

---

---

# Simulated future development of the Greater Dublin Area: consequences for protected areas and coastal flooding risk

Michael Brennan<sup>1,2</sup>, Tamara Hochstrasser<sup>1</sup>, Harutyun Shahumyan<sup>2</sup>

<sup>1</sup> School of Biology and Environmental Sciences, University College Dublin, Dublin, Ireland

<sup>2</sup> Urban Environment Project, UCD Urban Institute Ireland, Richview, Dublin, Ireland

## Abstract

The Greater Dublin Area (GDA) has experienced rapid urban expansion over the past 20 years. The development pattern has been described as economically driven and developer-led. These changes have had some well recognised consequences such as urban sprawl, congestion and a decrease in environmental quality. Despite the economic downturn, it is projected that the population of the GDA will continue to increase, potentially exacerbating the negative consequences of urban expansion. The objective of this study was to assess the consequences of continued urban expansion on the region, with particular emphasis on protected areas and flooding risk.

To assess the consequences of continued urban expansion we used the MOLAND model; a cellular automaton-based spatial decision support system that has been widely applied across Europe. This model allows the user to explore urban growth under different population, infrastructure and policy scenarios. Using MOLAND we simulated urban expansion in the GDA under four population projections to 2026, assuming spatial trends of urban development stay similar to the recent past. In all scenarios development disperses widely across the study area, formerly separate towns merge and coastal regions are subject to particularly high growth. We discuss the simulated development in terms of its ecological, environmental, social and health effects.

## Introduction

Ireland has undergone massive changes over the past three decades: recession in the 1980s, boom in the 1990s and economic collapse at the end of the 2000s (Bartley and Kitchin, 2007). Over this period there have been substantial land-use changes and increases in population. The Greater Dublin Area (GDA) has been the focus of much of this change (Williams *et al.*, 2007). The built fabric of the city of Dublin increased by 9,569 hectares while built fabric within the entire GDA increased by 26,287 hectares over this time period (McInerney and Walsh, 2009). Land use change in the GDA was driven by population growth and economic development, as well as house type and price. With house prices rising within the city, the rural fringes of the city, where it was cheaper to buy or build a house, attracted a growing number of people (Mitchell, 2004). At the fringes of the city, individuals could acquire houses in open countryside while retaining the benefits of the proximity to the capital or other urban areas. A planning regime that imposed few constraints on the conversion of agricultural areas to low-density housing areas facilitated this realisation. Nearby rural towns and villages

grew and merged with Dublin city as urban–rural migration continued, with growth radiating outward along the lines of road and rail transport links (Williams *et al.*, 2007).

Such a massive and rapid expansion of the city has had several well publicised consequences: loss of urban green space, increased ecological pressure on sites of importance, traffic congestion and increased stress, to name but a few (Stapleton *et al.*, 2000, O’ Regan and Buckley, 2003, European Environment Agency, 2006, Brennan *et al.*, 2009). These undesirable consequences have led to the introduction of new planning legislation (Dublin and Mid-East Regional Authorities, 2004, Government of Ireland, 2009b) in an attempt to direct development toward more sustainable patterns. The desired goal of spatial planning policies at national and regional level has been to promote consolidation of the GDA, thereby facilitating a shift from private to public transport, reducing environmental and socio-economic impacts associated with car dependency and traffic congestion (Department of Arts Heritage Gaeltacht and the Islands, 2002, Dublin and Mid-East Regional Authorities, 2004, McInerney and Walsh, 2009). Such an integrated view of planning policy is often hindered by a lack of available spatial information and the necessary tools to address multiple development goals simultaneously (Seder *et al.*, 2000). Developing such tools may alleviate pressures that have led to significant divergence between spatial planning policy and practice in the past (MacLaran and Williams, 2003, Scott *et al.*, 2006). In addition, it may allow improvement of spatial planning with regards to aspects that have so far been neglected, such as the conservation of natural heritage (Clerkin, 2002) and the prevention of flooding.

There is considerable uncertainty concerning Dublin’s continued growth into the future (Department of Environment and Local Government, 2002, Convery *et al.*, 2006). The Central Statistic Office (CSO) has produced a range of population projections for the region over the period 2011–2026, all of them forecasting a rise in population to a greater or lesser extent ([www.cso.ie](http://www.cso.ie)).

Since the rapid economic development and land-use change of the past has had lasting impacts on the quality of life and environment of the city (Brereton *et al.*, 2008), it would be useful to forecast development into the future, expose potential issues before they occur and structure policy accordingly. Urban growth has been successfully modelled using cellular automaton-based models that incorporate real-world spatial information (White and Engelen 2000). Indeed, this approach has been used in other cities both within Ireland and abroad to evaluate alternative policy scenarios, highlight potential antagonism between continued urban expansion versus limited water resources, and illustrate that urban centres can grow while valuable land-uses, such as agriculture, can be retained (He *et al.*, 2006, Browne *et al.*, 2009, Rafiee *et al.*, 2009).

The MOLAND model is a spatial decision support system widely applied since 1998 at urban/regional scale (Barredo and Demicheli, 2003, McCormick, 2003, Lavalley *et al.*, 2004, Lavalley *et al.*, 2005, Convery *et al.*, 2006, Petrov *et al.*, 2009). MOLAND allows a user to construct a spectrum of future development scenarios, taking into consideration varying levels of economic, population and policy regimes.

In this paper we have constructed **four** future scenarios based on regional population projections provide by the CSO, where we explore how the GDA may develop if the current development trends continue. This paper will provide summary statistics of the simulated

land-use in 2026 in each scenario and discuss the corresponding implications for protected areas and flooding risk.

## Methodology:

### The MOLAND model:

The MOLAND spatial decision support system comprises two sub-models working at different spatial scales. At the regional scale (macro scale), the model takes as inputs the population and the economic activity (number of jobs by sector) in a region. The model then splits this population and economic activity between the sub-regions encapsulated in the model area. In the Greater Dublin Area (GDA) application, the sub-regions are the administrative counties within the region (Louth, Meath, Kildare, Wicklow, Dublin). At the local scale (micro scale) the demand for housing (based on population estimates) and economic activities is translated into a number of land uses. For example, housing will be provided within residential land use types and economic activity is linked to commercial and industrial land use types (e.g. offices buildings, shopping centres, etc.). 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 (Engelen *et al.*, 2007)

At the regional level, the split of population and economic activity into sub-regions is based on the past relative importance of each sub-region for accommodating population and on job data, including place of work and distance travelled to work. Most of these data for GDA were obtained from CSO Census 1991, 1996, 2002 and 2006 datasets (Shahumyan *et al.*, 2009a).

At the local level, the spatial allocation of land use is modelled by a cellular automaton algorithm. The area modelled is represented as a mosaic of grid cells of 4ha each (200m on the side). Together they constitute the land use pattern of the area. Land use is classified in 24 categories for GDA, eight of which are land use functions (e.g. residential, commercial, etc.), seven are vacant land uses (e.g. arable land, pasture, etc) and nine are land use features (e.g. restricted areas, airports, etc.). This model is driven by the demand for land per region generated at the regional level. Four elements determine whether a piece of land (each 4 hectare cell) is allocated to a particular land use or not:

- The accessibility of the cell, calculated based on a input map consisting of the transport network;
- Physical suitability of the cell, determined by the topographic and environmental appropriateness of cell to support a particular land use and associated activity;
- Zoning status or institutional suitability (e.g. legal constraints);
- The quality of the neighbourhood of the cell, which consists of a circular area with a radius of eight cells. For each land use a set of user-defined rules determines the degree to which it is attracted to, or repelled by, the other land uses present in the neighbourhood.

Based on these elements, the micro model calculates for every simulation step (typically one year) the transition potential for each cell for each land use type (White and Engelen, 2000). In the course of time, and until regional demands are satisfied, cells will change to the land

use for which they have the highest potential. Further details of the MOLAND model can be found elsewhere (Barredo *et al.*, 2003).

Calibration is achieved by running simulations over a known historical period (in this case 2000–2006). The simulations are initiated using the historical dataset (2000) in order to test the simulation results using the reference dataset (2006). Subsequently the simulations are validated by running the model forward (to 2050) and checking the consistency of the resulting map. The future simulation of land-use can then be performed using the parameters of the already calibrated model, assuming, however, that the calibrated factors will remain relatively stable during the studied period. Detailed description of the calibration technique and used datasets for GDA is presented in a separate paper (Shahumyan *et al.*, 2009a).

### **Population projections:**

The population projections used were based on the Central Statistics Office (CSO) Regional Population Projections 2011-2026, published December 2008 (<http://www.cso.ie/releasepublications/documents/population/current/proppro.pdf>).

The national projections included three international migration (M0, M1, M2) assumptions and two fertility (F1, F2) assumptions, giving a total of six scenarios; M1F1, M1F2, M2F1, M2F2, M0F1 and M0F2. Of these, the regional projections for the eight Regional Authorities only considered M2F1 and M0F1. When coupled with the two internal migration scenarios the regional projections included four scenarios; M2F1 Recent (M2F1R), M2F1 Traditional (M2F1T), M0F1 Traditional (M0F1T), M0F1 Recent (M0F1R).

### **Projection assumptions:**

M2 assumes an annual net inward international migration of 21,400 to the region in the period, while M0 assumes zero annual net inward migration. F1 assumes the total fertility rate to remain at its 2006 level of 1.9 for the lifetime of the projections. The internal migration scenarios, 'Recent' and 'Traditional', 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' assumes we apply the patterns observed in 2002 and 2006 up to 2026, while under 'Traditional', 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.

### **Greater Dublin Area (GDA) versus MOLAND study area:**

The GDA, comprising the Mid-East region and the Dublin region, is of similar, though not identical, extent to the MOLAND study area named Greater Dublin Region (GDR). The GDA consists of the Dublin counties, Meath, Kildare and Wicklow. The GDR consists of the Dublin counties, Meath, Kildare, Wicklow and *Louth*. Thus it was necessary to estimate the population for *Louth* in 2026 and add it to projected GDA population in 2026.

Louth’s population in 2006 was known from CSO data to be 111,267 people. To estimate Louth’s population in 2026 under each scenario we used the formula:

$$2026 \text{ population} = (\text{Border region 2026 population} / \text{Border region population 2006}) * (\text{Louth 2006 population})$$

The resulting values for each scenario were added to the corresponding GDA population projections (Table 1).

**Table 1. Projected populations in the GDR by 2026 under the four regional population projections**

	2026 M2F1T	2026 M2F1R	2026 M0F1T	2026 M0F1R
Border 2026 population	592,000	651,000	523,000	575,000
Louth Multiplier	1.26	1.39	1.11	1.22
Louth 2026 population	140,149	154,117	123,814	136,125
GDA 2026 population	2,413,000	2,195,000	2,010,000	1,816,000
GDR 2026 population	2,553,149	2,349,117	2,133,814	1,952,125

**Table 2: Cell numbers and mean population density within Urban Land Use Types for Calibration**

County	Residential Class	Cell number			Mean Population Density		
		1990	2000	2006	1990	2000	2006
Louth	Continuous Dense	0	0	0	0.0	0.0	0.0
	Medium Dense	0	0	0	0.0	0.0	0.0
	Discontinuous	212	265	319	174.0	192.4	222.2
	Discontinuous Sparse	273	336	466	138.4	104.7	83.0
Meath	Continuous Dense	0	0	0	0.0	0.0	0.0
	Medium Dense	0	0	0	0.0	0.0	0.0
	Discontinuous	149	268	462	279.4	199.7	185.6
	Discontinuous Sparse	414	414	561	184.9	200.7	148.5
Dublin	Continuous Dense	24	24	30	519.2	1,349.5	1,585.5
	Medium Dense	65	68	83	1,503.3	2,141.7	2,594.7
	Discontinuous	3,511	3,925	4341	407.0	379.1	362.7
	Discontinuous Sparse	405	481	556	151.3	130.7	102.2
Kildare	Continuous Dense	0	0	0	0.0	0.0	0.0
	Medium Dense	0	0	0	0.0	0.0	0.0
	Discontinuous	247	405	483	251.1	215.8	216.5
	Discontinuous Sparse	394	526	811	121.3	115.2	105.5
Wicklow	Continuous Dense	0	0	0	0.0	0.0	0.0
	Medium Dense	0	0	0	0.0	0.0	0.0
	Discontinuous	214	267	309	230.1	210.2	198.7
	Discontinuous Sparse	388	486	635	142.3	122.5	114.0

**Estimating population share per residential class:**

There are four residential land use classes, namely Continuous Dense, Medium Dense, Discontinuous and Discontinuous Sparse, used in the current land use map in the MOLAND model (Engelen et al., 2004). However, in the Greater Dublin Region the majority of population is concentrated in discontinuous and discontinuous sparse land use categories. To increase the accuracy of the model we split the population into two groups: ‘Sparse’, which includes discontinuous sparse urban fabric, and ‘Other’ which includes the remaining three categories. To estimate the share of the population in each class on a per county basis we used population densities in sample Electoral Districts (EDs) from each county. The EDs were sampled only if the relevant residential class was the sole residential class within the ED and was present in all three time periods of model calibration (1990, 2000 and 2006). Population densities were calculated using the mean value of the sample of EDs.

The population present in the two groups was calculated based on cell number and density values for each county using the following formulae:

$$\text{Sparse Population} = \text{Density Sparse} * \text{Sparse Cell Number}$$

$$\text{Other Population} = \text{Total population} - \text{Sparse population}$$

**Table 3: Residential populations within urban land use types for the calibration period**

	Estimated Sparse Population			Estimated Other Population		
	1990	2000	2006	1990	2000	2006
Louth	37,783	35,170	38,661	53,158	63,433	72,606
Meath	76,552	83,093	83,334	28,521	42,821	79,497
Dublin	61,290	62,858	56,826	963,243	1,038,444	1,130,350
Kildare	47,783	60,570	85,581	73,591	93,724	100,754
Wicklow	55,193	59,525	72,391	41,527	51,154	53,803

The population of the two groups in the projected year 2026 was calculated as follows:

$$\text{Sparse population 2026} = \text{Projected Population 2026} * \text{Sparse Population 2006} / \text{Population 2006}$$

$$\text{Other Population 2026} = \text{Projected population 2026} - \text{Sparse population 2026}$$

When calculating the effect of population growth on land use in the Greater Dublin Region we therefore assumed that current population density will be maintained, i.e. there is little ‘infilling’ and/ or high density urban development.

**Employment Projections:**

Employment data is divided into three broad categories in MOLAND: Industrial, Commercial and Services. It should be noted that this employment data should ideally be by place of work (POW) and not by place of residence (POR). In Ireland, place of work data has only been made available for 2002 and 2006, when Sample of Anonymised Records (POWSAR) and Census of Anonymised Records (POWCAR) were implemented. Prior to this censuses recorded employment data by place of residence.

Since POW employment data was available for only one of the model calibration time periods (2006) it was necessary to estimate POW employment data for the other two periods.

POW employment data for 2000 was calculated using the 2002 census which contained both POR, and POW employment data and the 1996 census which contained only POR employment data. The proportion of jobs in each sector per county was calculated using the formulae:

$$\text{POR 2002/POW 2002} = \text{POW coefficient}$$

$$\text{POR 1996/Unknown POW 1996} = \text{POW coefficient}$$

$$\rightarrow \text{Unknown POW 1996} = \text{POR 1996/POW coefficient}$$

*Assumption: POW coefficient remains unchanged between 2002 and 1996.*

$$(\text{POW 2002} - \text{POW 1996})/6 = \text{Yearly increase of POW}$$

$$\text{POW 2000} = \text{POW 2002} - 2 * (\text{Yearly increase of POW})$$

POW employment data for 1990 was calculated by a similar process using the 1996 and 1991 censuses.

POW employment data for 2026 was estimated using an annual linear growth rate:

$$\text{POW 2026} = \text{POW 2006} + 20 * (\text{POW 2006} - \text{POW 2000})/6$$

The employment data was projected for 2026 M2F1 traditional scenario at first. Then taking into account population ratios between different scenarios the other three cases were estimated:

$$\text{Employment 2026 other} = \text{Employment 2026 M2F1 traditional} * \text{Population 2026 other} / \text{Population 2026 M2F1 traditional}$$

The final data used in MOLAND for the current research is presented in Table 4.

**Table 4: Data used in MOLAND for the 2026 scenarios simulation**

	2000	2006	2026 Scenarios			
	Estimated	POWCAR	M0F1R	M0F1T	M2F1R	M2F1T
Population (total)	1,590,790	1,773,803	1,952,125	2,133,814	2,349,117	2,553,149
Population (other)	1,289,575	1,437,010	1,581,474	1,728,666	1,903,089	2,068,381
Population (sparse)	301,215	336,793	370,651	405,148	446,028	484,768
Industry	223,494	259,800	290,984	318,067	350,160	380,573
Commerce	250,386	321,790	427,805	467,622	514,806	559,519
Services	166,673	211,656	161,831	302,652	333,190	362,129

**Scenario outputs:**

Each scenario represented a distinct end point along a spectrum of population growth. In order of increasing 2026 projected population the scenarios are M0F1R, M0F1T, M2F1R and M2F1T. M0F1R represents the lowest projected population of 1,952,125, with the projected populations of M0F1T, M2F1R and M2F1T containing approximately 200,000, 400,000 and 600,000 more people respectively. MOLAND simulated 2026 maps for each scenario were exported to ArcGIS system in raster format. Cell counts for each landuse type were calculated using the Hawth's tools free extension for ArcGIS (<http://www.spatialecology.com/>) and then tabulated in MS Excel. For ease of data handling the cell counts were aggregated into three classes; *Agriculture*, *Semi-natural and green urban*, and *Built*. Cell counts were converted to an area value in hectares by multiplying by 4. The outputs from the four scenarios were contrasted in MS Excel.

**GIS analysis of scenario outputs:**

Since raw area values alone, even when compared on a county by county basis, are not greatly informative output maps for each scenario were examined using GIS to visualise the forecasted 2026 landuse patterns and to identify areas of landuse change between 2006 and differences between scenarios.

**Protected areas:**

A GIS layer containing the locations of all legally protected sites (National Heritage Areas (NHAs), Special Areas of Conservation (SACs) and Special Protected Areas (SPAs)) and sites proposed for protection (proposed NHAs (pNHAs)) was overlaid on the scenario maps. To identify which sites would be threatened and quantify the impact of forecasted development a 1km buffer was created around the protected areas and cell counts for each landuse type within this buffer were calculated, aggregated and converted to area values as above.

**Coastal Development:**

When the scenario outputs were first viewed, coastal areas seemed to be forecast for particularly heavy development. To investigate this further a 2km coastal buffer was created. Cell counts for each landuse type within this buffer were calculated, aggregated and converted to area values as above. The buffer outputs from the four scenarios were contrasted in MS Excel. The number and type of protected areas within this buffer were found. The flooding

history of coastal towns which were forecast to experience pronounced development were reviewed using the Office of Public Works (OPW) National Flood Hazard Mapping website (<http://www.floodmaps.ie>).

## **Results:**

### **Changes in landuse share:**

As would be expected development was greatest in the scenarios which had the highest 2026 populations. New *Built* was generated primarily from the conversion of *Agriculture*, with *Semi-natural and green urban* being much less affected. The area of *Semi-natural and green urban* converted to *Built* was 1% or less of the area of converted *Agriculture* in all scenarios. M0F1R has a projected increase in *Built* landuse area of 18,096 hectares; M0F1T, M2F1R and M2F1T have greater projected increases by approximately 7,000, 14,000 and 21,000 hectares respectively, i.e. for each additional 200,000 people projected to live in the study area by 2026, approximately 7,000 hectares of *Agriculture* is converted to *Built*.

### **Areas with heavy urban development:**

Several areas were identified that undergo development in every scenario. Significant expansion occurs in the peripheral towns of Celbridge, Rathcoole, Clonee, Swords and Malahide, a continuation of current trends (Williams and Shiels, 2002). Also of note is the pronounced development around the coastal settlements such as Rush, Balbriggan, Malahide and Portmarnock north of the city and Bray, Greystones and Wicklow south of the city (Figure 2).

In addition to the above, under the M2F1 scenarios an unbroken strip of coastal urban fabric stretches from Malahide in the north to Bray in the south. The towns of Lusk and Rush merge; Swords, Malahide and Portmarnock form a ring of coastal development (Figure 3), encircling a pocket of agricultural land and isolating this area from both the wider countryside and the coast. Also of note is the isolation of the Phoenix Park from the wider countryside. In 2006 this area is connected by the Liffey river valley (Figure 1), under the M2F1 scenarios this area is forecasted to be engulfed by development by 2026.

### **Impact on protected sites:**

The most heavily impacted sites remained constant across all scenarios, these being the Tomnafinnoge Wood, Royal Canal, North Dublin Bay, and Knocksink Wood. Other heavily affected sites include Loughshinny coast, Barmeath Woods, Liffey Valley and Feltrim Hill. Sites with legal protection (NHAs, SPAs & SACs) and non-protected sites of recognised ecological and/or heritage value (pNHAs) were also affected (Table 5).

Figure 1. Landuse in the GDR in 2006. The Liffey river valley is circled.

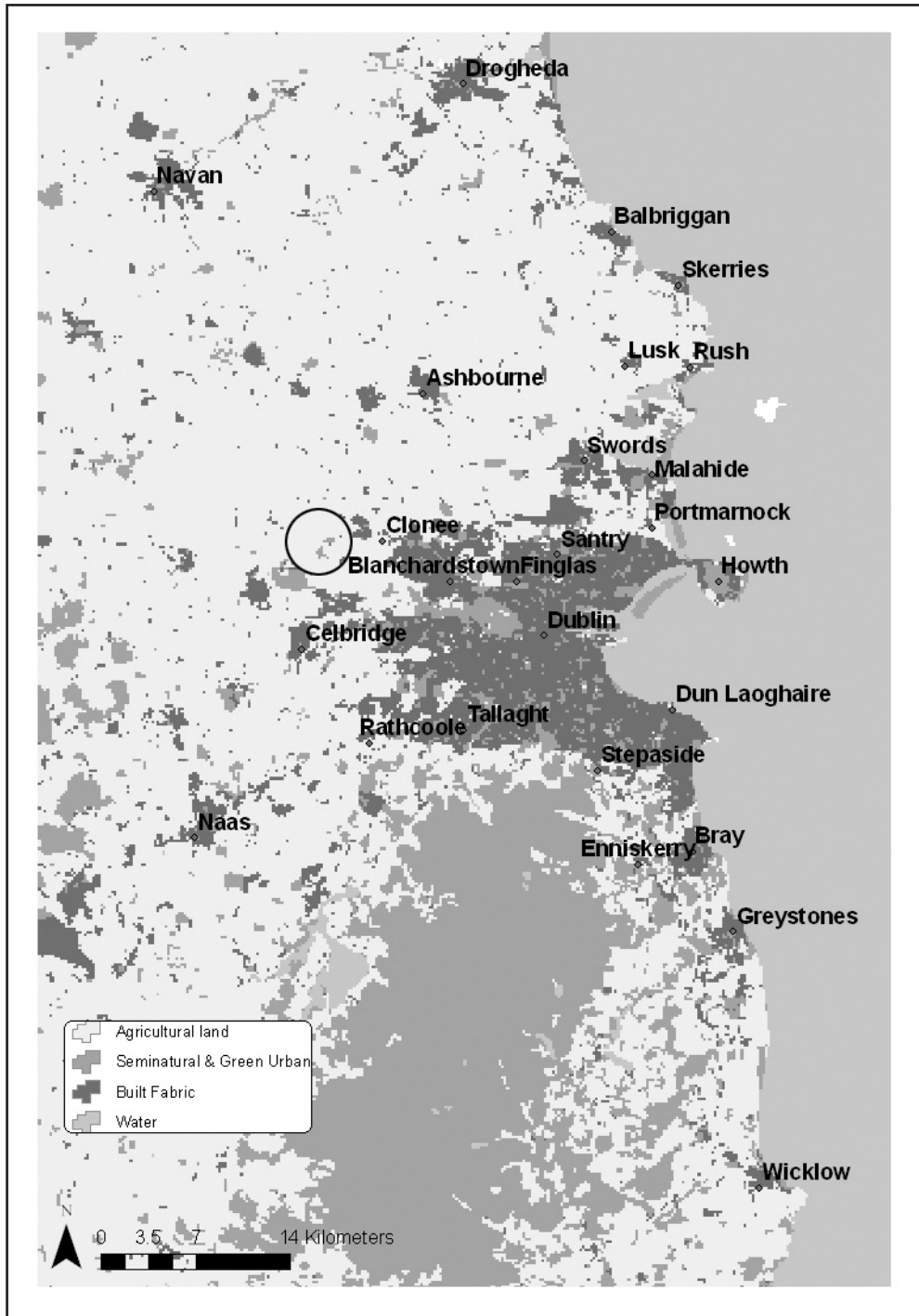


Figure 2. Forecast landuse in the GDR in 2026 under the M0F1R (left) and M0F1T scenarios (right). Note the expansion of Rathcoole, Celbridge, Clonee and Rush, and the merger of Swords and Malahide.

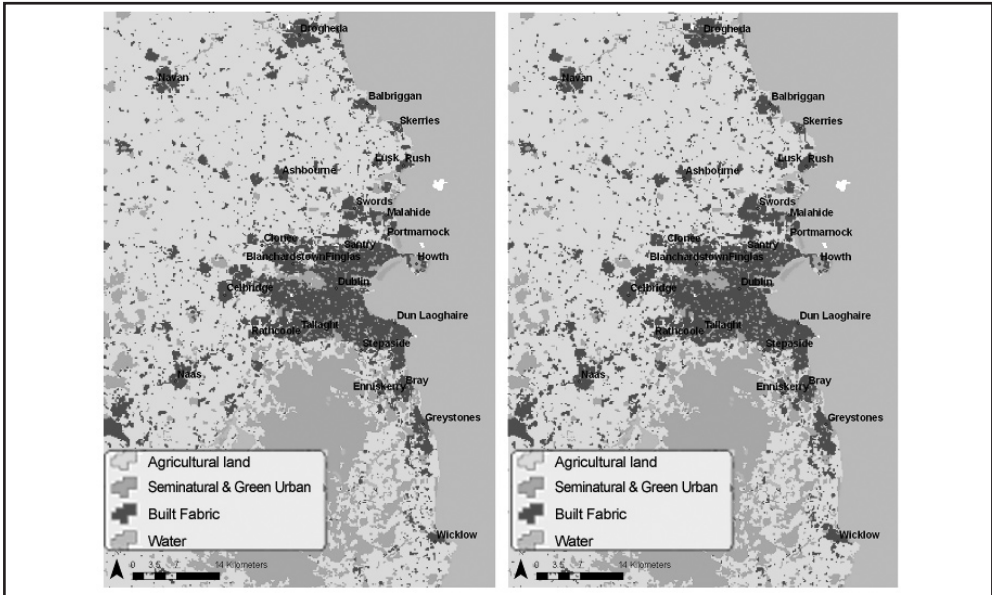
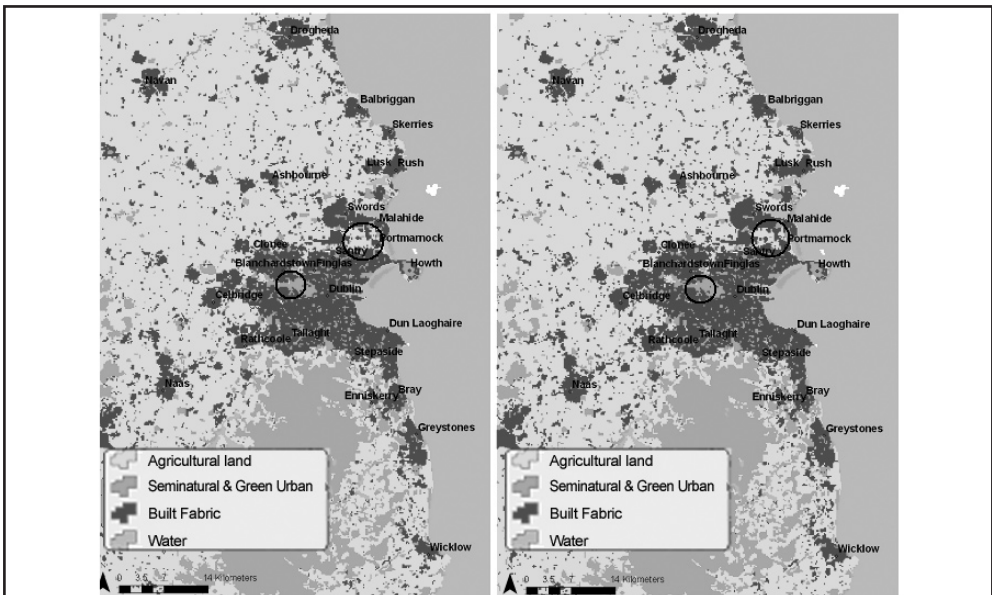


Figure 3. Forecast landuse in the GDR in 2026 under the M2F1R (left) and M2F1T scenarios (right). Areas isolated from the wider countryside by development are circled.



**Table 5. Protected sites forecasted as impacted by development. The area of vegetated land lost in hectares (ha) within 1km of the sites is listed by scenario.**

Site name	Designation	M0F1R	M0F1T	M2F1R	M2F1T
Tomnafinnoge Wood	SAC	-632	-784	-900	-1204
Royal Canal	pNHA	-452	-592	-1084	-1128
North Dublin Bay	pNHA	-112	-408	-612	-900
Knocksink Wood	pNHA	-200	-404	-460	-592
Loughshinny Coast	pNHA	-156	-216	-364	-516
Barrow Valley At Tankardstown Bridge	pNHA	-160	-184	-228	-292
Kilpatrick Sandhills	SAC	-156	-168	-232	-220
Liffey Valley	pNHA	-144	-220	-236	-276
Buckrone-y-Brittis Dunes And Fen	SAC	-144	-124	-196	-256
Barmeath Woods	pNHA	-144	-208	-188	-228

**Coastal Development:**

In 2006 25.6% of land within 2km of the coast consisted of *Built*. All scenarios forecast an increase in this percentage; *Built* comprised 30.5%, 32.7%, 35.4% and 37.7% of the 2km buffer in M0F1R, M0F1T, M2F1R and M2F1T respectively. Almost a quarter (24.8%) of all protected sites fell within the coastal buffer, though there were differences between types (Table 6).

**Table 6. Number and type of protected sites within 2km coastal buffer.**

	Total within study area	Number within 2km coastal buffer	Percentage within 2km coastal buffer
SPA	44	15	34.1
SAC	83	24	28.9
NHA	5	0	0.0
pNHA	219	48	21.9
Total	351	87	24.8

**Coastal flooding:**

As noted above all scenarios forecast pronounced development around the coastal settlements of Rush, Balbriggan, Malahide, Portmarnock, Bray, Greystones and Wicklow. The OPW have records of flooding in all the areas over a variety of timescales (Table 7.)

**Discussion:**

This work clearly underlines the need for a change in the spatial planning of development in the Greater Dublin Region. The scenarios presented here explore a continuation of the trends of development within the GDR over the past 16 years (Scott *et al.*, 2006). The results

**Table 7. Flooding events recorded by the OPW**

Town	Flooding events listed by OPW	Recurring events	Timeframe of events
Rush	9	4	2000-2004
Balbriggan	4	1	2000-2002
Malahide	7	4	2002
Portmarnock	10	5	1986-2002
Bray	9	4	1905-2003
Greystones	6	5	2003
Wicklow	3	3	N/A

highlight that if current trends of urban development driven by private interest continue, significant negative environmental effects can be expected. While more pronounced in the M2F1 scenarios, in all scenarios development disperses widely across the study area, formerly separate towns merge and coastal regions are subject to particularly high growth, even though these regions are particularly sensitive to urban development.

**Potential effects of development trends on biodiversity and protected sites:**

The forecasted dispersed development in the GDR would likely result in habitat loss and fragmentation, particularly in the M2F1 scenarios, with all the associated consequences of population isolation, local extinctions and altered community structure (Soulé *et al.*, 1988, Forman and Alexander, 1998, Fernandez-Juricic and Jokimaki, 2001, Fahrig, 2003, Shochat *et al.*, 2006). Areas of ecological importance are forecast to be affected by development in all scenarios (Table 5). Although the importance of these areas are recognised in County Development Plans (Dún Laoghaire Rathdown County Council, 2004, Kildare County Council, 2005, Meath County Council, 2007), the proximate nature of the modelled development means that Local Authorities will have to be vigilant in monitoring and enforcement of regulations and legislation to ensure the integrity of the sites.

Furthermore in all scenarios, but particularly in the M2F1 scenarios, development along the coast is intense. Increased development is simulated to occur adjacent to all coastal protected sites, particularly SPAs. It has been documented that human activity disturbs wildlife in SPAs (Burton *et al.*, 2002a, Burton *et al.*, 2002b, Northern Ireland Executive, 2003, Burton *et al.*, 2006, Holm and Laursen, 2009) and the forecast development would in all likelihood increase disturbance in these areas. Beyond the borders of the protected sites disturbance can be expected to be more intense. Given that the European Court of Justice has already ruled that the Irish Government has already failed to meet its obligations under both the Birds and Habitats Directives (EU Commission v. Ireland, 2010) any increase in disturbance could be expected to incur additional censure from the EU which Ireland can ill afford at present. By identifying sites that may be pressured by future development action can be taken to create appropriate conservation and management plans before development pressure adversely affects these sites.

**Potential effects of development on ecosystem services:**

The dispersed nature of the simulated development in each scenario implies an exacerbation of existing issues. The spread of *Built* across the region would result in the alteration of soil processes such as decreased carbon (C) sequestration and nitrogen (N) cycling (Lehmann and Stahr, 2007, Tratalos *et al.*, 2007, Lorenz and Lal, 2009). Urban land use planning can help to reduce urbanisation effects on biogeochemical C and N cycles; for example, by limiting disturbance to unproductive urban soils while promoting dense plant cover on productive soils, using permeable/semi-permeable materials to avoid total soil sealing and incorporating green-roofs and living walls to mitigate vegetation loss.

In addition to the soil, dispersed development can be expected to affect the air and water. Dispersed development would necessitate car centric transport for the population (Cervero and Gorham, 1995) leading to increased air and water pollution (Forman and Alexander, 1998). As emissions from road traffic are the primary threat to the quality of air in Ireland (EPA (Environmental Protection Agency), 2004), and as all urban areas are forecast to expand in all scenarios, air quality within urban areas could be expected to degrade, all other things being equal. To mitigate these effects an urban afforestation campaign could be enacted as research suggests urban vegetation can ‘scrub’ the atmosphere of pollutants (Nowak, 2006, Bealey *et al.*, 2007, McDonald *et al.*, 2007, Jim and Chen, 2008)

Wastewater provision over such a dispersed area would be extremely difficult and expensive, necessitating septic tank use in a large number of dwellings. Even though technology is improving, this higher number of tanks can be expected to increase the rates of groundwater contamination (Yates, 1985, Jamieson *et al.*, 2002).

The intense coastal development merits attention for two reasons. Firstly, it is well known that urbanisation within a drainage basin tends to increase the volume of run-off, increase peak discharge and decrease the time taken to reach peak discharge. Many of the coastal areas that undergo intense development within the simulations are on rivers (e.g. Dublin City, Malahide, Balbriggan, Rush, Bray, Wicklow) and have experienced flood events in the recent past. As extreme weather events are predicted to increase globally (Few, 2003) and nationally (Sweeney and Fealey, 2002), care must be taken to ensure that if development does occur, it incorporates effective drainage systems such as protected buffers along river banks, artificial wetlands for water retention and porous pavement materials to reduce run-off (Booth, 1991, Braune and Wood, 1999, Hood *et al.*, 2007).

Secondly, human settlements on coastal areas can influence the effective sea level rise experienced by those areas (Ericson *et al.*, 2006). The particularly high coastal development merits special attention by Regional and Local Authorities to ensure human activities do not exacerbate the effects of global sea level rise (Church and Gregory, 2001). Furthermore, the OPW reports recent flooding in all coastal towns and as sea levels rise these flooding events can be expected to increase (Bosello *et al.*, 2007).

**Potential social and health effects of development:**

The development simulated here - i.e. dispersing to a greater or lesser degree across the region - represents a continuation of current unfavourable trends (Scott *et al.*, 2006). These trends imply increased isolation of residents within urban centres from the surrounding natural areas and relatively less green space within the urban centres (Brennan *et al.*, 2009). This could lead

to negative social effects, such as increased crime rates, increased stress, decreased physical activity and decreased longevity (Frumkin, 2001, Kuo and Sullivan, 2001, Humpel *et al.*, 2002, De Vries *et al.*, 2003).

The spread of development across the region would make the provision of services and public transport extremely difficult, and while national and regional planning guidelines have been created to attempt to steer development toward a more consolidated, sustainable settlement pattern, these efforts have had mixed results (Scott *et al.*, 2006).

Commuting in the GDA is already a stressful experience (O' Regan and Buckley, 2003), with time lost due to congestion costing the economy an estimated €640m (DTO (Dublin Transportation Office), 2001). An increase in car dependency implied by the dispersed nature of the forecasts would likely exacerbate the situation. Furthermore, work has already been carried out that suggests that growth in the several areas across GDA will outpace future wastewater treatment provision (Shahumyan *et al.*, 2009b). Similar deficiencies could be expected for other services such as waste disposal, education, health provision and emergency service response time.

### **Conclusion:**

While the economic growth fuelling this development pattern was regarded as a boon to the country, the consequences of such rapid and developer-led urban expansion have been widely recognised as unfavourable (Williams and Shiels, 2002, European Environment Agency, 2006, Williams *et al.*, 2007). As shown here, the negative consequences are likely to be exacerbated if the fundamental trends in how the development occurs are not guided in a different direction. With the current economic slow-down there is an opportunity to implement more rigorous planning policy to ensure that planning at national, regional and local levels pursues the same agenda and is implemented effectively. As an aid to cohesive planning, tools such as MOLAND are highly valuable in that they allow users to both visualise the results of differing policy choices, in this case maintenance of the status quo, and add an evidence base to policy decisions that has so far been lacking from Irish planning.

The forthcoming planning bill is a step along this path, in that it requires county development plans to set out a core strategy demonstrating that the development objectives in the development plan are consistent with national and regional development objectives set out in the National Spatial Strategy and regional planning guidelines (Government of Ireland, 2009a). Using MOLAND, or a similar tool, it would be possible to simulate the effects of various county development plans upon the region and highlight issues of conflict between county and regional level plans. If such measures were put in place, it could be hoped that development within the GDR will evolve along a more sustainable path.

### **Acknowledgement**

The authors acknowledge the support of the Environmental Project Agency under contract 2005-CD-U1-M1.

## References:

- Barredo, J.I., and L. Demicheli (2003), 'Urban sustainability in developing countries' megacities: modelling and predicting future urban growth in Lagos', *Cities*, 20, 297-310.
- Barredo, J.I., M. Kasanko, N. McCormick, and C. Lavalle (2003), 'Modelling dynamic spatial processes: simulation of future scenarios through cellular automata', *Landscape and Urban Planning*, 64, 145-160.
- Bartley, B., and R. Kitchin (2007), *Understanding Contemporary Ireland*, Pluto Press, Dublin.
- Bealey, W.J., A.G. McDonald, E. Nemitz, R. Donovan, U. Dragosits, T.R. Duffy, and D. Fowler (2007), 'Estimating the reduction of urban PM10 concentrations by trees within an environmental information system for planners', *Journal of Environmental Management*, 85, 44-58.
- Booth, D. B. (1991), 'Urbanisation and the Natural Drainage System - Impacts, Solutions, and Progress', *The Northwest Environmental Journal*, 7, 93-118.
- Bosello, F., R. Roson, and R.S. J. Tol (2007), 'Economy-wide Estimates of the Implications of Climate Change: Sea Level Rise', *Environmental & Resource Economics*, 37, 549-571.
- Braune, M.J., and A. Wood (1999), 'Best management practices applied to urban runoff quantity and quality control', *Water Science and Technology*, 39, 117-121.
- Brennan, M., D.O. McInerney, T. Hochstrasser, and T. Hayden (2009), 'Landuse change in Dublin: perspectives and consequences of urban greenspace change within the city between 1990 & 2006', *Urban Institute Ireland Working Paper Series 09/02*, 8pp.
- Brereton, F., J.P. Clinch, and S. Ferreira (2008), 'Happiness, geography and the environment', *Ecological Economics*, 65, 386 - 396.
- Browne, D., B. O'Regan, and R. Moles (2009), 'Use of ecological footprinting to explore alternative domestic energy and electricity policy scenarios in an Irish city-region', *Energy Policy*, 37, 2205-2213.
- Burton, N.H.K., M.J.S. Armitage, A.J. Musgrove, and M.M. Rehfisch (2002a), 'Impacts of Man-Made Landscape Features on Numbers of Estuarine Waterbirds at Low Tide', *Environmental Management*, 30, 857-864.
- Burton, N.H.K., M.M. Rehfisch, and N.A. Clark (2002b), 'Impacts of Disturbance from Construction Work on the Densities and Feeding Behavior of Waterbirds Using the Intertidal Mudflats of Cardiff Bay, UK', *Environmental Management*, 30, 865-871.
- Burton, N.H.K., M.M. Rehfisch, N.A. Clark, and S.G. Dodd (2006), 'Impacts of sudden winter habitat loss on the body condition and survival of redshank *Tringa totanus*', *Journal of Applied Ecology*, 43.

Cervero, R., and R. Gorham (1995), 'Commuting in Transit Versus Automobile Neighborhoods', *Journal of the American Planning Association*, 61, 210 - 225.

Church, J., and J.M.I.E. Gregory (2001), 'Changes in sea-level' in J.T. Houghton, Ding Y., Griggs D.J., N.M., P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.), *Climate Change 2001: the Scientific Basis. Contribution of Working Group 1 to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge.

Clerkin, S. (2002), 'Incorporating Biodiversity considerations in policy', *Biology and Environment: Proceedings of the Royal Irish Academy*, 102 B, 177-182.

Convery, F., D. McInerney, M. Sokol, and P. Stafford (2006), 'Organising Space in a dynamic economy - insights for policy from the Irish experience', *Built Environment*, 32, 172-183.

De Vries, S., R.A. Verheij, P.P. Groenewegen, and P. Spreeuwenberg (2003), 'Natural environments - healthy environments? An exploratory analysis of the relationship between greenspace and health', *Environment & Planning*, 35, 1717-1731.

Department of Arts Heritage Gaeltacht and the Islands (2002), *National Biodiversity Plan*. Dublin.

Department of Environment and Local Government (2002), *The National Spatial Strategy 2002-2020: People, Places, Potential*, Stationery Office, Dublin.

DTO (Dublin Transportation Office) (2001), *Annual Report*, Dublin Transportation Office, Dublin.

Dublin and Mid-East Regional Authorities (2004), *Regional Planning Guidelines: Greater Dublin Area 2004-2016, Implementing the National Spatial Strategy*, Regional Planning Guidelines Project Office, Wicklow.

Dún Laoghaire-Rathdown County Council (2004), *Dún-Laoghaire Rathdown County Development Plan 2004-2010*.

Engelen, G., C. Lavalle, J.I. Barredo, M.v.d. Meulen, and R. White (2007), 'The MOLAND modelling framework for urban and regional land-use dynamics', pp. 297-319 in E. Koomen, J. Stillwell, A. Bakema, and H.J. Scholten (eds.), *Modelling Land-Use Change, Progress and Applications*, Springer, Dordrecht.

Engelen, G., R. White, I. Uljee, A. Hagen, J. van Loon, M. van der Meulen, and J. Hurkens (2004), *MOLAND model for urban and regional growth: Model description and User Manual*, Maastricht, The Netherlands.

EPA (Environmental Protection Agency) (2004), *Ireland's Environment 2004*, Environmental Protection Agency, Dublin.

Ericson, J.P., C.J. Vörösmarty, S.L. Dingman, L.G. Ward, and M. Meybeck (2006), 'Effective sea-level rise and deltas: Causes of change and human dimension implications', *Global and Planetary Change*, 50, 63-82.

EU Commission v. Ireland (2010), Case C-418/04.

European Environment Agency (2006), *Urban sprawl in Europe - The ignored challenge*, Report No. 10/2006, European Environment Agency.

Fahrig, L. (2003), 'Effects of Habitat Fragmentation on Biodiversity', *Annual Review of Ecology, Evolution, and Systematics*, 34, 487-515.

Fernandez-Juricic, E., and J. Jokimaki (2001), 'A habitat island approach to conserving birds in urban landscapes: case studies from southern and northern Europe', *Biodiversity and Conservation*, 10, 2023-2043.

Few, R.(2003). 'Flooding, vulnerability and coping strategies: local responses to a global threat', *Progress in Development Studies*, 3, 43-58.

Forman, R.T.T., and L.E. Alexander (1998), *Roads and their major ecological effects*. 29: 207-231.

Frumkin, H (2001), 'Beyond Toxicity human health and the natural environment', *American Journal of Preventive Medicine*, 20, 234-240.

Government of Ireland (2009a), *Planning and Development (Amendment) Bill 2009*, Dublin.

Government of Ireland (2009b), *Sustainable Residential Development in Urban Areas: Guidelines for Planning Authorities*, Dublin.

He, C., N. Okada, Q. Zhang, P. Shi, and J. Zhang (2006), 'Modeling urban expansion scenarios by coupling cellular automata model and system dynamic model in Beijing, China', *Applied Geography*, 26, 323-345.

Holm, T. E., and K. Laursen (2009), 'Experimental disturbance by walkers affects behaviour and territory density of nesting Black-tailed Godwit *Limosa limosa*', *Ibis*, 151, 77-87.

Hood, M.J., J.C. Clausen, and G.S. Warner (2007), 'Comparison of stormwater lag times for low impact and traditional residential development', *Journal of the American Water Resources Association*, 43, 1036-1046.

Humpel, N., N. Owen, and E. Leslie (2002), 'Environmental factors associated with adults participation in physical activity: a review', *American Journal of Preventive Medicine*, 22, 188-199.

Jamieson, R.C., R.J. Gordon, K.E. Sharpies, G.W. Stratton, and A. Madani (2002), 'Movement and persistence of fecal bacteria in agricultural soils and subsurface drainage water: A review', *Canadian Biosystems Engineering*, 44, 1.1-1.9.

Jim, C.Y., and W.Y. Chen (2008), 'Assessing the ecosystem service of air pollutant removal by urban trees in Guangzhou (China)', *Journal of Environmental Management*, 88, 665-676.

Kildare County Council (2005), *Kildare County Development Plan 2005-2011*.

Kuo, F.E., and W.C. Sullivan (2001), 'Environment and crime in the inner city: Does vegetation reduce crime?', *Environment & Behavior*, 33, 343-367.

Lavalle, C., J.I. Barredo, N. McCormick, G. Engelen, R. White, and I. Uljee (2004), *The MOLAND model for urban and regional growth forecast: A tool for the definition of sustainable development paths*. EC-DG-Joint Research Centre, Institute for Environment and Sustainability-Land Management Unit Ispra, Italy, European Communities.

Lavalle, C., J.I. Barredo, V. Sagris, M. Gierk, A.D. Roo, and J. Thielen (2005), *Integrating Flood Mitigation in Spatial Planning*. ICID 21st European Regional Conference 2005 Frankfurt (Oder) and Slubice - Germany and Poland.

Lehmann, A., and K. Stahr (2007), 'Nature and significance of anthropogenic urban soils', *Journal of Soils Sediments*, 7, 247-296.

Lorenz, K., and R. Lal (2009), 'Biogeochemical C and N cycles in urban soils', *Environment International*, 35, 1-8.

MacLaran, A., and B. Williams (2003), 'Dublin: Property Development and Planning in an Entrepreneurial City', pp. 148-171 in A. MacLaran (ed.), *Making Space: Property Development and Urban Planning*, Edward Arnold, London.

McCormick, N., Lavalle, C., Kasanko, M., Demicheli, L., and Barredo, J. (2003), 'Mapping and modeling the impact of land use planning and management practices on urban and peri-urban landscape's in *Europe: the MOLAND project*. 2nd GRSSnSPRS Joint Workshop on Data Fusion and Remote Sensing over Urban Areas.

McDonald, A.G., W.J. Bealey, D. Fowler, U. Dragosits, U. Skiba, R.I. Smith, R.G. Donovan, H.E. Brett, C.N. Hewitt, and E. Nemitz (2007), 'Quantifying the effect of urban tree planting on concentrations and depositions of PM10 in two UK conurbations', *Atmospheric Environment*, 41, 8455-8467.

McInerney, D.O., and C. Walsh (2009), 'Spatial distribution of urban land-use change in the Dublin city region: 1990-2006', *Irish Geography*, 42, 207-223.

Meath County Council (2007), *Meath County Development Plan 2007-2013*.

Mitchell, C.J.A. (2004), 'Making sense of counterurbanization', *Journal of Rural Studies*, 20, 15-34.

Northern Ireland Executive (2003), *Northern Ireland Habitat Action Plan: Mudflats*, HMSO, Belfast.

Nowak, D.J. (2006), 'Institutionalizing urban forestry as a "biotechnology" to improve environmental quality', *Urban Forestry & Urban Greening*, 5, 93-100.

O'Regan, B., and F. Buckley (2003), 'The Psychological Effects of Commuting in Dublin', *Centre for Research in Management Learning and Development Working Paper Series*.

Petrov, L.O., C. Lavallo, and M. Kasanko (2009), 'Urban land use scenarios for a tourist region in Europe: Applying the MOLAND model to Algarve, Portugal', *Landscape and Urban Planning*, 92, 10-23.

Rafiee, R., A.S. Mahiny, N. Khorasani, A.A. Darvishsefat, and A. Danekar (2009), 'Simulating urban growth in Mashad City, Iran through the SLEUTH model (UGM)', *Cities*, 26, 19-26.

Scott, M., N. Moore, D. Redmond, and M. Gkartzios (2006), 'Housing Growth, Land Delivery and Sustainable Urban Management', pp. 163-192 in J. Yarwood (ed.), *The Dublin Belfast Corridor: Ireland's Mega-City Region?*, Aldershot, Ashgate.

Seder, I., R. Weinkauff, and T. Neumann (2000), 'Knowledge-based databases and intelligent decision support for environmental management in urban systems', *Computers, Environment and Urban Systems*, 24, 233-250.

Shahumyan, H., R. White, B. Twumasi, S. Convery, B. Williams, M. Critchley, J. Carty, C. Walsh, and M. Brennan (2009a), 'The MOLAND Model Calibration and Validation for Greater Dublin Region', *Urban Institute Ireland Working Paper Series 09/03*, 32pp.

Shahumyan, H., B. Williams, R. White, S. Convery, and I. Boyle (2009b), 'Adapting an Urban-Regional Model (MOLAND) for supporting the planning and provision of strategic regional infrastructure: Providing Wastewater treatment capacity in the Dublin region 2006-2026', *Urban Institute Ireland Working Paper Series 09/05*, 39pp.

Shochat, E., P.S. Warren, S.H. Faeth, N.E. McIntyre, and D. Hope (2006), 'From patterns to emerging processes in mechanistic urban ecology', *Trends in Ecology and Evolution*, 21, 186-191.

Soulé, M.E., D.T. Bolger, A.C. Alberts, R. Sauvajot, J. Wright, M. Sorice, and S. Hill (1988), 'Reconstructed dynamics of rapid extinctions of chaparral-requiring birds in urban habitat islands', *Conservation Biology*, 2, 75-92.

Stapleton, L., M. Lehané, and P. Toner (eds.) (2000), *Ireland's environment: a millennium report.*, Environmental Protection Agency, Wexford, Ireland.

Sweeney, J., and R. Fealey (2002), 'A preliminary investigation of future climate scenarios for Ireland', *Biology and Environment: Proceedings of the Royal Irish Academy* 102B, 121-128.

Tratalos, J., R.A. Fuller, P.H. Warren, R.G. Davies, and K.J. Gaston (2007), 'Urban form, biodiversity potential and ecosystem services', *Landscape and Urban Planning*, 83, 308-317.

White, R., and G. Engelen (2000), 'High-resolution integrated modelling of the spatial dynamics of urban and regional systems', *Computers, Environment and Urban Systems*, 24, 383-400.

Williams, B., B. Hughes, and P. Shiels (2007), 'SCS Housing Study 2007: Urban Sprawl and Market Fragmentation within the Greater Dublin Area', Society of Chartered Surveyors.

Williams, B., and P. Shiels (2002), 'The Expansion of Dublin and the Policy Implications of Dispersal', *Journal of Irish Urban Studies*, 1, 1-19.

Yates, M.V. (1985), 'Septic Tank Density and Ground-Water Contamination', *Ground Water*, 23, 586-591.

