibility

This layer describes the accessibility of land to the transport network in the region. It includes road and rail networks and the level of accessibility is determined by the type of transport link present. For example, locations close to motorway intersections are considered highly accessible whilst the accessibility decreases as one moves away from the intersection. The model uses an ArcGIS shape file of the transport network to generate the appropriate accessibility map for the region.

Suitability

Suitability represents the degree of relevance of each cell to each land use type, according to a set of predefined criteria. Thus, land use suitability displays locations that fulfil a suitability criteria defined for each land use class. Using multi-criteria analysis techniques, the relevant criteria can be derived from surveys of experts' opinions and longitudinal studies that detail suitability of land use classes over time.

Zoning

The MOLAND model uses a zoning raster file with binary cell values, namely, permitted (0) and not permitted (1). That is, zoning specifies whether a cell may or may not be taken over by a specific land use. For each land use category it is possible to introduce a different zoning map. We have used maps of conservation, national

heritage and special protected areas as a base for zoning maps, prohibiting future residential development in these parts of the region.

Neighbourhood rules

In addition to the above factors, the dynamic impact of land uses on each other, and in their immediate neighbourhood is modelled using distance curves. The neighbourhood curves model the attraction and repulsion between pairs of land uses and aggregate this effect within a defined neighbourhood.

On the basis of these elements, the model calculates for every simulation step the transition potential for each cell and function. Cells are changed to the land use function for which they have the highest potential until regional demands are met (Figure 2).

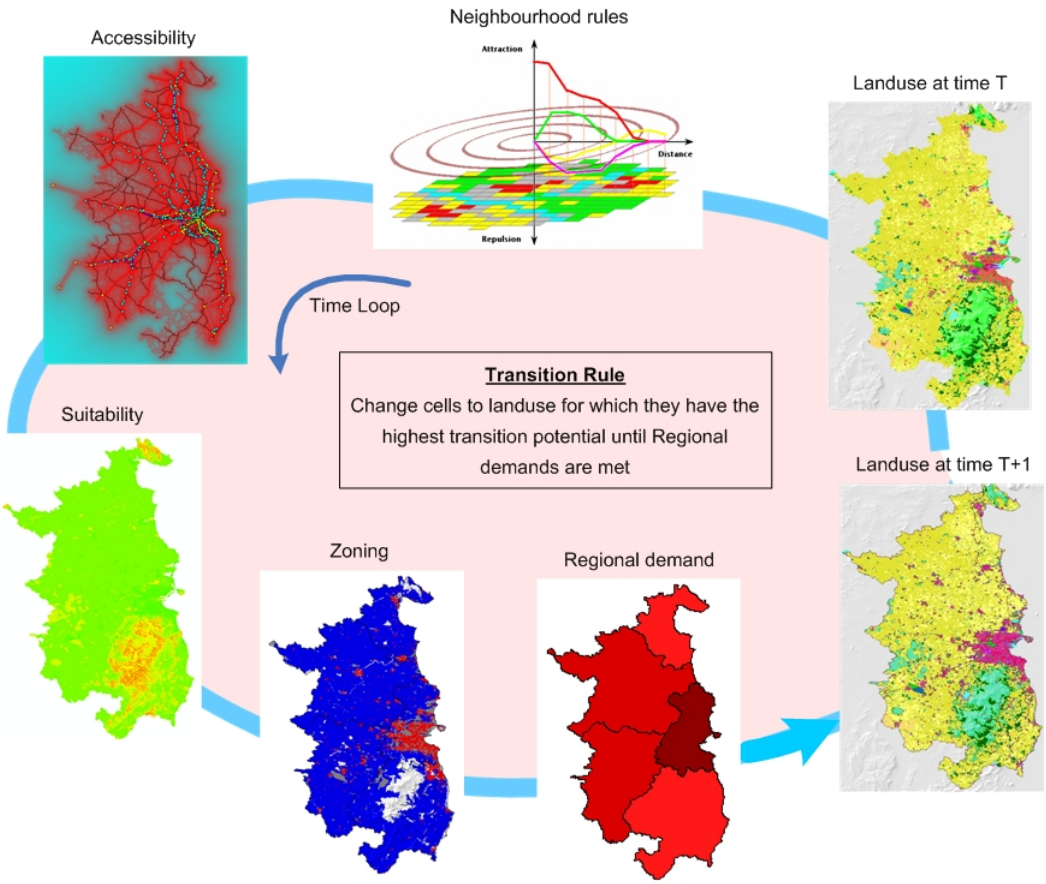

Figure 2: Land use transition in MOLAND model (source: RIKS)

Population Growth Scenarios

The population projections used in our study are based on the Irish Central Statistics Office' (CSO) regional population projections (CSO, 2008). They contain projections for the eight Regional Authority areas for 2011-2026. Assumptions for regional fertility and mortality trends and international migration to and from each region were consistent with those used at national level. In addition two internal migration scenarios were used, namely, "Recent" and "Traditional".

From the six published projections we have selected two extreme projections for our study. Hereafter, we will call them population high growth scenario (M2F1T in CSO, 2008) and low growth scenario (M0F1R in CSO, 2008). The first scenario combines continuing though declining international migration with constant fertility and a return to the traditional pattern of internal migration by 2016. Whilst the second scenario assumes zero annual net inward migration. As a result relevant growth rates under the low growth scenario will be less than the corresponding rates under the high growth scenario across the region. The internal migration scenarios were developed due to differences found between censuses carried out up to 1996 versus the 2002 and 2006

censuses. The 1996 and pre-1996 censuses reveal a fairly stable picture in terms of the magnitudes of the inward, outward and net migration flows, with the Dublin and Mid-East regions receiving positive net migration flows while all other regions had negative flows. This flow pattern was reversed in the 2002 and 2006 censuses. Due to the lack of stability in internal migration movements over the period 1996 to 2006 the two internal migration scenarios were formulated. "Recent" (used in our low growth scenario), assumes that the patterns observed in 2002 and 2006 apply up to 2026, while under "Traditional" (used in high growth scenario) the 1996 pattern of inter-regional flows is applied in 2016 and kept constant thereafter, with the difference between the 2006 and 1996 patterns apportioned over the years between 2006 and 2016. In both scenarios the total fertility rate is assumed to remain at its 2006 level of 1.9 for the lifetime of the projections.

For increased accuracy employment data used in MOLAND should be gathered by place of work and not by place of residence. Then it should be grouped in three broad categories namely, Industrial, Commercial and Services. In Ireland, place of work data is currently only available for 2002 and 2006 (when the CSO implemented the Sample of Anonymised Records (CSO, 2002) and Census of Anonymised Records (CSO, 2006)). These datasets were used to estimate the appropriate place of work data for 2026 using an annual linear growth rate. The employment data was projected for 2026 using the high population growth projection at first. Then taking into account population ratios between two projections, employment data for the low growth scenario was estimated. The final data used in MOLAND for the current research is presented in the following table:

Table 1: Data used in MOLAND for the 2026 scenarios simulation

	2006	**2026 Scenarios**	
		Low growth	High growth
Population (total)	1773803	1952125	2553149
Population (other)	*1437010*	*1581474*	*2068381*
Population (sparse)	*336793*	*370651*	*484768*
Industry	259800	290984	380573
Commerce	321790	427805	559519
Services	211656	161831	362129

Simulation Results

The calibration of the model follows the approach recommended by RIKS b.v. the software developers (Engelen et al, 2004). The model was calibrated for the Greater Dublin Region using available 1990, 2000 and 2006 datasets. Results showed a good comparison with the Constant Share Model which provides a measure of the effectiveness of the calibration (see Appendix for more information). A test run for 50 years was implemented to check the map pattern generation process. Cluster size analysis proved that the simulated maps are not unrealistic.

Once model calibration for the Greater Dublin Region was complete, urban growth and land cover change was simulated into the future. The model was implemented using the 2006 land use map and data for the base year and simulations were run to 2026 using the two population growth scenarios mentioned above.

While the overall patterns under the two scenarios are broadly similar, the detailed study shows a larger increase of residential areas in the case of the high growth population scenario. Figure 3 displays the land use development pattern in Dublin County. The first map is the actual land use map of the county in 2006. The second map is the simulated map of 2026 according to the low population growth scenario. And the third map is the simulated map of 2026 according to the high population growth scenario. In order to see the differences between two simulated maps of 2026 we have used the Map Comparison Kit developed by RIKS (Hagen-Zanker 2008). In particular, we have produced a map which for every pair of cells indicates whether the land use classes are identical or not in the compared maps. Figure 4 shows the results of such cell-by-cell comparison. The comparison map contains green cells where the two maps agree and blue and red cells where they do not. Thus, in the case of blue cells the residential development which occurred in the low growth scenario only is shown with the blue cells and the red cells show where residential development has occurred only in the in case of the high population growth scenario.

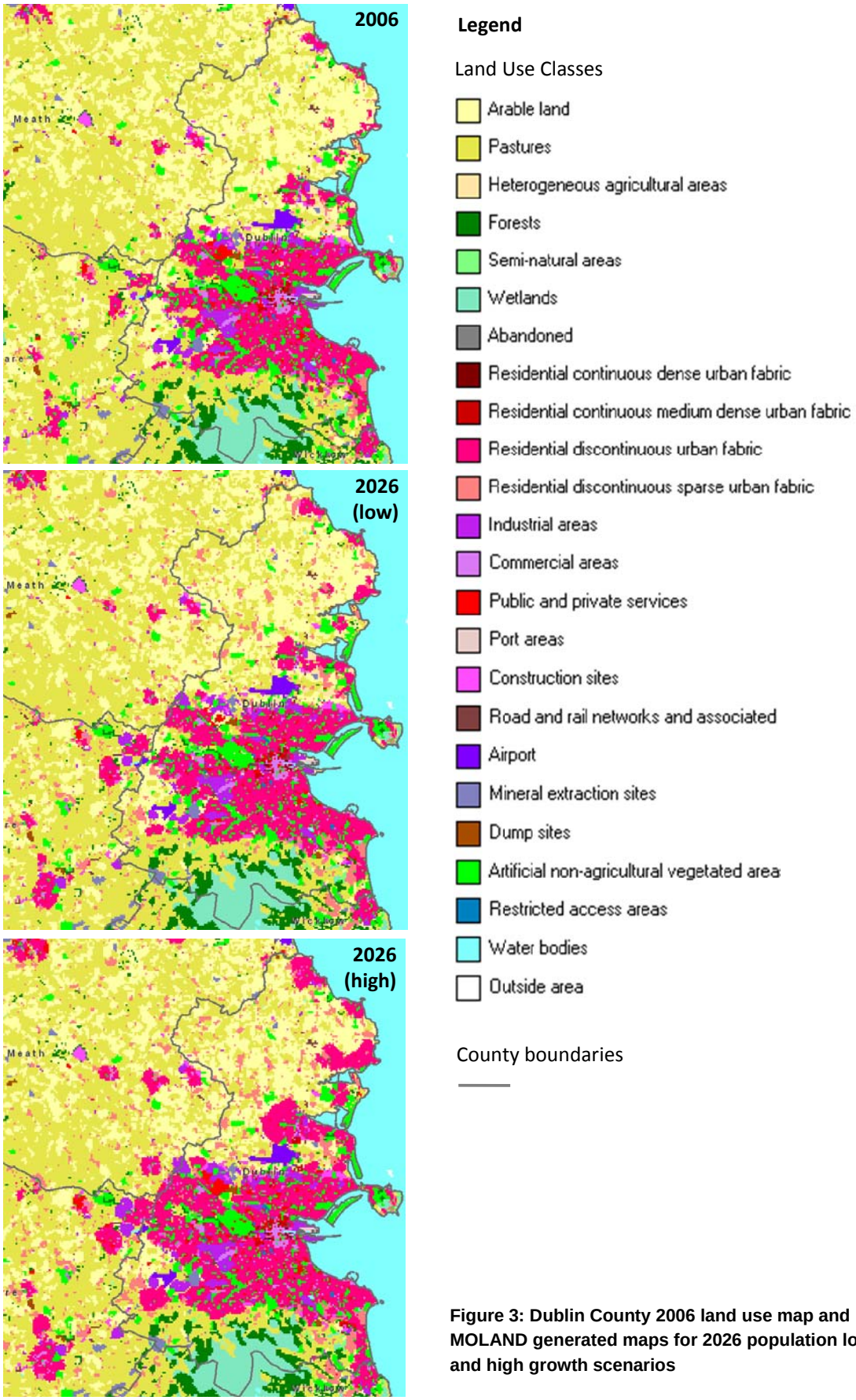

Figure 3: Dublin County 2006 land use map and MOLAND generated maps for 2026 population low and high growth scenarios

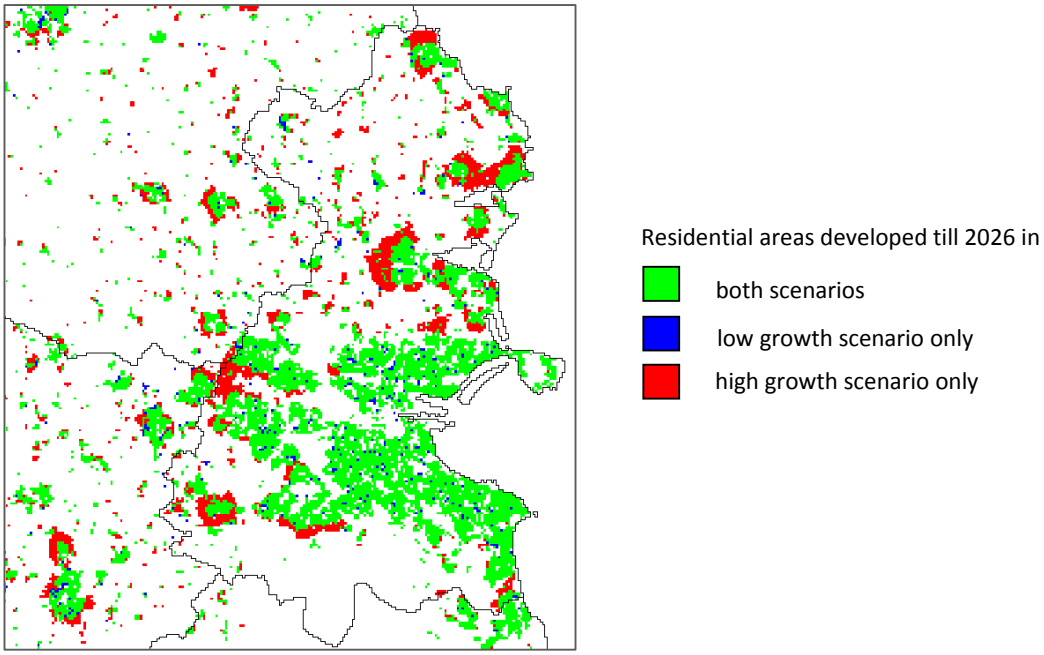

Figure 4: Dublin county 2026 land use map comparison results

Hawth's Analysis Tools in ArcGIS 9.3 were used to calculate cell statistics by county for land use maps in 2006 and 2026. Calculations show an increase of residential areas in all counties for both population growth scenarios. The maximum increase (409% in case of high growth and 264% in case of low growth) occurred in County Kildare. The minimum increase (54% in case of high growth and 4% in case of low growth) took place in County Dublin (Figure 5). For other activity areas like industry, commerce and services different development patterns were observed. These are presented in the Figures 6, 7 and 8. In particular, commercial areas are shown to increase for all counties except Dublin in the case of the low population growth scenario, when the number of commercial cells remains equal to the number of commercial cells in 2006. A similar picture for industrial areas is observed but this time the total number of industrial areas in Dublin has actually decreased in 2026 in the case of the low population growth scenario. For services a decreased number of cells were observed in the case of the low population growth scenario and an increase observed in the number of cells in the case of the high population growth scenario for all counties in the study region.

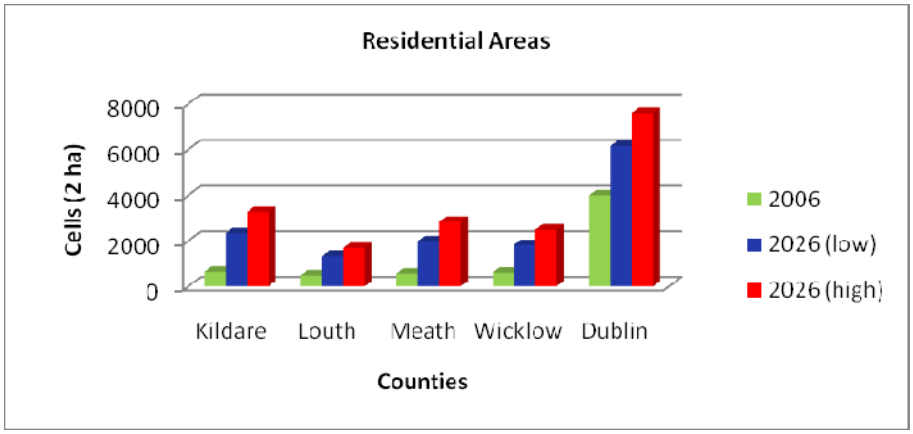

Figure 5: GDA 2006 and 2026 land use map comparison results for residential areas.

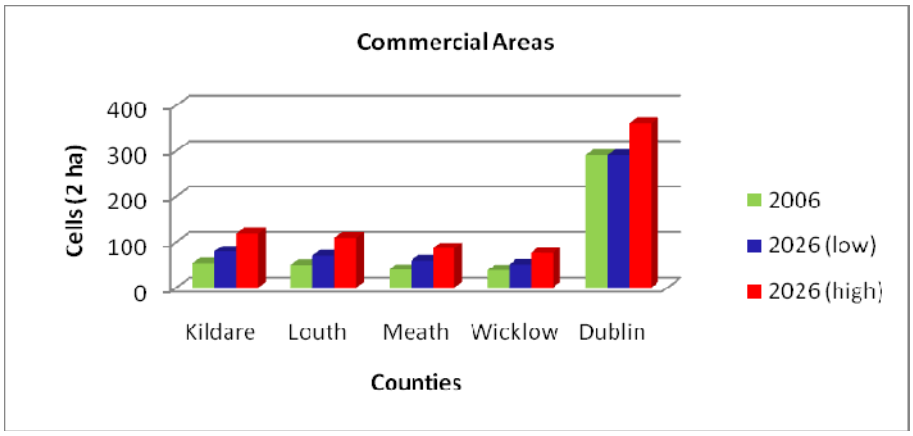

Figure 6: GDA 2006 and 2026 land use map comparison results for commercial areas.

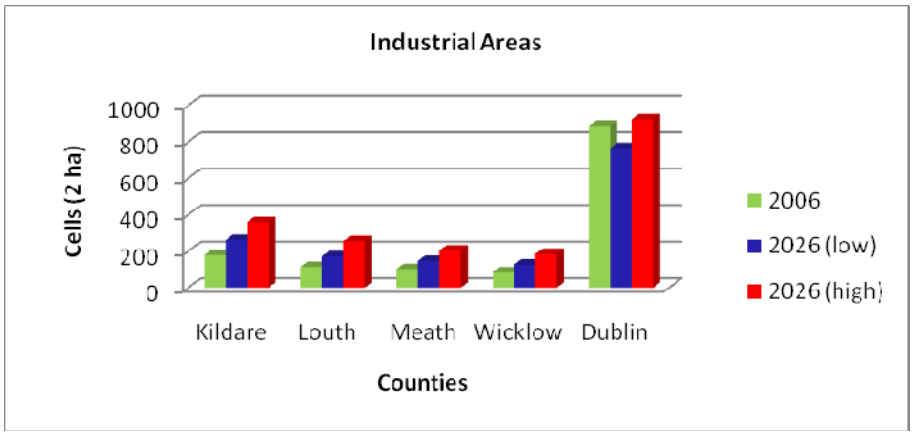

Figure 7: GDA 2006 and 2026 land use map comparison results for industrial areas.

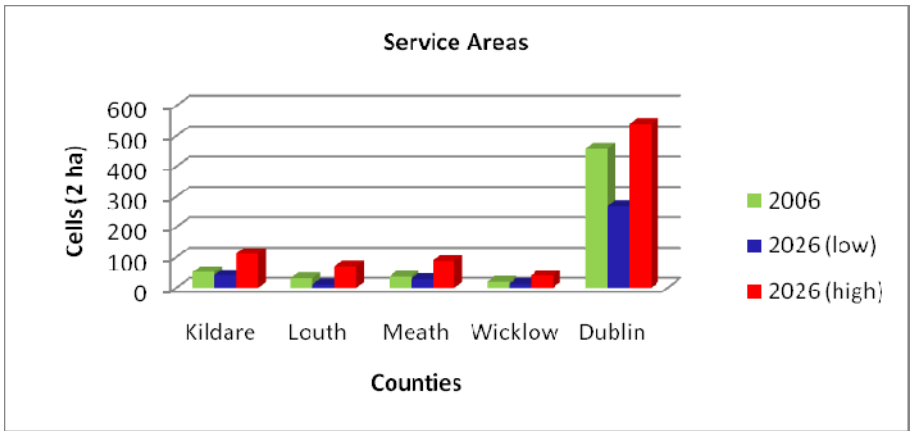

Figure 8: GDA 2006 and 2026 land use map comparison results for service areas.

The calculations described were done based on one simulation run for each population growth scenario. But as will be shown below, an improved prediction of future development trends can be achieved through the use of probability mapping.

Predictions and Probability Mapping

The MOLAND model helps us to understand trends we are interested in and provides predictions of future land use changes. But in reality it offers not predictions of the future, but predictions of possible futures. Indeed, each time the model is run it will give different predictions, both because of random elements and because of

bifurcations inherent in the dynamics of the model. Therefore the proper way to view the output of the models is probabilistically. To do this a simulation in MOLAND can be run a sufficient number of times and a map of all the output possibilities produced. Of course some possible outcomes will be very similar, and some can be quite different. The ability to know the range of future possibilities, and perhaps their relative probabilities of occurring, is extremely useful, and it is this sort of knowledge that a good model can offer us (White 2008).

Returning to Greater Dublin Region, rather than showing a single land use map as the prediction for 2026 as shown above, a series of probability maps is presented; one for each land use class. Beginning in the data year 2006, the model is run to 2026 for 10 iterations. As a result 10 probable land use maps for 2026 are produced. Though at the first glance they look similar, as a result of the random factor and possible bifurcations in the model there are some differences between them. Using Raster Calculator in ArcGIS Spatial Analyst Extension probability maps for residential and activity land use classes were created (Figure 9). These describe the likelihood and character of land cover change.

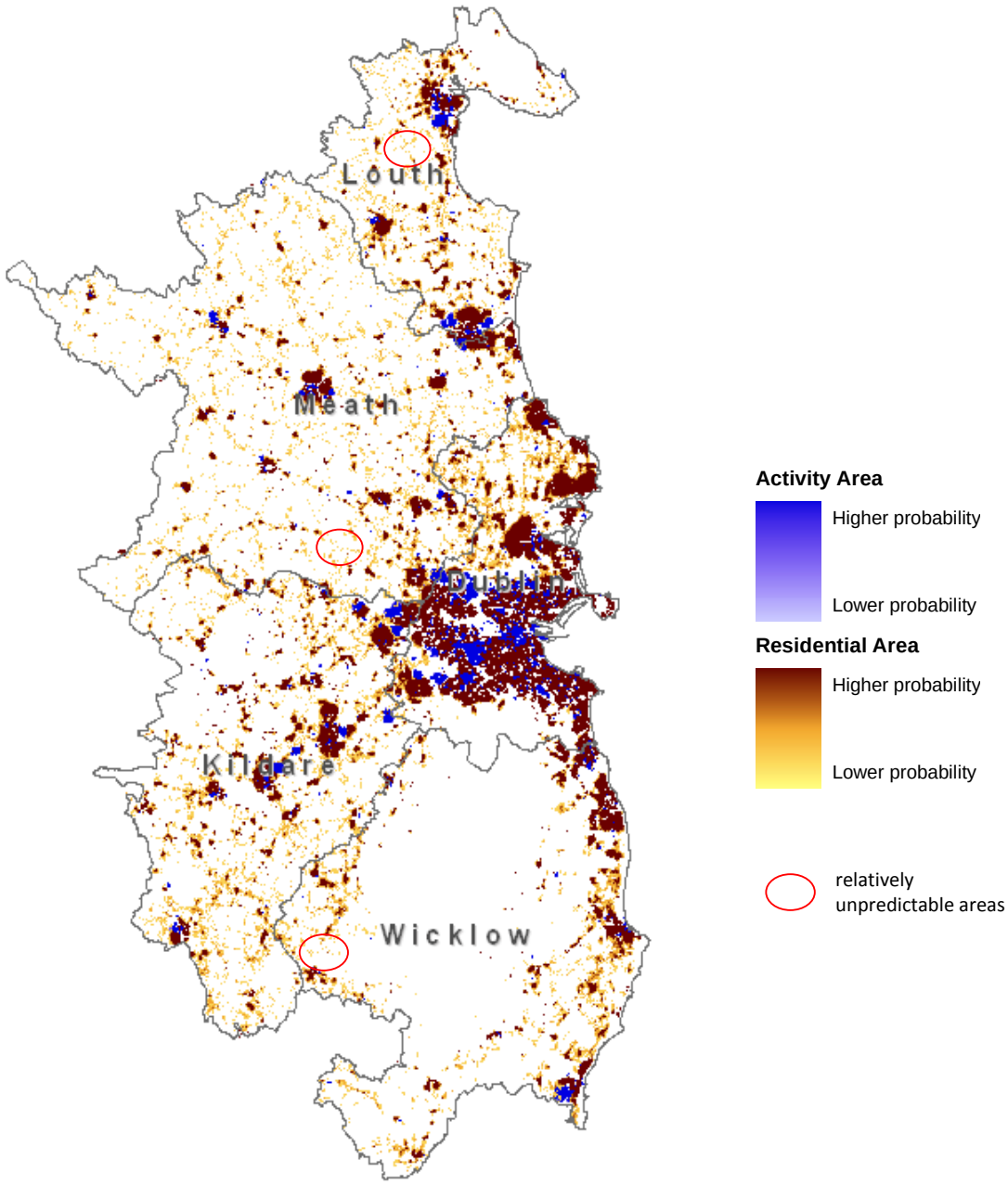

Figure 9: GDA probability map of residential and activity areas in 2026.

Figure 9 shows the probability map of the residential and combined industrial, commercial and service activity areas for the year 2026. Each location is classified by its probability level to become a land use cover type.

It is apparent that most areas around Dublin are relatively predictable in terms of future urban land use: either they are very likely to be developed or they are very unlikely to be developed. However, if one land class is equally as likely as another of being present, there is a high degree of uncertainty related to the modelled class transition. Thus some areas, for example the circled one, are not very predictable; these areas are approximately equally as likely to be developed as not to be developed, so the model can't really predict what will happen in these areas. However, for planners and decision makers this is very useful information. It is useful to know in a spatially explicitly sense, where the probabilities of particular land use transitions are intermediate because in these areas future land uses can be influenced by small interventions in the present; in contrast, in the highly predictable areas, major efforts by way of interventions may be needed in order to alter future land use patterns.

Conclusion

The study has shown how MOLAND may be usefully applied in exploring the spatial distribution of land uses under a range of population scenarios in the Greater Dublin Region. The probability maps allow for estimates to be produced of the likelihood of certain land use transitions. They provide a valuable tool to describe predicted land cover change and its uncertainty. By utilising the functionality of ArcGIS spatial context can be given to land use change predictions and the associated level of confidence in each of the predictions produced can be assessed.

In this study the scenarios used relied on modifying only one variable, that is the future population in the region. However, the MOLAND framework allows for scenarios encapsulating changes in a range of variables to be explored. For example scenarios demonstrating various activity levels, changes in zoning practice and provision of transport infrastructure or a combination of all of these elements can be considered within the MOLAND framework.

MOLAND as a spatial decision support system goes some way to provide decision makers in the area of spatial planning and infrastructure development with a tool that overcomes some of the shortcomings of common GIS systems. The limitations of present-day GIS include its poor ability to handle dynamic spatial models i.e. poor handling of temporal dimensions. In coupling GIS with a cellular automata model like MOLAND, the model serves as an analytical engine which provides a flexible framework for the running of dynamic spatial models. Such models are useful platforms for conducting what-if experiments on various planning and policy options, in order to gain some insight into their likely effects, indirect as well as direct, before they are implemented.

Acknowledgements

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All work undertaken on the MOLAND model, for the Greater Dublin Region is subject to the license conditions of the software developers, Research Institute Knowledge Systems b.v. (RIKS b.v.) and the data set owners, DG JRC under license no. JRC.BWL.30715.

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Appendix: Calibration quality: Assessment of population and activity estimates per county

In order to assess the quality of the calibration the simulated job and population estimates of the macro-model are analyzed. The results are compared with a reference projection model, and it is determined how much the model deviates from this reference model. For this, we use the so-called constant shared projection technique. Simply stated, the Constant Share Model (CSM) assumes that the local share of a larger region's activity remains constant. For example, the CSM approach assumes that if county X has 6.2% of Industrial employment in 2000, then this share will remain constant through the year 2006. The CSM assumes this is true for all economic sectors, and thus provides a basic reference for testing the macro-model. The CSM estimates are calculated as follows:

$$\text{Projected Estimate at time } (t+1) = \frac{\text{Total Estimates at time}(t+1)}{\text{Total Estimates at time } t} \times \text{Estimate at time } t$$

This formula is applied to all the four socio-economic sectors and the results are compared with the estimates from the macro model. Results of the comparison are given in numeric form in the table below. The difference between the actual and CSM / MOLAND simulated population estimates per county for 2006 are presented.

	Population		**Industry**		**Commerce**		**Services**	
	CSM	MOLAND	CSM	MOLAND	CSM	MOLAND	CSM	MOLAND
Louth	-1.19%	3.14%	-15.99%	6.75%	-21.54%	6.53%	-13.00%	8.84%
Meath	-13.78%	-3.17%	-35.27%	-9.14%	-52.88%	-7.74%	-47.89%	-7.94%
Dublin	3.44%	0.03%	15.87%	0.00%	15.27%	0.00%	16.28%	0.02%
Kildare	-7.67%	-2.52%	-23.15%	-0.33%	-43.55%	0.45%	-39.21%	-3.95%
Wicklow	-2.21%	4.76%	-17.17%	8.84%	-36.53%	3.62%	-36.28%	8.99%
Root Mean Square Error (given as the percent of the mean of the measured values)	**6.15%**	**1.24%**	**24.71%**	**3.05%**	**28.3%**	**1.53%**	**28.75%**	**2.45%**

It is obvious from table that MOLAND gives much more accurate estimation of the population and activities by counties then the constant share model.