Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

STRIVE

Report Series No.92

Urban Environment Project

STRIVE

Environmental Protection Agency Programme

2007-2013

SSTI
Strategy for Science, Technology and Innovation

Comhshaol, Pobal agus Rialtas Áitiúil
Environment, Community and Local Government

Environmental Protection Agency

The Environmental Protection Agency (EPA) is a statutory body responsible for protecting the environment in Ireland. We regulate and police activities that might otherwise cause pollution. We ensure there is solid information on environmental trends so that necessary actions are taken. Our priorities are protecting the Irish environment and ensuring that development is sustainable.

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EPA STRIVE Programme 2007–2013

Urban Environment Project

Decision-Support Tools for Managing the Urban Environment in Ireland

(2005-CD-U1-M1)

STRIVE Report

Prepared for the Environmental Protection Agency

by

University College Dublin

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The EPA STRIVE Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

EPA STRIVE PROGRAMME 2007–2013

Published by the Environmental Protection Agency, Ireland

ISBN: 978-1-84095-452-4

Price: Free

ACKNOWLEDGEMENTS

This report is published as part of the Science, Technology, Research and Innovation for the Environment (STRIVE) Programme 2007–2013. The programme is financed by the Irish Government under the National Development Plan 2007–2013. It is administered on behalf of the Department of the Environment, Community and Local Government by the Environmental Protection Agency which has the statutory function of co-ordinating and promoting environmental research.

The authors benefited from generously given help from many quarters. The services of Seán Morrish and, more recently, Daniel McInerney in providing access to the URBIS database and support services were invaluable. The development of the Green City Guidelines would not have been possible without the leadership and input of Gerry Clabby, Heritage Officer, Fingal County Council, and Tim Carey, Heritage Officer, Dún Laoghaire–Rathdown County Council. The testing of the model and its potential as a decision support tool depended crucially on the interest and support of the Dublin and the Mid-East Regional Authorities, and specifically Patricia Potter of Dublin and John Byrne, their respective Directors, as well as the team involved with the development of the Regional Planning Guidelines, Deirdre Scully and Walter Foley.

The MOLAND (Monitoring Urban Land Use/Cover Dynamics) model owes its application across Europe to the leadership and interest of the Joint Research Centre at Ispra, Italy. Carlo Lavalle and Laura Petrov provided the crucial authorisations and support that ensured coherence and relevance in the wider European context. Regular interaction with RIKS b.v. as the developer of the software was essential, and Hedwig van Delden and Jasper van Vliet ensured that both training and support needs were well met. All work undertaken on the MOLAND model for the Greater Dublin Region is subject to the license conditions of the software developers, Research Institute for Knowledge Systems b.v. (RIKS b.v.) and the data set owners, DG JRC, under license no. JRC.BWL.30715.

The interest and engagement of the Department of Environment, Community and Local Government is essential if the investment in this decision support tool is to be of long-term value. Ministers Dick Roche and John Gormley, and their officials are greatly acknowledged for their encouragement and support.

All Digital Atlas maps were derived using Ordnance Survey Ireland base data under Permit No. MP009006© Government of Ireland. Access to Place of Work Census of Anonymised Records (POWCAR) was made possible by the kind agreement of the Central Statistics Office.

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Table of Contents

Executive Summary

1 Background

The Greater Dublin Region (GDR) was one of the fastest growing urban regions in Europe during the period 1990–2006. Therefore, it offers a good example of the complex interactions at play in fast-growing city regions and provides a suitable test bed for developing innovative decision-support systems. It is also home to over 50% of Ireland's population and, therefore, environmental improvements that can be brought about for residents of this region will have a significant impact in terms of both quality of life and national economic performance.

The recession from 2007 to 2012 has highlighted the major impacts on the environment and society of a contraction in economic activities and legacy issues of inappropriate development decisions. Decision processes incorporating an evidence-based assessment of alternative approaches can therefore be seen as necessary in both periods of growth and in the current period when resources are severely reduced.

The interactions between urban development, spatial configuration and the natural environment are complex and, therefore, difficult to manage effectively. An integrated and evidence-based approach is needed to ensure that decision makers can adequately assess the effect of different policy options in a robust and objective way. Also, the approach needs to be able to take account of a range of interactions that are difficult to capture and have different and interconnected environmental impacts. An integrated framework, such as MOLAND, which is spatially explicit, utilises the considerable power of geographical information systems and includes the capability to simulate future land-use change based on socio-economic activity as well as environmental themes, is one means to analyse these interactions and the associated implications.

2 Research Methodology

The MOLAND[1] (http://www.moland.jrc.ec.europa.eu) model, developed under the aegis of the Joint Research Centre of the European Commission by RIKS b.v. (http://www.metronamica.nl/models.php) is a state-of-the-art dynamic land-use change model that has been applied to a number of city regions in Europe. It was developed in response to the need for an integrated and robust framework for assessing policy options relating to land-use change in Europe. This research adapts the MOLAND model for application in the GDR through updating the model with region-specific information as well as extending its scope to provide analytical capacity relating to five priority environmental themes.

The model has two main components, namely a regional model and a detailed land-use model. The current version of the MOLAND model analyses and illustrates demographic, economic and transportation interactions between these inputs. National data such as population growth and Gross Domestic Product (GDP) expansion are inputs into the regional component.

Data from the regional sub-model feeds into the land-use model ('micro model') which allocates a land use to each grid cell. This model can in principle run at any level of spatial resolution (e.g. grid cells of 20 × 20 m, 100 × 100 m, etc.). It allocates land uses through a process called Cellular Automata (CA). The CA process uses a variety of inputs to determine the land use in any particular grid cell, including rules that indicate how compatible land uses are with each other. Random factors as well as trends and stable interrelationships between land uses can be factored into the scenario-generation process, as can new infrastructure and land-use zonings.

MOLAND provides output on an annual basis into future scenarios or projections. Outputs from the model include 'predicted' land-use patterns at future dates and related indicators.

The MOLAND research initially involved

1. MOLAND, Monitoring Urban Land Use/Cover Dynamics.

understanding the process of adapting the model regarding data collection, data preparation, calibration, validation and indicator development, etc., to allow use in the Dublin region. This model was subsequently used and applied as a tool in specific decision-making contexts to support decision-making processes in areas including scenario generation, comparison of scenario outputs, application of environmental indicators and their analysis.

Within each thematic area – air quality, urban transport, urban biodiversity, climate change and urban sprawl – both primary and secondary data were gathered and analysed to both inform the development of the Dublin Region application of MOLAND as well as to explore theme-specific research hypotheses. Once the model had been fully calibrated and tested it was then used to simulate future scenarios for the region.

The 'scenarios' approach provides a tool for reaching a better understanding of the possible outcomes of different policy options as well as providing a means of exploring the effects of the 'business-as-usual' scenario. It also enables qualitative storylines to be converted into quantitative scenarios, the effects of which can be measured, repeated, compared and analysed.

Two additional applications were selected in collaboration with stakeholders – one a study relating to the provision of wastewater treatment facilities in the GDR as the population expands over time and the second relating to scenarios for regional settlement strategies, which was used in the official review of the region's planning guidelines demonstrating how MOLAND could be used to support specific integrated decision-making processes.

These applications show the practical use of the tools developed during the project in 'real-world' policy settings. In order to compare scenarios, sample indicators were developed, which provide quantitative measures of the key environmental impacts related to the land-use changes that are simulated under the different scenarios. Some of the indicators are spatially explicit and can be used to assess the spatial aspects of alternative spatial planning strategies and environmental policies.

3 Research Findings

CA-based urban models as used in the MOLAND framework have been identified as a powerful platform for simulating future land-use changes under a range of conditions at a regional scale. The effectiveness and accuracy of the model are dependent on the resolution and availability of contextual spatial data to populate the model and the associated efforts in calibrating and validating it. Considerable investment is needed to adapt the model to local conditions, which has been achieved by this research, but this is the first step in applying the model to assist in specific decision-support situations. To realise the full potential of the model and associated tools, ongoing capacity is needed to continuously maintain and refine the input data and model outputs, as well as the consideration of appropriate decision situations to which it can be applied. In future planned research, it would be useful to compare MOLAND with other models that use a similar methodology and to develop a similar framework using open-source programming approaches (Twumasi, 2008)[2]. This would ensure that a wider community of programmers and modellers could engage with refinements and improvements to the model, which is currently restricted under licence.

MOLAND provides a dynamic representation of land-use change over time and offers powerful alternatives to traditional static mapping systems used to analyse and manage land use in Ireland. It also provides a means of visualising the effects of a business-as usual scenario with regard to spatial planning policy in the GDR. It allows for the quantitative interrogation and comparison of the environmental impacts and settlement patterns that may result under a number of strategic spatial planning policy options.

This research indicates that managed increased density land use is inherently more energy efficient and, if combined with improvements in public transport, results in lower per capita emissions. Well-designed mixed-use developments can reduce transport-related emissions by reducing travel to employment and services and could enable an

2. Twumasi, B.O., 2008. *Recommendations for Further Improvement to the MOLAND Model.* UCD Urban Institute Ireland Working Paper Series (08/01), Dublin, Ireland.

increased modal shift to public transport. For example, hinterland areas show up to 15 times higher transport-related energy consumption[3]. When compared with a business-as-usual scenario, a compact city scenario represents a saving of 18% in transport-related energy consumption. In addition, a compact urban form could provide a 16% decrease in energy demand for space heating under the climate change scenario tested.

The spatial distribution of development can have a significant impact on biodiversity assets in the region and spatial planning strategies need to take this into account. For example, in the period 1990–2006, although the overall percentage of green space to built fabric remained constant over time, the losses and gains of green space were not evenly distributed throughout the city. Green space was mainly lost near the city centre to infill development, where it was converted to built areas whilst the green space gained was at the perimeter of the city, reducing the area of agricultural land and semi-natural vegetation types. This resulted in a net loss of vegetated surfaces both within and outside the city.

The spatial distribution of population has increased considerably without a parallel increase in public transport infrastructure resulting in a significant reliance on the car. This research developed a methodology for an activity-based description of the emissions of pollutant species from either a single vehicle or a specific category of vehicles. This allows for the calculation of a daily distribution of speed, based on real traffic flows rather than an average vehicle speed estimation based on the national average. Thus, more accurate calculations of the impacts of vehicle usage on air quality at a local scale can be made.

In working with MOLAND, a number of significant data gaps have been identified, including a lack of harmonised data (scalar, temporal and contextual) relating to the zoning status of lands in the region and also a lack of biodiversity data at a fine spatial scale. This highlights a lack of co-ordination between and across local authorities and regional authorities working in the GDR.

There are costs and benefits associated with physical planning decisions and the exact direction pursued will be decided by the interaction between planners, policy makers and the public working together. Infrastructure, development, environmental and zoning decisions should be undertaken on the basis of a rational methodology that incorporates inputs, including evidence of population and employment projections, land-use surveys, assessment of housing needs, and the demand for retail space and community facilities (including education and open space/amenities provision). This process should culminate in the quantification of future urban land demand and its location. In addition, the suitability of the land itself in terms of topography, physical characteristics and the linkages to the existing urban area are essential criteria in rational decision making. The MOLAND model allows diverse policy options to be evaluated before concrete decisions are made and provides a useful basis for discussion on the issues facing policy interests.

Research reports and detailed analyses are available for download at the Urban Environment Project website (http://www.uep.ie) in the form of journal publications, working papers and conference presentations.

3. Transport-related energy consumption is a composite made up of journey length, time, mode and occupancy for the commute to work.

1 Introduction

1.1 Project Overview

The context for this research is that while there has been a growing awareness of the potential problems associated with rapid urban growth, research and responses have tended to focus on single aspects of the urban environment such as transport or air quality. This research has explored urban environment impacts in an integrated manner, recognising the interplay of environmental factors but underpinned by discrete analyses on a thematic basis to inform both environmental policy relating to urban areas and strategic spatial planning policy.

In supporting the formulation and implementation of environmental policy, the key challenge was to understand the linkage between development and environmental performance. As environmental impacts often depend on location, where the development and associated impacts take place is also an important consideration. This project has developed the analytical capacity to link development–space–environment dimensions of this important policy debate.

Under the aegis of the European Commission (EC) (Joint Research Centre (JRC) at Ispra, Italy), the MOLAND[1] urban land analysis model was developed by RIKS b.v.[2] (and formerly the University of Maastricht), which, for a given area, generates predictions as to future land uses under various economic and demographic scenarios. This was been pilot-tested in 2009 in the Greater Dublin Area (GDA) using 1990, 2000 and 2006 data, and is also being applied in Northern Ireland and the Border Counties by colleagues at the University of Ulster. In addition, this model has been updated and extended by incorporating additional environmental variables, and sample environmental indicators have been produced.

Each of the relevant sub-projects in the study cluster – air quality, biodiversity, climate change, transport and urban sprawl – was structured to both provide data for the MOLAND model and also to answer theme-specific questions (the selection of these themes was informed by the priorities of the project sponsors). This ensured consistent integration of the various strands of the research. Integration was also facilitated by the fact that the research and a number of the key seminars and workshops were carried out in University College Dublin's Urban Institute Ireland (UII), which was the home (state-of-the-art labs and office space) for much of the research, with key actors engaged in both formal and informal interactions.

The research was carried out at two scales – regional and local. The first was defined as the Greater Dublin Region (GDR)[3] as shown in Fig. 1.1. It comprises four Dublin councils, and Counties Louth, Meath, Kildare and Wicklow. It was chosen because it comprised in research terms a Functional Urban Region and it accounts for close to half of the Republic of Ireland's population and employment (Table 1.1 and Fig. 1.2). The second scale is the east coast corridor, where the airport, port, traffic, commercial and residential development all combine with particular intensity, with access to SCATS[4] and other data, which allowed the development of specialised data for some of the themes. The experience at both of these scales has allowed the extension of the model to other urban regions, and linkages have been developed with parallel activity in Northern Ireland and with other European regions (e.g. Andalucia, Spain, and Leipzig, Germany) with research experience in this area. In addition, there was a value in investigating the process

1. MOLAND (Monitoring Land Use/Cover Dynamics) is an initiative of the Institute of Environment and Sustainability at the JRC of the EC (http://moland.jrc.ec.europa.eu/).
2. RIKS, Research Institute for Knowledge Systems (http://www.riks.nl).
3. The GDR is a descriptive term to describe the study region. It includes eight counties as mentioned in the text which form part(s) of three regional authority areas – the Dublin Region (Dublin City, South Dublin, Dún Laoghaire–Rathdown, and Fingal); the Mid-East (Meath, Kildare and Wicklow) and Border (Louth and other counties). The GDA consists of the total area of the Dublin Region and the Mid-East Region but does not include Louth.
4. SCATS, The Sydney Co-ordinated and Adaptive Traffic System is the traffic management employed by Dublin City Council.

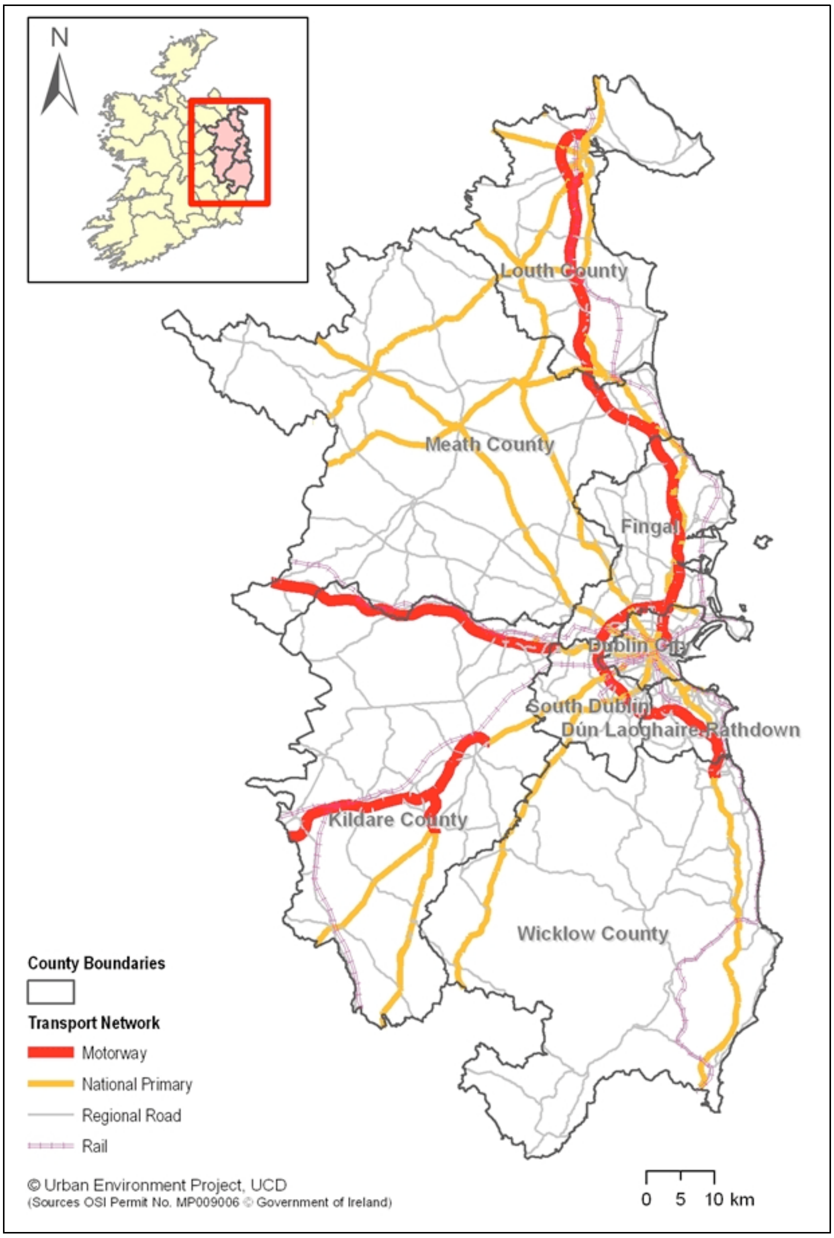

Figure 1.1. The Greater Dublin Region showing key transport infrastructure.

Table 1.1. Population and employment in Ireland and in the Greater Dublin Region (GDR) (source: CSO, 2006).

<table>
<tr><th></th><th></th><th colspan="2">Population</th><th colspan="2">Labour force</th></tr>
<tr><td>Ireland</td><td></td><td>4,239,848</td><td></td><td>1,930,042</td><td></td></tr>
<tr><td rowspan="5">GDR</td><td>Louth</td><td>111,267</td><td rowspan="5">1,773,803
(41.8% of total population in Ireland)</td><td>48,129</td><td rowspan="5">848,369
(43.9% of total number of people at work in Ireland)</td></tr>
<tr><td>Meath</td><td>162,831</td><td>78,437</td></tr>
<tr><td>Dublin</td><td>1,187,176</td><td>572,896</td></tr>
<tr><td>Kildare</td><td>186,335</td><td>91,581</td></tr>
<tr><td>Wicklow</td><td>126,194</td><td>57,326</td></tr>
</table>

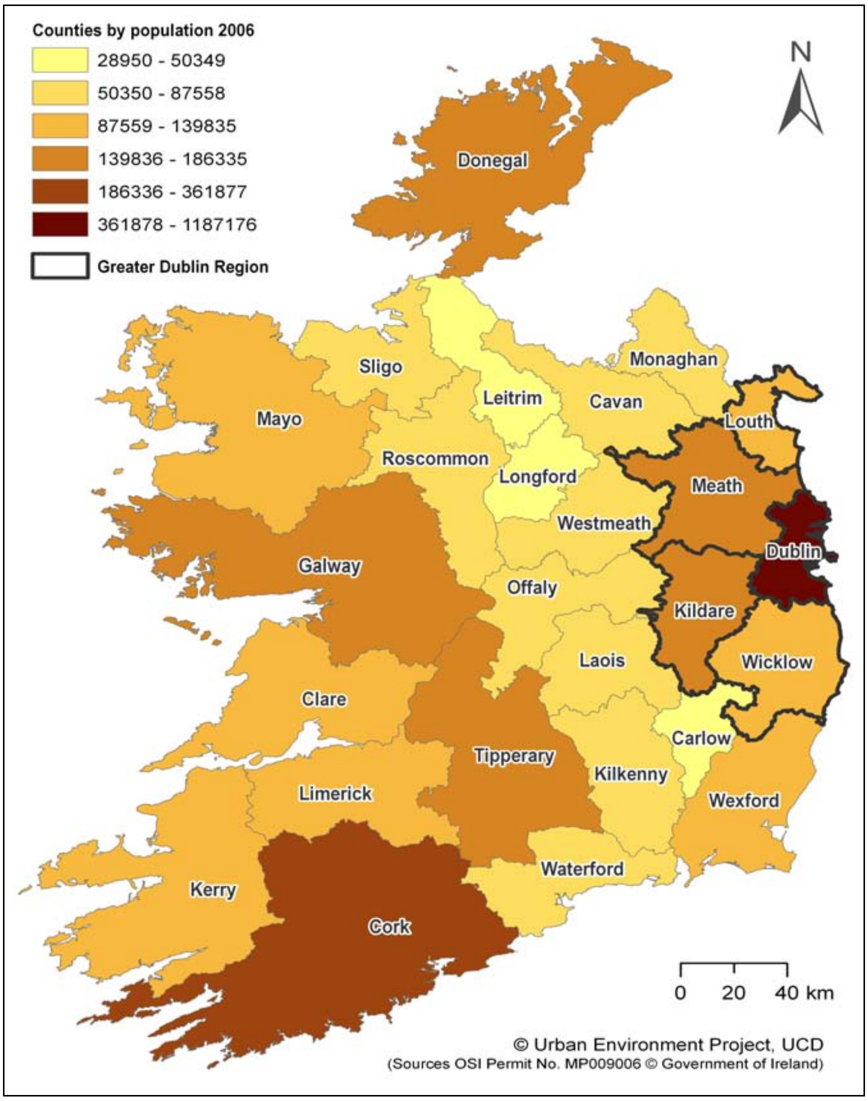

Figure 1.2. Population in Ireland by county. Greater Dublin Region highlighted (source: CSO, 2006).

in a multi-scalar way to try and identify connections between the regional and local scales.

The final results of the research of this multidisciplinary team represent a substantial contribution to national decision making and policy support, and contribute substantially to the intellectual endowment in this field in Ireland and internationally. Also, this research has enabled a multi-institutional research cluster to develop as a centre of excellence in this field, with a capacity for further research and policy contributions in the urban and environmental research areas.

1.2 Background to the Project

MOLAND is a state-of-the-art European Union (EU) land-use model that has been pilot-tested in the GDR using 1990, 2000 and 2006 data. The model has two main components – a regional model and a detailed land-use model. The current version of the MOLAND model analyses and illustrates demographic, economic and transportation interactions between these inputs. National data such as population growth and Gross Domestic Product (GDP) expansion are inputs into the regional component.

Data from the regional sub-model feed into the land-use model ('micro-model'), which allocates a land use to each grid cell. This model can in principle run at any level of spatial resolution (e.g. grid cells of 20 × 20 m, 100 × 100 m, etc.). It allocates land uses through a process called Cellular Automata (CA). The CA process uses a variety of inputs to determine the land use in any particular grid cell, including rules that indicate how compatible land uses are with each other. Random factors, as well as trends and stable interrelationships between land uses, can be factored into the scenario-generation process, in addition to new infrastructure and land-use zonings.

MOLAND provides output on an annual basis into future scenarios or projections. Outputs from the model include 'predicted' land-use patterns at future dates and indicators related to a variety of issues (e.g. proximity of residential areas to green spaces, housing densities, etc.).

Regarding the Urban Environment Project (UEP), the work programme was divided into several sub-projects, each with a leader and team members across the participating institutes. These included air quality, biodiversity, climate change, urban sprawl, urban transport, and the green city. Work involved each group developing new knowledge in its respective field, each of which had its own integrity which fed into the modelling sub-project. The remaining four sub-projects – project management, capacity building, academic output, and communication and dissemination – were steered by the management team and were focused on delivery.

The data sets that emerged from the sub-projects were prepared in a format that could be integrated into MOLAND. The integration of all data sets (from ancillary and sub-projects) into MOLAND was completed to the greatest possible extent and was carried out in conjunction with RIKS b.v. and the JRC. As part of the process, new indicators have been developed as plug-ins for MOLAND.

1.3 Research Objectives

The aim of the project was to adapt and create a generic land-use model that can be applied to urban areas in Ireland and that can be used with and compared with international models. An integrated platform for predictive modelling and scenario building based on new and existing data sets has been developed. This platform has been tested in an applied research setting in the support of policy development in the regional planning context for the GDR.

The purpose of this research was to develop a methodology that may be utilised for the examination of development in functional urban regions and the general management of urban development in the context of its long-term economic and environmental consequences. This concept is particularly relevant in considering the emphasis in the National Spatial Strategy (NSS) on balanced regional development. The debate on the Irish urban system and its dynamics was carefully explored in the NSS and related Regional Planning Guidelines (RPGs) (DRA & MERA, 2004). It is therefore appropriate that evidence-based analysis of how Dublin and other functional urban regions have developed should be examined. The implications of a functional regional approach to planning and development issues are especially relevant to long-term and strategic policy planning issues.

1.4 Research Approach

The principal methodology driving the project was the use of a multidisciplinary approach. The MOLAND model and the work package associated with it provided a reliable and robust platform for the knowledge and methods from different disciplines to interact and to allow for synergies to develop. Given the scale of the work and the backgrounds of those involved in the project, a strong emphasis was placed on ensuring communication between members of the team. This was facilitated by providing a single physical location for researchers involved in the project, as well as convening regular monthly meetings of the entire project team. The meetings included items on general organisational and administrative matters but mostly focused on communicating and discussing important issues concerning the development of the research.

Each of the scientific packages had a PhD researcher associated with it and was led and supervised by a member(s) of the academic staff at the resident institution. An additional cross-cutting work package 'Modelling' was the core integrating work package of the project and provided a platform for the knowledge and understanding developed in the thematic work packages to be brought together in a coherent way.

This work package focused on the development of the capabilities of both the MOLAND model and the knowledge developed in the thematic work packages for use as practical decision-support tools that can be used to assess the environmental performance of the region. Two key approaches were used to address this in order to compare the environmental, social and economic performance of the scenarios:

1. Scenario development; and
2. Indicator analysis.

1.5 Research Applications and Capacity Building

The applications of this research to real policy problem areas and increasing policy-maker capacities to employ evidence-based analysis in decision making were essential parts of the research. With the relevant public agencies, priority policy areas, including the provision of wastewater treatment facilities and strategic regional planning, were selected for case study analysis incorporating this research approach.

Capacity building was conducted in two distinct channels. The first channel focused on ensuring increased awareness of the various activities of the project and, in particular, the significant contribution towards development of modelling techniques for assessing regional environmental problems. The second focused on teaching students, researchers, professionals and decision makers how to use the tools and facilities that were developed over the lifetime of the project.

A number of awareness-raising activities were carried out focused on fourth-level students undertaking programmes in spatial planning, environmental policy, sustainable development and geographic information systems (GIS). To a lesser extent, final-year undergraduates were exposed to the activities of the project as a number of final-year projects were conducted to support the work of the PhD students engaged in the project.

The UEP convened a number of workshops and seminars, with invited audiences from key user groups, to inform about the capabilities of the team and, in particular, the usefulness of the MOLAND suite. In addition, two key events, one in Brussels (2009) and the other in Dublin (2009), were convened to ensure that the widest possible audience would be made aware of the project and its outputs.

In parallel, the academic staff and five PhD students involved in the project have developed a good understanding of MOLAND, how it works, how best it can be applied and where it may be of use in the policy and decision-making context through ongoing interactions of the project team and the associated training sessions, seminars and workshops that have been carried out. Through their activities presenting at conferences, submitting papers and participating in workshops, the profile of the project was enhanced.

A full listing of research outputs developed over the course of the project is presented in Appendix 1 of this report. In addition, the UEP website (http://www.uep.ie) contains, where possible, downloadable journal articles, research papers and conference presentations which will be updated as new material comes available.

2 Brief Technical Literature Review

Computerised decision-support systems (DSSs) became practical with the development of computers, timeshare operating systems and distributed computing. The history of the gradual implementation of such systems in applied settings commences in the mid-1960s (Eom and Lee, 1990; Silver, 1991; Power, 2003; Arnott and Pervan, 2005). From the 1960s onwards, researchers began systematically studying the use of computerised quantitative models to assist in decision making and planning (Raymond, 1966; Turban, 1967; Urban, 1967). Ferguson and Jones (1969) reported the first experimental study using a computer-aided decision system. Scott-Morton's (1971) production planning management decision system was the first widely discussed model-driven DSS. The idea of a model-driven spatial DSS (SDSS) evolved in the late 1980s (Armstrong et al., 1986) and, by 1995, the SDSS concept became firmly established in academic literature (Crossland et al., 1995).

The starting point of the history of raster-based spatial modelling was the development of CA models by von Neumann and Ulam at the Los Alamos National Laboratory in the 1940s (Hagen, 2008). To give a mathematical proof of the possibility of self-reproduction, von Neumann outlined the construction of a 200,000-cell configuration that would reproduce itself; additions were then completed by Burks in the early 1960s.

The best-known two-dimensional cellular automaton is Conway's game of life, discovered by J.H. Conway in 1970 and popularised by M. Gardner (Gardner, 1970). In this CA model, cells in a regular square grid can be in one of two states, alive or dead. Dead cells become alive if three of their eight neighbours are alive. Alive cells remain alive only if two or three of their neighbours are alive. Based on these rules, simple initial patterns evolve rapidly to landscapes with static, oscillating and moving structures.

The simplest type of cellular automaton is a binary, nearest-neighbour, one-dimensional automaton. Such automata were called 'elementary CA' by S. Wolfram, who has extensively studied their properties (Wolfram, 1983). The models by von Neumann, Ulam, Conway and Wolfram are first and foremost mathematical constructions and their relation with real-world phenomena is only at the highest level of abstraction (Hagen, 2008).

The spatial nature of raster-based models makes them of particular interest for geographical applications and, in particular, the neighbour-based transition rule of CA models offers potential for representing geographical processes. However, there are also raster-based geographical models that are CA-like but that do not have all the characteristics defining a CA (Hagen, 2008). An early example of such a geographical model is Schelling's dynamical model of segregation (Schelling, 1971). With his model, Schelling investigated the dynamics that underlie the formation of residential ghettos. The Schelling model addresses the real issue of segregation. Nevertheless, it is still a highly abstract model that is not specific to a particular region. A further development is the model of Tobler (1970), which is a spatially explicit simulation model that represents urban growth in the Detroit region. This region-specific model also shares some characteristics with CA – it is grid based and the dynamics are governed by neighbourhood interaction. In a later paper the link between CA and geographical simulation models is explicitly made (Tobler, 1979).

The land-use model that is of particular interest in this research is the Constrained Cellular Automata (CCA) model of White et al. (1997). The first application of the model concerned an imaginary island with characteristics typical of Caribbean islands (Engelen et al., 1995). Later applications focused on the Cincinnati Metropolitan Area (MA) on a timescale of more than 100 years (White et al., 1997). Further developments have elaborated the use of GIS, including road network data and the dynamic integration with socio-economic land-use models at multiple scales (White and Engelen, 2000). The model became part of Policy Support Systems, such as the Environment Explorer (Engelen et al., 2003a). Currently, the model is the cornerstone of several research modelling frameworks of urban and regional growth, including the METRONAMICA (van Delden and Engelen 2006) and MOLAND (White et al., 2000; Barredo and Demicheli, 2003) frameworks. The latter is applied by the UEP for the GDR and will be discussed in more detail in later chapters.

This development towards continuously higher levels of operability also led to increasing demand for analytical tools and procedures concerning model set-up and calibration (White and Engelen, 2003; Straatman et al., 2004; Verburg et al., 2004; Geertman et al., 2007). Clearly, the quality of a model is very dependent on the spatial data used to set it up and the specific computational rules used to generate future scenarios. Other land-use models have followed similar trajectories. In particular, the SLEUTH CA model (Clarke et al., 1997) has been steadily developed and been subject to methodological refinements and empirical and theoretical analyses (Silva and Clarke, 2002; Dietzel and Clarke, 2004; Dietzel et al., 2005; Herold et al., 2005; Jantz and Goetz, 2005).

CA modelling of land-use processes is a field that remains under development. New developments take place in different directions, for instance integrating processes at multiple scales (Andersson et al., 2002; White, 2006) incorporating economic principles in the CA rules (Webster and Wu, 1999a,b) and modelling land-use–transport interaction (Geurs et al., 2006).

An agent-based model (ABM) is another class of computational model for simulating the actions and interactions of autonomous agents with a view to assessing their effects on the system as a whole. In an ABM, a system's dynamic behaviour is represented through rules governing the actions of a number of autonomous agents. Such models can be regarded as generalisations of CA in which agents are able to move around in space, rather than being confined to the cells of a raster (Maguire et al., 2005).

The idea of agent-based modelling was developed as a relatively simple concept in the late 1940s. Since it requires computation-intensive procedures, it did not become widespread until the 1990s. The history of the agent-based model can be traced back to the von Neumann machine, a theoretical machine capable of reproduction. The concept was then improved by Ulam, who suggested that the machine be built on paper, as a collection of cells on a grid. The idea was developed by von Neumann – creating the first of the devices later termed CA.

Agent-based modelling has found many interesting applications to geographic phenomena. Benenson (2004) has explored the use of such models to represent the behaviour of households in cities. Several efforts have been made to apply ABMs to the emergence of land-use and land-cover patterns, with particular emphasis on the process that leads to greater fragmentation of land cover as a result of development (Maguire et al., 2005).

Land-use transport interaction (LUTI) models have been developed and refined since the 1970s and are in widespread use (Wegener, 2004). This class of model is somewhat different to land-cover models in that land use/land cover is not modelled in a spatially explicit manner. One such example is SATURN (Simulation and Assignment of Traffic in Urban Road Networks), which has been applied to the Dublin region by the National Transportation Authority (formerly DTO[5]) However, SATURN is mainly used to assign traffic to a road network. In addition, SATURN is an equilibrium model and contrasts with dynamic models such as MOLAND in that the time it takes for a system to adapt to changes is not described. This means that whilst SATURN can assess the effect of changes in the transport network on traffic flows, it does not give information on the influence of the network on spatial development trends, including the allocation of new residential areas (van Delden et al., 2007).

5. DTO, Dublin Transportation Office.

3 MOLAND

There are several research projects addressing land-use changes and their potential impacts (EC DG ENV, 2008). Recent work by the European Environment Agency (EEA, 2007) and the ESPON[6] 2013 Programme, European Observation Network for Territorial Development and Cohesion, illustrates the potential for dynamic spatial modelling and scenario generation to influence policy debates and discussions on future territorial and environmental visions for Europe. In both cases, quantitative modelling is combined with narrative-based qualitative techniques to produce meaningful and plausible visions of future environmental conditions and territorial development patterns.

Land-use change modelling helps in understanding the complex cause–effect relationship between land use and various competing sectors. The models predicting land-use changes caused by different policy measures can provide valuable information on possible future land use (EC DG ENV, 2008).

A land-use model is usually applied to allocate land-use change based on competition between different land uses and the use of spatial allocation rules. Various modelling approaches exist for modelling land-use change, including:

- Rule-based systems based on either theory or expert knowledge;
- Suitability maps based on empirical analysis; and
- Transition rules dependent on the land uses in the neighbourhood.

One of the most popular methods to implement neighbourhood interactions in dynamic land-use change models is CA. In land-use models using CA, the transition of a cell from one land use to another depends on the land uses within the neighbourhood of the cell. There is no single approach that is clearly superior to other models for simulating land-use change. The choice of one land-use model or another will depend on the policy questions that need to be answered, while issues of data availability are also important (Verburg et al., 2006; Pontius et al., 2008). It can be observed that European institutions, such as the EC, the JRC and the EEA, have supported and collaborated in the development of these types of tools. The application of these types of tools in policy making at the European scale is still limited (EC DG ENV, 2008). An analysis of the evolution of various land-use modelling techniques is included in Appendix 2.

The MOLAND model is the property of the JRC and was developed by RIKS b.v. It has been applied to an extensive network of cities and regions and, since 2004, MOLAND has contributed to the evaluation and analysis of the impact of extreme weather events, as well as research on adaptation strategies to cope with climate change. The MOLAND model was identified as the most potentially inclusive model by the UEP research group. A more detailed description of the model and its application for GDR is given in the following sections.

The MOLAND model was developed as part of an initiative of the EC's JRC 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). It comprises two sub-models working at different scales. At the macro-scale (regional scale), the model takes as inputs the population and the economic activity in a region, which are then split between the sub-regions encapsulated in the model area. To improve the model's manageability and performance, the economic sectors are aggregated into four main activity categories:

1. Industry;
2. Services;
3. Commerce; and

6. ESPON, European Spatial Planning Observation Network.

4. Port.

The population is assigned to four residential categories:

1. Residential continuous dense;
2. Residential continuous medium;
3. Residential discontinuous urban; and
4. Residential discontinuous sparse.

At the micro-scale (land parcel or cell), the provision for population and economic activities is translated into a number of land uses. The micro-model is based on the CA. The land-use type assigned to any given cell is determined by an algorithm that aims to satisfy the demands for land use in each time step. The following are the main elements of the model which determine whether a cell is taken in by a land use or not:

- **Suitability** – representing the degree of relevance of each cell to each land-use type;
- **Zoning** – specifying whether a cell may or may not be taken over by a specific land use. It is usually based on planning documents available from municipal authorities;
- **Accessibility** – describing the accessibility of a cell to the transport network; and
- **Neighbourhood rules** – expressing the dynamic impact of land uses in the surroundings of a location. For each cell a set of rules determines the degree that it is attracted to, or repelled by, the other land-use cells present in the neighbourhood.

Based on these elements the model calculates the transition potential for each cell for every simulation time step (Fig. 3.1). Cells are changed to the land use for which they have the highest potential until regional demands are met.

The linkage between the models at the Global, Regional and Local levels is bi-directional and very intense: the Global (national) growth figures are imposed as constraints on the Regional model, the Regional model distributes and allocates the regional growth to the five counties in the region and imposes in the cellular model (local) the regional growth numbers.

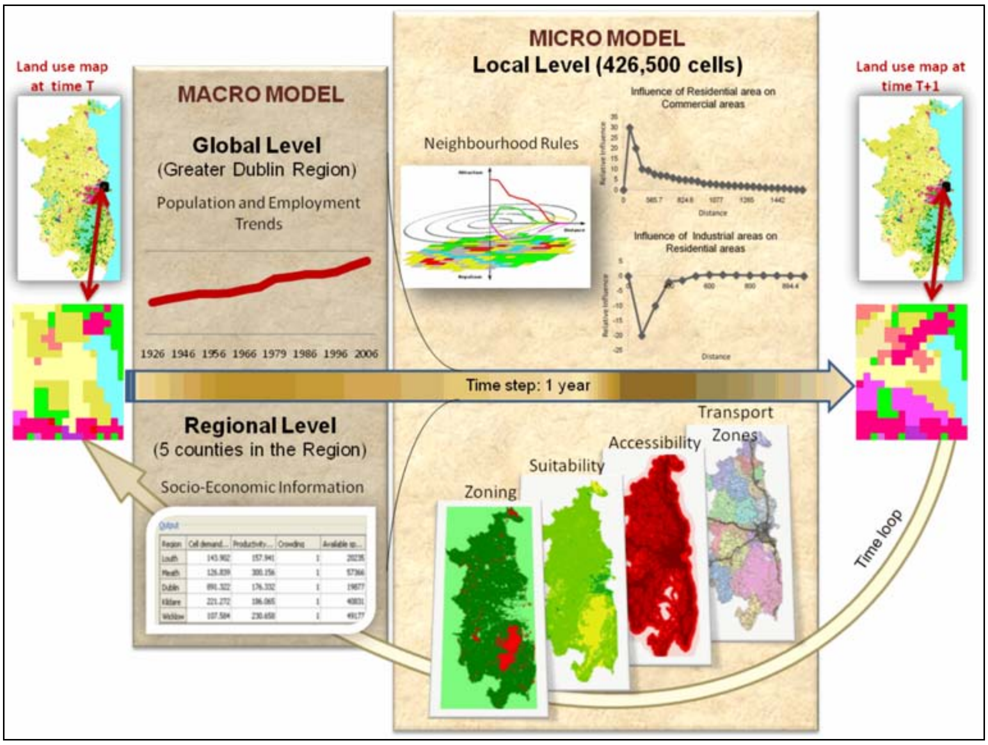

Figure 3.1. Land-use transition in the MOLAND model.

The cellular model finally determines at the highest level of detail where the growth is taking place.

In this process, the cellular model returns to the Regional model information on the quality and the availability of space for further expansion of each type of economic or residential activity. This information is an input into the spatial interaction calculations at the Regional level and it strongly influences the relative attractiveness of the individual counties. In the course of time, the counties gradually run out of space for one of the other activities, they lose part of their competitive edge and exert less attraction. Growth is consequently diverted to other, more attractive, counties.

In the MOLAND model, a crucial role in coupling the Regional and Local levels is played by the land-productivity parameter, as it converts the jobs and residents into land claims for economic and residential activities. Land productivity is a measure of the amount of activity that can be allocated per cell. It is calculated for each economic sector as well as the residential activity in each region (Engelen et al., 2004).

3.1 MOLAND Application to the GDR

Within the scope of the UEP, the model was adjusted and calibrated for the GDR, as illustrated in Fig. 3.2. A detailed description of the data preparation and calibration procedure is presented in Shahumyan et al. (2009a,b). Here, key issues encountered during this work are discussed in order to provide the context for improvements to the model which are suggested as a result of experience working with the application of MOLAND to the GDR.

The MOLAND model expects all input maps to be strictly comparable; they must cover the same area and have the same resolution. Additionally, land-use

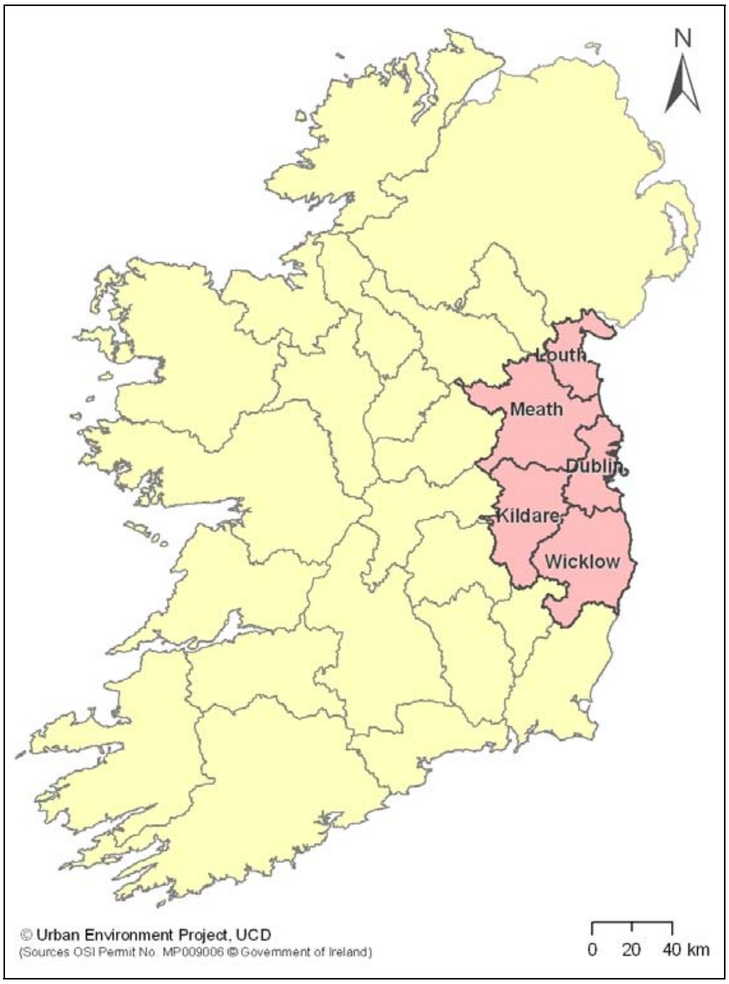

Figure 3.2. The Greater Dublin Region is highlighted in the map of Ireland.

maps and socio-economic data should be available for the beginning and end years of the calibration period. Thus, 1990, 2000 and 2006 data sets were used for the GDR application.

The data preparation and processing steps required to provide input for MOLAND were considerable and resulted in an extension in the length of time needed to complete the calibration exercise. The main problem encountered was missing or incompatible data sets for the region. A satisfactory solution was reached that involved using auxiliary data and interpolation/ extrapolation methods to adjust data to the correct scale and resolution. The key input data sets for ingestion into MOLAND are land-use maps, suitability maps, accessibility maps and zoning maps, as well as socio-economic data aggregated by county. These are described in the next sections.

3.1.1 Land-use maps

The minimum mapping unit (cell-size resolution) for urban areas is 1 ha and for non-urban areas, 3 ha. The classification is based on the CORINE[7] land-cover classification system. The ancillary data, such as Ordnance Survey maps and aerial photography, were used to assist in the interpretation. The final land-use maps were converted into 200-m (4-ha) resolution rasters. Due to this conversion, there is some loss of detail in the data set, but this was considered acceptable given the negative impact on the computational efficiency of the model if higher resolution rasters were used. In addition, the final choice of a 4-ha resolution allowed for better data matching of initially incompatible data sets.

Some inconsistencies between the land-use maps for 1990, 2000 and 2006 were also observed and rectified in the production of the 2006 land-use layer, as well as some post-adjustment to the 1990 layer. These issues arose due to the differing resolutions of satellite and other imagery available at the time of the creation of the land-use layers. For example, in 2000 5-m resolution imagery was used whereas in 2006 Quickbird satellite imagery was used for the main urban sector. An example of the difference in resolution quality is illustrated in Fig. 3.3. A more detailed discussion of these processes and solutions found is available in the End of Project Report (UEP, 2010).

3.1.2 Suitability maps

The suitability maps describe the relative suitability of a particular cell of land for a particular land use. For example, a cell that is located on a very steep slope on poorly drained soil is not as suitable for residential development as that on a gentler slope or flat ground with no drainage problems. In the MOLAND model GDR application, the suitability values are expressed on a scale of 0 (completely unsuitable) to 10 (highly suitable), and are computed using as input elevation, slope, aspect, soil type and existing land-use data sets. Researchers at the JRC, Ispra, had previously

7. CORINE, Coordination of Information on the Environment.

Figure 3.3. (a) Indian Remote Sensing (IRS) and (b) Quickbird images.

developed suitability maps for the region under the aegis of an earlier project, MURBANDY. Due to a lack of resources, it was not possible to generate new suitability maps using the same methods for this application of MOLAND. Therefore, the 1990 suitability layer was used and was then duplicated for 2000 and 2006. As the factors for suitability relate to the physical nature of the land and as these characteristics are unlikely to change significantly over a 16-year period, it was considered practical to use the suitability layers provided by previous researchers working with MURBANDY. In further refinements of the model, a methodology could be developed to validate these suitability criteria.

3.1.3 Zoning maps

In MOLAND, zoning is modelled with only binary options, 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. This may reflect the origins of the modelling framework, which was derived from the Dutch land-use planning system. However, in Ireland, the zoning systems allow for more than binary options. Examination of the Irish zoning maps reveals four main zoning categories:

1. Permitted, i.e. generally acceptable in principle, but subject to normal planning consideration, including policies and objectives outlined in the plan;

2. Open for consideration, i.e. permitted where the planning authority is satisfied that the proposed development will be compatible with the overall policies and objectives for the zone;

3. Not permitted; and

4. Other uses such as transitional zone areas.

For the GDR application, initially attempts were made to apply direct translation of the zoning maps published as part of the County Development Plans (CDPs) for the region into zoning maps for MOLAND. This process was, however, tedious and time consuming due to poor data quality, incomplete and inconsistent data, and lack of homogeneity within one county and across counties within the region. Therefore, an alternative approach was implemented, whereby zoning maps were developed that included special protection, conservation and national heritage areas. However, further research on more realistic zoning maps would be useful for integration of MOLAND into the practical decision-making process.

3.1.4 Transport network

A general assessment of the integrity of the 1990 and 2000 road data set versus the 2006 data set highlighted a number of inconsistencies. Positional errors of up to 400 m were identified, which is significant, given that the cell size of the model is 200 m^2. Moreover, different digitising rules were applied at complex junctions. Due to the above inconsistencies, it was concluded that the two data sets could not be used without modification. To avoid having to substantially modify the data sets for 1990, 2000 as well as for 2006, the 1990 and 2000 data sets were derived from the 2006 data set, thus ensuring positional accuracy between the reference years. With the help of local knowledge, the 2006 data set was edited for 1990 and 2000. A similar approach was adopted for deriving the rail network.

3.1.5 Socio-economic data

At the regional level, MOLAND requires socio-economic data for each of the modelled counties for the calibration years (1990, 2000 and 2006). The results of the last five Central Statistics Office (CSO) censuses in the Republic of Ireland (1986, 1991, 1996, 2002 and 2006) were used to estimate the population data for 1990, 2000 and 2006.

Employment data for the model are best input as place of work data when available. This is explained by the link between job data from the macro-model and the location of activity land-use cells in the micro-model. As was mentioned above at the micro-scale, the provision for economic activities is translated into corresponding land uses. Place of work data in Ireland are available only for 2002 and 2006, since the CSO implemented the Place of Work Sample of Anonymised Records (POWSAR) (CSO, 2002) and the Place of Work Census of Anonymised Records (POWCAR) (CSO, 2006). For all other censuses, occupational data were collected by place of residence only. The 2002 and 2006 data sets were used to estimate the appropriate place of work data for 1990 and 2000.

A combination of interpolation and extrapolation methods was applied to estimate missing data and fill the gaps with reasonable figures; there are still concerns about the accuracy of the estimated numbers. Indeed, over the period 1990 to 2000, Ireland's economic profile changed from one of the weaker economies of North-West Europe to one of the strongest in terms of economic and employment growth, followed by a major decline in the period since 2008 (ESRI Quarterly Economic Commentaries 2000–2009[8]). The relative speed and complexity of such short-term variations are hard to capture using quinquennial Census data.

3.2 Calibration and Validation

Calibration and validation are necessary and important processes for the application of most models. In general, calibration is an iterative procedure of parameter valuation and fine-tuning, as a result of comparing simulated and observed values. Validation is an extension of the calibration procedure. It is intended to assure that the calibrated model properly assesses all the variables and conditions that can affect model results, and demonstrate the ability to predict observations for periods separate from those included in the calibration effort.

8. ESRI (Economic and Social Research Institute). ESRI, Dublin, Ireland.

Initially, the use of the 1990–2000 period for calibration and the 2000–2006 period for validation was considered, but detailed analysis of the available data and several calibration exercises revealed some unforeseen challenges. In particular, though the calibration gave reasonable estimates for the 1990–2000 period, the validation results were poor for 2000–2006. Though the results were satisfactory for population, this was not the case with regard to employment data. This can probably be explained by the variations in wider socio-economic interactions taking place in Ireland during these two periods. Therefore, it was decided to fine-tune the calibration using the 2000 and 2006 data sets.

Comparison of the Constant Share Model and the MOLAND macro-model output shows that the MOLAND gives much more accurate estimates for all activities including population. For assessment of the calibration results at the cellular level (micro-model), two map comparison methods were used, namely Cell-by-Cell and Fuzzy Kappa. Figure 3.4 shows the result of the fuzzy map comparison method for 2006 actual and simulated land-use maps. The legend gives the degree of agreement on a scale of 0 (no agreement) to

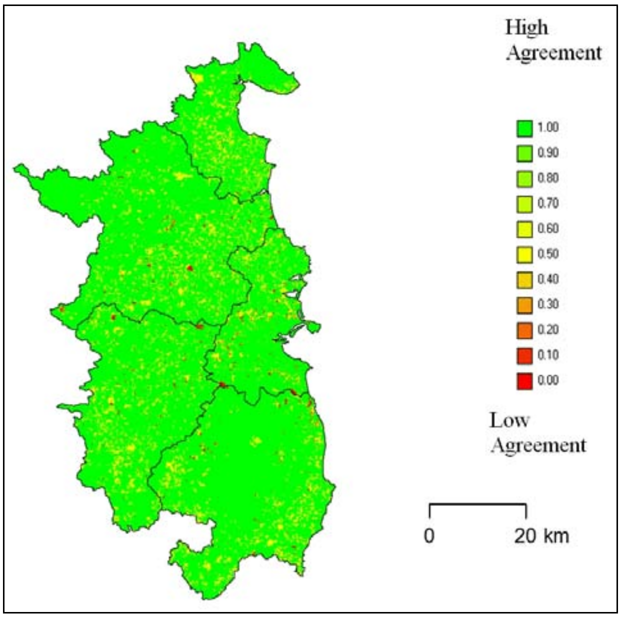

Figure 3.4. Fuzzy kappa comparison for aggregated classes.

1 (high agreement). Thus, the areas of main disagreements are the red areas, which can be further investigated to improve the calibration.

These analyses as well as cluster size frequency plots also showed that MOLAND simulates realistic images of development trends and the spatial dynamics of the region (Shahumyan et al., 2009a).

3.3 Some Limitations of the MOLAND Model

Whilst working on the MOLAND GDR application, a number of limitations were identified relating to the resolution and classification of land-use maps, the customisation of the transition rules, the paucity of conflict-resolving rules, and the lack of flexibility in the zoning rules. It should be noted that this problematisation was an important part of the process in understanding not just how the land-use change is modelled within MOLAND, but also in providing some insights into where the model was most effective in its predictions.

3.3.1 Land-use map resolution and classification

The 200-m resolution of land-use maps used in this application of MOLAND somewhat limits the potential applications of the model. In particular, the resulting cell represents 40,000 m^2. The minimum cell size that the MOLAND framework supports is 50 × 50 m. This represents 2,500 m^2, which is too large an area to be considered homogenous, considering that such an area can contain up to three to four terrace houses, adjoining front and back gardens and adjacent roads. This results in a loss of information regarding small-scale conditions, which is needed to adequately explain local species variations (Jokimaki, 1999) and in the current application of MOLAND, with grid cells of 200 × 200 m, this issue is exacerbated.

Another limitation of the model comes from the land-use classification. The MOLAND classification system uses the detailed CORINE Level 4 nomenclatures for the classification of urban land cover. In the MOLAND model as applied to the GDR, 24 land-use classes are modelled. The GDR covers 783,916 ha of land, of which some 92% is vegetated. In the MOLAND classification, vegetated areas are made up of seven land-use classes, but the dominant two are Arable Land and Pasture. Together, these two classes comprise nearly 80% of habitat and over 72% of the total area as of 2006. To consider over 80% of the vegetated area as belonging to one of only two possible categories is unrealistic for the purposes of assessing biodiversity (Brennan and Twumasi, 2008).

Consequently, the MOLAND methodology that the UEP employs is not very suitable for the direct assessment of biodiversity in a detailed and meaningful way. However, it could form part of a useful biodiversity assessment tool if coupled with detailed habitat maps (Brennan and Twumasi, 2008).

Whilst the selected examples touch only on the case of biodiversity, these limitations can be an obstruction to the application in other sectors too, particularly where the objects of interest are smaller than the minimum mapping unit. The same concerns apply to the land-use classification. However, if the goal of the model is to reproduce existing patterns or create reasonable future predictions and broad classes are dominated by only one or two relatively homogenous conversion processes, then using finer resolution classes may not be necessary. Nevertheless, if a broad class includes evenly represented heterogeneous processes, then the use of finer resolution classes representing that variety should be considered (Conway, 2009).

This is a general problem for most land-use models. The implications of changing class resolution in a land-use model are unclear. Fewer classes at a broader resolution may mean fewer errors associated with predicting specific sites converting to the wrong class, but trying to predict the location of future changes using more broadly defined classes may lead to errors associated with heterogeneous conversion processes being represented by one homogeneous relationship. Thus, potentially important process-oriented information is absent. However, if numerous fine resolution classes are included there may be problems associated with limited calibration data, conversion mis-specification, and the challenge of predicting very rare cases (Conway, 2009).

3.3.2 Lack of conflict-resolving rules

A clear weakness in nearly all CA models, including MOLAND, is that transition rules do not include conflict-resolving rules (Junfeng and Boerboom, 2006). In MOLAND, cells are simply changed to the function to which they have the highest potential in terms of the factors modelled. In reality, however, other factors may contribute to deciding on the final locations of cells and simply changing cells to the highest potential may not be sufficient (Twumasi, 2008). Unlike many natural processes to which CA algorithms have been applied, land uses do not mutate autonomously. Rather, human agents, namely developers, firms, regulatory authorities, landlords, tenants and home buyers, manoeuvre, collaborate and compete to change the city for their own purposes (O'Sullivan and Torrens, 2000). In reality, conflicts do occur among these spatial agents in their competition for space. Consequently, the transition rules should capture both the locational preferences and behaviour of these spatial agents, as well as any practical guidelines that are used to resolve conflicts in the real world.

A simple approach to addressing this issue is to allow users to define a priority map and a set of criteria that could be used by the algorithm to resolve conflicts. Another option is to leave conflict resolution entirely to the users to implement, though this was not permitted due to the relatively closed nature of the software.

3.3.3 Inadequacy of zoning

Development Plans (see for example Dublin City Development Plan 2005–2011) constitute the basic policy document of the land-use and development system in Ireland. It is a statutory function of local government to produce CDPs and, since 2001, they have a 6-year statutory time frame. The Development Plan generally contains a written statement in addition to a number of maps. Land-use development policy is primarily articulated through the designation of land-use objectives specific to particular lands within the planning authority's jurisdiction. The approach taken to the zoning of land varies between planning authorities. However, in general, most if not all land within urban areas is 'zoned' for a particular objective, while in the case of many rural areas specific land-use zoning objectives are not designated. The interpretation of each zoning objective may be further refined through the inclusion of a matrix where a large number of potential land uses are classified under each zoning objective as 'Acceptable', 'Open for Consideration' or 'Not Acceptable'. Whilst traditionally land-use zones have been single-use designations, i.e. commercial, residential, industrial or open space, mixed-use zones are increasingly used, particularly in areas such as city, town and neighbourhood centres. Nevertheless, as was described above, the MOLAND model's zoning with only binary options – permitted (0) and not permitted (1) – may be adequate for some locales where zoning is a 'black and white' issue; however, in the Irish context, this seems inadequate (Twumasi, 2008).

In the current framework of the model, a quick solution to overcome this limitation can be ingestion of zoning constraints through the use of the suitability layers. In this case, particular areas will not be forbidden for development but will have comparably low suitability, which will reduce the likelihood of development in those areas without completely eliminating such a probability.

3.3.4 Limitations on the scenario-generation capacity

The potential of MOLAND for scenario generation is restricted by the limited number of variables that it is possible for the user to specify. In order for scenarios to be structurally different from each other and to succeed in challenging the conventional wisdom about the future, the user must have the capacity to influence the parameters and assumptions that the model treats as 'autonomous' to the dynamics of the urban system (Walsh and Twumasi, 2008).

Here are some examples of possible scenarios that cannot be specified by MOLAND:

- A scenario with a specific population distribution between regions that differs significantly from the distribution in the starting year;
- A scenario where population or employment densities at particular locations are significantly higher or lower than in the starting year;
- A scenario where the relationship between neighbouring land uses is radically different to the starting year; and/or
- A scenario where zoning policy becomes more restrictive after a certain state.

3.3.5 Limitations of transport modelling in MOLAND

The relationship between transport and land use in MOLAND is implemented using accessibility parameters. These accessibility parameters are made up of an importance factor and a distance decaying factor to represent the relationship of each type of land use to each mode of transport. This approach is extremely limited with regard to understanding the actual dynamics of transport flows in the region. For example, the number of trips on a particular part of the network is not considered nor is there any information relating to traffic flows or modal share. This limitation was recognised by the model developers and, over the course of the project, a full transport model was developed and integrated with MOLAND. Unfortunately the extended transport model was not delivered to the UEP until the final stage of the project and, therefore, work with this version of the model was limited in scope.

Some other limitations of MOLAND and possible ways of improvement are discussed by Twumasi (2008) and Walsh and Twumasi (2008).

3.4 Conclusion

This chapter has discussed some limitations of the MOLAND model that have been identified during the calibration and application of the model for the GDR. Some of them are specific to the Irish context. For example, zoning is important in driving land-use dynamics in Ireland and attempts to motivate planners to use the model without adequate zoning integration may not be very successful. Some solutions for improving the model were also suggested.

In addition, to make the model even more extensible, the core functionality of the MOLAND model could be compiled and licensed as software components that can be plugged into existing development tools such as ArcGIS or Microsoft Visual Studio. This would give the opportunity to develop further programs and extend the functionality of the model by different users. There are still many aspects of CA-based land-use models that require further research and validation.

One thing hampering the progress of CA-based land-use models is the lack of such development tools, which forces researchers in the field to write their own programs from scratch – reinventing the wheel. Consequently, the availability of such components would be very welcome.

4 Integrated Modelling Frameworks and the Scenarios Approach

As mentioned, MOLAND was considered a suitably flexible framework for use in the GDR application because of its flexibility with regard to converting qualitative storylines into quantitative scenarios (see Section 4.1), giving it potential as a decision-support tool and as a means to integrate environmental thematic information to provide an integrated robust framework.

One of the key strengths of the modelling framework is the ability to integrate models from different domains through the land-use model. The premise is that all regional and local dynamics will have an expression in the land use observed in a particular region. As described in Section 3.1, MOLAND consists of the socio-economic model (macro-model) and the CA model (micro-model) and is best applied to urban regions. Figure 4.1 shows the system diagram depicting how the interactions are captured in the macro-model.

At the project outset, the hypothesis was that models from different domains might be integrated into the MOLAND model to reflect the environmental dimensions within the urban region that may not be explicitly represented within MOLAND. Key themes selected were air quality, urban transport, biodiversity, climate change and urban sprawl, which represent the key environmental concerns of urban regions. As the experience and knowledge of the project team in relation to the MOLAND model evolved over the course of the project, the extent to which these environmental elements could be fully integrated into the framework was explored.

For each theme, differing levels of integration were possible. In fact, full integration of sub-models was not

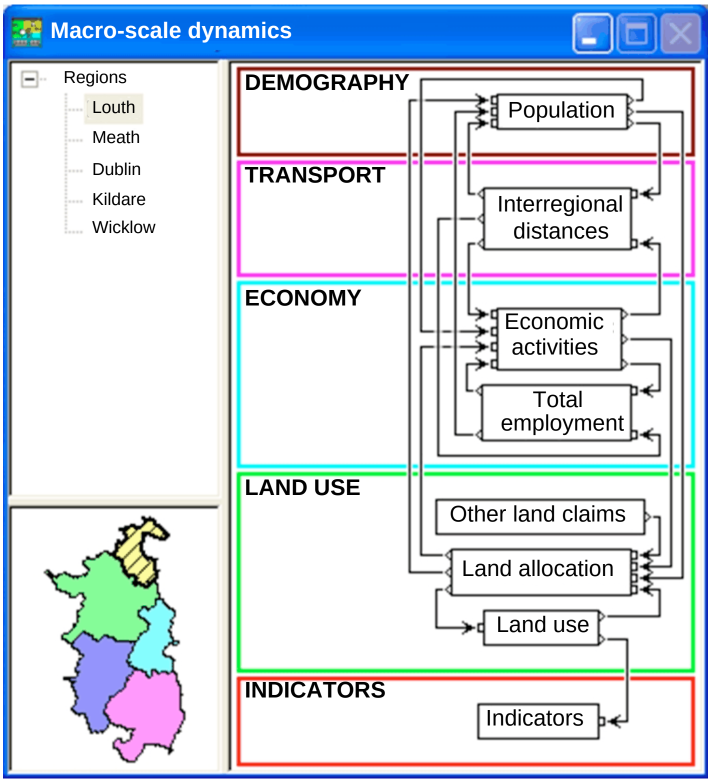

Figure 4.1. System diagram showing macro-scale dynamics in MOLAND.

feasible for any of the themes by the UEP team (see Section 8.2). Instead, thematic data were used at a number of stages in the set-up and use of MOLAND as a decision-support tool. Nonetheless, these were very important steps in moving towards a fully integrated framework and establishing a baseline for future development (as discussed in Section 8.2) These stages included:

- Input data for populating MOLAND for calibration and validation (described in Section 3.1);
- Development of scenarios and storylines (see Sections 4.1, 5.1 and 5.2);
- Input data for quantification of qualitative storylines (see Section 4.1 (planning scenarios – urban sprawl, transport infrastructure/land-use interaction scenarios, regional planning strategies (SEA[9] process)));
- Secondary data for contributing to analyses using MOLAND scenario outputs (see Sections 6.2.3 and 6.2.4); and
- Informing the selection of indicators and associated analysis in the comparison of scenario outputs.

In the least integrated themes, the approach involved using MOLAND scenario outputs and overlaying these with spatially explicit thematic data (e.g. air quality, climate change, biodiversity). In the case of urban sprawl and urban transport, integration is almost complete in that MOLAND inherently simulates future land-use patterns (sprawling or otherwise) and integrates transport and land-use interactions. In the case of transport, however, the limitations of the initial MOLAND model (see Section 8.2) were addressed through the development of a specialised transport model that was integrated with the land-use model (by RIKS b.v.). As the updated version of MOLAND with the extended transport model was not made available within the time frame of this research, the work of populating the transport model with relevant data and associated calibration has been preliminary (for details, see Shahumyan et al., 2010).

9. SEA, Strategic Environmental Assessment.

4.1 Scenarios

The management of resources is complex and demanding, particularly where multiple actors and agents are involved. It often involves difficult decisions that have to be made based on scant evidence. The management of the environment and, in particular, land resources can be greatly assisted through the ability to see the likely implications of policies and decisions into the future. The use of scenarios or storylines is a powerful means of exploring possible futures and helping to define common or shared visions of the future. It also assists in the analysis of the likely implications of different decisions. Spatial decision-support systems are designed specifically to provide an inherently spatial representation of the future. Thus they are particularly helpful in the domains of land use and environment, which are also inherently spatial.

Dynamic urban land-use models such as MOLAND seek to provide the capacity to simulate alternative scenarios of urban development into the future. Recent models explicitly reject the principle of attempting to produce a single absolute projection of the future in favour of numerous alternative visions. The aims of scenario development through land-use modelling are, therefore, to promote structured discussion and awareness among stakeholders rather than to provide predictions of future development patterns and trends (Barredo et al., 2005).

Within the UEP, scenarios were implemented by the core modelling team, with key input from the thematic groups where necessary. Initially, simple alternative scenarios were tested where only one or two elements were changed in each scenario.

4.1.1 Demographic and economic scenarios

Three population scenarios (WWT1, WWT2 and WWT3) based on the CSO's recent Regional Population Projections for 2011–2026 (CSO, 2008) were used, and are summarised in Table 4.1. The projections combine a continuing decline in international migration with constant fertility and a return to the traditional pattern of internal migration by 2016 (M2F1 Traditional in CSO 2008). The CSO projection was chosen as the medium growth scenario with low and high growth scenarios computed by using

Table 4.1. Description and coded name of scenarios developed and implemented in MOLAND.

Short name	Brief description	Coded name	Socio-economic variables		Scenario specified adjustment		
			Population	Jobs	Zoning	Suitability	Transport
Wastewater Treatment Capacity Study	Only the population inputs were modified in this scenario. Based on the Central Statistics Office's regional population projection (CSO, 2008)	WWT1	2,170,173	1,302,221	No	No	No
		WWT2	2,553,148		No	No	No
		WWT3	2,936,123		No	No	No
Strategic Environmental Assessment	Baseline/Continued Trends Scenario: exploring the consequences of continuing the current settlement patterns, whereby actual settlement patterns are somewhat at odds with Regional Planning Guideline (RPG) policy	SEA1	2,362,499	1,204,981	No	No	Yes
	Finger Expansion of Metropolitan Footprint Scenario (SEA2): Development is focused within the Metropolitan Footprint (MF) of Dublin city, with minimal growth in other areas and expansion of the MF along key transport corridors.	SEA2			Yes	Yes	Yes
	Consolidation of Key Towns and the City Scenario (SEA3): Explores a settlement pattern similar to that proposed in the original Strategic Planning Guidelines published in 1999 (DRA & MERA, 1999). This settlement pattern requires development to be consolidated within the existing MF and a small number of development centres along major transport routes. The MF is not expanded along these routes.	SEA3			Yes	Yes	Yes
	Managed Dispersal Scenario (SEA4): Dispersal of development is managed by focusing new growth within the existing MF and several development centres across the region. Strictly enforced strategic green belts were used to prevent the merger of towns and ensure that corridors remained between urban and rural natural areas.	SEA4			Yes	Yes	Yes
Strategic Planning Policy	Compact City – future growth directed to the Dublin Metropolitan Area as defined in the Regional Planning Guidelines (DRA & MERA, 1999).	SPP1	2,305,510	871,547	Yes	No	No
	Dispersed City – continuation of trends seen 1990–2006 with limited planning control or regulation.	SPP2	2,305,510	871,547	Yes	No	No

Table 4.1 ***contd***

Short name	Brief description	Coded name	Socio-economic variables		Scenario specified adjustment		
			Population	Jobs	Zoning	Suitability	Transport
Transport Infrastructure Investment	Modest population increase. No new transport projects after 2006. Modification to zoning layers to focus on areas adjacent to transport hubs.	TII1	2,090,746	871,547	Yes	No	No
	Modest population increase. Full implementation of Transport 21[a] by 2026. Modification to zoning layers to focus on areas adjacent to transport hubs.	TII2	2,090,746	871,547	Yes	No	Yes
Air Quality	High, medium and low population growth. Jobs unchanged from 2006 levels. Modest population increase. No new transport projects after 2006. Modification to zoning layers to focus on areas adjacent to transport hubs. Modest population increase. Full implementation of Transport 21 by 2026. Modification to zoning layers to focus on areas adjacent to transport hubs.	AQ1H	262,0450	871,547	No	No	No
		AQ1M	2,305,510	871,547	No	No	No
		AQ1L	2,017,520	871,547	No	No	No

[a]Transport 21 is a capital investment framework under the National Development Plan. It consists of investment in infrastructure projects nationally and in the Greater Dublin Area http://www.transport21.ie/What_Is_Transport_21/Transport_21/What_is_Transport_21.html

an adjustment of 15% downwards and upwards, respectively. MOLAND was used to simulate population growth by county. Activities in MOLAND (industry, commerce and services) were estimated based on the CSO Census 2002 and the 2006 Place of Work (CSO, 2002, 2006) data sets. The same projections were used in all three scenarios.

The patterns of land uses in 2026 under the three scenarios are broadly similar. A consolidation of residential land uses in the core city region is observed in each case, as well as a significant shift from arable and pastoral land use to residential land uses along the western edge of the city core. Existing agglomerations, such as Drogheda and Dundalk (Louth), Navan (Meath), Bray (Dublin) and Wicklow town (Wicklow), show an increase in residential and commercial activity in all three scenarios.

The settlement trends for urban land uses in each scenario were then compared with the projected catchment areas for planned wastewater treatment facilities to give an indication of whether the sites and capacities planned would be sufficient to serve the projected populations. For further contextual information, see Section 5.2.

4.1.2 *Regional spatial planning strategies*

Initial scenarios were produced simulating the impact of policies aimed at concentrating future growth close to the existing built-up area of the city. This analysis resulted in the development of two contrasting scenarios illustrating Compact City (SPP1, see Table 4.1) and Dispersed Development (SPP2, see Table 4.1) settlement patterns (see Section 4.3.5). The Dispersed Development scenario broadly assumed a continuation of current trends but with no constraining planning control or land-use regulation. Under the Compact City scenario, all future growth (up to 2026) was directed to the Dublin MA, as defined by the *Regional Planning Guidelines for the Greater Dublin Area 2010–2022* (http://www.rpg.ie/). The two scenarios were deliberately developed to represent extreme cases and to test the capacity of the model to provide structurally different scenario outputs that would potentially challenge the conventional wisdom about the future (see Barredo et al., 2005). Full details of the process are published in Walsh and Twumasi (2008). These scenarios show that under The Dispersed Development scenario, future development is widely dispersed throughout the region, predominantly in small clusters. In the case of 'residential discontinuous urban fabric', increases are strongly concentrated in Fingal and North Kildare, with some evidence of densification in Dublin city areas. In the case of 'residential sparse discontinuous urban fabric', the new developments are very dispersed but mostly proximate to existing settlements. In the Compact City scenario, all types of new development are heavily concentrated within the MA.

4.1.3 *Investing in transport infrastructure*

To compare the effects of the implementation of significant transport investment on settlement patterns, two scenarios were implemented (TII1 and TII2, see Table 4.1). No specific zoning criteria were used in these scenarios and the population and economic projections utilised were based on an assumed population increase of 500,000 by 2026.

The first scenario shows the likely development patterns in the case of no change in transport infrastructure in the region by 2026. The second shows the effect of implementation of the Transport 21 (T21) strategy, in full, by 2026. The study then looks at the impacts in more localised areas in the region, namely at key transfer interchanges – within 2 km of motorway junctions and within 1 km of train stations.

In the second two scenarios, the impact of a proposed new motorway route on land-use patterns is examined. Again, the population and economic projections are held constant in each scenario. Then, the impact of the implementation of the new route on land-use patterns is analysed. Additionally, the zoning layer is modified to promote commercial development at interchanges.

4.1.4 *Regional planning policy*

More complex scenarios were developed in collaboration with the Dublin and Mid-East Regional Planning Authorities (DRA & MERA) relating to potential strategies for the future of the region. In total, six scenarios were produced, which were based on qualitative descriptions of possible futures for the region (SEA1, SEA2, SEA3 and SEA4 and two other scenarios that are variations of SEA1 and SEA2).

These scenarios are described in detail in Section 5.3 and in Brennan et al. (2009b). In these scenarios, multiple variables were changed to provide complex scenarios of potential futures. In summary, the key variables amended in these scenarios were:

- Population projection and associated economic projections (same projection used in each of the six scenarios);
- Zoning (green infrastructure) – each scenario required different green infrastructure zoning layers; also, some scenarios required that residential land uses be directed into specific areas (metropolitan areas, key towns, etc.), which were implemented as suitability layers in the model; and
- Transport infrastructure – different phasing of infrastructure components was included in each scenario.

The scenarios described above (and in detail elsewhere in the report and in other published works) illustrate the flexibility and robustness of the MOLAND framework. Indeed, whilst adapting the model for the region is time consuming and intensive (e.g. data preparation, calibration, etc.), the application of the framework to explore a range of scenarios is straightforward and the ability to apply a range of analytical methods to the outputs of the model makes it extremely powerful, not least the use of the tool as a communication and visualisation tool.

4.2 Analysis Using Outputs of MOLAND

Where thematic data could not be directly integrated into MOLAND, an alternative approach was utilised. The outputs from MOLAND scenarios (as described in general above) were overlaid with thematic data to provide further levels of analytical capacity using a GIS. Examples include the assessment of household energy demand for space heating, which used a combination of the scenarios of compact and dispersed urban forms, and which showed that about 16% of energy use for space heating and related carbon dioxide emissions could be decreased by a compact city pattern compared with a dispersed city scenario.

In the case of the air quality analysis, a simple projection of vehicle fleets was created using a logarithmic extrapolation of current vehicle ownership trends. Using the COPERT[10] emissions factors, emissions levels were projected for each of the high, medium and low population growth scenarios, assuming that existing engine technologies would remain dominant in the future. This projection showed an increase of 2 million tonnes of carbon dioxide emissions from private cars by 2026 under the high population growth scenario, from a base of 2.2 million tonnes and a decrease in emissions of –0.1 million tonnes by 2026 in the low growth scenario.

4.3 Themes

4.3.1 Air quality

A large number of sources contribute to the degradation of air quality in the urban environment (Reynolds and Broderick, 2000). These sources include power generation stations burning fossil fuels close to urban centres, construction work within the city, commercial or residential heating, or power systems based on a combustion process, or vehicular combustion systems in automotive applications. These vehicular emissions are believed to be one of the most important contributors to poor air quality in any city (North et al., 2005; Caplain et al., 2006; Tzirakis et al., 2006) and include oxides of nitrogen, carbon monoxide, unburned or partially oxidised hydrocarbon and particulate matter.

The combination of narrow streets (Berkowicz et al., 2006), high traffic volumes and large populations (Williams et al., 2007) living and working in close proximity to major roads (Roorda-Knape et al., 1998) means that both local and national authorities must be proactive in assessing the level of pollutant emissions and employing measures that reduce the negative impacts on human health.

The goal of the Air Quality Work Package was to assess the quantity of pollutant emissions emitted from road vehicles within the urban area of the GDR. This information was to be used to assess the exposure levels and health risks to humans living and working in

10. COPERT, Computer Programme to Calculate Emissions from Road Transport – see http://lat.eng.auth.gr/copert/.

these areas. In order to do this, a 'local' approach was taken, which looks at the activity of individual vehicles, assesses pollutant matter output and aggregates these values for local fleets. The vast majority of vehicles within a given area of the city moves en masse at similar speeds and consequently relatively similar engine operating conditions. Hence, the pollutant output for a given vehicle class can be determined and combined with other classes to describe the total output levels.

The focus of the work was on private cars, since these contribute enormously to local pollutant levels in the GDR. Regulations restricting the use of heavy goods vehicles (HGVs) within the city mean that the relative contributions of these vehicle classes are relatively low. Outside these urban areas, National Road Authority (NRA) data suggest that HGVs make up about 10% of vehicle flows on national routes and motorways. The open, exposed nature of these roads, combined with the scarcity of population in these areas, means that such extra pollutants are not of huge concern.

The first step in the process was to examine the cause and effect relationship between vehicle operation and pollutant formation. As described above, a significant literature survey was compiled (Casey et al., 2007). Having established how pollutant species are formed, it was necessary to describe what steps are in place to limit emissions and hence reduce negative health impacts on humans.

Since pollutant emissions are very much dependent on vehicular activity (Joumard et al., 2000; Andre et al., 2006), it was necessary to devise a method for the accurate determination of these activities. Standard models are based very much on average speed (Andre, 1996) but the derived emissions factors have been shown to be less than ideal for use at local levels (Berkowicz et al., 2006). That said, the vast majority of emissions estimation schemes are based on vehicle speed.

Assessment of real-world kinematics was deemed to be an adequate solution to this problem – using On-Board Diagnostic (OBD) kits, fitted to a number of different test vehicles, including a Euro 3 Petrol Honda Civic, a Euro 2 Petrol Toyota Yaris, a Euro 4 Petrol Volkswagen Golf and a Euro 4 Diesel Citroen Dispatch. In all cases, the OBD system extracted each of vehicle speed for kinematic analysis, engine load and engine speed for power analysis and coolant temperature to help in the description of cold start conditions.

The combination of the OBD data collection and the synchronous global position information means that the specific kinematics can be related to both position and traffic situations. Thus, rather than have a single description of vehicle speed, based on national averages, a daily distribution of speed, based on real traffic flows is now possible (Casey et al., 2009). This was identified in other work as a significant flaw with current estimation systems (Andre et al., 2005) and is lacking in many of the national models for the determination of emissions outputs. Thus, a significantly more detailed description of diurnal pollutant emissions is possible, provided suitable emissions factors are established.

The simple speed-based models do not adequately describe emissions from vehicles. As part of this work, a more detailed examination of kinematic-based emissions factors, as prepared by ARTEMIS[11], has been carried out. This allows for detailed local descriptions, on a vehicle by vehicle basis, of pollutant output based on actual activity. Aggregation of these individual values to local street 'fleets' allows for local pollutant loads to be determined on a mass basis. Comparison of local emission concentrations levels, as reported by the EPA (O'Leary, 2009), means that a correlation between vehicle numbers and pollutant output can be made with local emissions concentration levels.

A simple study, based on projected populations from yearly MOLAND simulations for high, medium and low population growth, showed that a link could be made between an emissions estimate scheme and land-use modelling. In this particular study[12], a projection of vehicle fleets was created using a logarithmic extrapolation of current vehicle ownership trends. (AQ1, AQ2, AQ3 – see Table 4.1). Using the COPERT

11. ARTEMIS, Assessment and Reliability of Transport Emissions Models and Inventory Systems.
12. This work was presented at the Conference of Irish Geographers in Liverpool, March 2008.

emissions factors, emissions levels were projected for each of the high, medium and low population growth scenarios, assuming that existing engine technologies would be dominant in the future.

Results showed that even without alterations to the fleet, significant savings on pollutant emissions could be made. However, the usefulness of these results is hindered by the number of flaws in this approach.

A more robust MOLAND model now exists that integrates a classic four-step transport model. This will negate the need to make estimates of vehicle fleets based on populations. The relative number of jobs to population will determine the number of trips and, hence, the requirements for both public and private transport. A more robust emissions estimation scheme in ARTEMIS should result in more accurate results.

Estimations of pollutant emissions were based on averaged and estimated vehicle speeds. Again, the MOLAND transport model will provide this information and reduce the need for estimates. No significant attention was paid to distances travelled by vehicle types within this study. New information provided through the National Car Test Service (NCTS) will allow for better determinations of distances. Thus, as outlined previously, the new system will provide detailed information about numbers of trips, speeds and distances, all of which are needed to adequately describe emissions.

However, the system did show that results of this nature are of significant benefit to people looking to examine futures. Many people suspect that larger vehicles are more damaging to the environment. However, the relative number of large cars and the proposed distances travelled by larger vehicles means that very often they operate in a reasonable way. A large number of older (pre-Euro 2) cars travelling short distances in urban conditions means that potentially these vehicles are more damaging. The new data provided through this research allow for a more scientifically robust determination of this phenomenon.

4.3.2 *Urban transport*

This theme looked at how changes in transport infrastructure affect the urban form in the study area. In particular, the research looked at what types of urban form are desirable and which may promote sustainable living and travel. The research examines how residential densities, employment densities and different mixtures of housing and employment impact upon transport needs and how this may reduce energy consumption and emissions. Should we allow dispersed cities to continue to develop or do we need to encourage more densely populated cities to bring about more sustainable living? How should we develop our transport infrastructure to promote the most sustainable type of urban form?

In this study, predicted future land-use maps were constructed for different scenarios (TII1 and TII2 – see Table 4.1). Development of new transportation infrastructure and zoning policy was examined and the potential impacts of these developments were shown using both statistical evidence and through the use of GIS software. The discussion will focus on two factors:

1. The performance of MOLAND and the improvements needed; and

2. The issues relating to how Dublin is expected to develop.

The use of MOLAND to examine the potential impacts of infrastructure changes on land use has proven useful. The study has shown that the impacts of new transportation developments can be easily represented using both the model's outputs and the spatial development indicator Transport Energy Consumption (TEC), which was developed using GIS. However, the study has also shown that the model uses an overly simplistic method to represent the relationship between transportation and land use. The relationship between transport and land use in MOLAND is implemented using accessibility parameters. These parameters are made up of an importance factor and a distance decaying factor to represent the relationship of each type of land use to each mode of transport. There is no documentary description of how the figures, which represent the weighting factors, were derived, so, in this study, the figures for the weighting factors were provided with the model. These figures are for the Netherlands, hence there is currently no way of telling how accurate they are in application in the GDR.

To improve the model's capability in the area of land use and transportation, it is recommended that it is integrated with a transport model. The necessary weighting factors could then be derived from this model, which would immediately improve the robustness of the model for the Irish context. This was carried out in the most recent version of MOLAND, where a transport model is included. However, it is still being tested and, therefore, the results presented in this report are obtained from the MOLAND version without the integrated transport model. The model developers, champions (JRC, Ispra) and researchers working with MOLAND recognised the limitations of MOLAND when transport is only modelled via the 'accessibility' term. A decision with regard to running the pilot testing of this new addition to the model was made in favour of application in the GDR, given the availability of specific data (POWCAR data set) and the expertise of the UEP team in regard to transport modelling.

Currently, the model allows the impact of new infrastructure on urban form to be examined but it is not possible to examine how this impacts upon modal share (public transport use versus private vehicle use). A major objective of the project under way in the Urban Institute is to examine how the planned infrastructure developments in Dublin will change residential density and how this, in turn, will change travel patterns in Dublin. MOLAND has shown that the construction of new light rail lines into the suburbs of Dublin will result in more high-density development along the transport corridors, as would be expected. However, there is no way, using MOLAND, to examine how this translates into a change in modal share.

Conventional wisdom would predict that there will be more public transport use and less car use. However, not all researchers agree nor do all the findings from other projects support the hypothesis that a denser city is necessarily a more sustainable one. Indeed, in Dublin, MOLAND shows that development will happen along the suburban light rail lines that are planned. Some of these lines, however, are quite long and high-density development along the length of very long suburban rail lines does not necessarily result in a compact city. Instead, Dublin may continue to develop as a dispersed city with homes situated far from the city centre, but with more pockets of high-density housing dispersed throughout this area. It is worth noting that development of residential areas has already started adjacent metro and Luas lines that are not yet built in the anticipation of the construction of these lines. This has actually led to an increase in car use as high-density developments are located on corridors that will eventually have public transport infrastructure but which at present are connected to the city centre only by road and private car. Will these residents, once used to using their cars, make the switch to public transport when the lines are completed in 3–8 years' time?

Integration of MOLAND with a transport model is currently taking place to allow the model to take account of other factors such as congestion, road pricing, and the individual attributes of each transport mode such as speed and capacity. It is intended that this model will be able to determine the type of modal share that Dublin's development will bring about. This extra functionality would allow the user to analyse the relationship between transport and urban form at a much greater level of detail, thus vastly improving the capability of MOLAND.

Analysis of the POWCAR data set (CSO, 2006) identifies that there are substantial variations in TEC in the commute to work with regard to individuals' socio-economic characteristics. The main characteristics that reveal this variation are gender, age, socio-economic group, number of residents in a household, number of resident workers in a household, and car availability. In terms of urban form factors, the main factors that establish a link between TEC and urban form are residential population density, employment density, distance from Dublin's Central Business District (CBD), proximity to railway stations and the jobs–housing balance at the electoral division (ED) scale. The regression analysis suggests that socio-economic characteristics explain more of the variation in TEC than do land-use characteristics. Socio-economic characteristics explain just under a half of the variation in TEC per person, whereas urban form characteristics often only explain 27% of the variation in TEC per person. The results show some similarities with research by Gordon and Richardson (1997), who report that around one-third of the variation in per capita TEC is attributable to land-use characteristics and another third of the variation in per capita TEC is attributable to socio-economic factors. There is clear evidence of a link between the distance between home and the urban centre and TEC per person. The research confirms the findings of Hickman and Banister (2007), who report a link between the distance from an urban centre and transport energy per person.

Clearly, the extent to which urban form might influence travel patterns may be lower than other studies have previously indicated (where they have not taken socio-economic characteristics into account). However, this does not mean that land use does not have an important role to play in influencing travel patterns or cannot contribute to more sustainable travel patterns. The results of the study indicate that urban form characteristics, such as density, mixed-use development, proximity to public transport and distance from urban centres, have a role to play in promoting more sustainable development. Furthermore, the findings in this study would support the theory that higher-density land use is inherently more energy efficient.

Developments in public transport (proximity to rail) and higher densities enable a more frequent and higher-occupancy public transport, with lower emissions per passenger. Mixed-use developments, better housing location and building design, and support for local services can reduce travel distances to employment, education, health services, and shops and therefore reduce TEC. These developments, in turn, encourage a shift in the mode of transport, and improve the safety and attractiveness of urban areas.

4.3.3 Biodiversity

The work relating to biodiversity fell into two main strands. The first was concerned with understanding better the quality and quantity of biodiversity in the study region. The second was concerned with exploring the usefulness of MOLAND in addressing key biodiversity concerns in the planning context. In both strands, some constraints were identified with regard to the availability of suitable data (i.e. gaps in extents and species for which data were recorded) and the temporal and spatial scales at which MOLAND in its current implementation can be applied and to what extent it can be utilised to assess strategic spatial planning options.

Biodiversity is defined as the variety of genes, organisms and ecosystems (UNEP, 1992). One of the primary difficulties with the conservation of biodiversity is that the initial quality of existing land with regard to biodiversity is often unknown. Biodiversity data have to be collated from a large variety of data sources and the use of these data sets often requires expert knowledge. In addition, the inclusion of specific spatial references for the data (i.e. geocoding) is frequently not available. If this information were included, collation and analysis of the data would be more straightforward. For the GDR, this work has only been partially completed and this research has assembled some of the data sets available. Some attempts were made to automatically georeference the data points using a combination of the Geodirectory (An Post) and a scripting process in a Microsoft Access database. However, the spatial and temporal coverage of the data sets was found to be so heterogeneous both spatially and temporally as to be rendered insufficient to work satisfactorily within the MOLAND context. In the longer term, some of these data sets may become available to planners through the National Biodiversity Data Centre[13]. However, even if the accessibility of biodiversity data is increased, this should not mask the need for current, site-specific information to effectively protect biodiversity. The best way to protect biodiversity in an urban environment is therefore an indirect way: the strengthening of the tools available in the development process for specific site evaluations.

High biodiversity of both plants and animals has been observed in urban contexts (Hayden and Bolger, 1996). Several studies of the biodiversity of Dublin have been conducted previously (e.g. Dunne, 2002; Kingston et al., 2003). These studies found that Dublin is very rich in biodiversity compared with surrounding areas and that the parks harbour important remnants of semi-natural vegetation and habitat for rare species (Kingston et al., 2003). While these studies were addressing patterns of biodiversity in Dublin, their spatial coverage of these studies is insufficient for

13. National Biodiversity Data Centre (http://www.biodiversityireland.ie/).

planning purposes. Generally, the plants and animals occurring at a certain place have selected the place because of the characteristics of the biotic or abiotic environment. For example, it was found that the presence of waterbodies and the size of gardens are related to the diversity of bird species (Chamberlain et al., 2007). Similar to these studies, this work package focused on describing the habitat available in the wider Dublin region, based on remote sensing data.

In order to test if these descriptions of habitat are meaningful in terms of biodiversity, the distribution of species was compared to these habitat descriptions. If good correlations were found this could potentially be helpful for planning of biodiversity conservation in an urban context. The latter will become increasingly important since urban biodiversity may be particularly vulnerable to climate change (Wilby and Perry, 2006).

This work package addressed the availability of biodiversity data for planners, as well as the amount and spatial configuration of urban green space. Even though the amount of urban green space in the Dublin region is comparable with that in other European cities (Baycan-Levent and Nijjkamp, 2009), the active protection and further expansion of this green space is highly recommended as a 'de-greening' of the Dublin city centre has been observed over the last decades (Brennan et al., 2009a). The MOLAND model seems to be a particularly useful tool in this context, as simplistic planning guidelines along the lines of compact versus dispersed city are not sufficient for planning purposes. In terms of finding scenarios that optimise between different ecosystem services, it is essential to work in a spatially explicit framework, which is provided by MOLAND. The usefulness of this model for strategic planning has already been recognised by the Regional Planning Authority (personal communication). In addition to planning for green space in an urban context, it is important to take into consideration the quality of the land that is developed.

This work package has gathered some of the biodiversity data available for the Dublin region, but further work is required to make these data available to planners, for example through the National Biodiversity Data Centre. Of prime importance in the planning process will also be the case-by-case evaluation of the planned land-use conversions in terms of their impacts on existing biodiversity (Convery et al., 2008), but possibly also in terms of future food production and other provisioning services (Thrupp, 1997; Rosegrant and Cline, 2003; Toledo and Burlingame, 2006). The MOLAND land-cover data have been found to be insufficient to provide enough detail on these existing values of land and further work is required to integrate aspects into the model that could be useful in this context. Therefore, while the MOLAND model is useful to assess general plans for green space, other considerations for land use, such as changes in biodiversity and the availability of agricultural land, are not incorporated well into the model and further work needs to be done on those aspects.

4.3.4 Climate change

The work carried out under the climate change theme was concerned with investigating the impact of climate change on household energy demand for space heating and cooling. The means for deriving the energy demand from the residential sector incorporated factors relating to urban form and population and were, therefore, readily transferable for integration with the MOLAND framework. This section describes the work that was carried out and what the likely implications of different regional planning strategies would be on energy demand from the residential sector by applying the MOLAND model and combining its outputs with theme-specific derived data.

The majority of the world's energy consumption takes place in cities or due to the transport of goods between cities. This proportion is set to grow as UN forecasts project that three in five people in the world will live in cities by 2030. This global trend toward increased urbanisation has the consequence that climate change impacts in most countries will mainly affect urban populations, not rural or traditional settlements. Climate change and urban growth are, therefore, inextricably linked, and general issues of sustainability require an urban focus that is shaping carbon emissions policy (Wilbanks and Lankao, 2007).

In addition, rising temperatures and enhanced 'heat island' effects may alter the spatial and temporal patterns of energy consumption of cities. The World Wildlife Fund survey of 16 European capitals, published in mid-August 2005, indicated that Dublin's average summer temperature has risen by 0.7°C since 1970. Though this is less than some comparable capitals elsewhere in Europe, it is still well above the Irish national average (Sweeney et al., 2002).

Household energy demand for space heating has been derived for different dwellings based on a thermal balance model (Liu and Sweeney, 2009). Consequently, the spatial distribution of household space heating energy demand in the GDR was derived based on the GDR's housing profile. The heating energy demands for categorised households were calculated by dwelling age, size and floor areas using the thermal model. The heating energy demands are, therefore, estimated at ED level for the GDR. Heating energy demand for different residential settlement patterns specified by the MOLAND model was also statistically derived and analysed.

The estimation of annual household travel energy use and carbon dioxide emissions was derived in KWh/year for residents in the study regions as functions of variables, such as average travel distance, travel mode and number of cars. The travel mode, distance and demographics were located and mapped onto the GIS database. The relationship between travel energy consumption and urban form was estimated based on this database. The average travel distance and travel pattern were derived for each of the four urban form types.

This study showed that there are strong relationships between urban form and household energy use for space heating and daily travel. Two important characteristics of urban form could significantly affect household energy consumption both for space heating and daily travel. One of those is urban density. Another is the distance between residential settlements and the MA.

Based on the 2006 census data, household energy consumption for space heating and daily travel was estimated. Relationships between urban forms and household energy consumption were developed for the case study region. Statistical analysis showed that high urban density could reduce both household energy demand and carbon dioxide emissions from space heating and daily travel. Compared with sparse urban residential settlements, dense urban residential settlements could reduce household energy use for space heating by 22%, and by about 70% of household energy consumption for daily travel. The Compact City and Dispersed City scenarios, simulated by the MOLAND model, were used to investigate the impact of urban land use on household energy consumption (SPP1, SPP2 – see Table 4.1). Based on the derived relationship between energy consumption and urban form, household energy uses for space heating and daily travel were estimated for the case study region. Climate change was also considered in the assessment of household energy demand for space heating. Results indicated that about 16% of energy use for space heating and related carbon dioxide emissions could be decreased by the Compact City pattern compared with the Dispersed City scenario. For both scenarios, increasing temperature is likely to reduce heating energy demand per household by the 2030s by 11–15% compared with that in 2006. The household daily travel carbon dioxide emissions would be cut by 18% for the Compact City scenario compared with the Dispersed City scenario.

4.3.5 Urban sprawl

The MOLAND land-cover data sets for 1990, 2000 and 2006 constituted a principal source of data for this research theme. The data were used to examine spatial patterns and trends of urban expansion over time, using GIS techniques. Further analysis explored the conversion history of particular land-use classes. This conversion history analysis made it possible to assess, for example, the level of new residential development on brownfield sites (industrial, commercial or abandoned sites). The analysis was conducted primarily through the use of ArcGIS and Microsoft Access software. In addition, statistics were produced analysing county-level variation in land-use distribution and change. A specific focus on residential land use explored the relationship between expansion of residential land cover and growth in the number of households over the 1990/1991–2006 period. The results of this analysis of land-use change were set in the context of current academic and policy debates on sustainable urban development, urban–rural relations and polycentric city regions and were published in *Irish Geography* (McInerney and Walsh, 2009).

The principal results and outputs of this research have not provided a direct thematic input to the MOLAND model. Nevertheless, associated research has contributed significantly to the scenario-generation process. Initial scenarios were produced simulating the impact of policies aimed at concentrating future growth close to the existing built-up area of the city. This analysis resulted in the development of two contrasting scenarios illustrating Compact City and Dispersed Development settlement patterns (Figs 4.2 and 4.3).

The Dispersed Development scenario (SPP2) broadly assumed a continuation of current trends but with no constraining planning control or land-use regulation. Under the Compact City (SPP1) scenario all future growth (up to 2026) was directed to the Dublin MA, as defined by the *Regional Planning Guidelines for the Greater Dublin Area 2010–2022*. The two scenarios were deliberately developed to represent extreme cases and to test the capacity of the model to provide structurally different scenario outputs that would

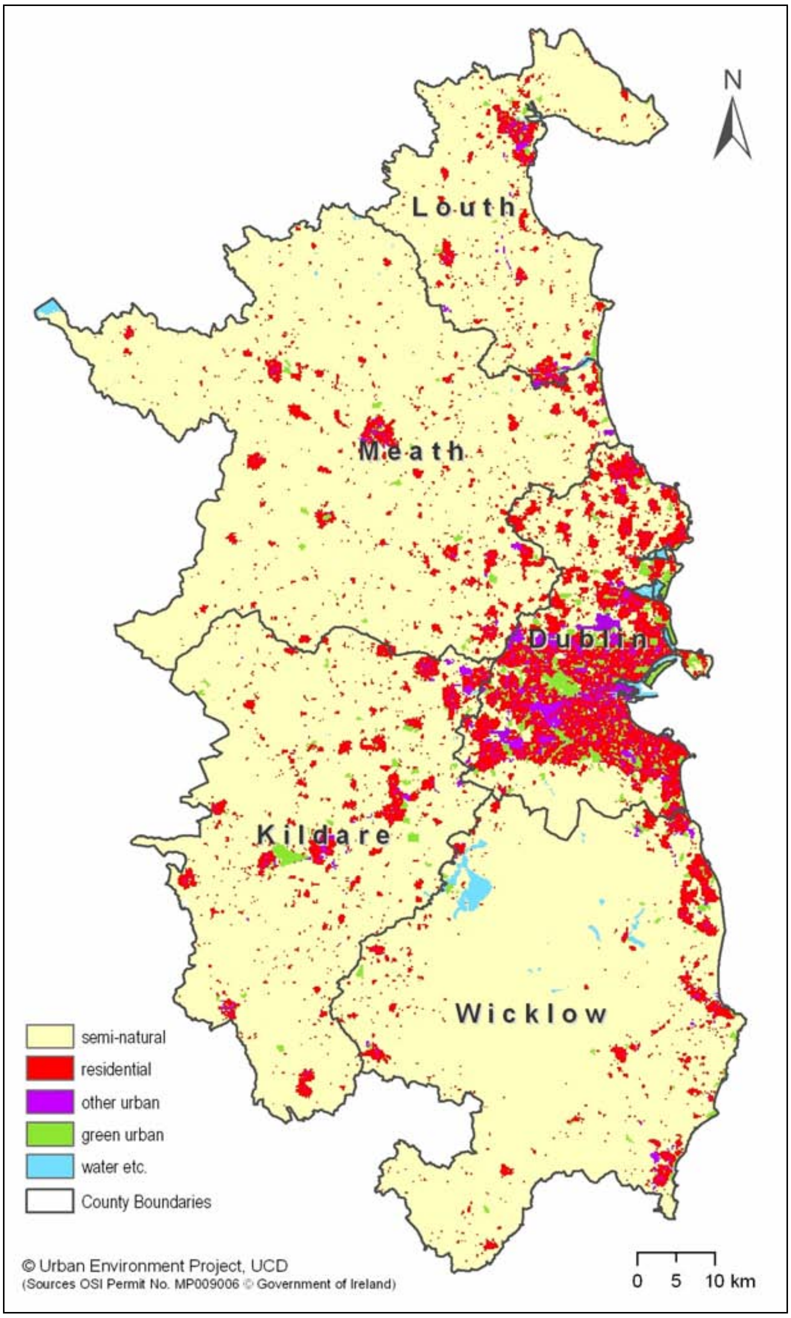

Figure 4.2. Dispersed Development 2026 scenario output.

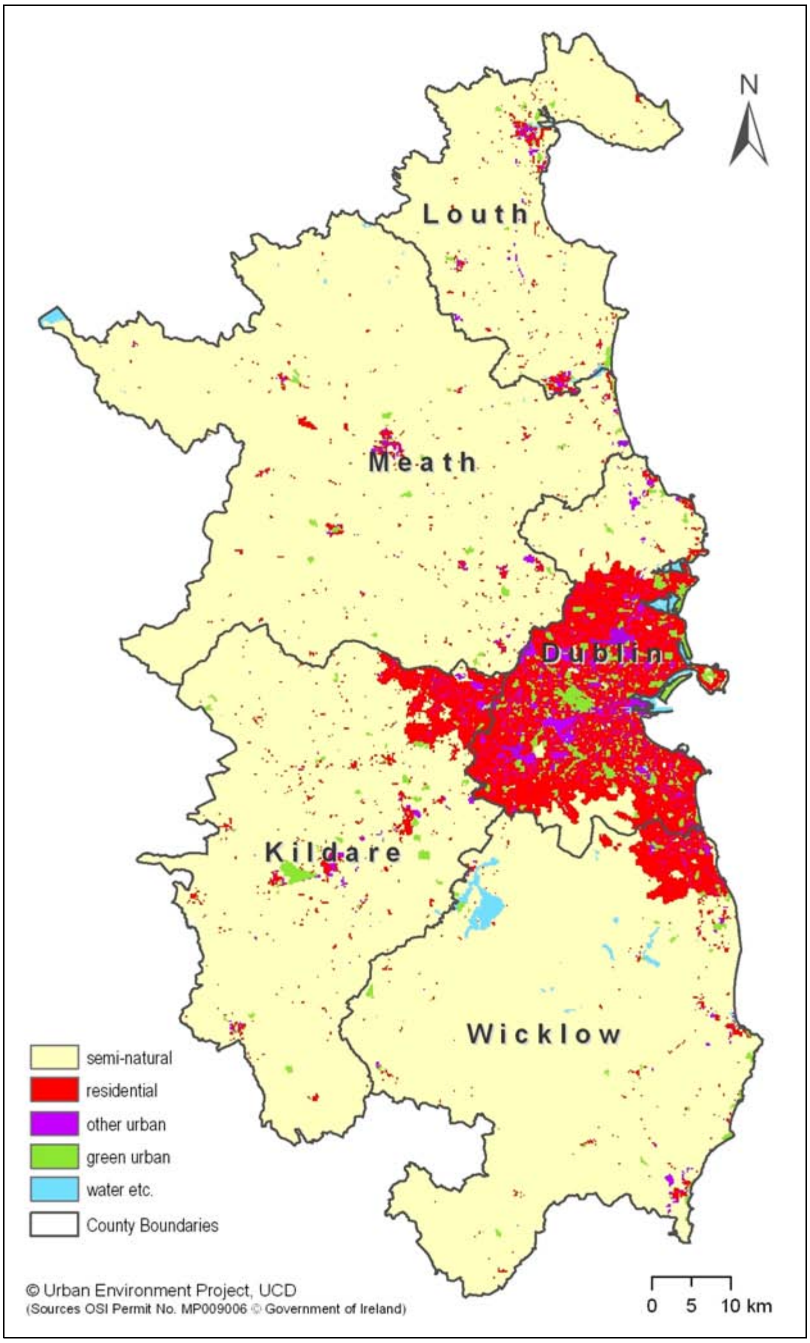

Figure 4.3. Compact City 2026 scenario output.

potentially challenge the conventional wisdom about the future (see Barredo et al., 2005). The results of this exploratory scenario-generation process were published as a UCD Urban Institute Ireland Working Paper (Walsh and Twumasi, 2008).

The spatial distribution of age profile types was subsequently mapped in ArcGIS. Spatial patterns of migration and residential mobility were estimated through an age cohort analysis of 1996 and 2006 Census of Population data sets. The results of this analysis were published in *Progress in Irish Urban Studies* (Walsh, 2009). The analyses showed strong evidence of the age-selective nature of patterns of settlement change and residential mobility within the GDA. Areas of recent rapid residential development located primarily in peri-urban areas outside of the metropolitan core of the GDA are characterised by young age profiles with a high proportion of young children, while central city areas appear disproportionately to attract young adults without children. Older suburban areas and more peripheral rural areas are characterised by ageing profiles and in some cases net out-migration.

A further aspect of the work conducted under the urban sprawl research theme concerned the analysis of office location patterns and their significance in the peripheral expansion of the city. This analysis concerned the period 1960–2008 and included a review of existing literature and an analysis of data on office development, held by the Centre for Urban and Regional Studies at Trinity College Dublin. This analysis was published as a UCD Urban Institute Ireland Working Paper (Attuyer et al., 2009). The paper identified the critical role that the suburbanisation of services sector employment played in the later dispersed residential development pattern.

5 MOLAND Applications

5.1 Providing an Enhanced Evidence Base for Irish Planning

The planning system in Ireland attempts to provide, in the interests of the common good, for proper planning and sustainable development (Planning and Development Act, 2000). The basis of the governance system in Ireland as it applies to local government and planning is that the functions of a local authority/ planning authority are separated into reserved policy functions carried out by elected councillors and executive or management functions carried out by the City or County Manager. Elected politicians have responsibility for the adoption of the Development Plan, including zonings for particular land uses, and the Manager (advised by appointed staff) makes individual planning decisions based upon the Development Plan as adopted. The public have a role in consultations before the Plan is adopted and can object/comment or make appeals on development proposals and applications. Local politicians carry out the important reserved function of adopting the Development Plan incorporating land-use zonings, which indicate the specific or primary land use that will be permitted for various lands, and can make material contraventions to the existing plan. The Development Plan once adopted is in written and map forms and is effectively the instrument by which regulation and control of land use and development control in the county over a 6-year period will be carried out. Zoning provisions indicate the authority's objective for the primary or sole land use to be permitted in specific areas included in the Plan.

The normal criteria that are intended for use in zoning or rezoning include an analysis of current and future development needs. Zoning should be undertaken on the basis of a rational methodology that incorporates inputs, including population and employment projections, land-use surveys, assessment of housing needs, and the demand for retail space and community facilities (including education and open space/ amenities provision). This process is intended to culminate in the quantification of future urban land demand and its location. Location selection should be in accordance with the availability of water/wastewater services, public transport, shops, schools, churches, etc. In addition, the suitability of the land itself in terms of topography, physical characteristics and the linkages to the existing urban area are essential criteria.

Statutory planning in Ireland largely acts as an indirect policy measure in terms of facilitating the development of new urban areas. Due to resource limitations, planning functions are dominated by development control functions and planning decisions are taken at a local level. Spatial planning activities are, therefore, a secondary factor in development activities, playing a facilitative rather than a causal role (Williams et al., 2010). More often, planning policy documents are prepared at central government level, requiring local authorities 'to have regard to' strategic objectives and inspirational goals. Regional development is, therefore, not principally driven through the provision of statutory obligations being placed on planning authorities, but rather by a local decision-making process that happens on the ground and is incorporated into Regional and Local Development Plans. The following examples of applying evidence-based models in infrastructure provision and regional planning guidelines illustrate the capacity of such models, including MOLAND, to assist policy makers in decision making.

5.2 Role of Land-Use Planning in Developing the Infrastructure for Wastewater: MOLAND Applications

In terms of locating and developing wastewater treatment plants (WWTPs), the CDP is, in turn, informed by national and regional strategic planning documents. In particular, the Regional Waste Management Plan (RWMP) plays an important role in the location selection of WWTPs. In many cases, some parts of wastewater policies and related objectives overlap – between the RWMP and the corresponding CDP. One of the principal aims of the RWMP is to provide a policy basis for the collection, treatment and reuse or disposal of non-hazardous wastewater/sludge arising within its functional area.

Local authorities will generally include objectives in their CDP emanating from policy within the appropriate RWMP. The aim is to protect environmentally sensitive and high-amenity areas. This is usually done by imposing specific planning restrictions and through the use of land-use zoning policy.

A key input in the decision-making process for the location and scale of WWTPs is the Water Services Investment Programme (WSIP). This document, is published by central government every 3 years, the most recent example being from 2007 to 2009. The WSIP is the largest component of the Water Services Programme and concerns the provision of major water and sewerage schemes nationally. Its aim is to meet the strategic objectives for investment in the country's water services infrastructure and can be considered as the primary framework document that sets the national agenda as to which projects are to be implemented. Prior to preparing the WSIP, the Department of the Environment, Community and Local Government (DECLG) requires each local authority to specify priority schemes in its administrative area. This is known as a Water Services Assessment of Needs report and is adopted by the elected members of each council. This report usually covers a period of 6 years. Decisions on the location of WWTPs ensue from local studies undertaken by local authorities which consider key environmental and costs issues in meeting future user needs. Once given approval by the DECLG, the council can make a planning application for proposed plant development.

A recent assessment carried out by local authorities was undertaken in 2006. The key criteria in selecting projects for possible inclusion in the WSIP are included in the Department's Circular L2/06 (Williams et al., 2009). In 2000, the DEHLG[14] adopted a 3-year rolling approach to investment in order to optimise the delivery of the Programme. The recent WSIP (2007–2009) included 955 projects that had an overall capital value of €5.8 billion. A key change in the approach to the needs assessment for the WSIP (2010–2012) is the requirement to review existing schemes that have not sufficiently advanced under earlier programmes (Department of the Environment, Heritage and Local Government, 2010). The aim is to ensure that these facilities have continuing relevance in light of programme priorities, reflect an appropriate scale of works, and are appropriately phased, affordable and cost-effective.

14. DEHLG, Department of the Environment, Heritage and Local Government – now the DECLG.

5.3 GDR Wastewater Case Study

Wastewater infrastructure in this area includes 26 plants, with catchment areas of approximately 1.5 million ha in 368 EDs. The population resident in the aggregated catchment areas was calculated using data from the 2006 Census (CSO, 2007). The catchment boundaries do not map directly with the ED boundaries, so some processing was required to determine the population. ArcGIS software was used to define EDs that have more than half of their area inside of a catchment boundary.

The DRA & MERA wish to increase the wastewater treatment capacity of plants in the region and propose to amalgamate some of the catchment areas and increase the capacity of some of the existing treatment plants over a 12-year period to 2020. The current and planned catchment boundaries are presented in Fig. 5.1. Catchments with small treatment plant capacity values are presented in light colours, while those with bigger capacity have darker colours.

The planned improvement of capacity in population equivalents (PEs) is focused on a particular selection of treatment plants and their catchments (as shown in Fig. 5.1). A key issue is how effective the proposed plan is with regard to catering for the future population in the region. This example shows how MOLAND can be used to generate different spatial scenarios of population distribution and how this impacts on the proposed plan.

Three different scenarios were simulated using different population projections (WWT1, WWT2, WWT3). They represent population low, medium and high growth and are named Scenarios 1, 2 and 3 hereafter. All scenarios are based on the CSO's Regional Population Projections for 2011–2026 (CSO,

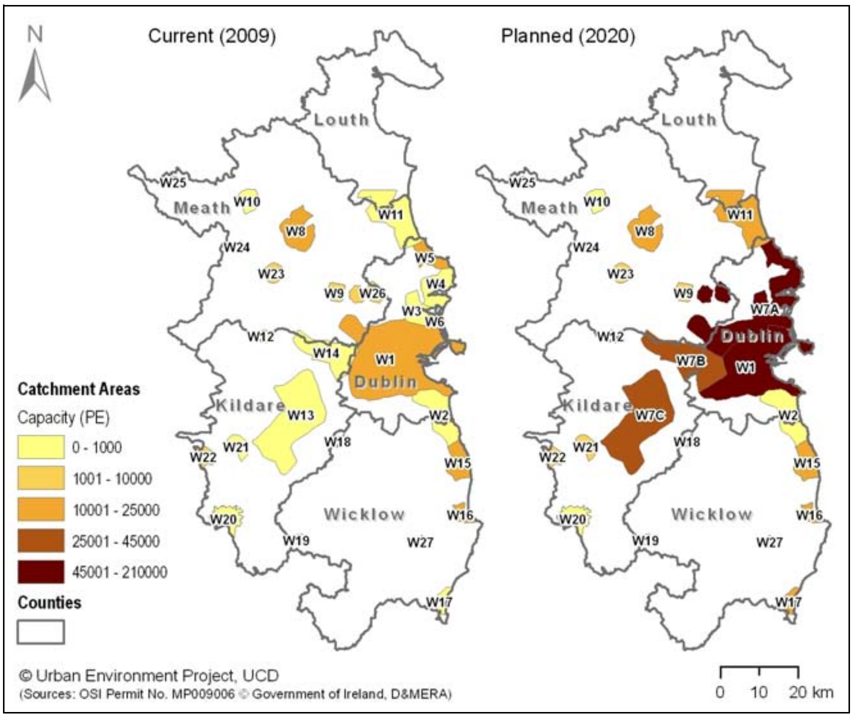

Figure 5.1. Catchment areas and capacities of wastewater plants in the Greater Dublin Region.

2008), which combine a continuing decline in international migration with constant fertility and a return to the traditional pattern of internal migration by 2016 (M2F1T in CSO, 2008). This research took the CSO projection as the medium growth scenario and then projected a low growth scenario with 15% less growth and a high growth scenario with 15% higher growth. MOLAND was used to simulate population growth by county. Activities in MOLAND (industry, commerce and services) were estimated based on CSO Census 2002 and 2006 Place of Work (POWSAR and POWCAR) data sets. The same projections were used in all three scenarios.

MOLAND's micro-model (CA based) currently uses four residential classes:

1. Residential continuous dense urban fabric;

2. Residential continuous medium dense urban;

3. Residential discontinuous urban fabric; and

4. Residential discontinuous sparse urban fabric.

The GDR is mainly covered by the last two classes. Therefore, in order to increase the accuracy of the macro-model, the population was split into two categories for input to the model:

1. Sparse, which includes the Residential discontinuous sparse urban fabric land-use class; and

2. Dense, which includes the remaining three classes.

It was calculated using the average population densities of each residential category in 2006. Figure 5.2 shows the actual population in 2006 and the projected population in 2026 for the two land-use categories under the three scenarios.

5.3.1 Simulation results – regional scale

The patterns of land uses in 2026 under the three scenarios are broadly similar. A consolidation of residential land uses in the core city region is observed in each case, as well as a significant shift from arable and pastoral land use to residential land uses along the western edge of the city core. Existing agglomerations, such as Drogheda and Dundalk (Louth), Navan (Meath), Bray (Dublin) and Wicklow town (Wicklow), show an increase in residential and commercial activity in all three scenarios. Table 5.1 shows the GDR

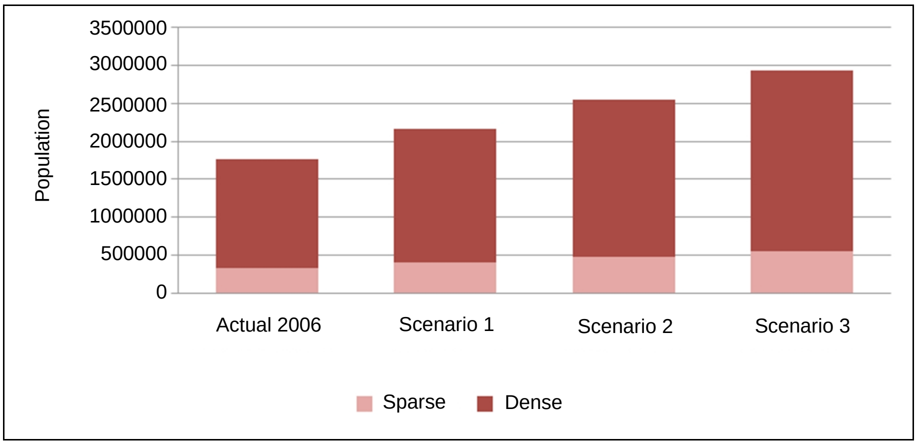

Figure 5.2. Greater Dublin Region actual 2006 population and 2026 projected population for different scenarios.

Table 5.1. Greater Dublin Region (GDR) catchment area statistics.

	2006	2026 (scenarios)		
	Actual	**1**	**2**	**3**
GDR population	1,495,111	2,179,480	2,553,148	2,936,123
Residential area within catchment boundaries (ha)	28,716	42,800	46,308	55,356
Capacity (population equivalent (PE))	**2009**		**2020**	**Increase**
	Present	**Available**	**Overall**	
	2,557,500	123,100	3,125,550	22%

population projections and the change in residential areas by hectare within catchment boundaries under the three scenarios.

In Scenario 1, the residential areas in the aggregated catchment areas increase by 49% and the overall population by 22% compared with 2006. In the case of Scenarios 2 and 3, these numbers are 61% and 93% for residential areas and 44% and 66% for population, respectively. However, the proposed overall capacity of the system is planned to increase about 22% in PEs (see Table 5.1). Detailed analysis of urban growth by individual catchment areas is provided in Williams et al. (2009).

5.3.2 Simulation results – county scale

Figure 5.3 shows the percentage growth in residential development by 2026 based on 2006 figures. Within the region, Dublin shows the smallest increase in residential development of between 36% and 84%, which is as expected given the existing density of built land uses in the county in 2006 and the inertia with regard to changes in existing land uses. County Meath shows the highest increase in residential development of between 140% and 222%. Given the intensive growth in residential development in Meath, it is likely that the wastewater infrastructure serving the county will experience the most pressure to provide increased treatment capacity.

The main residential development in the combined Dublin Counties takes place in the north-east of Fingal and the south-west of South Dublin, while Dún Laoghaire–Rathdown gets a little development in all scenarios.

Figure 5.4 focuses on changes in residential land-use types only, and indicates the main differences with regard to residential development patterns under the three population scenarios and is followed by a specific

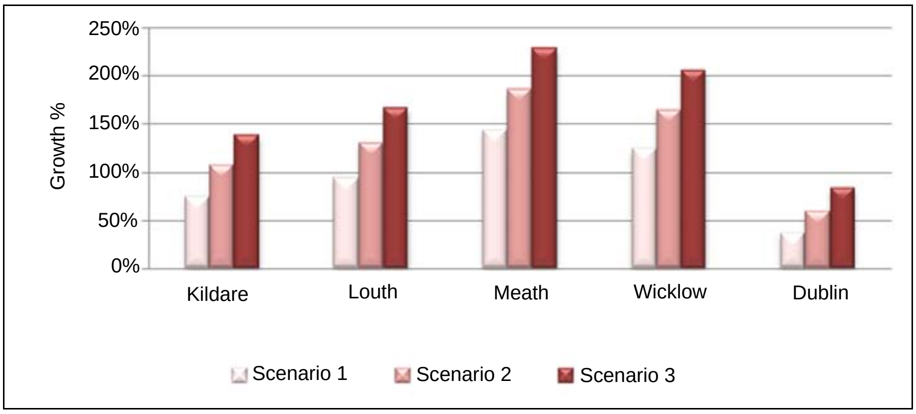

Figure 5.3. Residential area growth in 2026 compared with 2006 by county for the three scenarios.

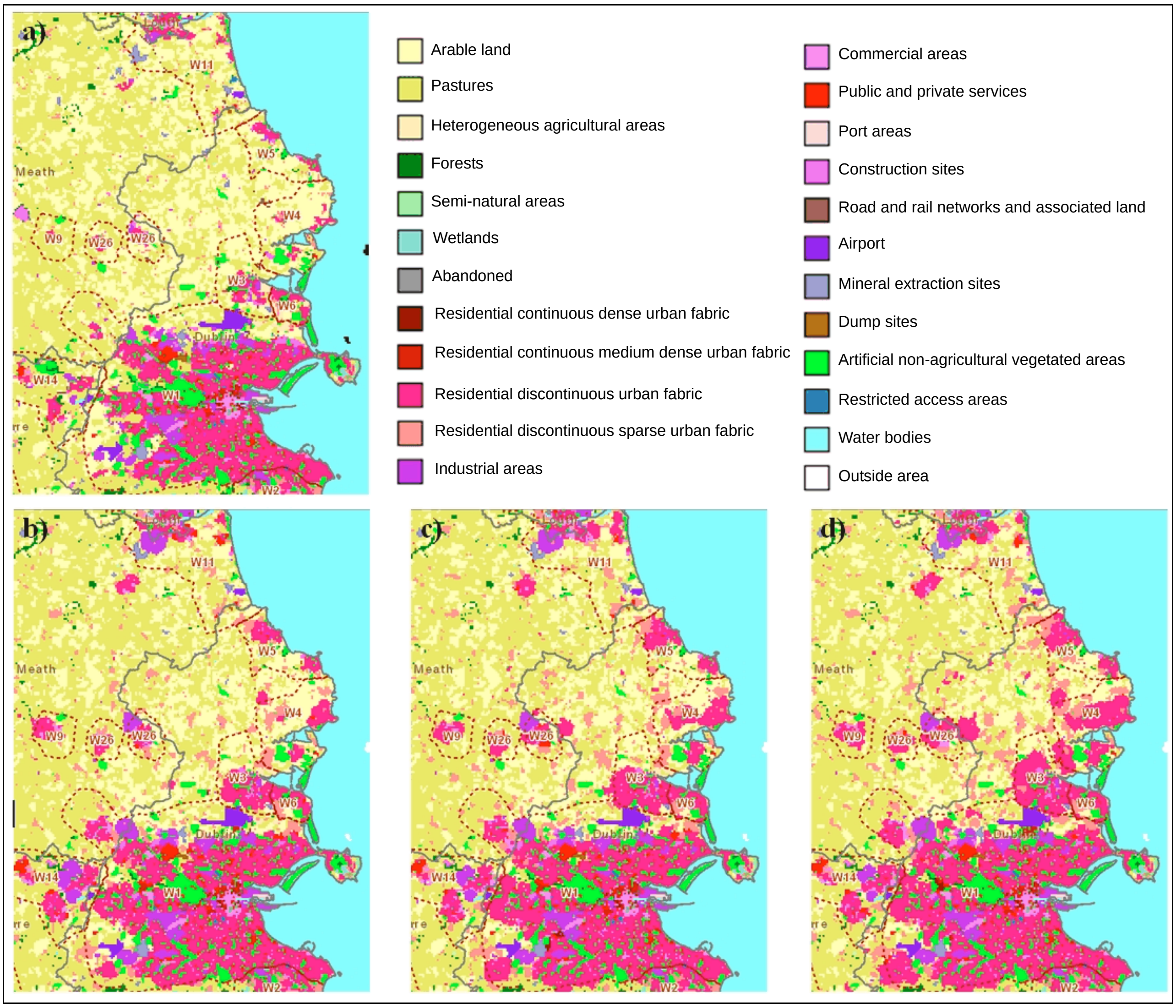

Figure 5.4. Dublin City and northern environs – pattern of land-use change in 2006 (a) and under three population Scenarios 1 (b), 2 (c) and 3 (d).

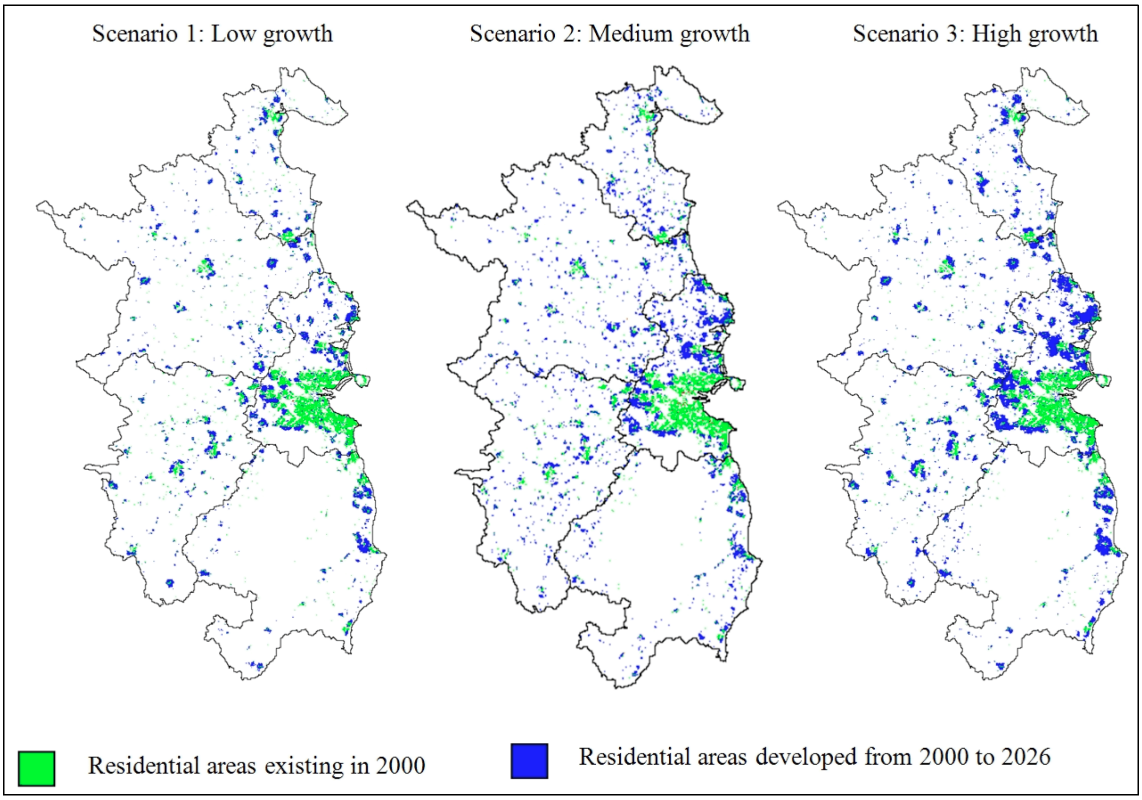

Figure 5.5. Residential development patterns under three population scenarios, showing spatial component of increases in residential development in the region.

catchment area example, whilst Fig. 5.5 shows residential development patterns under three population scenarios, showing spatial component of increases in residential development in the region. Examples of specific catchment areas were also subject to a more detailed analysis, as is illustrated in the example of the Donabate catchment located in Dublin (see Fig. 5.6).

5.4 RPG Review: Using MOLAND as Part of the SEA Process

Following the work on wastewater provision, the study team liaised with the DRA & MERA who were conducting the reviews of the RPGs. The DRA & MERA had completed their pre-draft consultations and SEA scoping processes as legally required and, in conjunction with consultants, were gathering and analysing baseline data and developing alternatives for discussion and negotiations with relevant stakeholders. As part of the process for the SEA element, contact was established between the UEP and the DRA & MERA.

Following consultations with the DRA & MERA, it was decided that the UEP management team would participate in a meeting with relevant stakeholders to decide on the choice of potential development scenarios for the region. As a result of these discussions, a further meeting was held with DRA & MERA officials and, with clarifications, the final four scenarios were chosen. Using the MOLAND model, the UEP team evaluated four scenarios describing four possible future development patterns.

The following scenarios were evaluated as part of the SEA:

1. Baseline/Continued Trends Approach (SEA1);
2. Finger Expansion of Metropolitan Area (SEA2);
3. Consolidation of Key Towns and the City (SEA3); and
4. Consolidation and Sustainability and Some Expansion at Nodes on Transport Corridors. (SEA4).

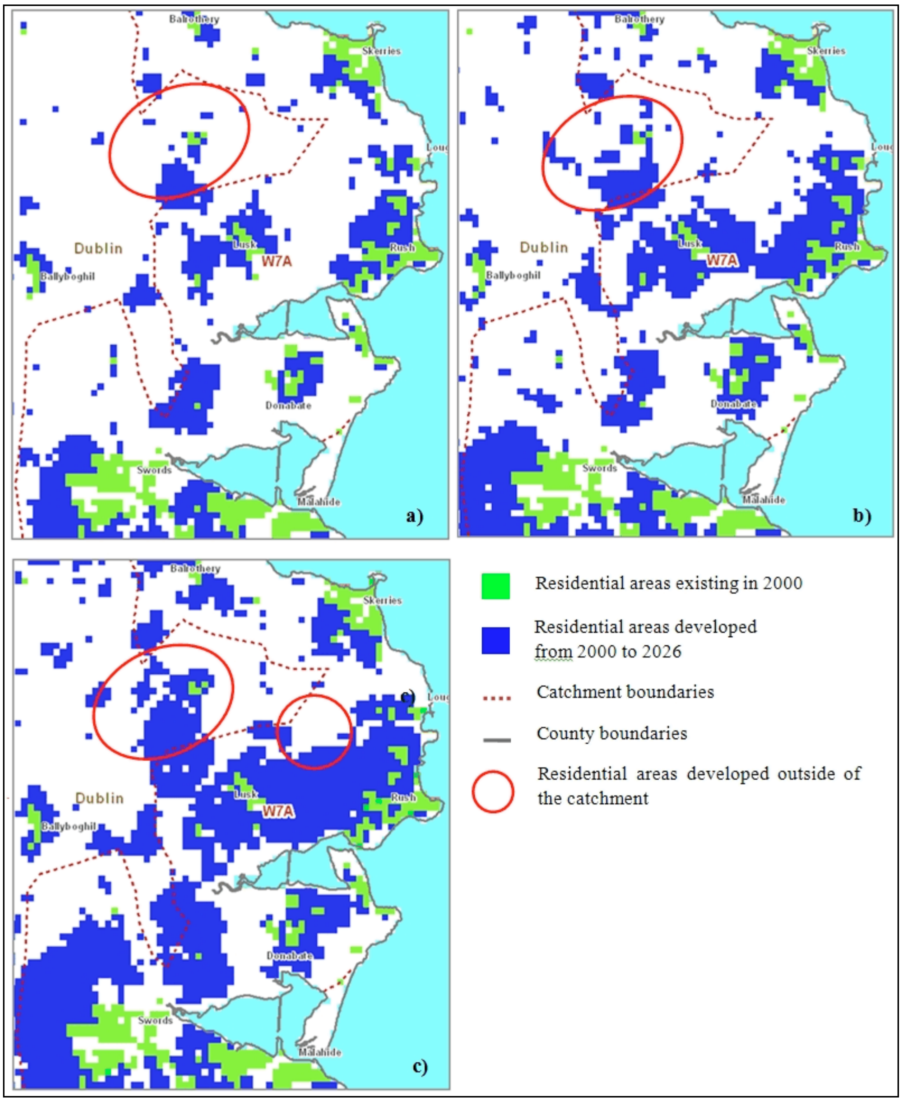

Figure 5.6. Residential area development in Donabate catchment area (W4 in 2006, W7A from 2018) in Fingal, Dublin County: for Scenarios 1 (a), 2 (b) and 3 (c).

5.4.1 Methodology – calculating populations for the region in 2026

The DRA & MERA provided population projections to 2022, with a high/low range, which was used in all scenarios. For use in MOLAND, these were extrapolated to 2026 based on the linear projection of the growth from 2006 to 2022 (Table 5.2). In consultation with the DRA & MERA and in light of the current economic downturn, it was decided to present results for scenarios run with the low projection in the research. This population was used in all scenarios.

The GDA, comprising the Mid-East region and the Dublin region, is of similar, though not identical, extent to the MOLAND study area named the 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 to add it to the projected GDA population in 2026.

Each of the four scenarios required different transportation networks to be derived from existing road and rail data sets. These data sets along with the proposed T21 network (Fig. 5.7) data sets were obtained from the DTO and the NRA. Using the ArcGIS platform, these data sets were manipulated to suit the required transportation network for each individual scenario. The following network links were included in scenario development: the Dunboyne Spur (rail),

Table 5.2. Projected populations in the Greater Dublin Region (GDR) by 2022 under the four regional population projections.

	Low	High
GDA 2022 population	2,103,900	2,161,700
GDR 2022 population	2,244,759	2,306,442
Linearly extrapolated GDR 2026 population	2,362,498	2,439,596

GDA, Greater Dublin Area.

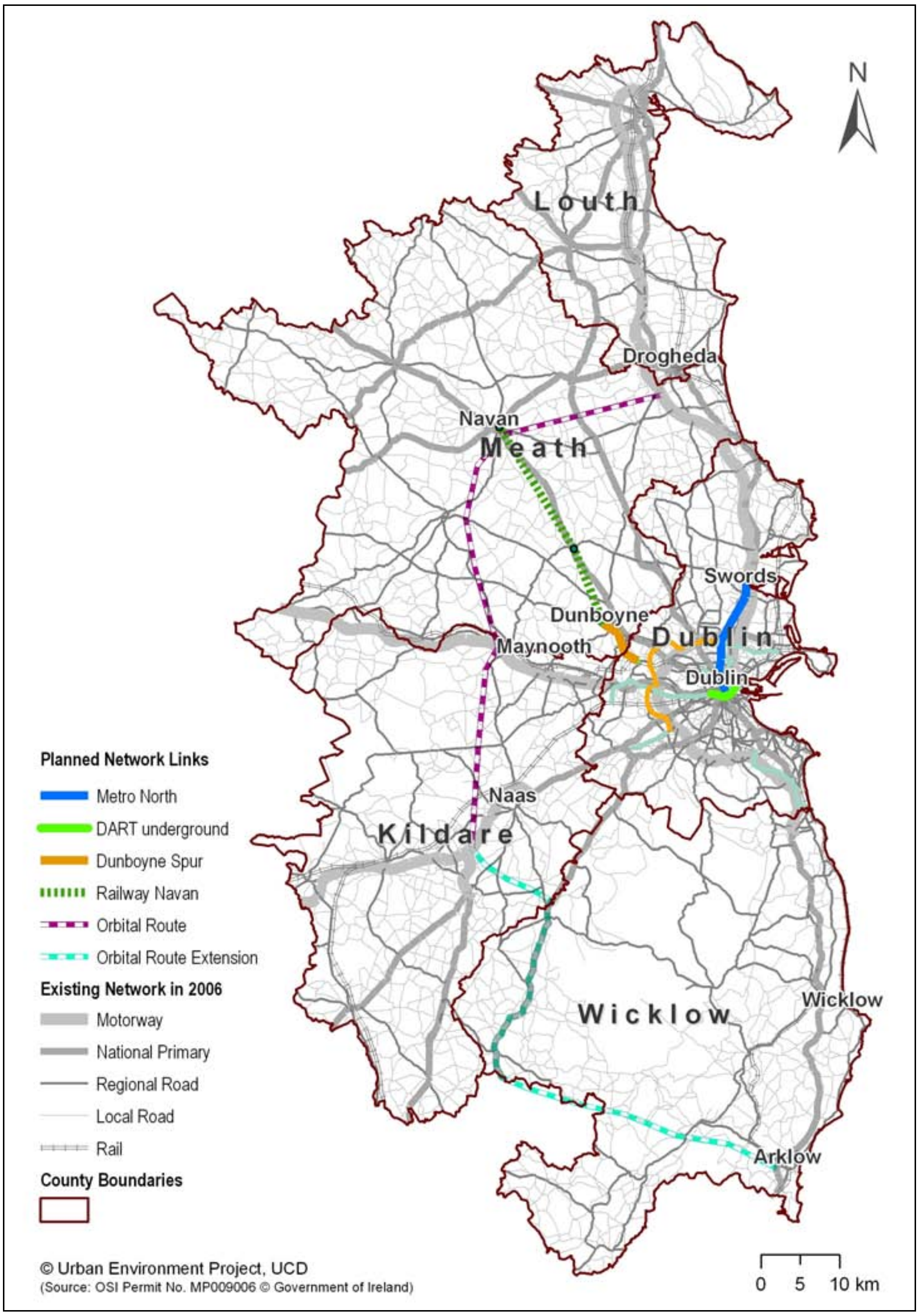

Figure 5.7. Transport 21 proposed network used for scenario development.

Metro North, the DART, the Navan Railway, the Outer Orbital Route (OOR). Each proposed network change was added to each modelled scenario at the specific date it was required.

5.4.2 The scenarios

- **Scenario 1: Continued Trends/Business As Usual**

  As the name suggests, Scenario 1 explored a continuation of the current, dispersed settlement pattern. Although both Strategic Planning Guidelines (SPGs) for the GDA, in 1999, and the subsequent RPGs, in 2004, emphasised a move toward a consolidated settlement pattern, strong green belt policy and improved transport links (Department of the Environment and Local Government, 2002; DRA & MERA 2004), recent studies have suggested that there has been a divergence between policy and practice (Convery et al., 2006; Scott et al., 2006). Scenario 1, therefore, simulates a business-as-usual future, whereby implementation of the SPGs/RPGs has been weak in places. Reflecting the current economic climate, delivery of T21 projects is delayed; Metro North and the DART Interconnector are not projected to be completed until 2020 and work on the Dunboyne Spur is delayed to 2012. With the divergence of policy and practice concerning green belts in mind, Scenario 1 does not contain a special green-belt layer. The decision not to include such a layer was taken to explore what the current trend of developer-led settlement patterns might lead to if left unchecked. Those areas that enjoy legal protection were zoned such that development was prohibited from occurring within. For this scenario, MOLAND default suitability and zoning maps were used as presented in Fig. 5.8. (Shahumyan et al., 2009a). The default transport network of 2006 was updated in 2012 by adding the Dunboyne Spur.

- **Scenario 2: Finger Expansion**

  In this scenario, the effects of a firm policy of consolidation are explored. Development is strongly directed toward an expanded MA, which is extended along key transport corridors. In support of this stance on consolidation, all T21 elements are included and two sub-scenarios were explored for the timing of T21 project delivery; projects were delivered in 2016 and 2020 in sub-Scenarios 1 and 2, respectively. The OOR was not included and large, strictly enforced strategic green belts are used to discourage excessive development in rural areas and to link protected areas. Since the theme of this scenario was to focus development in an expanded MA and along key corridors, large green belts were placed between the major roads to encourage development adjacent to transport links. Two types of green belts were created:

  (i) Large outer green belts designed to designate areas where development should be kept to a minimum; and

  (ii) Smaller connector green belts, designed to preserve links between urban green space and rural areas.

  Suitability and zoning maps used for this scenario are presented in Fig. 5.9. The default transport network of 2006 was updated in 2016 (sub-Scenario 1) or 2020 (sub-Scenario 2), adding all T21 links presented in Fig. 5.7.

5.4.3 Comparison of scenarios

- **Scenario 1: Continued Trends/Business As Usual**

  Should development proceed as simulated, i.e. dispersing to a greater or lesser degree across the region would imply a continuation of current unfavourable sprawl trends. 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., 2009a). 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).

  Commuting in the GDA is a major problem (O'Regan and Buckley, 2003), with time lost due to congestion costing the economy an estimated €640 million (DTO, 2001). An increase in car dependency implied

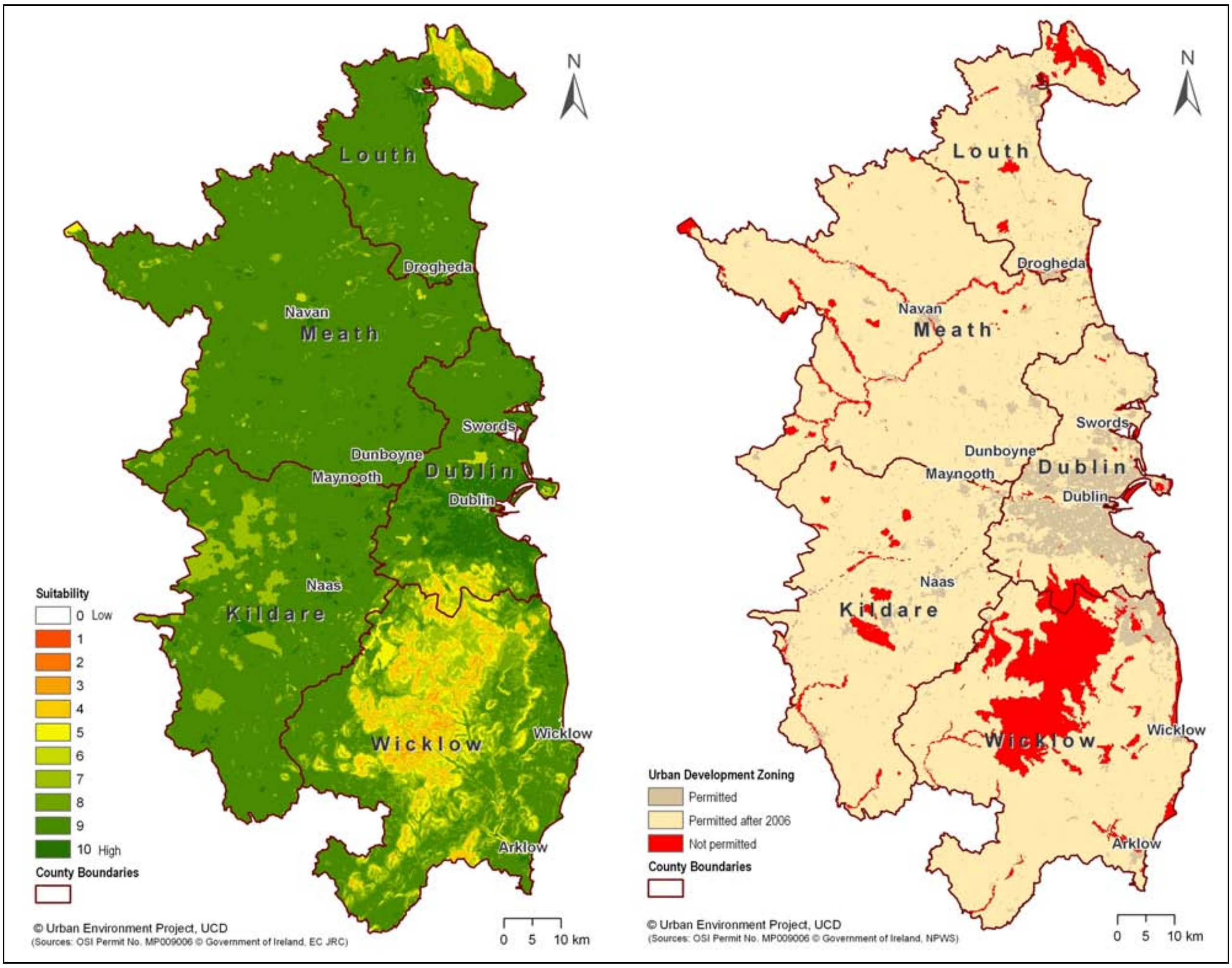

Figure 5.8. Default suitability (left) and zoning (right) maps for urban land uses.

by the dispersed nature of the forecasts would likely exacerbate the situation.

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). Furthermore, work has already been carried out that suggests that growth in several areas across the GDA will outpace future wastewater treatment provision (Williams et al., 2009). Similar deficiencies could be expected for other services, such as waste disposal, education, health provision and emergency service response time.

- **Scenario 2: Finger Expansion**
  This scenario represents the result of a strict enforcement of consolidation within the existing built-up area which is in line with current European policy promoting the compact city (Commission of the European Communities, 1990). Compact cities have been advocated as a way of increasing space for city dwellers, while at the same time reducing transport, energy and material consumption (Katz, 1994). Critics of compact urban form argue that benefits are often exaggerated and that consumer-demand preferences are for a more dispersed housing development pattern. Development within an existing urban centre benefits from pre-existing infrastructure (drinking and wastewater pipes, electricity, street lighting, etc.) and is also easier to extend to adjacent areas. In addition, many

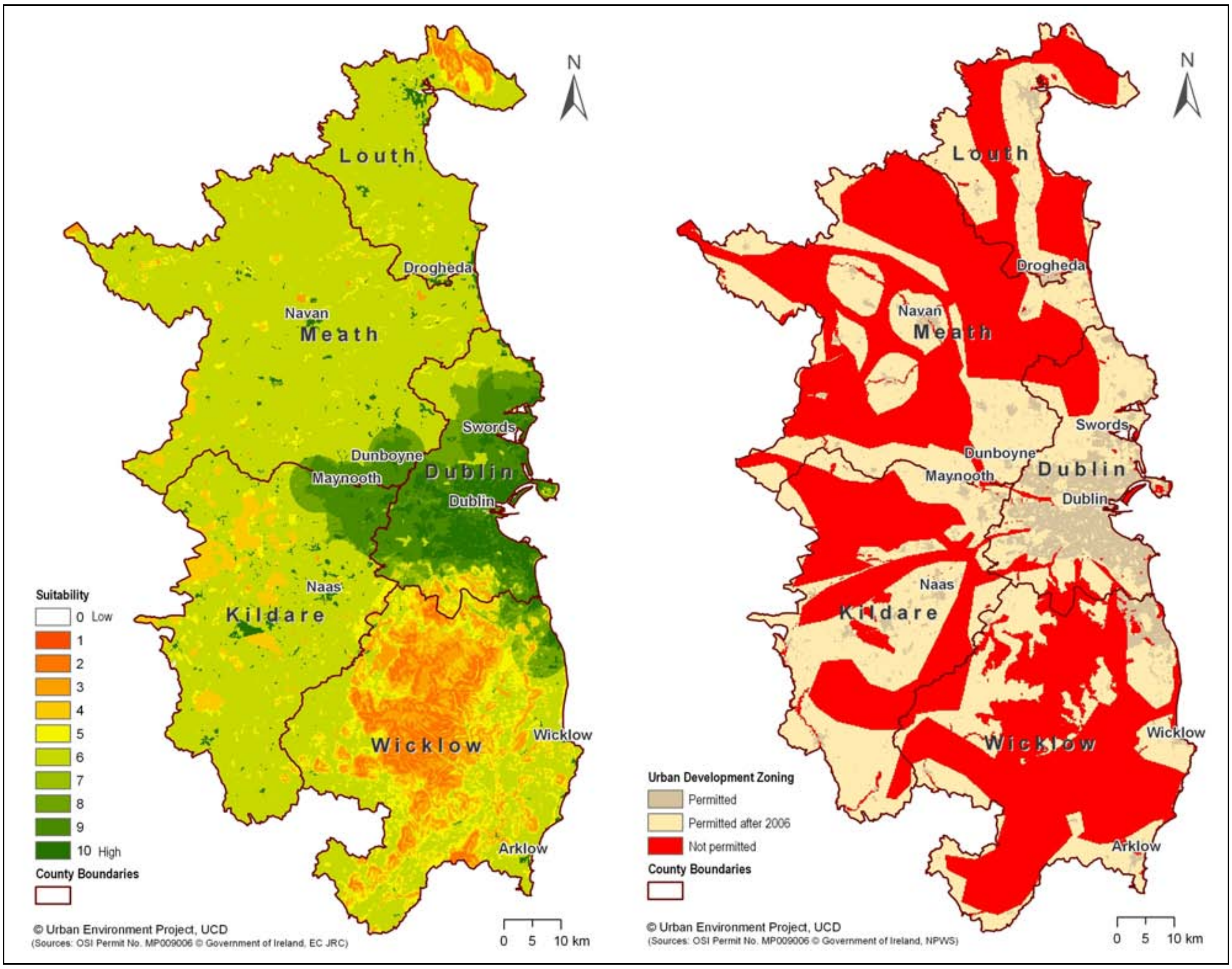

Figure 5.9. Scenario 3 suitability (left) and zoning (right) maps for urban land uses.

studies have tested hypotheses regarding the relationship between urban structure (especially density) and energy consumption in the transportation system. Under these hypotheses, raising urban densities is expected to lead to a decrease in energy consumption (e.g. Newman and Kenworthy, 1989). From the indicator analysis, it can be concluded that compared with Scenario 1, Scenario 2 performs better in terms of promoting settlement near transport nodes and many other categories. Similar analysis was used in terms of Scenarios 3 and 4 and variations on these which were considered by stakeholders, for example extensions to proposed rail lines.

The results of this research were used to develop and explore the contrasting trends which might emerge across several scenarios and also options within such scenarios.

5.5 Results

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 GDR. This allows for the proposed increase in wastewater treatment capacity for the region to be evaluated in a spatial context under spatially explicit scenarios of population expansion in the region. It also demonstrates the potential of the MOLAND model and the CA approach to dynamically integrate information in an inherently spatial manner.

In this element of the research, the scenarios principally relied on modifying one variable, that is the future population in the region. However, the 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 an SDSS goes some way to provide decision makers in the area of spatial planning and infrastructure development with a tool that overcomes some of the obstacles encountered in the formulation of regional development policies. This comes about through the capacity of MOLAND to work at both the regional and the sub-regional scale, thereby providing a link between issues at different temporal scales, for example county and regional levels.

The scenarios presented here represent hypothetical end points of different policy directions. There are costs and benefits associated with following any of these paths, and the exact direction pursued will be decided by the interaction between planners, policy makers and the public working together. Urban regions such as the GDR have undergone major change in the recent past and it would be useful to simulate development into the future, expose potential issues before they occur and structure policy accordingly. As shown above, the MOLAND model allows diverse policy options to be evaluated before concrete decisions are made and provides a useful basis for discussion on the issues facing policy interests.

6 Key Scientific Findings

6.1 A Model-Based Approach

The principal objective of this project has been to provide policy makers with the tools to better inform decisions across a wide spectrum of urban sustainability issues. Such is the nature of these issues that integration of sometimes competing considerations is central to the process. The integrative engine employed here has centred on the widely used land-use change model MOLAND, developed initially under the aegis of the EC to provide future scenarios under different economic and demographic assumptions. The project has built considerably on earlier experiences with the model and customised it, where appropriate, for Irish conditions. A primary focus on the GDR, comprising half the population of the State, with a secondary focus on a smaller corridor of strategic development importance, has been achieved with particular outputs in key areas.

A powerful platform for predictive modelling of future land-use changes in the study area has been identified and applied and has been used to address real-world policy concerns. In the course of the work, a number of flaws and limitations were found relating mainly to the nature of the spatial data that underpin it and the locally specific factors that are not well represented in the model. Despite this, the tool (and the process of making it operational) has many benefits, not least its role in supporting policy makers in addressing key 'what if' questions arising in this rapidly developing region.

Comparability with other European urban regions is now possible by use of this common platform. This enables both learning from, and contributing to, knowledge concerning urban sustainability issues on a wider pan-European scale. While obviously special local conditions apply everywhere, shared experience equals saved costs and a more robust approach to addressing the key issues concerned.

Compliance with national and international obligations is facilitated by the model-based approach. At a national level, the approach has facilitated the integration of different levels of governance across eight local authority jurisdictions as required to comply with RPGs, as well as across disciplines. Air Quality, Biodiversity, Climate Change, Transport and Urban Planning are interacting disciplines subject to international governance to varying degrees and the project has provided a valuable decision-support tool relevant to these concerns.

The approach has made additional use of emerging powerful technologies in GIS that can provide a temporal dimension not hitherto available. Coupled with new data sets emerging at a national level (e.g. POWCAR), this has enabled a very useful analytical engine to be developed.

Many environmental aspects require to be managed on an all-island basis in Ireland. For example, the Water Framework Directive can only be complied with on such a basis. Given that researchers in Northern Ireland (University of Ulster and Ordnance Survey Northern Ireland) are also working with the MOLAND framework and applying it in the six counties of Northern Ireland, there is significant potential to realise a model-based approach for policy makers in both jurisdictions.

Experience with the model has exposed its strengths and weaknesses. Undoubtedly it provides a powerful tool for guiding decision makers as to the likely consequences of particular courses of action in several key areas. It is relatively portable and once operationalised can be used by a wide range of individuals. Caution though is necessary in a number of areas:

- Problems of regionalisation exist related to the particular circumstances of local and national governance. These are often of crucial importance and the insight of the individual remains essential to interpret the functioning of the model at a local level. It is essential to preserve and enhance capacity in this area in order to ensure that the benefits of the approach taken in this project are fully realised.

- A spatial modelling tool whose algorithms and rule behaviours were derived within a separate geographical setting may not be readily applied in a new setting without some adjustment to recognise such local factors.
- The benefits of the approach taken can only be maximised in conjunction with other related work already undertaken in the key thematic areas. For example, considerable expertise exists in the metropolitan transport model used by the Dublin Transportation Office and synergies abound when improved integration with such approaches are implemented.
- The model essentially provides an economically driven perspective on land-use change. Its potential for other uses such as in SEA, Flood Risk Management, etc., is considerable but will require further development and capacity building. While new, more powerful, model-based approaches may emerge in coming years, the capacities developed in this project will be adaptable and capable of responding to new opportunities only if the skills acquired obtain ongoing support.
- In addition, the accuracy and usefulness of the model in applications for the region depend on the availability of high-quality spatially referenced data sets and ongoing data collection to ensure that the model accurately incorporates the dynamic land-use processes.

The experience of this research group has been that this model-based approach is most effective in dealing with issues with a regional dimension (wastewater treatment, energy demand and regional planning strategies).

6.2 Thematic Results and Discussion

6.2.1 Air quality

A new air quality directive (2008/50/EC) entered into force on 11 June 2008, which Member States had 2 years to transpose into national legislation. Compliance with limit values, especially for particulate matter up to 10 µm in size (PM_{10}) and nitrogen dioxide (NO_2), requires knowledge of how future housing energy-related emissions and transport-related emissions will affect ambient values. Both of these aspects have been addressed in this thematic section.

The expansion of the GDA has not been accompanied by a commensurate expansion of public transport, and the growth in commuter sprawl has been largely serviced by an increase in private cars. This part of the project investigated the nature of this phenomenon, with a view to incorporating the findings into alternative futures scenarios. To facilitate this, an analysis of fleet size and composition was undertaken and emissions estimates derived and applied to traffic data. A preliminary study was carried out to link these data with MOLAND output for both a high and a low population growth scenario. As a first step, this indicated how substantial savings in pollutant emissions could be achieved. However, clearly a more comprehensive integration with the transport model could be achieved that would bring more explicit information concerning planning and transport aspects. In particular, the following conclusions were drawn:

- The latest calibration of MOLAND should be used to refine future projections.
- The transport model within MOLAND could be used to more efficiently characterise the vehicle fleet and the nature of trips undertaken.
- New data sources such as from the NCTS will enable improved estimations of trip distances and emissions and better facilitate analysis of the economic viability of potential new public transport plans as well as relative pollutant emission commitments.

6.2.2 Urban transport

A primary objective of this part of the project was to examine the relationship between transport infrastructure and sustainable urban form. For this, the advantages of a GIS-based approach were employed to assess the likely impact of various aspects of the T21 proposals on population, employment and development patterns in the GDA. A considerable impact on containing sprawl was discovered with the construction of the planned transport infrastructure. Particular findings of relevance to the planning process included:

- Proximity to motorway junctions and railway stations will exert a strong magnetism for development over the next two decades, with improved efficiency for the major transport arteries. In the absence of these transport infrastructural developments, the GDR develops along the low density/urban sprawl trajectory which currently is occurring.

- These patterns are replicated especially with reference to the proposed OOR. However, improved accessibility between and within the affected towns can be forecast to produce greater car dependency for the nodal towns concerned.

- Transport energy consumption increases substantially with distance from central Dublin, with hinterland areas showing up to 15 times higher transport-related energy consumption. Young males living in smaller household sizes, in the higher socio-economic groups, are the highest transport energy users.

- Residents of higher density residential developments consume less energy for transport, particularly if they are in a 'jobs-rich' area close to public transport arteries.

These findings can be used to interrogate the MOLAND model for future conditions. However, some inbuilt constraints emerge, particularly in terms of the weighting factors which are not derived specifically for Irish conditions. For this reason, integration of MOLAND with a transport model is considered essential before drawing too many conclusions concerning the impact of planned public transport improvements on private car use. The residential development process appears to lead the transport development process to the extent that some concerns exist that established car usage along planned new public transport arteries may prove difficult to reverse. In addition, given the changing economic fortunes of the region in more recent years, it would be important to look at the impacts of contracting economic activity in the region and its effect on commuting patterns and capacities.

Overall though, this project supports the contention that higher density land use is inherently more energy efficient and, combined with improvements in public transport, results in lower per capita emissions. It is concluded that well-designed mixed developments can reduce transport-related emissions by reducing travel to employment and services and enable a modal transport shift to public transport to be sustained which ultimately improves the safety and attractiveness of such areas.

6.2.3 Biodiversity

Growing awareness of the necessity to halt biodiversity loss is the basis of the International Convention on Biodiversity. Pressures are particularly acute in a rapidly growing urban region such as the GDA, where substantial assets exist. In terms of green space, patch size, shape, connectivity and neighbourhood formed the basis of this analysis. The scale of analysis required did not lend itself to an approach based on MOLAND, and so an automated process using spatial georeferencing using the An Post Geodirectory was developed. While a number of data sets exist to populate such a spatial data set, these were often fragmented, developed using a variety of methodologies and inaccessible during most of the study period.

Garden bird data indicated that the mean number of bird species reported per garden in Dublin is 12.2, compared with a national average of 18.9. Attempts to relate bird diversity to habitat features were not successful, though a survey of habitat classes did appear to explain bat distributions. Nonetheless, the project has demonstrated the need for site-specific studies to be undertaken as the key to biodiversity management as part and parcel of the development process. To activate an alternative strategy for biodiversity analysis, an examination of changes in urban green space was undertaken.

MOLAND was more effectively used to analyse changes in urban green space over a 16-year period. This indicated that most of the losses had occurred in inner city areas, while commensurate gains had occurred in fringe areas. Using projections of the effects of the compact versus dispersed city, it was clear that general biodiversity comes under less pressure in the former scenario, though acute pressures become manifest in high value assets such as forest, wetlands, etc. Using the CSO four Regional Population Projections in conjunction with data on protected sites, a continuation of present trends indicated particular pressures on coastal sites.

The scenarios that were devised as part of the review of the Regional Planning Guidelines which included strong consolidation policies demonstrated least encroachment on protected areas. These results were found by designating hypothetical green belts within each of the scenarios simulated. Significant differences in the extent and location of encroachment on protected areas were noted in each of the consolidation scenarios (Brennan et al., 2009c).

It is clear that biodiversity considerations require more explicit consideration in the planning process throughout the study region. First and foremost, a major effort to map and standardise baseline biodiversity aspects is urgently required. This must be done in a manner that permits accessibility for researchers and is amenable to continuous updating based on well-founded correlations with aspects such as habitat classifications derived from high-resolution satellite or air photography. Spatially explicit models such as MOLAND also require considerable refining both in scale and methodology to account for ecosystem services and the availability of green space and agricultural lands, aspects currently not well catered for. Most importantly though in the short term, biodiversity considerations require to be actively incorporated at the development design stage. This is not being done adequately in Environmental Impact Assessment (EIA), with the result that erosion of biodiversity assets, especially in the central city area, is occurring and their replacement by less valuable assets in fringe areas is not adequate compensation to ensure the maintenance of important ecosystem components. Such a case-by-case evaluation will be aided by reference to the Green City Guidelines (UCD Urban Institute Ireland, 2008), but ultimately must be carried out as an integrated component of the planning and development process in order to ensure that biodiversity considerations are given the adequate weighting they require as part of efforts at maintaining a sustainable urban environment in the GDA.

6.2.4 Climate change

Climate change strategies have been prepared by some of the authorities in the study area, a reflection of the growing awareness of cities as innovation nodes in efforts to combat the emergent problem. This project sought to integrate climate change considerations into the achievement of sustainable planning practices.

Initially, an analysis of household energy demand for space heating was conducted using future climate scenarios to estimate likely changes in per capita demands as temperature increases occurred. Slight reductions in per capita annual electricity and gas demands were projected for the next decade, though more significant reductions (of the order of 10%) in annual per capita gas demand were projected for 2050. Such estimates however are likely to be overwhelmed in aggregate increases in energy consumption in the GDA due to population and economic changes. There are also some indications of an emerging space cooling energy demand during warmer summers. Data limitations, however, exist in these areas and it is desirable that a greater range and sectoral breakdown of energy consumption data are available for researchers to address these aspects in more detail in future.

Calculations of heat loss by housing characteristics enabled energy consumption for space heating for a range of housing types in the GDA to be analysed. These included such characteristics as floor area, housing age and house type, and allowed the existing housing stock to be profiled in terms of their energy consumption. This was achieved for each Ward and Enumeration District in the GDA. Housing density emerged as a key variable, with sparse urban residential settlement form having 22% less efficiency than dense urban forms as regards energy consumption. Using the MOLAND model to project alternative planning strategies for the study area subsequently enabled the energy cost of planning scenarios to be examined. In this respect, the future Compact City would save 16% in energy demand for space heating relative to the Dispersed City scenario.

Such an approach was also coupled to travel energy consumption using the POWCAR to map each individual daily work-related journey and project future changes with the MOLAND scenarios. Major potential reductions in travel-related energy demand were seen, with a dense urban settlement strategy having a 70% advantage over the dispersed settlement alternative.

The second dimension of energy demand studies of this nature is that they provide the opportunity to assess planning alternatives in terms of their likely greenhouse gas commitment. This has not been done hitherto in Ireland and is a highly desirable approach for the future as carbon trading increases. For this study, the household space heating and travel to work carbon dioxide emissions could be quantified for various future scenarios based on informed judgement of future housing type. In the case of travel-related carbon dioxide, a saving of 18% in emissions was estimated for the compact city alternative. In addition, the approach taken also provides a technique for estimating policy impacts on greenhouse gas emissions, for example vehicle fleet changes, house insulation standards, employment geography, etc. The advantages of this approach also are clear as a tool for SEA, now a requirement for policies, plans and programmes throughout Ireland. In particular, the SEA of RPGs should now incorporate energy/carbon dioxide assessments to comply with the Directive's intent. This project offers a platform for further development of these opportunities and, as GIS and climate change scenarios become more sophisticated, the integration of climate change considerations into the planning process can be facilitated.

The analyses relating to air quality, transport-related energy use and climate-change-induced changes in demand for heating provide insights that can be used to support a better understanding of the importance of effective land-use management and associated provision of transport infrastructure to impact on the environmental performance of the city region.

6.2.5 Urban sprawl

The EEA has identified Dublin as one of Europe's worst examples of urban sprawl. Uncoordinated urban sprawl is associated with several serious economic negative externalities, including low accessibility, inefficient utilisation of infrastructure and services, as well as serious environmental impacts in the area of biodiversity and climate change. In this context, the planning process can be viewed as the arbiter of processes involved in the contestation of urban and rural space.

By its nature, planning is not always amenable to a strictly objective model-based approach. Zoning strategies, landscape evaluation and heritage considerations frequently cannot be adequately incorporated into, for example, land-use models. Nonetheless, these considerations were used to inform the scenario-generation process as far as feasible, resulting in the two contrasting scenarios of dispersed and compact city discussed earlier. The approach has also provided input to the draft RPGs for the Dublin and Mid-East regions.

It is clear from the analysis of urban developments in the region that the pressures for dispersed settlement are not being adequately resisted by the planning process. This is resulting in unsustainable development, particularly in the hinterland areas. Financial and environmental resource commitments are resulting from this, which are not in the best interests of the State in the long term. The quantification of these trends and their spatial expression in this project provides also a useful benchmark against which future policies to contain urban sprawl may be measured.

6.3 Discussion and Conclusions

A model-based approach of the type undertaken here offers many advantages in terms of integrating the multifaceted components essential for charting an overall sustainable strategy for urban development. Using this in the GDR offers a clarity of vision often lacking in strategic approaches in the past. However, the nature of Ireland's recent economic development has meant that calibrating the model has been a particularly difficult task. The rapid growth period of the decade following 1997 has now ebbed away and any strategy based on assumptions of continuity requires to be revisited. For MOLAND, this means that the timescales for future projections as well as the underlying economic drivers of spatial change should be updated. Notwithstanding this, however, a number of important aspects emerge from this study.

Urban sustainability has important spatial dimensions that can be incorporated into a land-use modelling strategy to inform the planning process. To be effective, the economic underpinnings of the CA approach require regular updating, as does the land-cover data. The experience gained in this project indicates that difficulties arise when the economic cycle changes. Matching of updated land-use data to changes in the drivers of land use is an ongoing refinement necessary to keep the assumptions of the model valid, especially for future scenario generation.

Air quality management can be facilitated at both the micro and the regional scale by employing sectoral data together with spatial data to simulate the impact of potential changes in the emissions environment. This could in future be enhanced by the incorporation of meteorological and climatic data to better consider concentration aspects and compliance with air quality standards. The makings of an air quality model for the GDA exist in the approach exemplified by this project.

Biodiversity, while not amenable to the scale of investigation offered by the GIS approach taken here, is likely to benefit from future developments in the technology that will enable higher resolution spatial analysis to be achieved. Pending this, it is clear that biodiversity considerations require greater sensitivity in the planning process as climate changes and urban development spreads into rural areas. In particular, opportunities presenting at individual development level can be grasped better to design more biodiversity friendly urban spaces.

Climate change considerations can be more explicitly incorporated into RPGs as a result of the approach taken in this study. These can be factored into scenarios as greenhouse gas emission commitments or energy commitments. Design standards may change in terms of housing and transport, but unsustainable urban developments can increasingly be flagged and their carbon dioxide commitment quantified. Policies, programmes and plans at regional and local levels are also amenable to ‘climate change proofing’ using this approach and this should be therefore incorporated into the SEA methodology.

The intrinsic nature of a CA model encourages, and to an extent, assumes contiguous development processes. There is, therefore, a risk that it will further stimulate urban sprawl around locations where unsuccessful efforts to constrain this have already occurred. Accordingly, it is important to emphasise that the MOLAND-based approach must not be used to determine land-use policies, but rather to inform locally based decision making founded on sustainability principles. Urban sprawl is a particularly serious threat to the achievement of strategic planning objectives and has undermined previous attempts at achieving such objectives within the GDR. It is, therefore, desirable that customisation of the MOLAND model for Irish conditions continues and that the spatial resolution be refined in coming years to better portray these sub-grid-scale phenomena.

Finally, it is clear that a powerful new methodological approach is offered by this project to address urban sustainability through better informing the planning process. Several other spatial data sets can usefully be incorporated into the procedures developed here in future years. In particular, environmental aspects, such as water resource changes, groundwater vulnerability considerations, soil characteristics, topographic detail, climate and landscape quality, can be better incorporated. In addition, a consideration from Ireland around house price modelling, whereby housing stocks are geographically weighted by age, average size and value, would also be an essential, if hard to replicate variable. Such essential economic drivers of urban development are also an example of a specific localised variation shaping urban form and sprawl, and need to be considered in any future modelling. All of this implies that the capacity developed in this project would not be allowed to wither away once the project is completed. Rather, the incorporation of the research as a tool should be institutionalised and its further development encouraged and exported to other areas and countries.

7 Policy Implications and Recommendations

How land is used has potentially huge impacts on the quality of economic development and social life and on environmental performance. However, planners at all levels and those in the policy process, more generally, lack the capacity to systematically interrogate choices and their implications. In the absence of credible information on outcomes associated with alternatives, politicians and other decision makers are not in a position to arrive at evidence-based decisions.

The UEP has developed a systematic approach to overcoming this crucial limitation and has shown with case studies how it can be applied. If the development and application of the system is continued, including making it nationwide, the potential impacts on policy are as outlined below.[15]

7.1 Economic Development

It will be possible to assess the implications of alternative choices for transport, water supply and other infrastructure, and identify the implications of alternatives in terms of land use, settlement, resource use and environmental impact. By making these implications transparent, the policy process will be able to design and locate infrastructure so that the balance of impacts is favourable. Over time, estimates of the public and private costs associated with each alternative, and the associated benefits can be provided.

The main client for this analysis will be the Department of Public Expenditure and Reform (DPER) and its evaluation at both policy and project levels (Sectoral Policy Division). As regards policy, the following captures the essence of the department's approach:

- A key responsibility of the DPER is to put before the Minister the full implications of policies, including financial implications. The Department is in the best position to appraise proposals in the light of financial and economic policy as a whole and in the light of the availability of resources. Because of the importance of these matters, every submission to Government and every proposal for legislation must include details of estimated costs and how it is proposed that these costs should be financed.

- As regards public capital project appraisal, the DPER requires that particular project appraisal techniques be applied depending on the level of capital expenditure involved (Department of Finance, 2005, 2006), the intensity of the analysis varying according to scale, with projects below €0.5 million requiring simple assessment while those in excess of €30 million require full cost–benefit analysis. The National Development Finance Agency of the Department of Finance is responsible for securing cost-effective funding and implementation of large-scale projects – it also may have a use for the model. It would be very helpful for the Department of Finance to have available to it evidence of the implications of choices at both policy and project levels.

7.2 Spatial Planning Policy

The MOLAND framework and the scenarios approach provide a robust and integrated framework for looking at the likely impacts or effect of a variety of strategic spatial planning strategies. In formalising strategic planning policy the EC requires that an SEA is carried out on plans or programmes likely to have a significant environmental impact. The MOLAND framework provides a suitable methodology for supporting this process in the case of Regional and City/County Development Plans. In some cases, it may contribute in the case of Local Area Plans.

The findings of this research indicate that MOLAND could be a useful took for developing Core Strategies as provided for in the Planning and Development (Amendment) Act (2010). MOLAND could play a significant role in helping to ensure that an evidence-

15. See: *Public Financial Procedures*, Department of Finance, 2008. Available at: http://www.finance.gov.ie/ViewDoc.asp?fn=/documents/department/main2.htm&CatID=24&m=a.

based approach is adopted and also in ensuring that the Strategy is consistent with RPGs and the NSS.

The MOLAND methodology provides for an evidence-based approach to developing strategic and county-scale planning policy as shown in the recently published *Draft Regional Planning Guidelines for the Greater Dublin Area for Public Consultation* (DRA & MERA, 2010).

7.3 Infrastructure Policy Implementation

7.3.1 Transport

The Department of Transport has singular responsibility for the provision of transport infrastructure, and as such can benefit from the evidence provided by the model, as it evaluates alternative mixes of infrastructure within and between modes (e.g. roads, light rail).

The National Transport Authority has recently been set up and has been charged with the implementation of national policy. Having the model as a tool for assessing implications of land-use choice will be a valuable decision support. Linking MOLAND to the National Transport model should be explored.

7.3.2 Green infrastructure

The move towards giving full recognition to the ecosystem services and other benefits of green infrastructure is gathering momentum and has been an explicit component of the UEP project. The model begins to allow this capacity to be assessed, in particular as regards biodiversity. Existing tools such as SEA and EIA aim to prevent impacts and to ensure that effective mitigation measures are included in Development Plans. However, this is essentially a reactive approach and there is a need to proactively develop green infrastructure to address ecological connectivity and fragmentation. Utilising MOLAND, a scenarios approach can be adopted to look at the likely impacts of alternative development strategies. By allowing for robust assessments at a strategic scale (e.g. extent of a region, rather than just county or local area scale) and by using repeatable calculations, the real priorities with regards to planning and maintaining green infrastructure can be defined. In addition, as well as providing quantitative indicators of impacts on green infrastructure, MOLAND also provides a means of visualising the likely effect of a 'business-as-usual' scenario. This is particularly useful given the nascent nature of green infrastructure policy implementation in Ireland at present.

7.3.3 Water supply and wastewater treatment

This is a major item of expenditure, and the location of existing and future treatment facilities is a key determinant of performance both with regard to the efficiency (economic and environmental) of the treatment plant itself and its role in providing for sustainable development within the region.

The provision of wastewater treatment facilities is particularly a responsibility of the DECLG but requires considerable co-ordination at both county and regional levels. The treatment plants need to be located at suitable sites and the planning of catchment areas and the most appropriate boundaries relative to existing and future populations is complex. The MOLAND tool allows for the effects of settlement strategies to be assessed in combination with the location and capacity planning of treatment plants and should lead to more informed decisions and discussions of alternatives.

7.3.4 Climate change strategy

The model can inform the greenhouse gas emission implications of alternative land-use strategies. To the extent that it is national policy to delegate responsibility for emissions reduction to local level, the model could be a key decision support. Unsustainable urban settlement patterns can be identified and their carbon dioxide commitment quantified. Plans at regional and local levels can be assessed in relation to climate change using this approach and factored into the SEA methodology. This is particularly a responsibility of the DECLG at policy level.

More broadly, the need to meet 2020 legally binding obligations, and the role of land-use and settlement strategy in this context, will be an important strand of policy. This too is particularly a responsibility of the DECLG at policy level, but the Department of the Taoiseach and the Cabinet Subcommittee will also be relevant.

8 Future Research Directions and Recommendations

8.1 Introduction

In common with the other 26 members of the European Union (EU), Irish environmental policy is largely influenced by EU policy implemented at national level. In regard to greenhouse gas emissions, Ireland's power sector and heavy industry are in the EU Emissions Trading Scheme, and the emissions from the rest of the economy are capped, with legally binding obligations to be achieved by 2020. Likewise, Ireland's emissions of acid precursors – sulphur dioxide, ammonia, nitrogen oxides – are capped by law. In the case of biodiversity, Ireland is legally required to protect particular habitats and species, and as regards water, Member States are required to implement measures to prevent deterioration of the status of all bodies of surface water, and to achieve particular treatment levels of wastewater. Water quality standards for drinking water likewise must be met, and EU rules dictate what can and cannot be included in cosmetics, in electrical and electronic goods and how much of the content of these must be recyclable. Except in the case of product quality, most EU legislation sets out the legally binding obligation – what must be achieved, by when – but leaves it up to the Member State to decide how this is to be achieved. There is considerable emphasis on informing the citizenry as regards performance. Examples include the requirements to provide information on the energy performance of buildings and white goods, and the carbon performance of cars, and the requirement to label foods that are genetically engineered.

It is striking in how many of these areas the manner in which land is used is an important determinant of outcomes. It affects – sometimes dramatically – water quality, nature conservation and biodiversity, greenhouse gas emissions and air pollution. It is something over which we have complete control – the EU has no mandate to dictate land-use planning – but there is virtually no capacity to systematically examine what the implications are of how we use land and how we locate transport and other infrastructure. And so those in the policy process – politicians at local, regional and national levels, officials, stakeholders and the general public – lack a credible assessment as to how alternative policies in regard to land use will affect their well-being, including their collective environmental performance. The ambition of this project was to begin to fill this huge lacuna in the armoury of the decision-making system.

The authors believe that significant progress has been made. A model that is comparable with best international practice has been developed and applied to the most economically dynamic region in Ireland. It has been tested and proved valuable in supporting the choice of settlement strategy in the 2010 RPGs for the Dublin and Mid-East regions. As such, its potential value as a way of evaluating major proposed infrastructure projects (e.g. transport, water supply and wastewater treatment) and alternative zoning and land-use controls has been demonstrated. For the first time, planners can access a modelling capacity comparable with that which economic managers can access as they assess alternative tax and expenditure options. They also have available a powerful tool for visually presenting spatial evidence of various facets related to well-being and quality of life.

The efficient and equitable management of environmental resources in a sustainable manner should be a high priority for all levels of government. Policy making and individual decisions made without a good evidence base carry a major risk of inefficient use or misappropriation of scarce resources. In particular, the impacts of a development-led planning and development system can be unmanaged development, with negative environmental impacts, poorly located and without ancillary transport and vital services.

Specific environmental policy themes addressed in this research include:

- The support of policy directions that assist appropriately located mixed-use developments to reduce transport-related energy consumption;

- Provide support for the development of systematic and spatially explicit monitoring of green space and biodiversity in urban regions;
- The use of the MOLAND transport model to more efficiently characterise the vehicle fleet and the nature of trips undertaken in order to refine future projections of how both future housing energy-related emissions and transport-related emissions will affect ambient air quality values; and
- The evaluation of higher-density land uses that are more energy efficient and that, combined with improvements in public transport, result in lower per capita emissions. Well-designed mixed-use developments can reduce transport-related emissions by reducing travel to employment and services and enable a modal transport shift to public transport to be sustained.

The following targets have been identified to move towards improved environmental resource management and a more effective planning and development system. Such improvements are expected to result in more integrated policies to ensure higher quality of resulting development, with improved environmental outcomes.

8.1.1 Targets

- Ensure that evidence-based support systems using an urban and regional modelling system are in place for strategic planning and environmental management in Ireland;
- Through using evidence-based approaches, reduce the negative environmental consequences of ad hoc development decisions and patterns;
- Develop a policy support network to assist effective policy and development decision making on a regional and national basis;
- Integrate the MOLAND land-use model developed in this research with other transport and environmental models in the State and on a cross-border basis on the island of Ireland; and
- Contribute to the refinement and development of best practice on urban and regional land-use modelling and environmental resource management on an international basis.

8.1.2 Key Recommendations

Table 8.1 shows the key recommendations arising from the research. The recommendations can be broadly considered in three categories.

1. The first relates to operationalising the key results of the research and ensuring that the initial investment in research capacity can be sustained (Actions 1–3);
2. The second relates to how the research findings and outcomes can be usefully employed by key agencies and policy makers (Actions 4–9); and
3. The third focuses on how the usefulness of the model can be improved at a technical level and the associated changes/requirements for supporting this (Actions 10–15).

Whilst numerous agencies, government departments and non-governmental organisations (NGOs) may be involved in these actions the most significant have been identified in both lead and supporting roles.

Table 8.1. Actions – key recommendations arising from the research.

	Description	Lead	Support
1	Further development and support of an evidence-based urban and regional modelling system (such as MOLAND) to underpin efficient fiscal and resource allocation decisions and policy making	DECLG	Regional Planning Authorities/EPA
2	Commitment to and support for multi-annual funding for a core team of researchers and modellers to continuously maintain and refine the input data and model outputs so that the integrity and accuracy of supporting evidence can be maintained	DECLG/EPA	DPER

Table 8.1 *contd*

	Description	Lead	Support
3	Development of a governance structure to support a core team of modellers and policy-support researchers to work continuously with urban and regional modelling approaches such that expertise is maintained and can be effectively integrated across agencies and policy practitioners	DECLG/Regional authorities/Local authorities	RES/IND
4	Interfacing of the National Transport Model with the MOLAND model for the Greater Dublin Region to ensure better integration of transport and spatial planning policy	NTA	NRA/RES
5	Utilising urban and regional analytical modelling to achieve better management outcomes with existing transport infrastructure	NTA	RES
6	Encouraging harmonisation of data regarding zoning status of lands by local authorities to achieve better integration in environmental and spatial planning policy outcomes	DECLG	Local authorities
7	Development of a database of indicators to monitor impact and compliance with strategic initiatives such as Strategic Environmental Assessment (SEA) of Regional and County Development Plans	DECLG/Regional and local authorities	RES
8	Adaptation and application of modelling to support decision making with regard to flood risk management and SEA or national and regional plans or programmes	RES/IND	OPW/EPA
9	Extending MOLAND coverage to all Ireland	DECLG/RES	EPA
10	Ensuring spatially explicit monitoring of green space and biodiversity in urban regions	DECLG/EPA/NPWS	EPA/NPWS
11	Integrated modelling – linking of models from different domains with different temporal requirements (e.g. air quality models, biodiversity models, etc.)	RES	RES
12	Comparing MOLAND with other urban and regional models using similar methodologies	RES	IND
13	Developing a similar framework using open-source programming approaches	RES	IND
14	Updating MOLAND with 2011 data sets, including new Census 2011 data when available	RES	RES/CSO
15	Development of a methodology to validate suitability criteria used in preparation of suitability maps	RES	RES

RES, Research bodies and institutes – Economic and Social Research Institute (ESRI), National Economic and Social Council (NESC), policy advisory boards (e.g. ForFAS), think tanks, etc.
IND, small to medium-sized enterprises, consultancies involved in research in the sphere of planning and environmental policy and support
NTA, National Transport Authority
NRA, National Roads Authority
EPA, Environmental Protection Agency
DECLG, Department of Environment, Community and Local Government (formerly the DEHLG, Department of Environment, Heritage and Local Government)
DPER, Department of Public Expenditure and Reform
NPWS, National Parks and Wildlife Service

8.2 Next Steps

Considerable work remains to be done to deliver the full potential of a model-based decision-support tool to urban environment policy formulation.

First, the model has been calibrated using three land-use maps from 1990, 2000 and 2006. As such, the impact of the great recession of 2008–2010 is not reflected in the model, and this may adversely affect its likely accuracy in looking forward to assess ‘what if’ questions. Re-calibration using a new set of land-use data for 2010 would enhance performance and credibility. In addition, the 2011 Census not only adds additional data for calibration but also records data at a finer spatial resolution than previously available which may improve the modelling accuracy.

Secondly, the incorporation of the effects of alternative scenarios on biodiversity, water and greenhouse gas emissions has only been partially realised. Further work will be needed to ensure that these crucial indicators of performance are available and credible.

Thirdly, as the software and associated programming and experience with the model continues to develop, these need to be incorporated into the system. This includes proposals by the JRC to simplify and make the model more user friendly and accessible. And this, in turn, is related to capacity building – the need to ensure that key decision makers at all levels understand the model, what it can deliver in terms of decision support, and how to access it; it needs to be mainstreamed into the education of planners at all levels.

Finally, as it stands, it applies only to the GDR. The capacity to intelligently interrogate choices is an island-wide requirement, and the ability to mobilise it should likewise be available on this basis. Within that national setting, the potential cross-impacts that multi-region modelling will have will tell us much about the potential impacts that growth in one region may have on another and provide a more holistic summary of how the futures of each region in the country will evolve.

8.2.1 Transfer of technology

Very few models are publicly accessible and actually used in the planning decision processes, including various stakeholders (except for project testing purposes). These are the main ‘bottlenecks’ of urban planning models, even though some initial steps towards increased participation have been made through Internet-based mapping and public participation GIS (PPGIS). To this end, Internet-based geoportals that would allow in the future for viewing of information, situation/problem analysis, scenario exploration and communication would facilitate the utilisation and add value to the existing modelling achievements. In this regard, consideration could be given by the DECLG to linking MOLAND with its national planning information system (DevPlanGIS).

8.2.2 Indicators

The understanding of impacts of various development opportunities and options also needs further work in the areas of environment, natural resources, economic development, public finance, social welfare, public health and quality of life. Translating numerous individual indicators into fewer composite indices that could be generated and displayed ‘on the fly’ and that are likely to be more easily understood by the public would also add value and ensure the utility of the modelling exercises. Linking to ongoing international (European and other) efforts in indicator-based assessments of territorial development and planning (e.g. ESPON) would increase the transferability and applicability of the research outcomes to other regions and cities in Ireland and other countries.

8.2.3 Alternative methods of data harvesting

The latest developments in volunteered geographic information (VGI) and humans as ‘sensors’ may also contribute to enhancing the link with the public/users/citizens regarding the perceptions and events in their immediate natural and urban environment. Similarly, but at the other end of the spectrum, is the provision of tools for ‘data mining’, and capturing of knowledge, events, trends and patterns relevant to planning. This is another possible direction for complementing formal in-house model development. In addition, the development and implementation of the EU INSPIRE Directive will provide for better and easier data sharing across European institutions and research agencies alike.

8.2.4 Collaboration

As highlighted by the external reviewers, this project has at all stages been conscious of the need to maintain cross-institutional co-operation in this important policy research area. The project from initiation has been cross-institutional and cross-disciplinary and this is regarded as a strength of the work. In addition, close liaison with policy stakeholders, both regionally and nationally, has been maintained. The DECLG has co-operated with the project and was briefed at all stages of the work as it progressed. Members of the study teams met with the then Minister and the Minister of State with responsibilities in this area and notified the Ministers and their responsible officials of progress and results. The application of this research in the review of the region's planning guidelines (Brennan et al., 2009b) has enabled the research to be tested in a thorough manner in an applied policy setting. In addition, throughout the project and on a continuing basis co-operation with the National University of Ireland Maynooth (NUI Maynooth), Trinity College Dublin and the University of Ulster in Northern Ireland has been ongoing. This resulted in shared research continuing with these important research groups in 2011 and proposals are now formulated to develop such linkages.

The UEP team is currently engaged in discussion with a major stakeholder in the DRA & MERA regarding the continued use of the MOLAND model and potential applicability to future priority areas such as the preparation of the Regional Retail Guidelines.

In a wider sense, the research group has also developed research links in this area on an international basis and is currently involved in an EU-funded exchange programme, sharing experiences of applied urban modelling with groups in Belgium and New Zealand.

8.3 Lessons Learnt/Recommendations

In delivering a large-scale research project over 4 years, many challenges arose for the project team, both technical and non-technical in nature. For the most part, solutions and workarounds were inspired by these challenges. Of course with the benefit of hindsight, problems unforeseen when designing the project come into sharp focus. To inform future research projects and agencies responsible for the funding of same, some observations on what might be done differently if the project were to be repeated and some points for consideration in regard to lessons learnt through practical implementation of the project are briefly presented below. Working with the MOLAND framework involved considerable gains in knowledge resulting from both the establishment of the model in fully usable form (i.e. data ingestion, calibration, etc.), as well as its application to specific decision-support situations.

8.3.1 Research design

8.3.1.1 Selection of a suitable modelling framework

The MOLAND model was the key integrative framework selected for use in the research. The model is considered 'state of the art' and has been proven in the research context in many territories in Europe through its championing by the EC JRC. Some aspects of how the model and associated data sets are managed proved challenging for the research undertaken as part of the UEP.

MOLAND is delivered as a 'black box' and changes to the model must be channelled through the software developer RIKS b.v. – this substantially limits the freedom of researchers to amend and update the code directly and to conduct experiments to test amendments or new developments. As detailed in Twumasi (2008), there would be huge advantages to making the model more extensible, which would allow, for example, the harnessing of a wider pool of developers and researchers. Also, their time and resources would be better utilised if they could build onto pre-existing frameworks rather than having to write programs from the very beginning. It has been mooted that RIKS b.v. is pursuing the implementation of MOLAND in an open source framework but no clear timelines are currently available.

Whilst the licence for the use of MOLAND includes any updates made to the model by the developers, at no extra charge, some delays were experienced by the UEP in receiving fully tested and debugged versions of the software. For example, on a number of occasions, delivered versions of the software had significant bugs or were missing elements of the functionality provided in previous versions. The technical issues are described in some detail in Shahumyan et al. (2009a) (WP0903 Appendix D). Given the central role of MOLAND in the project design, the delays experienced here considerably impacted on timelines for the dependent studies in the project.

At project outset, the ambitious goal was to roll out the use of MOLAND to key end-users/stakeholders in Ireland over the course of the project. Whilst some training of key groups was possible towards the end of the project, the complexity in understanding and using the tool was considerably underestimated. In fact, the perception that a wide range of non-specialist stakeholders had successfully adopted the tool was erroneous. Despite the MOLAND framework being adopted in a number of territories across Europe, the use of the tool in real-world applications is still limited and in the main has resided within highly skilled specialist groups. This is echoed in plans mooted by DG JRC and RIKS b.v. at the May 2009 workshop to develop a 'MOLAND-Light[16]'. This product would be a version of the tool that can be understood and utilised by decision makers in a wide range of settings without recourse to high-level specialist support, except where the complexity of the application demands, and would allow for a much wider take-up in the use of the tool. By building a large-scale user base, it is likely that the tool would be considerably enhanced through feedback from multiple users and the product would straddle the research/end-user divide.

The standard MOLAND model has a limited means of modelling land-use/transport interactions. As outlined in Carty and Ahern (2008), the use of the 'accessibility' term goes some way to providing information about the dynamic interactions of land use and the transportation network and allows for modified zoning strategies to be tested. However, the addition of a classic four-stage transport model as an additional component in the model provides for considerably enhanced analytical capabilities. For example, by linking to a more developed transport model key data can be analysed with the model, such as number of vehicles on a transport link, congestion levels, average travel times, etc., under different scenarios. Both the DG JRC and RIKS b.v. recognised the limitations of the original MOLAND framework and have commenced updating it. The new version of the model with a significantly upgraded transport model was made available to the UEP at the later stages of the project and its capabilities have not been tested in this research.

16. MOLAND-Light has been made available as part of PLUREL – Peri-urban Land Use Relationships – Strategies and Sustainability Assessment Tools for Urban – Rural Linkages, http://www.plurel.net/, a collaborative research project funded under the European Commission's Framework Programme 6.

8.3.1.2 Selection of environmental themes and research methodologies

A key objective of the project was to integrate environmental themes into the MOLAND framework. Whilst this presented a welcome challenge to researchers, the extent to which it was possible varied depending on the state of the art in each area, the expertise of the thematic research teams and the resources available to them (both human resources and data) over the course of the project.

Both the air quality theme and the urban transport theme were limited by the available functionality within MOLAND to deal with modelling the transport network of the region. At project conception, it was proposed that the MOLAND model would be dynamically linked to existing transport models for the region, for example SATURN[17] – currently under the stewardship of the National Transportation Authority – thereby precluding the need for development of a new transport model to link dynamically with the MOLAND land-use model. In the case of the air quality theme, it was proposed that emissions from vehicle engines could be modelled using advanced dynamic fluid modelling techniques and that this might be linked dynamically to the MOLAND land-use model. At an early stage in the research, it became apparent that these two proposed approaches were not practicable given the operating specifications of MOLAND. This related, in the main, to basic incompatibilities between the models being linked, for example drastically different computational loads, drastically different temporal scales and different capabilities, with regard to ingesting data. Therefore, approaches that required less close-

17. SATURN is a suite of flexible network analysis programs developed at the Institute for Transport Studies, University of Leeds and distributed by WS Atkins.

coupling of modelled components were adopted by these thematic work packages.

8.3.2 Management

8.3.2.1 Licensing arrangements for use of MOLAND and associated data

The dual licensing arrangements for the use of MOLAND (i.e. licence for the use of pre-existing data from the DG JRC and for the software framework (RIKS b.v.)) resulted in delays in getting access to the software and data. In particular, considerable delays were experienced in securing a licence from the DG JRC as the agreement had to be signed by the head of the DG and could not be dealt with at Institute level, where staff were, by and large, co-operative and supportive. Use of the Metronamica model, which is wholly owned by RIKS b.v., would have circumvented this problem. However, this approach would preclude the support and endorsement of the DG JRC and its support in working with a Europe-wide network of existing users.

8.3.2.2 Lack of documentation

Unlike other commercially available software, there is a dearth of documentation outlining the methods and techniques for calibrating the model. Whilst there are numerous academic papers outlining the key conceptual aspects of the model and the approach, for example White and Engelen (2000), White et al. (2000), Barredo et al. (2003), Engelen et al. (2003a), White (2006) and Hurkens et al. (2008), there is little published on the calibration process, for example Silva and Clarke (2002), White and Engelen (2003) and Straatman et al. (2004).

There was no documentation or meta-data available to describe the data sets delivered as part of the MOLAND model. In particular, the suitability layer used in the previous version of MOLAND (e.g. 1990 land-use data) did not include any supporting documentation to explain how the layer was produced and what data sets were used to create the layer.

8.3.2.3 Data specifications and issues relating to the Irish application

1990 Land-use layer: The methodology used for preparation of the 1990 land-use layer was different to that used for the 2000 and 2006 land-use layers. Thus, the 1990 layer had to be validated and updated such that it matched the 2000 and 2006 validations. This step was unforeseen at project design stage and had some impact on the timeline for completion of the calibration tasks.

Zoning: Initially, it was assumed that the zoning layers needed for ingestion into MOLAND for the years 1990, 2000 and 2006 would need to be prepared using the zoned status, in those time periods, of the actual land parcels in the study region. Work was begun to gather together the data required from each of the local authorities in the study region. As outlined in Shahumyan et al. (2009b), it quickly transpired that the magnitude of the job was outside the resources of the project team. In addition, a number of limitations in regard to how zoning is implemented in MOLAND were highlighted through this process. For example:

- Zoning status is presented in binary form in MOLAND, i.e. permitted (0) and not permitted (1). However, in Ireland zoning statuses are more complex and include permitted, open for consideration, not permitted, and other uses (Twumasi, 2008);

- MOLAND uses only three zoning periods, which are meant to correspond to the planning periods for the whole region for which zoning regulations are typically prepared. In the study region, the zoning periods for individual counties differ significantly (Twumasi, 2008);

- Zoning policies which are not spatially explicit – for example "*Irish planning policy in relation to rural housing 'urban generated' single rural dwellings are not permitted whereas 'rural generated' single rural dwellings may be permitted at the same location*" (Walsh and Twumasi, 2008: p. 3); and

- Density (Walsh and Twumasi, 2008) – solutions to these problems were found; in particular, zoning constraints were ingested into MOLAND through use of the suitability layer (see Brennan et al., 2009).

Zoning is crucial in making the modelling more meaningful – one key finding/recommendation from the process is that local authorities in Ireland come up with a more co-ordinated and standardised approach to the production and maintenance of zoning maps at variable scales. This would greatly enhance consistency from regional down to local area plan detail. In this regard, the DECLG is developing a planning information system that would enable zoning to be viewed and interrogated at national, regional and local levels.

Land-use classifications in the Irish context: As outlined in Shahumyan et al. (2009b), the current MOLAND classification system for describing Irish urban areas may need to be updated. Examples of specific urban morphologies are described that do not readily fit the existing classes, particularly in the case of residential fabric and urban green space.

In addition, the MOLAND framework and predisposition towards land-use classification is not particularly helpful when concerned with issues relating to population density. This arises in regard to implementation of zoning policies whereby higher densities are desired in particular areas but where the increase in density would not necessarily constitute a switch between land-use classes, for example from discontinuous to continuous.

Initial explorations were conducted to see if there was a suitable methodology for estimating population density based on specific land-use classes (see Foley et al., 2008) but results were inconclusive. In the case of biodiversity the land-use classification system has some limitations, which are outlined in Brennan and Twumasi (2008).

8.3.3 Staffing

The PhD students engaged in the project received stipends for a period of 36 months, whilst the project duration was extended from 36 months to 48 months at no extra cost to the funding agency. The involvement of the research fellows in the project added considerably to their fourth-level experience but it did also require a considerable commitment of time and energy over and above that required to research, develop and write up a PhD thesis in a single discipline setting. In addition, delays at project outset and, in particular, in accessing MOLAND meant that in some cases the key objectives of the researcher's work programmes had to be tailored, which led to divergence between the proposed research and what was carried out.

The modelling team provided the core engine of the project. On paper this team included members of ERA Maptec Ltd and researchers from NUI Maynooth and University College Dublin (UCD). However, the key role in this team was that of the postdoctoral researcher with strong contributions from the research fellows and project manager. Given the unexpectedly onerous task of calibrating the model and working with the software framework, it became clear over the course of the project that more resources should have been allocated to this area. This was further exacerbated by the need to replace the key postdoctoral staff halfway through the project. Fortunately, it was possible to leverage additional funding through the Science Foundation Ireland ETS Walton Visiting Professor scheme and Prof. Roger White of Memorial University, Newfoundland and Labrador, Canada, was willing and available to visit the team at UCD UII for a period of 4 months. His unsurpassed understanding of MOLAND and how it works and his ability to communicate effectively with the team greatly accelerated the project's understanding of the model and how it could best be adapted for use in the GDR application.

This was a complex multidisciplinary project, bringing together a range of existing experiences while developing some new ones. This developing integration of knowledge was a core part of the project's design and some of that wider learning on project management and contribution might inform future EPA-funded work. While many, though not all, of the original targets were met, the real learning was in the project's own progression and where a series of 'key moments' was central, in data, staffing or technical terms, to its ultimate completion. This process of problem definition and analysis and working around barriers were central to project learning and point to an infrastructure of knowledge/experience which can be passed on to other researchers working in the environmental arena in Ireland in the future.

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Acronyms and Annotations

ABM	Agent-based model
ARTEMIS	Assessment and Reliability of Transport Emissions Models and Inventory Systems
CA	Cellular Automata
CBD	Central Business District
CCA	Constrained Cellular Automata
CDP	County Development Plan
COPERT	Computer Programme to Calculate Emissions from Road Transport
CORINE	Coordination of Information on the Environment
CSM	Constant Share Model
CSO	Central Statistics Office
DECLG	Department of the Environment, Community and Local Government
DEHLG	Department of the Environment, Heritage and Local Government
DPER	Department of Public Expenditure and Reform
DRA	Dublin Regional Authority
DSS	Decision-support system
EC	European Commission
ED	Electoral Division
EEA	European Environment Agency
ERTDI	Environmental Research and Technological Development and Innovation
ESPON	European Spatial Planning Observation Network
ESRI	Economic and Social Research Institute
GDA	Greater Dublin Area
GDP	Gross Domestic Product
GDR	Greater Dublin Region
GIS	Geographic Information Systems
HGV	Heavy goods vehicle
INSPIRE	Infrastructure for Spatial Information in Europe
IRS	Indian Remote Sensing
JRC	Joint Research Centre
LUTI	Land-use transport interaction
MA	Metropolitan Area
MERA	Mid-East Regional Authority

MF	Metropolitan Footprint
MOLAND	Monitoring Land Use/Cover Dynamics
NCTS	National Car Test Service
NGO	Non-governmental organisation
NHA	National Heritage Area
NRA	National Roads Authority
NSS	National Spatial Strategy
NUIM	National University of Ireland, Maynooth
OBD	On-Board Diagnostic
OOR	Outer Orbital Route
PE	Population equivalent
POWCAR	Place of Work Census of Anonymised Records
POWSAR	Place of Work Sample of Anonymised Records
PPGIS	Public Participation GIS
RIKS b.v.	Research Institute for Knowledge Systems b.v.
RPGs	Regional Planning Guidelines
RWMP	Regional Waste Management Plan
SAC	Special Area of Conservation
SATURN	Simulation and Assignment of Traffic in Urban Road Networks
SCATS	Sydney Co-ordinated and Adaptive Traffic System
SDSS	Spatial DSS
SEA	Strategic Environmental Assessment
SPA	Special Protected Area
SPGs	Strategic Planning Guidelines
SUDS	Sustainable Urban Drainage Systems
T21	Transport 21
TEC	Transport Energy Consumption
UCD	University College Dublin
UEP	Urban Environment Project
UII	Urban Institute Ireland
UNEP	United Nations Environment Programme
URBIS	UII Spatial Data Repository
VGI	Volunteered Geographic Information
VUB	Vrije Universiteit Brussel
WSIP	Water Services Investment Programme
WWTP	Wastewater Treatment Plant

Appendix 1 Publications

PhD Theses

Brennan, M. *Application of the MOLAND Model as an Aid for Biodiversity and Greenspace Planning in the Greater Dublin Region*.

Carty, J. *Reducing Transport Carbon Dioxide Emissions through More Sustainable Urban Forms: A Case Study of the Greater Dublin Region*.

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Appendix 2 Summary of Recent Collaborative Land-Use Modelling Projects

- PRELUDE is a project of the European Environment Agency aimed at developing coherent scenarios to describe plausible future developments for land use in EU25 plus Norway and Switzerland and their potential environmental impacts for the period 2005–2035.

- SENSOR (http://www.sensor-ip.org/) is a project funded through DG Research, Framework Programme 6, and aims at developing an ex ante Sustainability Impact Assessment Tool to support decision making on policies related to multifunctional land use in European regions. It uses the CLUE-S land-use model (Verburg et al., 2002). The CLUE model has been used by a large number of both universities and governmental research institutes from all over the world. Case study versions for a variety of regions exist. In addition to SENSOR, the model was used also in other European-funded collaborative research projects such as Eururalis, GEO4, and NITRO-Europe, which are described below.

  - Eururalis (http://www.eururalis.nl/) (Rienks et al., 2008) sketches what could happen to rural Europe based on conditions that differ in nature, course, duration or place. The integrated impact on People, Planet and Profit indicators as well as on land use is assessed for four possible and plausible main scenarios.

  - GEO4 (Global Environment Outlook 4 http://www.unep.org/geo/geo4/media/) places sustainable development at the core of the assessment, particularly on issues dealing with intra- and intergenerational equity. The analyses include the need and usefulness of valuation of environmental goods and services, and the role of such services in enhancing development and human well-being, and minimising human vulnerability to environmental change (UNEP, 2007).

  - NitroEurope (NEU) (http://www.nitroeurope.eu/) (de Vries et al., 2006) addresses the major question: What is the effect of reactive nitrogen (Nr) supply on net greenhouse gas budgets for Europe?

- The LandSHIFT model (http://www.usf.uni-kassel.de/cesr/index.php?option=com_projectand_task=view_detailandagid=27) was developed by the Centre for Environmental Systems Research at the University of Kassel, Germany (Alcamo and Schaldach, 2006). First applications of the model include a simulation study on land-use changes for the African continent and an analysis of the potential impact of bioenergy production on natural land in India.

- The MedAction PSS (http://www.riks.nl/projects/MedAction) (2001–2004), commissioned by the EC and developed by RIKS b.v., assesses physical, economic and social aspects of land degradation and desertification, sustainable farming and water resources. It has been applied in Northern Mediterranean coastal watersheds (Engelen et al., 2003b).

- The Land Use Scanner model (http://www.objectvision.hosting.it-rex.nl/) (Hilferink and Rietveld, 1998) was developed in close co-operation between the Netherlands Environmental Assessment Agency, the Vrije Universiteit, Amsterdam, and Object Vision. Applications of this model include, amongst others, the simulation of future land use following different scenarios, an outlook for the prospects of agricultural land use in the Netherlands, and assessments of flood risk and water shortage in the Netherlands.

The Environment Explorer (http://www.riks.nl/projects/Environment%20Explorer) is an integrated model that uses a CA land-use model with a regionalised, spatial-interaction-based economic–demographic location model. The model covers, in this case, the whole of the Netherlands; the CA has a resolution of 500 m, while the macro-scale model operates on 40 urban-centred economic regions (White and Engelen, 2000).

Appendix 3 UEP Events

Events were run over the course of the project to highlight the project's work to key stakeholders. In April 2007, a workshop with an invited audience of planning and GIS practitioners from local authorities in the study region was convened. In May 2009, a meeting to highlight the results of UEP was convened in Brussels that was targeted at the European policy process. In November 2009, a half-day seminar was convened to highlight significant findings of the project to academics and practitioners working in Ireland. A number of hands-on training sessions were delivered to stakeholders in local authorities and central government as well as to practitioners in environmental management, planning and landscape architecture in the use of MOLAND as a decision-support tool.

The following sections include details of the three events including target audience, session titles, etc.

A3.1 23 April 2007 Workshop

Integrating the National Development Plan (NDP) 2007–2013 and the National Spatial Strategy (NSS) – Issues and Opportunities in the Greater Dublin Area

The purpose of the workshop was to highlight opportunities arising out of closer integration of the NSS and the NDP and to solicit suggestions and ideas from potential MOLAND users to provide direction and insight for the direction of MOLAND development. The potential audience included spatial planners from all planning and development sections within the local authorities based in the Greater Dublin Area (GDA) (including Drogheda Borough Council) as well as Geographic Information Systems (GIS) and supporting technical staff. The invitation was presented in the first instance to the County Managers who nominated key personnel to attend. This was to ensure commitment from senior management with regard to the Urban Environment Project (UEP) objectives and to ensure maximum involvement by the local authorities in the region.

The workshop consisted of three 30-min presentations from invited speakers with significant expertise in the area indicated by the workshop theme.

1. National Development Plan and the National Spatial Strategy – Regional Perspectives
   Deirdre Scully – Dublin and Mid-East Regional Authorities

2. Integrating the National Spatial Strategy and the National Development Plan
   Bruce McCormack – Department of the Environment, Heritage and Local Government

3. MOLAND for Planners
   Dr Martin Critchley – ERA Maptech Ltd

The presentations were followed by an interactive session where participants were invited to break into four smaller groups and each group was then led through a practical demonstration of the key aspects of MOLAND functionality. This was followed by a forum session where participants could input their thoughts and feedback from the morning events. In addition the PhD students prepared posters describing their research work which were on display at the event. Participants included representatives from Dublin City Council, Dún Laoghaire–Rathdown County Council, Fingal County Council, South Dublin County Council, Louth County Council, Dundalk Town Council and Drogheda Borough Council. Key outcomes from the event included the identification of five key tasks to be further pursued by the project. These were:

1. Calibration of the model with data from three time steps (1990, 2000, 2006);

2. From land cover to land use – assessing how the MOLAND land-use classifications may be restrictive with regard to true representation of Irish land-use types – particularly in urban areas;

3. Identification of a specific case study at a regional scale to which MOLAND could be usefully applied once fully calibrated;

4. Identification of a specific case study at a county scale to which MOLAND could be usefully applied once fully calibrated; and

5. How we got here – a description of the story of land-use change in the region – using maps and essays.

A description of the work that evolved following this direction-setting exercise is included elsewhere in the report. A full description of the calibration and validation of the MOLAND model is given in Section 3.2. A detailed description of the issues involved in interpretation in the preparation of the data for the land-use layer by ERA Maptech Ltd is described in Shahumyan et. al 2009b. The application of MOLAND to a specific case study at the regional scale is outlined in Chapter 5. A description of the changes in land use in the region is available in McInerney and Walsh (2009), whilst electronic maps showing land-use change are available from the Digital Atlas section of the UEP website (http://www.uep.ie/outputs/index.html).

A3.2 25 May 2009 Half-Day Seminar

Applying MOLAND as a Decision Tool for Sustainable Development

The half-day seminar was convened in collaboration with the Joint Research Centre (JRC) of the European Commission's Institute for Environment and Sustainability. The objectives of the session were to highlight the role of land-use management in delivering sustainable development by demonstrating the current state of the art in spatially enabled decision-support systems. The target audience was the policy system at European level: members of Directorate-General (DG) Regional Policy, DG Environment, ESPON (European Spatial Planning Observation Network), European Environment Agency, National and Regional Territorial Authorities, DG Eurostat, DG Energy and Transport, DG Research and Technological Development and Members of the European Parliament and the Committee of the Regions with responsibility for policy where land use is important.

A list of invitees was developed in collaboration with JRC colleagues and an invitation was circulated by email to proposed participants. Also, notice of the meeting was given in the circular of the Irish Regions Office (http://www.iro.ie) and to the network of European Environment and Sustainable Development Advisory Councils (http://www.eeac-net.org).

Participants included a number of policy makers from DG Environment, including Section C.2 Market-based instruments including GHG Emissions Trading, D2 Protection of Water and Marine Environment and B2 Nature and Biodiversity. There was also representation from DG Research. A number of end-users and researchers working with MOLAND were also present with representation from Leibniz Centre for Agricultural Landscape Research (ZALF) and Satakuntalkitto, the Regional Council of Municipals in Stakunta, Finland. In addition, researchers based at Vrije Universiteit Brussel (VUB) who are working on an associated project (MAMUD) were present.

The workshop involved the following invited speakers:

- Dr Marjan van Herwijnen, European Spatial Planning Observation Network (ESPON)
  Land Use Integration: The ESPON View

- Prof. Roger White
  Land Use – The Integrative Dimension

- Guy Engelen
  Supporting Strategic Plan Development, Belgium Case study

- Carlo Lavalle
  Land Use Modelling Framework from Europe – Future Directions

- Francisco Caceres-Clavero and Alejandro Iglesias-Campos (Ministry of Environment – Junta de Andalucia)
  Using MOLAND to Support Policy Development in Andalucia

- Laura Petrov, Brendan Williams, Eda Ustaoglu
  Metro North in the Greater Dublin Region – a Light Rail Case Study

- Richard Gordon (New Zealand Landcare Research)
  Linking with the Wider World – the Experience in New Zealand

- Dr Thierry Goger (COST)
  COST Activities and Priorities

Inputs from the UEP team were given by Dr Harutyun Shahumyan, who presented on the topic of *Applications of GIS and Urban Modelling for Environmental Policy.* The research fellows prepared posters, which were on display at the event, describing the usefulness of the MOLAND tool for policy makers (listed in Appendix 1).

A3.3 15–18 June UCD Urban Institute Ireland 2009 Summer School

Spatial Simulation for the Social Sciences Summer School

Through leveraging funding from the Irish Research Council for Human and Social Sciences (IRCHSS), UCD Urban Institute Ireland hosted a summer school in June 2009 entitled *Spatial Simulation for the Social Sciences*. Applications were invited from fourth-level researchers and academics to attend the 4-day course, which included basic training in GIS, as well as a demonstration of a range of research areas which rely on GIS. This included three sessions incorporating techniques and theory from the project work with MOLAND. Details of the participants who attended and the sessions (both lecture and workshops) related to UEP research are given below:

- Session (2.5 h) – *Scenarios Technique and Modelling* (Dr Laura Petrov)
- Workshop (2 h) – *The Use of Scenarios and Cellular Automata Model (MOLAND) for Simulating Future Land Development* (Dr Laura Petrov)
- 15 Participants (postgraduate researchers, postdoctoral researchers and academics).

A3.4 13 November 2009 Half-Day Seminar

Dublin 2026 The Future Urban Environment

Co-hosted by the Centre for Urban and Regional Studies at Trinity College Dublin and in association with the *Journal of Irish Urban Studies*, the half-day seminar comprised the delivery of a number of academic papers. Five papers were submitted by the UEP team and were among those published in a special issue of the *Journal of Irish Urban Studies* in early 2010.

1. Williams, B. and Walsh, C. *Future urban form; expansion contraction and dispersal*;
2. MacLaran, A. and Attuyer, K. Regional Office *Development trends and impacts*;
3. Brennan, C. and Convery S. *Biodiversity in Dublin, A case study approach*;
4. Brennan, M. *Simulated future development of the Greater Dublin Area: consequences for protected areas and coastal flooding risk*; and
5. Carty, J. *Identifying the relationships between urban form, socio-economic factors and transport energy consumption in the Greater Dublin Area*.

Also included in the special issue was: O'Broin, D. *Local governance and future regional development.*

Additional capacity-building activities will continue beyond the duration of the project period, based on the training sessions delivered in November 2009 and January 2010. During the project, the emphasis was on highlighting the potential applications of the modelling and decision-support tools developed. Towards the close of the project and into the future, the focus shifted towards applications of the tools developed by end-users and, in particular, their application to real world problems.

A3.5 23 November 2009 Half-Day and Whole-Day Session

Decision-Support Tools for Managing Urban Environment

The training was broken into three sessions. The first session consisted of a lecture-style presentation that included an overview of the context for decision-support tools, a description of how MOLAND works and the main data inputs needed as well as illustrated examples of practical applications of MOLAND to investigate:

1. Alternative regional planning strategies;
2. The effects of improved transport infrastructure on

development patterns; and

3. The provision of wastewater treatment facilities.

In addition, a ‘pathways’ document was presented showing how end-users can access and work with MOLAND and associated specialist support services. The second session was ‘hands-on’, with participants going through worked examples to get an understanding of the MOLAND interface and the main features of the modelling package. In addition, an overview of data types and formats needed and background information on GIS was covered. The third session was delivered by Dr Laura Petrov and focussed on the use of scenarios. Dr Petrov led participants through a workshop session whereby different scenarios were defined qualitatively and were then implemented in MOLAND.

A3.6 20 January 2010 Half-Day and Whole-Day Session

Decision-Support Tools for Managing Urban Environment

Following the November session, this training was modified a little based on feedback from participants. There was more focus on ‘hands-on’ training and the session on GIS data types was removed from Session II. The third session was delivered by Prof. Piotr Jankowski, an Science Foundation Ireland ETS Walton Visiting Professor, based at UCD UII, and involved the use of multi-criteria evaluation techniques to compare scenario outputs.

The sessions included opportunity for feedback by practitioners with regard to changes to course content and suggestions for topics to be included in further training programmes. Support materials which included worked examples and reference material – a workbook, copies of slides and background papers (working papers, journal articles) – were made available to participants.

Participants at the courses included spatial planners from private practice and local authorities, environmental management professionals, architects, urban designers, GIS professionals, researchers with interests in forestry, resource management and spatial planning, and members of state agencies responsible for environmental management, etc.

An Ghníomhaireacht um Chaomhnú Comhshaoil

Is í an Gníomhaireacht um Chaomhnú Comhshaoil (EPA) comhlachta reachtúil a chosnaíonn an comhshaol do mhuintir na tíre go léir. Rialaímid agus déanaimid maoirsiú ar ghníomhaíochtaí a d'fhéadfadh truailliú a chruthú murach sin. Cinntímid go bhfuil eolas cruinn ann ar threochtaí comhshaoil ionas go nglactar aon chéim is gá. Is iad na príomh-nithe a bhfuilimid gníomhach leo ná comhshaol na hÉireann a chosaint agus cinntiú go bhfuil forbairt inbhuanaithe.

Is comhlacht poiblí neamhspleách í an Ghníomhaireacht um Chaomhnú Comhshaoil (EPA) a bunaíodh i mí Iúil 1993 faoin Acht fán nGníomhaireacht um Chaomhnú Comhshaoil 1992. Ó thaobh an Rialtais, is í an Roinn Comhshaoil, Pobal agus Rialtais Áitiúil.

ÁR bhFREAGRACHTAÍ

CEADÚNÚ

Bíonn ceadúnais á n-eisiúint againn i gcomhair na nithe seo a leanas chun a chinntiú nach mbíonn astuithe uathu ag cur sláinte an phobail ná an comhshaol i mbaol:

- áiseanna dramhaíola (m.sh., líonadh talún, loisceoirí, stáisiúin aistrithe dramhaíola);
- gníomhaíochtaí tionsclaíocha ar scála mór (m.sh., déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta);
- diantalmhaíocht;
- úsáid faoi shrian agus scaoileadh smachtaithe Orgánach Géinathraithe (GMO);
- mór-áiseanna stórais peitreail;
- scardadh dramhuisce.

FEIDHMIÚ COMHSHAOIL NÁISIÚNTA

- Stiúradh os cionn 2,000 iniúchadh agus cigireacht de áiseanna a fuair ceadúnas ón nGníomhaireacht gach bliain.
- Maoirsiú freagrachtaí cosanta comhshaoil údarás áitiúla thar sé earnáil - aer, fuaim, dramhaíl, dramhuisce agus caighdeán uisce.
- Obair le húdaráis áitiúla agus leis na Gardaí chun stop a chur le gníomhaíocht mhídhleathach dramhaíola trí comhordú a dhéanamh ar líonra forfheidhmithe náisiúnta, díriú isteach ar chiontóirí, stiúradh fiosrúcháin agus maoirsiú leigheas na bhfadhbanna.
- An dlí a chur orthu siúd a bhriseann dlí comhshaoil agus a dhéanann dochar don chomhshaol mar thoradh ar a ngníomhaíochtaí.

MONATÓIREACHT, ANAILÍS AGUS TUAIRISCIÚ AR AN GCOMHSHAOL

- Monatóireacht ar chaighdeán aeir agus caighdeáin aibhneacha, locha, uiscí taoide agus uiscí talaimh; leibhéil agus sruth aibhneacha a thomhas.
- Tuairisciú neamhspleách chun cabhrú le rialtais náisiúnta agus áitiúla cinntí a dhéanamh.

RIALÚ ASTUITHE GÁIS CEAPTHA TEASA NA HÉIREANN

- Cainníochtú astuithe gáis ceaptha teasa na hÉireann i gcomhthéacs ár dtiomantas Kyoto.
- Cur i bhfeidhm na Treorach um Thrádáil Astuithe, a bhfuil baint aige le hos cionn 100 cuideachta atá ina mór-ghineadóirí dé-ocsaíd charbóin in Éirinn.

TAIGHDE AGUS FORBAIRT COMHSHAOIL

- Taighde ar shaincheisteanna comhshaoil a chomhordú (cosúil le caighdéan aeir agus uisce, athrú aeráide, bithéagsúlacht, teicneolaíochtaí comhshaoil).

MEASÚNÚ STRAITÉISEACH COMHSHAOIL

- Ag déanamh measúnú ar thionchar phleananna agus chláracha ar chomhshaol na hÉireann (cosúil le pleananna bainistíochta dramhaíola agus forbartha).

PLEANÁIL, OIDEACHAS AGUS TREOIR CHOMHSHAOIL

- Treoir a thabhairt don phobal agus do thionscal ar cheisteanna comhshaoil éagsúla (m.sh., iarratais ar cheadúnais, seachaint dramhaíola agus rialacháin chomhshaoil).
- Eolas níos fearr ar an gcomhshaol a scaipeadh (trí cláracha teilifíse comhshaoil agus pacáistí acmhainne do bhunscoileanna agus do mheánscoileanna).

BAINISTÍOCHT DRAMHAÍOLA FHORGHNÍOMHACH

- Cur chun cinn seachaint agus laghdú dramhaíola trí chomhordú An Chláir Náisiúnta um Chosc Dramhaíola, lena n-áirítear cur i bhfeidhm na dTionscnamh Freagrachta Táirgeoirí.
- Cur i bhfeidhm Rialachán ar nós na treoracha maidir le Trealamh Leictreach agus Leictreonach Caite agus le Srianadh Substaintí Guaiseacha agus substaintí a dhéanann ídiú ar an gcrios ózóin.
- Plean Náisiúnta Bainistíochta um Dramhaíl Ghuaiseach a fhorbairt chun dramhaíl ghuaiseach a sheachaint agus a bhainistiú.

STRUCHTÚR NA GNÍOMHAIREACHTA

Bunaíodh an Ghníomhaireacht i 1993 chun comhshaol na hÉireann a chosaint. Tá an eagraíocht á bhainistiú ag Bord lánaimseartha, ar a bhfuil Príomhstiúrthóir agus ceithre Stiúrthóir.

Tá obair na Gníomhaireachta ar siúl trí ceithre Oifig:

- An Oifig Aeráide, Ceadúnaithe agus Úsáide Acmhainní
- An Oifig um Fhorfheidhmiúchán Comhshaoil
- An Oifig um Measúnacht Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáide

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag ball air agus tagann siad le chéile cúpla uair in aghaidh na bliana le plé a dhéanamh ar cheisteanna ar ábhar imní iad agus le comhairle a thabhairt don Bhord.

Science, Technology, Research and Innovation for the Environment (STRIVE) 2007-2013

The Science, Technology, Research and Innovation for the Environment (STRIVE) programme covers the period 2007 to 2013.

The programme comprises three key measures: Sustainable Development, Cleaner Production and Environmental Technologies, and A Healthy Environment; together with two supporting measures: EPA Environmental Research Centre (ERC) and Capacity & Capability Building. The seven principal thematic areas for the programme are Climate Change; Waste, Resource Management and Chemicals; Water Quality and the Aquatic Environment; Air Quality, Atmospheric Deposition and Noise; Impacts on Biodiversity; Soils and Land-use; and Socio-economic Considerations. In addition, other emerging issues will be addressed as the need arises.

The funding for the programme (approximately €100 million) comes from the Environmental Research Sub-Programme of the National Development Plan (NDP), the Inter-Departmental Committee for the Strategy for Science, Technology and Innovation (IDC-SSTI); and EPA core funding and co-funding by economic sectors.

The EPA has a statutory role to co-ordinate environmental research in Ireland and is organising and administering the STRIVE programme on behalf of the Department of the Environment, Heritage and Local Government.

epa
Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

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