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Data Preparation for the MOLAND Model Application for the Greater Dublin Region

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Abstract

This paper presents the data preparation and processing steps that were taken to provide inputs for the MOLAND model application for the Greater Dublin Region. The model requires spatial and socio-economic data by county for the beginning and end years of the calibration period i.e. 1990, 2000 and 2006. In addition, projections of socio-economic variables are required for implementing different scenarios. Basic data requirements of the new transport model and description of related data collection works are also presented. Heretofore detailed information and justification for approaches taken in preparing data for ingestion to MOLAND has been undocumented. This paper aims to address that gap. Therefore the steps that have been taken to prepare and process these datasets are described in detail including background information, interpretation and processing methods used and the main assumptions and generalisations adopted.

Keywords: *MOLAND, model, data, maps, Greater Dublin Region, land use, suitability, zoning, accessibility, population, employment, transport.*

1 Introduction

The MOLAND model was developed as part of an initiative of the European Commission's Joint Research Centre as a response to the challenge of providing a means for assessing and analysing urban and regional development trends across European member states (Engelen et al, 2007). It comprises two sub-models working at different scales. At the macro scale, the model takes as inputs the population and the economic activity (number of jobs) in a region; this population and activity is then split between the sub-regions (counties) encapsulated in the model area. At the micro scale the provision for population and economic activities is translated into a number of land uses; for example, estimates of the population will be provided for within residential land use types and estimates of the economic activity generated will be provided for within commercial, industrial and service land uses. The micro model is based on the cellular automaton algorithm. The land use type assigned to any

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given cell is determined by an algorithm which aims to satisfy the demands for land use in each time step.

In the scope of Urban Environmental Project (UEP) the model was calibrated for the Greater Dublin Region (GDR) in Ireland (Shahumyan et al, 2009). 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 maps and socio-economic data should be available for the beginning and end years of the calibration period. The following datasets covering the GDR for 1990, 2000 and 2006 were used during calibration and will be described in detail in this paper:

- Land use maps – source satellite images, minimum mapping units, land use classes and raster formats are explained.
- Suitability maps – suitability criteria are discussed.
- Zoning maps – county development plan periods for the GDR and the data layers used are presented.
- Transport network maps – structure of the network shapefiles and required attribute data are described.
- Transport data – development of a transport zones map and calculation of transport flows between zones are presented.
- Social and economic information – population and employment data sources and estimation methods are explained.

The paper focuses on the data preparation and processing steps that have been taken to provide inputs for the MOLAND model GDR application, including background information, interpretation and estimation methods used, and the main assumptions and generalisations adopted. The model itself is described briefly only to the extent necessary to understand data requirements. Meanwhile, the detailed description of the model calibration is provided in a separate paper by Shahumyan et al (2009) and can be considered as a continuation of this paper.

2 The Study Area

The UEP study area covers the Greater Dublin Region which is comprised of the following local authority[1] areas: South Dublin, Dublin City, Dún Laoghaire-Rathdown and Fingal joined into one Dublin County, and its surrounding counties; Kildare, Meath, Wicklow, and Louth (Figure 1).

County and model area maps were developed based on the official Electoral Divisions[2] (ED) map available from the Central Statistics Office Ireland (CSO) website in shapefile

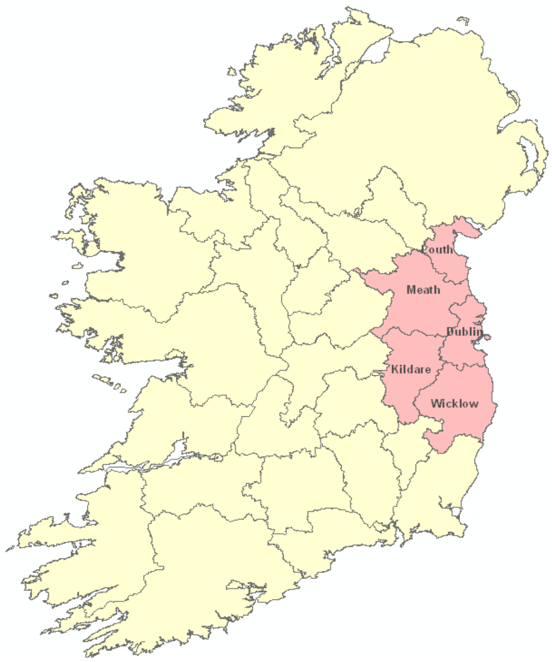


Figure 1- The GDR highlighted in the map of Ireland.

[1] Local government in Ireland at county/city level consists of 29 County Councils, 5 City Councils, 5 Borough Councils and 75 Town Councils; at regional level eight regional authorities and two regional assemblies.

[2] Electoral Division – the smallest legally defined administrative area in Ireland for which small area populations statistics are published by the CSO.

format. In total, 628 EDs where included in 5 counties in the GDR (Table 1). Donabate and Howth EDs have in addition to their mainland extents, small off-shore islands. For simplification purposes, the islands have been excluded from the area modelled.

The final modelling area map was converted into ASCII raster format using ArcGIS 9.3 "Polygon to Raster" (Appendix B) and "Raster to ASCII" conversion tools. Table 1 presents the counties with their appropriate codes used in the GIS layers and in the MOLAND model.

Table 1 - Counties in the GDR

County	Code	Included EDs
Louth	1	43
Meath	2	92
Dublin	3	322
Kildare	4	89
Wicklow	5	82
Total		628

3 Land Use Maps

The land use maps of 1990, 2000 and 2006 for the GDR were produced by ERA-Maptec Ltd. Figure 2 summarises the procedures involved in the preparation of the land use maps for ingestion into MOLAND. The initial stages involve the visual interpretation of aerial photography and satellite imagery to produce a land use map codified using the MOLAND classification system. The MOLAND classification system is based on the CORINE Land Cover database, level 4 nomenclature which includes over 80 classes.

For input into the MOLAND model, the number of classes in the land use map is reduced to 24 by aggregating related classes from the initial land use layer (see Appendix A). This is required because it would be too computationally intensive to model each individual land use class separately. The resulting land use map is then converted into the ASCII raster grid format supported by MOLAND. These procedures are further described in the following sections. This is followed by validation procedures using the GeoDirectory[3], local knowledge and other ancillary data to ensure the accuracy and consistency of the land use classes.

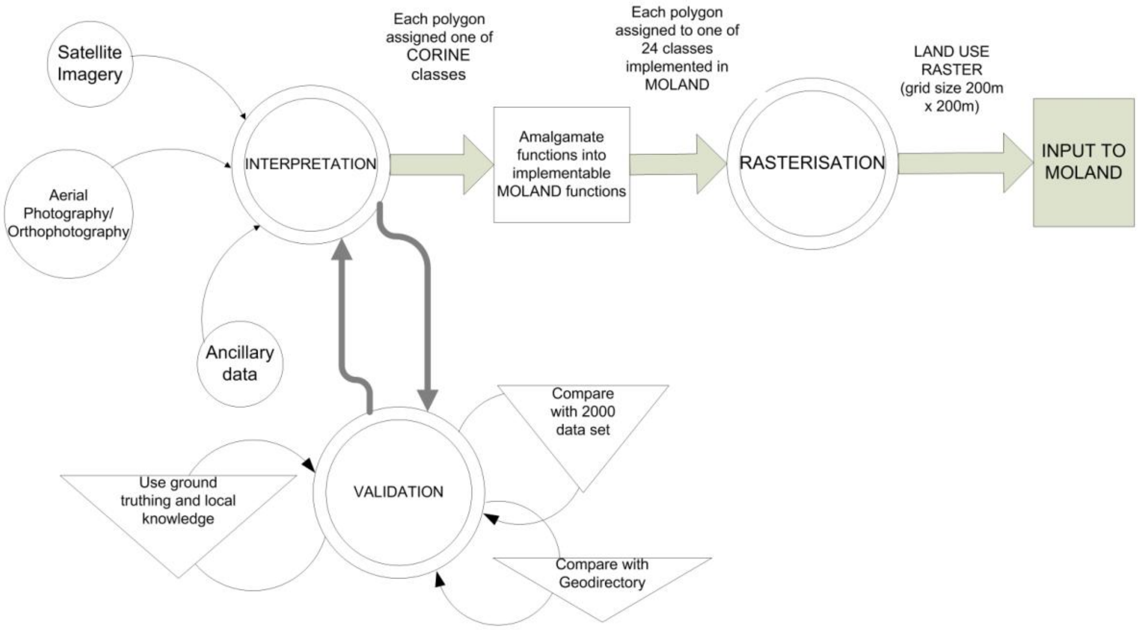


Figure 2 - Process of preparing land use map for input into MOLAND

[3] A georeferenced database containing a unique identity (stored as a point) for every building in Ireland.

3.1 MOLAND classification system

The MOLAND land cover dataset uses the CORINE land cover nomenclature that was first derived in 1985 by the European Commission Environment Directorate-General (DG) XI. In 1998 this was expanded by the Joint Research Centre (JRC) for the MURBANDY[4] project. MURBANDY was a precursor to MOLAND, which saw the minimum mapping area reduced from CORINE's 25 hectares (ha) to 1 ha for urban areas and 3 ha for rural areas. In 2000 this was further expanded to include unique areas in some new participating regions. The MOLAND classification system uses the more detailed CORINE level 4 nomenclatures for the classification of urban land cover (See Appendix A).

The CORINE land cover classification system was derived with a European-wide perspective, applying consistent criteria to land cover categories throughout the participating nations. For the most part these criteria can be applied to the Irish context without difficulty. However, residential development in Ireland can differ from typical European development patterns. Some specific cases are explained in further detail below.

3.2 Residential urban fabric

The nomenclature allows for two types of residential fabric – Continuous and Discontinuous. In the Level 4 system these are further broken down into dense, medium dense and sparse urban fabric. Difficulties arise when applying the criteria to developments in Ireland as the predominant residential structure type is two storey semi-detached housing with most having both a front and rear garden. The surface area covered by these residential developments would suggest continuity of urban fabric from an Irish point of view however they are disqualified from the 'Continuous' category as the criteria call for 80% structural coverage with three or more storeys. Intervening green spaces are not considered as part of the structure. We are then left with Discontinuous Urban Fabric. In the original 2000 interpretation the JRC determined that all such residential developments in Ireland should be classified as 'discontinuous sparse urban fabric' (CORINE class 1.1.2.2 in Appendix A). Issue was taken with this and in 2006 for the Urban Environment Project it was decided that these areas should come under the discontinuous urban fabric class (CORINE class 1.1.2.1 in Appendix A). The sparse urban fabric was reserved for rural residential areas and ribbon development.

The nature of Irish suburban development is changing. Residential developments are closer together. Most of the houses being built are still just two storeys but gardens and green areas are smaller than they were just 10 years ago (Figure 3). Interpreters believe that there is a case for regarding these areas as continuous urban fabric. It may be argued that, at the very least, in the Irish context there is a category missing between 'Continuous medium dense' and 'Discontinuous urban fabric' — a continuous fabric of residential structures that is based on units per hectare rather than on building height or presence of green areas.

The increase in the construction of apartment complexes, mostly on the edge of established residential housing estates, is a new feature in the development of Irish suburban areas. Building policy still favours limiting the height of these new structures and many are rarely higher than 5 storeys. Most will be 3 or 4 storey in height (DEHLG, 1999).

[4] MURBANDY – the name of the initial project managed by Institute for Environment and Sustainability, Joint Research Centre, European Commission circa 1990, which later evolved into MOLAND.

These new developments will often include common green areas as well as parking facilities. Many developments will offer a range of residential structures – 2 storey houses, 2-3 storey duplexes and 3-4 storey apartment buildings. There may occasionally be small commercial units incorporated into the development. It may be the case that one or more of these elements on their own may not reach the minimum mapping unit of 1 ha. In cases such as that illustrated in Figure 4 it was decided that such developments be regarded as 'discontinuous urban fabric' (CORINE class 1.1.2.1 see Appendix A).

(a) Established residential fabric (b) New residential fabric

Figure 3- Google Earth 2008 Images

Figure 4 - 2006 Quickbird Image – 0.6m resolution

3.3 Image interpretation for UEP MOLAND land cover dataset

The entirety of the 2000 MOLAND land cover dataset was interpreted from 5m pan-sharpened IRS satellite images displayed in true colour. False colour LISS images with a functional resolution of 20m were used to aid interpretation of vegetation cover in rural areas. While one of the highest resolution satellites providing imagery to the commercial sector at the time, the limitations of IRS for large scale urban mapping were evident from the outset. MOLAND employs a minimum mapping area of 1 ha for urban areas.

The images in Figure 5 show the difference in operating resolution between the imagery used for the 2000 interpretation (IRS) and that used for the main urban sector (so called Malahide corridor) of the 2006 interpretation (Digital Globe’s Quickbird satellite).

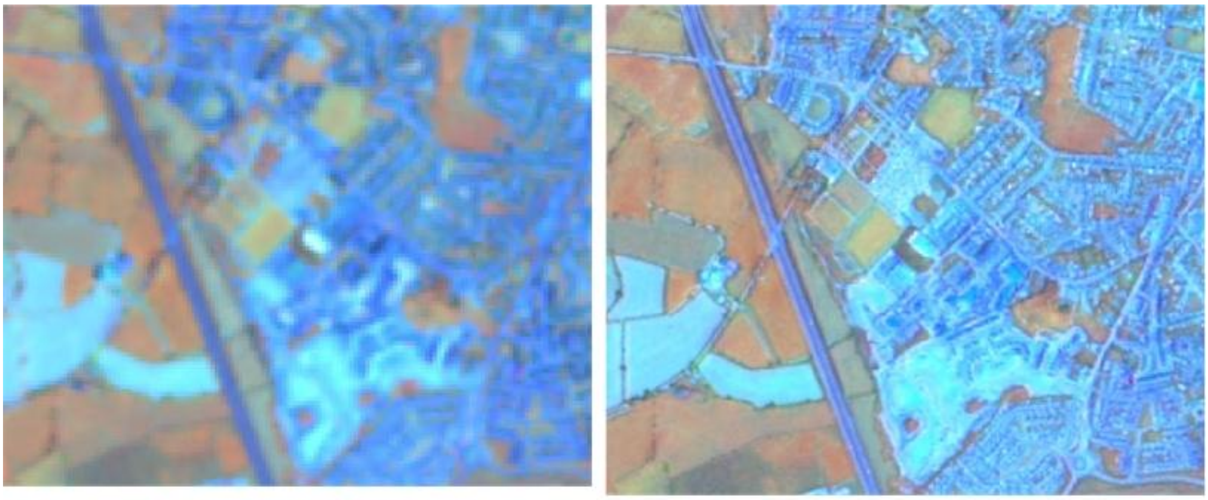
(a) IRS (b) Digital Globe’s Quickbird satellite

Figure 5 - IRS and Quickbird images

The land parcel highlighted is just slightly larger than 1 ha in area. This parcel was originally incorporated into the surrounding residential land cover class, as the observable commercial area seems too small to be identified as a separate polygon. The higher resolution image, however, shows a clearly defined parking area attached to the shopping complex in addition to further commercial premises in the south of the polygon. While both commercial structures existed in 2000, visual interpretation of this parcel was hampered by the homogenous nature of the southern building. It blended in with the surrounding residential pattern leaving the obvious commercial area polygon less than the minimum mapping unit size. Whilst local knowledge or a field survey for specific cases would have improved the accuracy of the dataset generated, this was not possible due to time and cost constraints.

These images show the difficulties faced by operators in 2000 while interpreting the land use of small parcels within the wider urban fabric. Decisions were made in good faith using the information that was available. It was decided though at the start of the 2006 project that, as well as interpreting changes in the land cover between 2000 and 2006; interpreters would endeavour to correct mistakes such as these as they were discovered.

Due to cost constraints image interpretation outside of the Malahide corridor area was based on SPOT 5 satellite images which are at a lower resolution (Figure 6). Where congruent images were available the 2.5m panchromatic image was merged with the 5m multi-spectral image to produce a pan-sharpened false colour 2.5m resolution image. The merged image product gives greater definition to artificial land cover and due to better edge detection allows for easier identification of land cover features. The images in Figure 6 show the difference in operating resolution between the merged and non-merged images. For the most part simultaneously acquired panchromatic and multi-spectral images were not available and unmerged images were used in tandem to identify features.



(a) 5m SPOT multi-spectral false colour (b) 2.5m SPOT pan-merged false colour

Figure 6 - SPOT 5 images

3.4 The importance of ancillary data

Ancillary mapping data was available to interpreters compiling the 2000 dataset; however it was, in places, inadequate or out of date. In some cases where the actual land use class was hard to distinguish there was no additional information available to assist in the classification. The publication date for the ancillary mapping data for Dublin city was 3 years prior to the acquisition of the imagery. The content itself can then be expected to be at least 1 year before this again. There was no comparable large scale mapping available to aid the interpretation of urban areas outside of Dublin city. This led to difficulties in the visual interpretation of the urban fabric.

Figure 7 shows an example of the two most mistaken land use categories in an urban context – Industrial Areas and Commercial Areas. Ancillary mapping data tells the interpreter, in this case, which of these remarkably similar buildings is the commercial area and which is industrial. However in the absence of this additional aid clues from the imagery are used to deduce the land use of each parcel. In this example, the blocks are located in a clearly residential area. At their closest point they are less than 200m apart. It is surmised that two commercial centres of this size would not be located so close to each other. Either they both are industrial areas or one of each. An interpreter would assume based on zoning or development policy that industrial facilities this close together would be continuous, uninterrupted by residential structures. Therefore it was deduced that the appropriate classification is one industrial centre and one commercial. To determine which is which the land immediately surrounding the structure is assessed. In the 2000 image the area above the factory does not appear to be a parking area. There are what appear to be containers, large vehicles or small structures. The shopping centre shows what would be expected of a parking area. So it was decided that the northern parcel was commercial and the southern area industrial. In the 2006 image it can be seen that the area beside the factory is indeed a car park - although it may not have been in 2000. The size of the parking area would confirm the assumption. A larger parking area would be associated with a commercial area. Underground parking structures connected to shopping complexes further complicate the matter. Ancillary mapping data greatly aid the interpretation of urban fabric.

Figure 7 - 2000 IRS and 2006 Quickbird images

3.5 Mixed use land cover parcels

The MOLAND nomenclature does not accommodate mixed-use classes. In city, town and village centre locations mixed-use residential/commercial units are common. There are no provisions for this in the interpretation rules for MOLAND. An interpreter has to decide which category is most prevalent and thereby takes priority. Where local knowledge was available, a note in the attribute table was inserted to indicate where mixed use classes occurred.

3.6 Preparing land use maps for input into MOLAND

In the MOLAND model as applied to the Greater Dublin Region, 24 land use classes are modelled. As the land use layer is initially codified into numerous classes (see Appendix A) these are aggregated to meet the model's requirements. In addition, MOLAND requires the land use maps to be in raster or grid format.

Sea and 500m inland buffer areas were added to the modelling area in order to increase the accuracy of the local sub-model (cellular automata) in the border areas (Figure 8).

The conversion from vector to raster grid was performed according to the maximum area principle which assigns pixel values based on the polygons with the largest combined area. To determine the maximum area, polygons with common land use classes are combined to produce a single area within the cell in question for consideration when determining the largest area. A polygon-to-raster conversion tool available in ArcGIS toolbox was used to accomplish this (Appendix B).

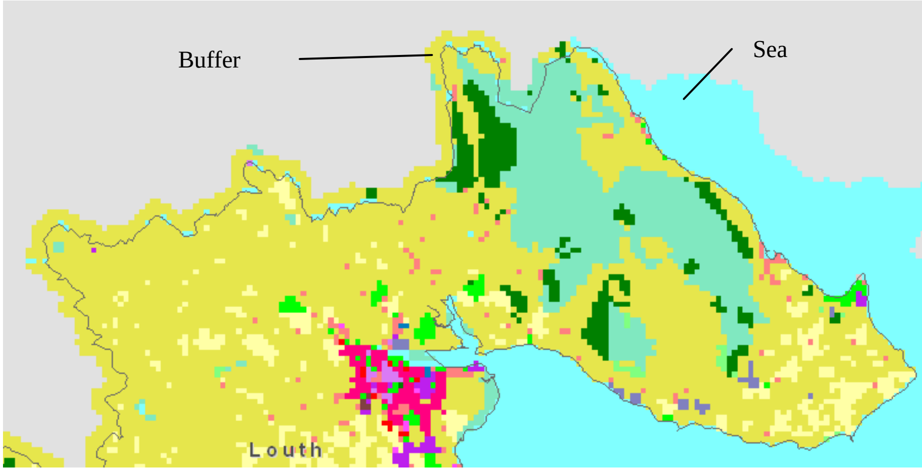


Figure 8 - A section of a land use map showing buffer and sea area

Figure 9 shows the 1990, 2000 and 2006 land use maps of the GDR. It was found that the residential cells increase significantly in 2006. Further comparison of these maps discovered an anomaly: in a few cases cells which are industrial, commercial or services in 1990 and 2000 raster maps, become residential in 2006 raster map (5, 2 and 3 cells respectively), although their areas remain unchanged in the 2006 source vector map. This is explained by the algorithm of the maximum area principle used during vector-to-raster conversion. In the mentioned cases, the polygons representing activities were surrounded by major residential areas in 2006. Due to the influence of the cells in each neighbourhood, these areas were converted to residential cells, using the "Polygon to Raster" tool in ArcGIS. Though it effects a relatively small number of cells (0.41% of all activity cells), the activity densities were affected: in some counties the number of activity cells decreased in 2006 in spite of an increase in the number of people engaged in that activity group. This influences on the MOLAND model productivity change calculation. In order to adjust this discrepancy a detailed check was implemented for activity classes after the polygon-to-raster conversion. Missing cells of activities were recovered in their location of 1990/2000; then appropriate quantity of residential cells was added on nearby arable land areas to ensure an accurate representation of residential cells.

4 Suitability Maps

Suitability represents the degree of relevance of each cell to each land use type, according to a set of predefined criteria. Thus, land use suitability displays locations that fulfil a suitability criteria defined for each land use class. Using multi-criteria analyses techniques, the relevant criteria can be derived from surveys of experts' opinions and longitudinal studies that detail suitability of land use classes over time. Depending on the land use types and purpose of the modelling, various datasets may be used as input for preparing the land use suitability maps, including the following (Engelen, 2004):

- Slope map
- Aspect map
- Soil quality map
- Agricultural capacity map
- Geomorphologic map
- Air, noise, water, soil pollution map
- Aquifers and salinisation
- Other maps that may be relevant to calculate physical suitability of the land
- Existing features such as water bodies, transportation networks, etc.

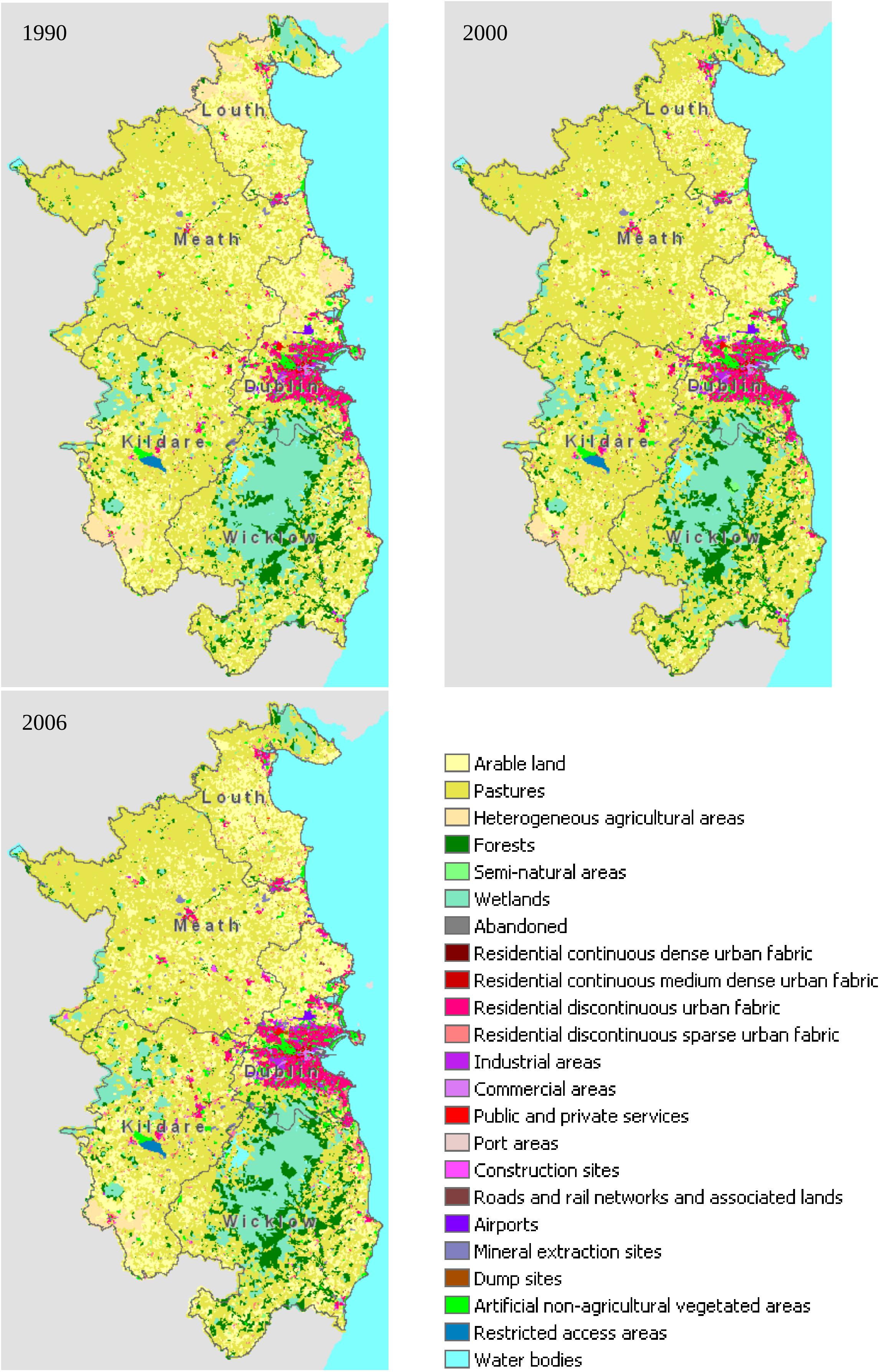


Figure 9 - GDR 1990, 2000 and 2006 land use maps.

For example, a cell's position relative to the transportation infrastructure might influence its suitability value. Also cells that are immediately adjacent to existing water bodies will have high suitability values for port related uses.

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 datasets. Researchers at the Joint Research Centre, Ispra had previously developed suitability maps under the aegis of MURBANDY. Due to time constraints it was not possible to generate new suitability maps 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 efficacious to use the suitability layers provided by previous researchers working with MURBANDY. The suitability criteria for elevation, slope, aspect and unidentified soil types have been manually extracted from the original suitability layer and have been presented in Appendix C for reference purposes. In further refinements of the model, a methodology could be developed to validate these suitability criteria.

Figure 10 shows examples of suitability maps for (a) residential continuous dense urban fabric and (b) port areas.

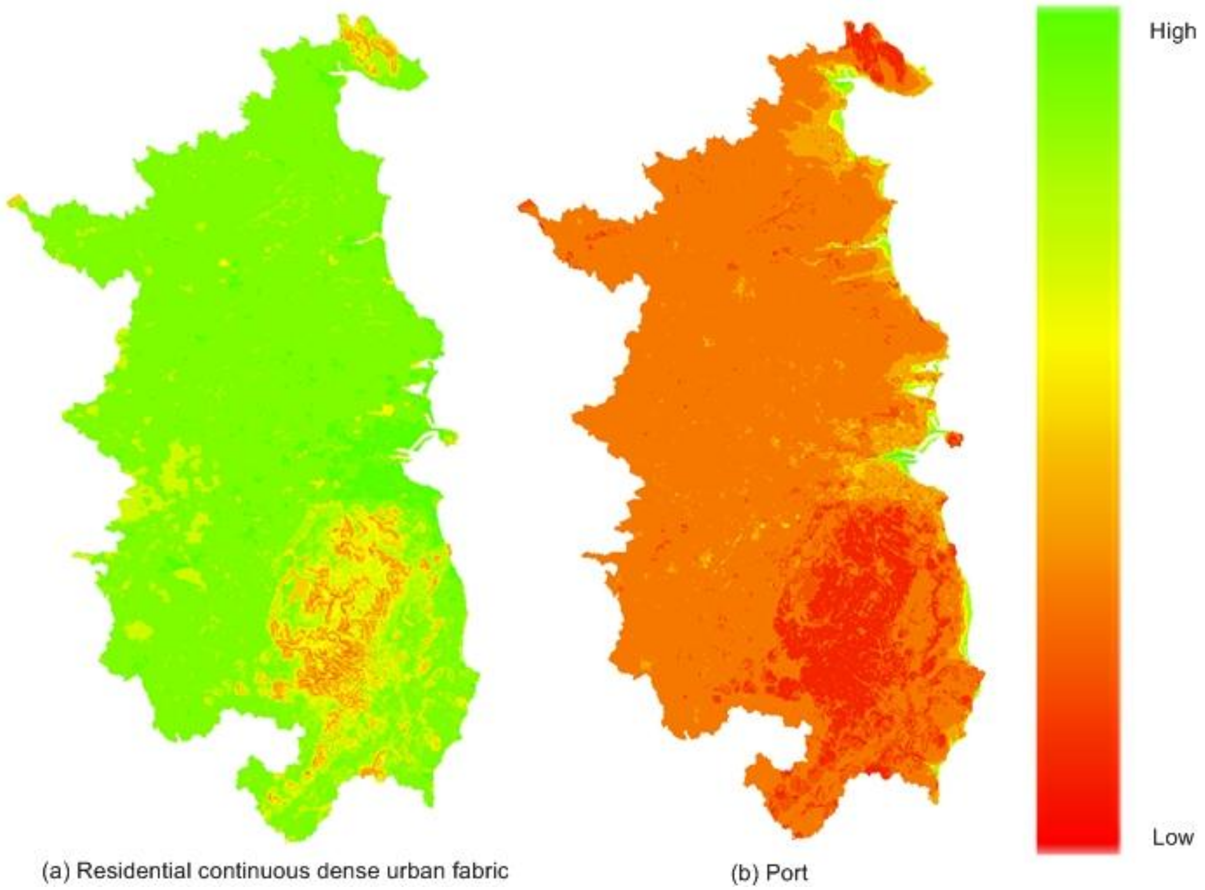


Figure 10 - Suitability maps of GDR for Residential continuous dense urban fabric (a) and Port areas (b)

5 Zoning Maps

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 a county development plan and since 2001 they have a six year statutory timeframe. Within the Local authorities of the UEP study area the majority of the plans cover the period 2005-2011 (Table 2). To accord with the reference year for updating MOLAND, 2006 was chosen as the nominal year for depiction of the zoning objectives across the GDR counties.

Table 2 - Time frame for current Development Plans, GDR Counties

GDR County	Current Development Plan
Fingal	2005 – 2011
Dublin City	2005 – 2011
Dun Laoghaire Rathdown	2005 – 2011
South Dublin	2004 – 2010
Kildare	2005 – 2011
Louth	2003 – 2009
Wicklow	2004 – 2010
Meath	2001 – 2007

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.

MOLAND models zoning 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 case is not reflected in the Irish context. Examination of the Irish zoning maps reveals four main zoning categories, namely:

- Permitted, i.e., generally acceptable in principle but subject to normal planning consideration, including policies and objectives outlined in the plan.
- 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.
- Not permitted.
- Other uses such as transitional zone areas.

Moreover, for permitted used of land, MOLAND uses only 3 zoning periods which are meant to correspond to the planning periods for which zoning regulations are typically prepared. These periods are as follows:

- Zoning period 0: from Start date of simulation ($t=t_0$) till first date set by user ($t=t_1$),
- Zoning period 1: from First date set by the user ($t=t_1$) till Second date set by user ($t=t_2$),
- Zoning period 2: from Second date set by the user ($t=t_2$) till the end of simulation.

The assumption is made that once a land use is allowed in a cell, it will be allowed for the remainder of the simulation period. Hence, in numbers varying from 0 to 3, the zoning maps indicate for each cell the period for which the land use is allowed in the cell:

- 0: the land use is allowed starting from zoning period 0,
- 1: the land use is allowed starting from zoning period 1,
- 2: the land use is allowed in zoning period 2,
- 3: the land use is never allowed.

Although, the time intervals t_1, t_2, and t_3 can be set by the user, they must be the same for all counties, but in the Irish context, this is hardly the case. Zoning regulations are prepared autonomously by each county and there is no guarantee that their period of validity will be the same for all counties (see Table 2).

For the GDR application initially attempts were made to apply direct translation of the development plans into zoning maps for MOLAND. This process was however tedious and time consuming due to:

- Poor data quality, incomplete and inconsistent data (e.g. attribute tables showing zoning objectives not coded consistently).
- Lack of homogeneity within one county (e.g. the use of different coding systems at different scales)

Due to the above problems, a one-to-one mapping of the zoning maps into MOLAND could not be incorporated into the model for calibration.

An alternative approach was implemented to avoid this problem, whereby zoning maps were developed which included special protection and conservation areas as well as national heritage areas. The same zoning map was applied for all residential and other urban (activity) land use classes (Figure 11).

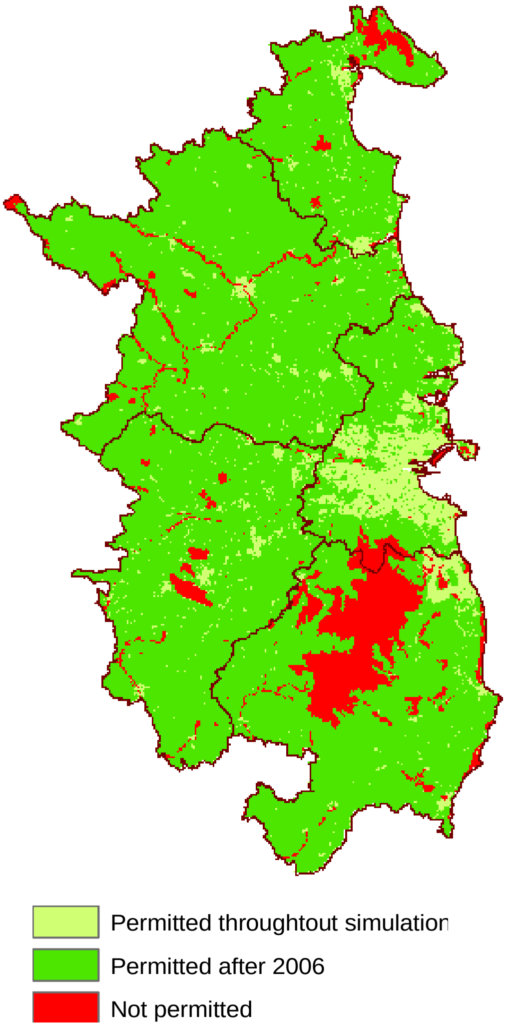


Figure 11 - Zoning map for residential and activity land uses

6 Transport Network

In addition to suitability and zoning, accessibility to the transportation networks is an important input into the MOLAND model, because arguably the most important driver of land use change is the degree to which services, markets and people can be reached. Accessibility maps capture the relative importance of access to the transportation networks for the various land uses. The MOLAND model creates accessibility maps as it runs based on the transport network and accessibility parameters. The networks of 1990, 2000 and 2006 years were used in the MOLAND model GDR application and are described in the following section.

A new transport sub-model is integrated in the latest version of MOLAND[5] (dated 07.04.2009, 13:55 in Shahumyan et al, 2009). The MOLAND transport model is based on a classical four step approach and is explained in RIKS' MOLAND Transport Model manual (RIKS, 2007). The land use model serves as an input to the transportation model, whilst the transportation model influences the land use model by means of a local accessibility term. This version of MOLAND requires a transport zone map of the region as well as data on transport flows between those zones. The number of people and jobs per zone are used to calculate the production and attraction of each transport zone. Trips are then assigned to the transport network based on these travel demands and the costs to move from one zone to another. The transport zone map and trips data used in the model are described in sections 6.2 and 8.

6.1 Roads and railway

The MOLAND model has specific requirements on the structure of the network files, which are especially important when the transport sub-model is included. Particularly, the road network should be a network where each link (edge) represents a road and each node represents a connection of roads (e.g. a junction or a change of properties). Along the link there may be waypoints, to give the road its shape. The network must be well connected, so that each node is reachable from every other node. The road network should be provided in shape format (.shp). The road network should not be limited to the region boundaries, but may be limited to the extent of the region map.

The road and rail networks of 1990, 2000 and 2006 years were used in the MOLAND model GDR application. A general assessment of the integrity of the 1990 and 2000 road dataset versus the 2006 dataset highlighted a number of inconsistencies. Positional errors of up to 400m were identified, which is significant given that the cell size of the model is $200m^2$. Moreover, different digitising rules were applied at complex junctions. Due to the above inconsistencies, it was concluded that the two datasets could not be used without modification. To avoid having to substantially modify the datasets for 1990, 2000 as well as for 2006, the 1990 and 2000 datasets were derived from the 2006 dataset, thus ensuring positional accuracy between the reference years. Using version numbers within the attribute table and comparing with reports produced by the National Roads Authority, as well as local knowledge, a high quality dataset for 1990 and 2000 was produced. This was done manually using the ArcGIS platform. With the help of local knowledge, the 2006 dataset was edited for 1990 and 2000, deleting all road segments which didn't exist in 1990 or 2000. Roads that were upgraded in the intervening years were renamed back to their status in 1990 and 2000, updating their attribute tables and colour codes.

A similar approach was adopted for deriving the rail network. This involved deleting stations, which were constructed between 1990-2000 and 2000-2006 and adding extra columns to the attribute table, one stating whether the mode is light or heavy rail and another containing a date stamp for when a particular line became operational.

For accessibility mapping the key data required is the position of motorways and primary and secondary road junctions. To ensure these positions were as accurate as possible the existing dataset was compared with ancillary data provided by the Dublin Transportation Office (DTO) and any required modifications applied to the dataset.

[5] MOLAND can be run both with and without the transport sub- model. To use the transport sub-model additional data is needed. This paper includes a full description of the data required in both cases.

The fields presented in Table 3 are required to be specified per link (road segment) for the MOLAND transport model.

Table 3 - Fields required in the road network shapefile for MOLAND transport model

Description	Field name	Unit
Accessibility type	AccType	-
Road type	RoadType	-
Free flow speed	SpeedLimit	kilometres/hour
Road capacity	Capacity	cars/hour
Road length	Length	metres
Road tax	ExtraCost	€

To use the same road network for the accessibility calculations in MOLAND, the road network requires an 'accessibility type' value. The first accessibility type should have value 0, and others should have consecutive values, corresponding to the road link styles provided in MOLAND. If a road should be neglected in the accessibility calculations, the accessibility type value is set to -1.

The free flow speed indicates the speed with which cars normally drive along the road if they are not hindered by other traffic (mostly this is the posted speed limit).

The road capacity indicates the number of cars that can maximally drive across this road. If this information is not available, it can be estimated by using the speed limit, the number of lanes available on this road and formula (1):

$$Capacity = \frac{nLanes \cdot 3600}{2 + \frac{CarLength \cdot 3.6}{SpeedLimit}} = \frac{nLanes \cdot 3600}{2 + \frac{16.2}{SpeedLimit}} \quad (1)$$

Road length indicates the length of a road segment, while road tax indicates the average road tax that has to be paid for using that road, for example tolls. Most of the road will have no road tax (value €0); only the road segments where a road tax is collected will have a positive value for road tax.

Table 4 summarises the road types and their appropriate field values used in the GDR road and rail network shapefiles.

Table 4 - Road types used in the MOLAND model GDR application.

	AccType	RoadType	Lanes	Speed	Capacity**
Motorway	0	1	2*	120	3372
Motorway Junctions	1	-1			
National Primary	2	3	2	100	3330
Regional Road	3	4	1	80	1635
Other Road	4	5	1	50	1549
Railway	5	-1			
Rail Stations	6	-1			

* In a few cases the motorway has 3 lanes.

** Capacity values are calculated using the above mentioned formula.

6.2 Transport Zones

The MOLAND transport model also requires a Transport Zones map: a map indicating the boundaries of the transport zones. It is recommended that these zones are sub-regions in the MOLAND model. The boundaries of the regions (counties) should also be boundaries of the transport zones; in other words a transport zone must be fully contained in only one county and every cell of each county should be covered by exactly one transport zone. The MOLAND model also requires that the transport zones map should cover exactly the same area as the region map and both maps should have the same resolution. The first transport zone is numbered 1; the other transport zones are numbered consecutively. Value 0 is used to indicate "not modelled area", and should cover the same cells as value 0 in the region map.

Based on the requirements described above the transport zone map of the GDR was developed using the boundaries of the Urban and Rural Districts defined by the CSO. Initially, thirty-three transport zones were defined for the 5 counties and Dublin city was covered by only one transport zone. Taking into consideration that most transport flows in the region take place in Dublin, the local electoral area[6] boundaries (Figure 12) were used in order to subdivide Dublin city into more than one zone.

Figure 12 - Dublin City Local Electoral Areas

The final transport zone map of the GDR has forty four zones and was converted to ASCII format.

Figure 13 shows the transport zone map and the transport network of the GDR developed according to the described requirements. The list of transport zones sorted by county is presented in Appendix D. Transport flow between the zones and data estimation methods are explained in Section 8.

[6] For the purpose of County Council and Corporation elections each county and city is divided into Local Electoral Areas. In general, these areas are formed by aggregating Electoral Divisions.

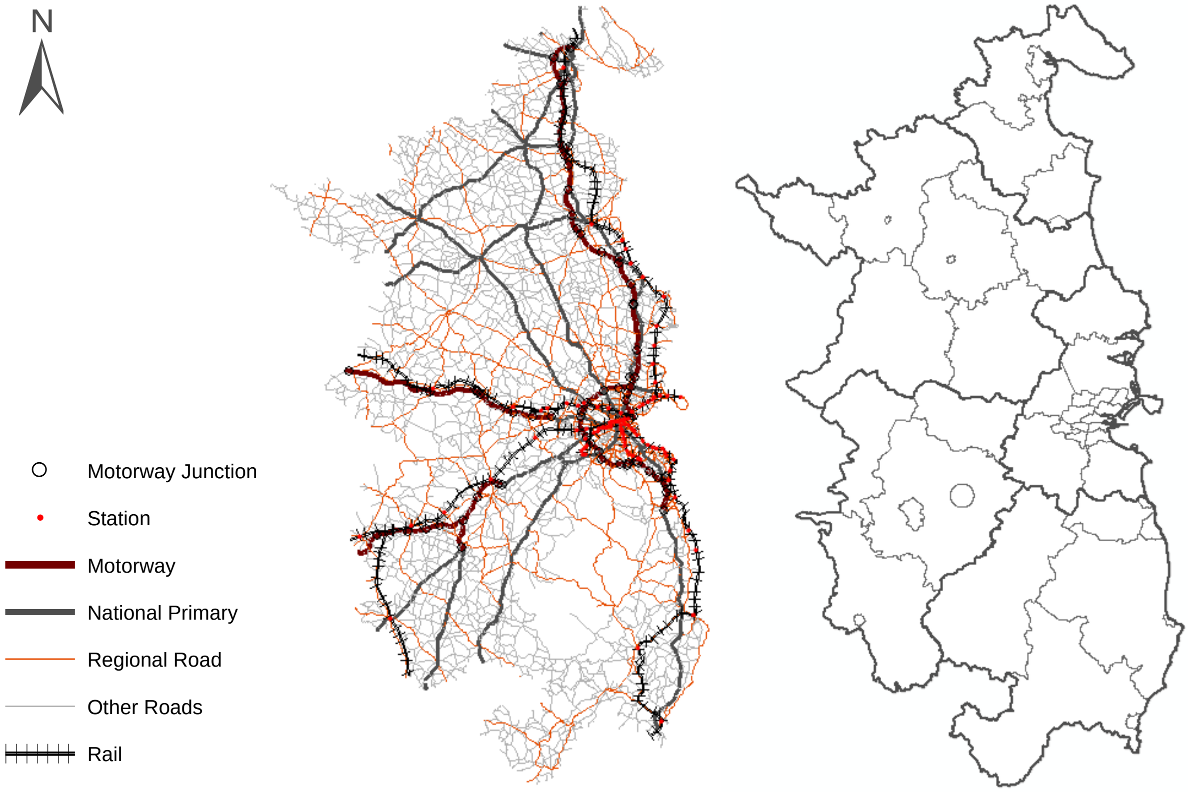


Figure 13 - GDR 2006 transport network (left) and transport zones (right)

7 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). These are:

- Population counts
- Employment counts by broad industrial groups
- Population projections

Unfortunately there were some significant gaps in data availability. A combination of interpolation and extrapolation methods was applied to estimate missing data and fill the gaps with reasonable figures. These are discussed in detail in the following sections.

7.1 Population counts

The CSO implemented the last five censuses in the Republic of Ireland in 1986, 1991, 1996, 2002 and 2006. Therefore population data for these years is reliable, while population counts for the intervening years are by definition estimates (Table 5). For the GDR model calibration population data for 1990 and 2000 are also required. The average annual increase between 1986 and 1991 has been applied for 1990 population estimation and an average annual increase between 1996 and 2002 years was applied for 2000 using the following formulas:

$$P_{1990} = P_{1986} + \frac{4}{5}(P_{1991} - P_{1986}) \,, \quad P_{2000} = P_{1996} + \frac{4}{6}(P_{2002} - P_{1996}) \,, \qquad (2)$$

where P_y is the population in year *y*. The results are presented in Table 5.

Table 5 - Population counts used in calibration

	1986	1990*	1991	1996	2000*	2002	2006
Louth	91,810	90,941	90,724	92,166	98,603	101,821	111,267
Meath	103,881	105,072	105,370	109,732	125,914	134,005	162,831
Dublin	1,021,449	1,024,533	1,025,304	1,058,264	1,101,302	1,122,821	1,187,176
Kildare	116,247	121,374	122,656	134,992	154,293	163,944	186,335
Wicklow	94,542	96,720	97,265	102,683	110,678	114,676	126,194
Total	1,427,929	1,438,641	1,441,319	1,497,837	1,590,790	1,637,267	1,773,803

* Estimated values

7.2 Populations within residential land use types

There are four residential land use classes, namely Continuous dense, Medium dense, Discontinuous and Discontinuous sparse used in the current land use maps in the model (Appendix A). In the last available version of MOLAND (Shahumyan et al, 2009) it was not possible to calibrate land use productivity values for each of the residential types separately and a single productivity value is used for all residential classes. To overcome this limitation, and taking into account that within the Greater Dublin Region discontinuous urban and discontinuous sparse urban categories form the vast majority of the residential land use cover, we have artificially split population into two groups for the macro-model. The two groups are i) Sparse; which is provided for within the Discontinuous sparse urban fabric land use class and ii) Other; which is provided for within the remaining three residential land use classes in the micro-model. This approach allows for two different productivity values to be used (one for residential sparse and another for the remaining residential classes), which increases the model's flexibility.

For estimation of population in each described group, population densities in sample EDs from each county were used. EDs were included in the sample only if the relevant residential class was present in all 3 time periods (1990, 2000 and 2006). County values were calculated as the mean of the sample of EDs (Appendix E). Then, population was distributed into two residential groups based on the cell number and density values by county using the formulas given by (3):

$$P_{sparse} = D_{sparse} \cdot C_{sparse}\ , \qquad P_{other} = P_{total} - P_{sparse}\ , \qquad (3)$$

where *P* is the population, *D* is density and *C* is cell numbers in that category. The results are shown in Table 6.

Table 6 - Population split within residential land use types for calibration

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

7.3 Employment data estimation

Employment data for the model is best input as place of work data when available. Unfortunately, in Ireland, place of work data is currently available only for 2002 and 2006, when the CSO implemented the Sample of Anonymised Records (CSO, 2002) and Census of Anonymised Records (CSO, 2006).

For all other censuses occupational data was collected by place of residence only. 2002 and 2006 datasets were used to estimate the appropriate place of work data for 1990 and 2000.

There were about 17 sub-categories in the CSO employment datasets altogether and these were reclassified to fit the broad Industrial, Commercial, Services classes that MOLAND requires (Appendix F). Besides the listed groups there were also "Other" and "Not stated" groups for each census (see Table 7). These have been distributed proportionally among MOLAND's three classes.

Table 7 - Percentage of "Other" and "Not stated" industries from the total employment figures of GDR.

Year	Source	%
1996	Census	2.6%
2002	Census	7.2%
	POWSAR	13.0%
2006	Census	8.0%
	POWSAR	16.7%

Initially, the place of work data was estimated for 1991 and 1996 using known proportions for 2002:

$$PW_y = PR_y \frac{PW_{2002}}{PR_{2002}} \quad , \quad (4)$$

where PW_y is number of employees by place of work, PR_y is the number of employees by place of residence in year *y* (1991 and 1996), and the equation is evaluated for each county.

Then 1990 and 2000 county data were estimated by (5) using data for 1991, 1996 and 2002:

$$PW_{1990} = PW_{1991} - \frac{1}{5}(PW_{1996} - PW_{1991}) \; , \quad PW_{2000} = PW_{2002} - \frac{2}{6}(PW_{2002} - PW_{1996}) \qquad (5)$$

The results are presented in Table 8.

Table 8 - Place of work data by counties for each industrial group.

	1990	2000	2002*	2006*
Industry				
Louth	9,669	13,179	13,968	18,236
Meath	9,888	17,285	19,435	31,040
Dublin	119,521	156,939	168,969	157,388
Kildare	11,934	22,231	26,844	33,626
Wicklow	8,959	13,860	15,234	19,453
Total	159,971	223,494	229,216	259,743
Commercial				
	1990	2000	2002	2006
Louth	6,101	9,139	10,202	14,970
Meath	4,555	8,688	10,108	23,693
Dublin	148,331	209,911	227,642	233,976
Kildare	6,499	12,826	14,674	29,199
Wicklow	6,065	9,822	10,898	19,886
Total	171,552	250,386	273,524	321,724
Services				
	1990	2000	2002	2006
Louth	5,142	8,310	8,957	12,130
Meath	3,828	7,284	8,166	17,750
Dublin	97,013	133,591	138,952	146,011
Kildare	6,395	10,790	11,806	22,539
Wicklow	3,864	6,699	7,218	13,349
Total	116,242	166,673	175,099	211,779

* 2002 and 2006 columns are official data from CSO POWSAR and POWCAR datasets. The remaining columns are estimates.

7.4 Population and employment projections

Population projections are necessary to check the reliability of the model as well as to run different scenarios into the future. 2026 was selected as an appropriate endpoint for running model simulations. It is 20 years after the most up-to-date dataset and it is used in the CSO's most recent population projections for Ireland (CSO, 2008). In addition, 2050 was defined as the end year for long term runs of the model for the purpose of testing the long term effect of calibration.

CSO's regional population projections contain projections for the eight Regional Authority areas for 2011-2026 (CSO, 2008). Assumptions for regional fertility and mortality trends and international migration to and from each region were consistent with those used at national level. The internal migration scenarios were developed due to differences found between censuses carried out up to 1996 versus the 2002 and 2006 censuses. The 1996 and pre-1996 censuses reveal a fairly stable picture in terms of the magnitudes of the inward, outward and net migration flows, with the Dublin and Mid-East regions receiving positive net migration flows while all other regions had negative flows. This flow pattern was reversed in the 2002 and 2006 censuses. Due to the lack of stability in internal migration movements over the period 1996 to 2006, two internal migration scenarios were formulated. "Recent", assumes that the patterns observed in 2002 and 2006 apply up to 2026, while under "Traditional" the 1996 pattern of inter-regional flows is applied in 2016 and kept constant thereafter, with the difference between the 2006 and 1996 patterns apportioned over the years between 2006 and 2016. The fertility rate is assumed to remain at its 2006 level of 1.9 for the lifetime of the projections (CSO, 2008).

The CSO projection "M2F1 Traditional" was used for calibration testing purposes. It combines continuing though declining international migration with constant fertility and a return to the traditional pattern of internal migration by 2016. But, the Greater Dublin Area (GDA) used in CSO projections, comprising the Mid-East region and the Dublin region, is of similar, though not identical extent to the MOLAND study area (GDR). The GDA consists of the Dublin, Meath, Kildare and Wicklow counties. The MOLAND study area consists of the Dublin, Meath, Kildare, Wicklow and Louth counties. Thus it was necessary to estimate the population for Louth in 2026 and add it to projected GDA population in 2026. This was done as follows:

Louth's population in 2006 was known from CSO data as 111,267 people. Louth's population in 2026 was estimated using (6):

$$P_{2026}^{Louth} = P_{2006}^{Louth} \frac{P_{2026}^{Border}}{P_{2006}^{Border}} \quad , \qquad (6)$$

where P_y^R is the population of region R in year y. "Border" refers to the Border region to which Louth belongs. The resulting value was added to the corresponding GDA population projections (Table 9). The population of the GDR in 2050 was estimated based on the linear projection of the growth from 2006 to 2026.

Place of work datasets for 2000 and 2006 were used to estimate the appropriate place of work data for 2026 and 2050 using an annual linear growth rate:

$$PW_{2026} = PW_{2006} + \frac{20}{6}(PW_{2006} - PW_{2000}) \ , \quad PW_{2050} = PW_{2006} + \frac{44}{6}(PW_{2006} - PW_{2000}) \ . \qquad (7)$$

The final data used in the MOLAND macro-model for the current research is presented in the following table:

Table 9 - Total population and employment data of GDR used in the MOLAND model.

	1990	2000	2006	2026
Population (total)	1,438,641	1,590,790	1,773,803	2,553,149
Population (other)	1,160,040	1,289,575	1,437,010	2,068,381
Population (sparse)	278,601	301,215	336,793	484,768
Industry	159,971	223,494	259,800	380,573
Commerce	171,552	250,386	321,790	559,519
Services	116,242	166,673	211,656	362,129

8 Traffic Flows

8.1 An introduction to the data requirements

In order to populate the various tables within the transport model, an examination was carried out of the 2006 Place of Work Census of Anonymised Records (POWCAR) data set provided by the CSO. This dataset contains just over 1.8 million records and provides information at an individual, but anonymised, level for all persons over the age of 15 years in the State (CSO, 2006). Information is provided about place of residence, down to an ED level, and place of work, down to a 250 sq m level, along with socio-economic information and information about the principal mode of travelling to work, school or college.

Within the remit of the transport model data preparation scheme, a series of matrices are required to describe the number of trips within the study area. These trips flow from one origin to multiple destinations and vice versa. As a result, the information from POWCAR of most use in this work is that pertaining to both place of residence and place of work, on an ED level, and on the means of travel to work. Thus, the transport model database under examination in this work is a reduced version of POWCAR, containing the following fields: county of residence (for tracking and verification purposes), ED of residence (for the allocation of appropriate transport zones), county in which the person works (again, for tracking purposes), place of work ED (for assignment of the appropriate transport zone number), mode of transport (using the CSO descriptors) and time of journey (for determination of model time steps).

The initial process involves the development of the 2006 transport situation matrices. From the point of view of adequate calibration, it is also necessary to develop a series of matrices that can describe the 2000 situation. In the absence of firm data for this year, a set of assumptions, described later, are made in order to estimate 2000 levels in terms of trip numbers.

8.2 Preparation of transport model matrices – the 2006 case

The main POWCAR table was reduced from 1.8 million records, to cover just those living and working in the study area, consisting of counties Dublin (incorporating each of Dublin City, Fingal, Dún Laoghaire-Rathdown and South Dublin), Louth, Meath Kildare and Wicklow. This amounts to 795,373 records. Since only mechanised modes of transport are considered by the model, this was further reduced to those who use public (bus, coach, train, DART or LUAS) or private (passenger car) transport. These account for 136,783 and 416,432 trips respectively each morning. It should also be noted that since we are interested in the number of vehicles on the road in the case of private transport, only entries where people reported that they were the driver of a vehicle are considered.

Although a number of trips do originate outside the study area and end within it, and vice versa (correspondingly 5.2% and 1.8% for private transport; and 2.2% and 0.4% for public transport), it is difficult to account for these extra trips in a reasonable way, particularly in the absence of suitable macro model data pertaining to the number of people or jobs outside the study area. Since these extra populations and jobs provide the origins and destinations for trips within the transport model, the inclusion of these excess trips would artificially skew the trip profiles, which should match both the population and the number of jobs within the study region.

Having described a set of 44 transport zones within the study area, a Structured Query Language (SQL) algorithm was developed to assign the appropriate transport zone number to each of the 628 EDs in the study are. The zone identifier was assigned to both the origin ED and the destination ED for each record. It was also necessary to introduce a virtual zone, denoted Zone 0 to account for the fact that certain trips were not assigned a specific end point but are assumed to end in the study area.

These allocations allowed for further interrogation of the SQL dataset, using the appropriate nested query loops, to generate a matrix containing the number of trips generated during the morning peak period from each origin zone (44 in total) to all destination zones (45 in total). The algorithm was applied separately for both public (Mode 3 and Mode 4 as per the POWCAR descriptions) and private (Mode 6) transport means.

The following sections describe some of the specific detail involved in preparing these data sets.

8.3 Private transport matrices

Having generated the appropriate matrix for counts of private transport trips for all zones within the study area, the so called initial matrix, it is necessary to redistribute trips which end in Zone 0. In order to do this, a simple algorithm was applied, whereby a proportional number of trips ending in Zone 0 were reassigned to each other destination according to (8):

$$T_{i,j}^{F} = T_{i,j}^{1} + T_{i,0}^{1} \cdot \left(\frac{T_{i,j}^{1}}{\sum_{1}^{j} T_{i,j}^{1}} \right), \quad (8)$$

where $T_{i,j}^{F}$ is the element entry in the final transport matrix, $T_{i,j}^{1}$ is the initial matrix element value, and $T_{i,0}^{1}$ is the initial matrix element entry for Origin Zone *i* going to Origin Zone 0.

Thus, a final matrix of 44 origins and their 44 corresponding destinations is described in terms of total trips by personal transport over a three hour period, as reported by POWCAR. While the original data does allow for people to start their journey before 6:30 am or after 9:30 am (3 hours), such trips account for only 6% of the national dataset for private transport and virtually none of the public transport entries. Thus, since within the MOLAND model we require a number of trips per hour, each value in the matrix is divided by three, resulting in a total of 138,810 trips per hour for the morning peak period.

Three time periods must be described within this version of the model, corresponding to a 3-hour morning peak, a 3-hour evening peak and an 18-hour rest of day situation. As a consequence it is necessary to define two further matrices. In each following case, the final morning peak matrix, describing hourly trip numbers, is used as the basis for all other derived matrices.

In a generalised sense, the evening peak matrix should simply be the transpose of the morning matrix. However, examination of traffic counts within the Dublin City area, provided by Dublin City Council, has shown that the evening flows of traffic within the Dublin area are often higher than the morning peak (Casey et al., 2009).

In order to examine this hypothesis more fully and since the study area is larger than just the Dublin City Council areas; an analysis of the National Roads Authority (NRA) traffic counts[7] was carried out for 14 sites, two on each of the seven major arterial roads into and out of Dublin. Hourly traffic flow data, average for an entire year, is presented for weekdays, Saturdays and Sundays. A selection of curves is described in Figure 14 and shows the very distinct diurnal pattern of vehicle flows within the Dublin area. The bulk movement of vehicles into the city takes place in the morning, from approximately 6:00 am to 9:00 am. The bulk movement of vehicle out of the city takes place from mid afternoon, say 2:00 pm, and continues until mid evening, say 6:00 pm. The middle of the day inbound traffic is effectively a plateau whereas the outbound flow tends to build steadily from mid-afternoon.

In order to account for this trend within the transport model data, it was decided that the transposed evening matrix should also be scaled in order to account for the extra flows of traffic. Table 10 shows data pertaining to traffic counts at various locations used to determine an appropriate scaling factor. These scaling factors are calculated by examining the maximum hourly flow values for the morning and evening peak periods and examining the average off-peak daytime and night-time flows.

Since the POWCAR data pertains to the morning peak traffic conditions, the morning peak value reported by the NRA was taken as the 100% condition. Thus, where the evening peak is higher, the value in the transposed morning matrix should also be higher. The general parameter value was set at 1.08, an average value for all 12 detector points as described by the 2006 NRA dataset.

However, it is not reasonable to suggest that a larger number of vehicles moved within each zone in the evening. Rather, the traffic counts would suggest that these extra trips were inter-zonal, rather than intra-zonal. As a consequence, only the off-diagonal values of the evening peak matrix were scaled by a factor of 1.08.

In order to account for the lower number of trips during the rest of the day, which sums to 18 hours, another scaling scheme was developed. As before, the final morning peak matrix is considered as the base condition and is scaled accordingly.

In Figure 14 the morning and afternoon peaks can be observed with a considerable number of vehicles moving during the interim day period, accounting for approximately 59% of the morning rush-hour value. The night period, that is, after 9:00 pm and before 6:00 am, accounts for a very small number of vehicles, perhaps only 3% of the morning peak. However, the current model requires that an hourly description of trips be described for this combined ‘all other times’ period. Thus, in the same way as the scaling of the evening peak, a compound scaling function was developed:

$$T_{i,j}^{F} = \frac{7 \cdot (T_{i,j}^{1} \times SF_{o,d}) + 11 \cdot (T_{i,j}^{1} \times SF_{o,n})}{18} , \qquad (9)$$

where $T_{i,j}^{F}$ and $T_{i,j}^{1}$ have the same meanings as before, $SF_{o,d}$ and $SF_{o,n}$ are the day and night scaling factors respectively, as described in Table 10, and the numeric values refer to the number of hours

[7] These datasets can be accessed at http://www.nra.ie/NetworkManagement/TrafficCounts/, last accessed 01 October 2009.

assigned to the daylight and night-time periods, totalling 18 hours. Thus, each value within this matrix refers to the per hour number of trips for the rest-of-day conditions.

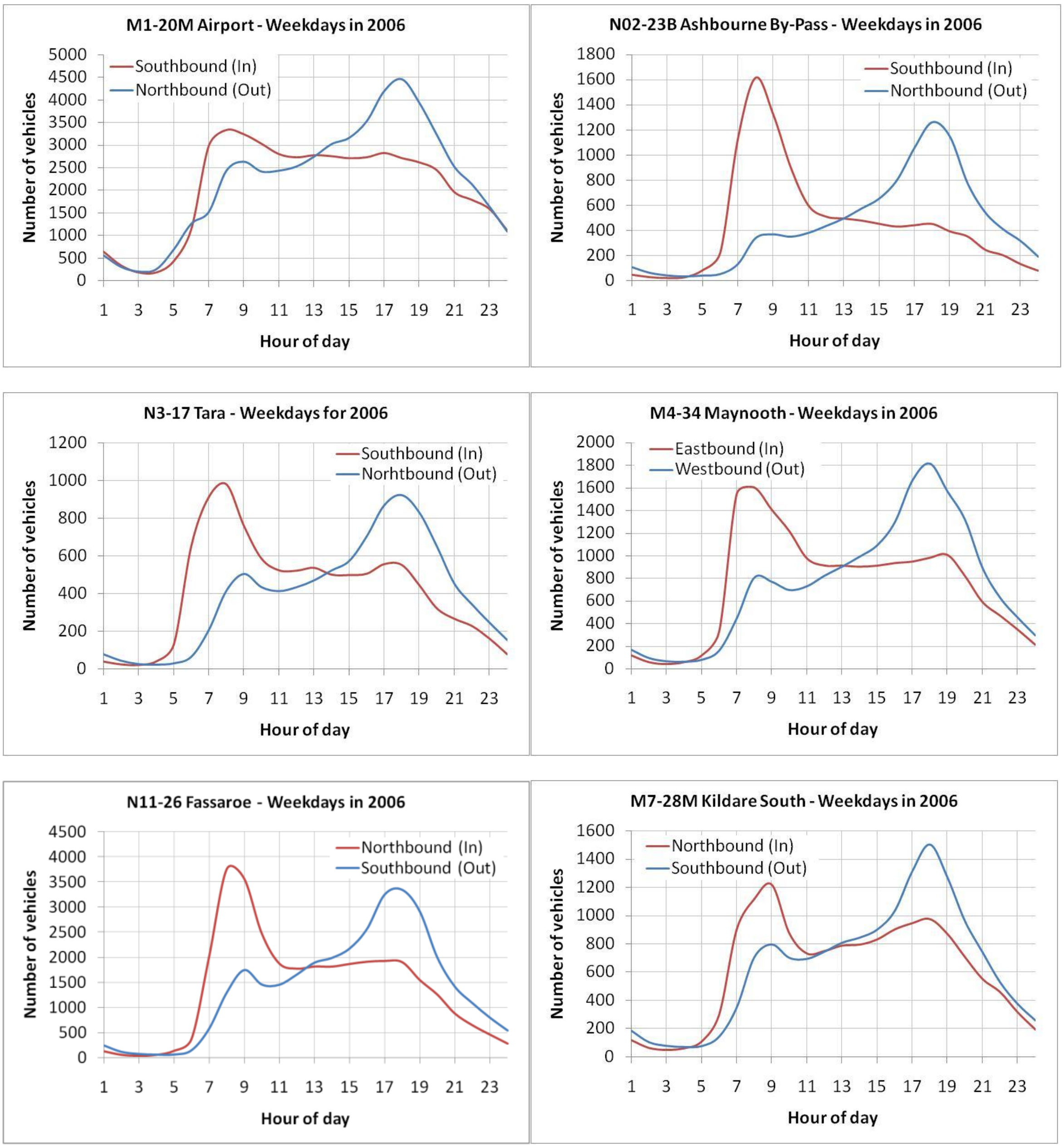


Figure 14 - Selection of traffic flow descriptions within the Dublin study area in 2006.

This particular scheme does mean that the number of 'daylight' rest-of-day trips is somewhat reduced and the number of 'night-time' trips is higher than it would normally be. However, since the model does not consider the actual time of the trips in a strict hour-by-hour sense, the average value is satisfactory.

Thus, at this point, a set of three matrices have been developed to describe the number of private transport trips per hour during each of the required time periods. The next phase is to prepare the same set of matrices for the public transport modes.

Table 10 - Traffic count values to determine scaling factors for peak and off peak traffic flows.

Road - Detector*	Traffic Volumes (vehicles per hour) Peak		Off-Peak		Scaling factors (against morning peak values) Peak		Off-Peak	
	Morning	Evening	Day	Night	Morning	Evening	Day	Night
N1-20M	4,467	3,334	2,763	196	1.00	1.34	0.93	0.06
M1-17M	2,995	2,992	1,280	83	1.00	1.00	0.43	0.03
N2-23B	1,617	1,260	495	31	1.00	0.78	0.31	0.02
N2-23	1,663	1,781	1,330	56	1.00	1.07	0.80	0.03
N3-13	593	669	398	19	1.00	1.13	0.67	0.03
N3-17	979	922	504	25	1.00	0.94	0.51	0.03
M4-34	1,604	1,818	908	51	1.00	1.13	0.57	0.03
M4-35	2,151	2,295	1,189	60	1.00	1.07	0.55	0.03
M7-28M	1,503	1,219	799	66	1.00	1.23	0.66	0.05
M7-35	2,372	3,014	1,438	99	1.00	1.27	0.61	0.04
N11-14	1,054	1,138	538	20	1.00	1.08	0.51	0.02
N11-26	3,758	3,345	1,856	48	1.00	0.89	0.49	0.01
Average Scaling factor values:					1.00	1.08	0.59	0.03
					$SF_{p,m}$	$SF_{p,e}$	$SF_{o,d}$	$SF_{o,n}$

* The detector numbers refer to the specific location within the NRA network from where measurements were taking. See http://www.nra.ie.

8.4 Public transport matrices

An identical process is carried out when preparing the public transport matrices. Again, a set of three matrices, describing morning peak, rest-of-day and afternoon, peak are required. A modified SQL query, asking for data pertaining solely to Travel Modes 3 and 4, is employed to derive two 44 × 45 matrices, one for each of the aggregated classes of public transport as described by POWCAR.

Again, trips that end in Zone 0 are proportionally redistributed according to (8) above.

These two matrices now contain 1,936 entries (44 × 44) and information about 136,783 trips, 87,181 pertaining to road based public transport (Mode 3) and 49,602 pertaining to rail based transport, completed over a three-hour period. Again, since only a single hour is needed the entries in the matrix are divided by three, resulting in 29,060 and 16,534 trips for road and rail methods respectively.

Unlike the private transport case, where a scaling had to be applied to the transposed morning peak matrix in order to describe the evening peak values, a straight-forward transpose is sufficient. This is due to the fact that, in general, the number of services by public transport systems tends to be similar for the morning and evening periods, as described in Figure 15. Here, a small sample of Dublin Bus's scheduled services is examined for diurnal trends. However, in a general sense, the very striking diurnal pattern observed in Figure 14 is not repeated here, in terms of a very definite inward flow of vehicles to the city centre in the morning and a mass exodus in the evening. Instead, the scheduled services tend to mirror each other in both directions, with some small variation. It is also interesting to point out that the afternoon peak in offered bus services occurs at around 4 pm, whereas the traffic flows show that the largest number of people use the network at around 6 pm or later. As a result of these observations, and similar analyses of rail services it is deduced that the morning matrix need only be transposed to produce a suitable evening matrix.

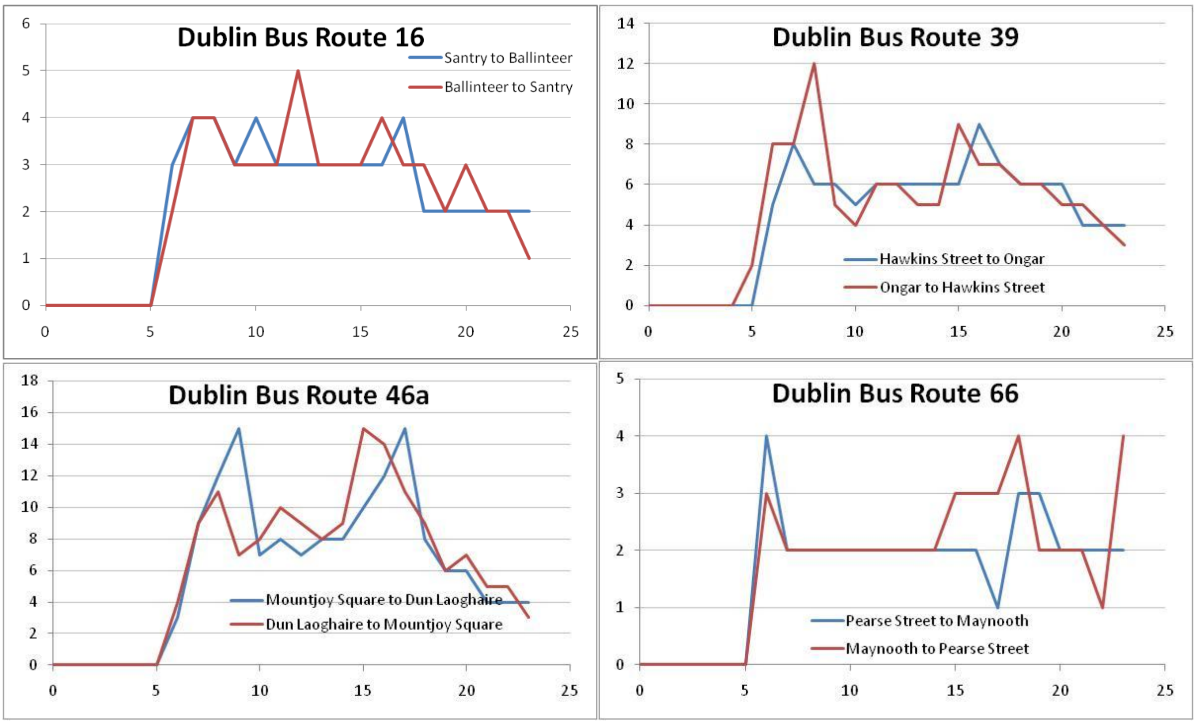


Figure 15 - Bus numbers as a function of time of day on selected Dublin Bus routes, serving Ballinteer (16), Palmerstown (39), Dun Laoghaire (46) and Maynooth (66). No significant diurnal trend is observable and numbers of busses both inbound and outbound effectively mirror each other.

Complications arise when trying to quantify rest-of-day trips. In the case of private transport, the number of vehicles that move within the transport matrix are considered and are easily quantified. However, for public transport, it is necessary to consider the number of people that move. Thus, detailed descriptions of the occupancy of busses and trains at off peak times are needed to better describe the number of trips during these periods. While ticketing systems can be used to describe the number of people entering a bus, tram or train, the number of passengers alighting can be difficult to quantify, making destinations difficult to determine accurately. The studies are still continuing at present to estimate these data in a reasonable way.

8.5 Preparation of transport model matrices – the 2000 case

In order to allow for a suitable calibration process, it is necessary to have transport information about the year 2000. However, no Census was taken in that year and the information contained in the nearest Census of 2002 does not contain the same level of information about travel patterns. Thus, a series of estimates had to be made in order to scale the 2006 matrices, of which there are now six, to a suitable level for 2000.

8.5.1 Private transport matrices for 2000

In the case of private transport, it was possible to examine more historic NRA data in order to determine if a sensible scaling factor could be applied to the 2006 matrices to produce reasonable values for 2000. This was achieved by examining the annual average daily traffic (AADT) values as reported by the NRA. This value describes the number of vehicles that use a road, in both directions, averaged over an entire year. Normally this value is used to determine suitable intervals for maintenance work but investigations as part of this work also showed that a standard trend was evident when examining AADT values for each of the detectors for both 2000 and 2006. Table 11 contains some summary information from these analyses.

Table 11 - Comparison of 2006 and 2000 AADT and hourly peak traffic flows for the determination of suitable scaling factors

Road - Detector	AADT			Maximum Hourly Peak Vehicle Flows					
	2006	2000	% of 2006	2006		2000		% of 2006	
				Morning	Evening	Morning	Evening	Morning	Evening
N1-17	49,253	25,105	51%	2,995	2,992	1,268	1,183	42%	40%
N2-23	19,311	20,370	105%	1,663	1,781	1,017	1,020	61%	57%
N3-17	18,417	15,178	82%	972	922	787	768	81%	83%
M4-35	45,091	32,273	72%	1,073	1,332	1,637	1,668	153%	125%
M7-35	50,384	31,962	63%	2,178	2,859	1,075	1,472	49%	51%
N11-26	61,710	35,816	58%	3,544	3,414	1,786	1,872	50%	55%
		Average:	72%				Average:	73%	69%

It should be noted that a considerable amount or work was carried out on the road network between these two years, including the opening of relief roads or the upgrading of the network. As a result, the AADT on some roads dropped between 2000 and 2006, most notably on the N2 at the Ashbourne Bypass. Similarly, maximum hourly flows have also been modified, such as on the M4 at Maynooth. In 2000, this road was still designated as N4 whereas by 2006 it had been fully upgraded to M4. The opening of alternative routes also removed a large number of vehicles from these roads.

A standard scaling factor became quite evident, as shown in Table 11 and analysis of the peak flow conditions for 2000 showed almost identical trends to that of 2006. Thus, a standard scaling factor of 0.71 was applied to each value in the morning peak, rest-of-day and afternoon peak 2006 matrices in order to develop the 2000 values.

Perhaps a more reasonable solution would be to simultaneously examine vehicle numbers in order to determine whether this number of trips could have been generated. It would also be useful to compare regional population figures to examine whether there was a suitable population to drive these vehicles, rather than just assume that the trends were valid. However, limited vehicle information, combined with limited availability of population estimates (since Census took place in 1996 and 2002) mean that this estimate is satisfactory.

8.6 Ancillary data

In conjunction with the principal data sets described above, the data sources that have been examined have also provided a significant insight into other aspects of transport in the region, much of which is needed as an input to the model.

From POWCAR analysis carried out for other work (Walsh and McNicholas, 2009) a description of the vehicle occupancy for private transport has been described. Vehicle occupancy levels, although varying for each county and ED, can be averaged at 1.2 people for every private car. Anecdotal evidence suggests that this value is, in fact, slightly higher than in reality, where vehicle occupancies tend to be closer to 1.1. The value for vehicle occupancy as part of the study was determined from the POWCAR data set according to (10):

$$O_v = \frac{N_D}{N_D + N_P} \qquad (10)$$

Where O_v is the vehicle occupancy, N_D is the number of people who are reported to be drivers of a personal vehicle and N_P is the number of people who are reported as being passengers in a car.

With regard to the fraction of trips accounted for by heavy duty vehicles the NRA provides a direct measurement of this value for each of its counters along national routes. This value was averaged over the 12 locations previously used and returns a value of 10%.

Conclusion

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 datasets for the region. While the problem was solved using auxiliary data and interpolation/extrapolation methods, the availability of newer more accurate data for more time periods would allow for the calibration results to be improved.

In this work, the aim was to systematically document the data sources, assumptions, generalisations and subjective knowledge underlying the derivation of the MOLAND model datasets for the GDR application. Particularly the development of the land use, suitability, zoning, transport network and transport zone maps was described; data estimation methods, formulas and calculated values were presented; obstacles and solutions were discussed.

As a result of the works described above, the MOLAND model was populated with all necessary data for calibration and further application for the GDR. Thus, a logical continuation of this paper can be considered the paper by Shahumyan et al, (2009) describing the MOLAND model calibration and validation for the GDR.

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Appendix A: Aggregated Land use classes used in the MOLAND model for the GDR.

MOLAND Code	Description	CORINE Code	Extended CORINE Land Use Classes
0	Arable land	2.1.1	Non-irrigated arable land
		2.1.1.3	Greenhouses
1	Pastures	2.3.1	Pasture
2	Heterogeneous agricultural areas	2.4.2	Complex cultivation patterns
		2.2.2	Fruit trees and berry plantations
3	Forests	3.1.1	Broad-leaved forest
		3.1.2	Coniferous forest
		3.1.3	Mixed forest
4	Semi-natural areas	3.3.1	Beaches, Dunes and Sand Plains
		3.3.2	Bare rock
		3.2.1	Natural grassland
		3.2.2	Moors and heathland
		3.2.4	Transitional woodland shrub
5	Wetlands	4.1.1	Inland marsh
		4.1.2	Peatbog
		4.2.3	Intertidal flats
6	Abandoned	1.3.4	Abandoned land
7	Residential continuous dense urban fabric	1.1.1.1	Residential continuous dense urban fabric
8	Residential continuous medium dense urban fabric	1.1.1.2	Residential continuous medium dense urban fabric
		1.1.2.3	Residential urban blocks
9	Residential discontinuous urban fabric	1.1.2.1	Residential discontinuous urban fabric
10	Residential discontinuous sparse urban fabric	1.1.2.2	Residential discontinuous sparse urban fabric
		1.1.2.4	Informal Discontinuous Residential Structures
11	Industrial areas	1.2.1.1	Industrial areas
		1.2.1.4	Technological infrastructures for public service
12	Commercial areas	1.2.1.2	Commercial areas
13	Public and private services	1.2.1.3	Public and private services
		1.2.1.6	Places of worship
		1.2.1.8	Hospitals
14	Port areas	1.2.3	Port areas
15	Construction sites	1.3.3	Construction sites
16	Roads and rail networks and associated lands	1.2.2.1	Fast transit roads and associated land
		1.2.2.2	Other roads and associated land
		1.2.2.3	Railways and associated land
		1.2.2.6	Parking sites for private vehicles
		1.2.2.7	Parking sites for public vehicles
17	Airports	1.2.4	Airports
		1.2.4.2	Military airports

18	Mineral extraction sites	1.3.1	Mineral extraction sites
19	Dump sites	1.3.2	Dump sites
20	Artificial non-agricultural vegetated areas	1.4.1	Green urban areas
		1.4.1.1	Vegetated cemetery
		1.4.2	Sports and leisure facilities
21	Restricted access areas	1.2.1.5	Archaeological sites
		1.2.1.7	Non-Vegetated Cemetery
		1.2.1.9	Restricted access services
22	Water bodies	5.1.1	Water courses
		5.1.2	Water bodies
		5.2.1	Coastal lagoon
		5.2.2	Estuaries
		5.2.3	Sea and ocean
23	Outside areas		

Appendix B: Rasterisation of new polygon shapefiles

When rasterising new layers to be input into MOLAND, it is very important to ensure both the spatial extent and resolution of the new raster are strictly comparable with the existing layers in MOLAND. To ensure that this requirement is achieved, the following routine can be used. The rasterisation algorithm, in ArcGIS was used in all polygon-to-raster conversions. Particularly, the combined maximum area principle was applied: features with common attributes are combined to produce a single area within the cell in question for consideration when determining the largest area (see ArcGIS documentation).

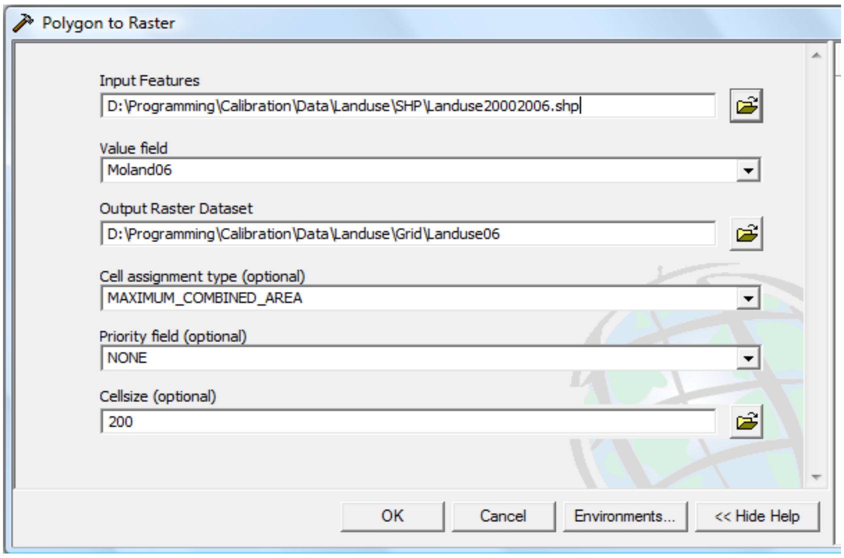

Figure 16 - Polygon to Raster Tool in ArcMap

In ArcMap, start the "Polygon to Raster" tool (Figure 16) from the ArcToolbox (Conversion Tools – To Raster).

Supply all the required data inputs. Select MAXIMUM_COMBINED_AREA in the Cell Assignment box and 200 in the output cell size box.

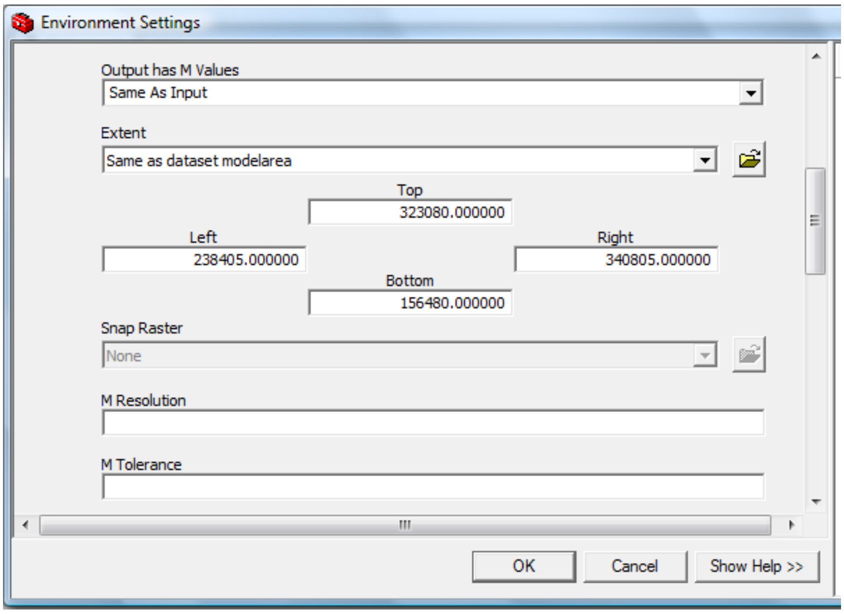

Figure 17 - Environment Settings in ArcMap – Setting Raster Extent

Click the Environment button to define the extent of the output raster (Figure 17). Under general settings, scroll down to the Extent option. This option defines the extent of the output raster. You can now browse to select one of the already defined raster datasets with consistent extent. For example, you can select the 'ModelArea.asc' raster file. The spatial extent of the newly created raster will now be snapped to the output extent provided when the rasterisation is complete.

Appendix C: Suitability criteria for preparing suitability maps

The suitability criteria presented here were taken from previous MOLAND calibration results provided by RIKS. Due to a lack of supporting documentation on how the suitability criteria were arrived at the only means of deducing the methods used was to look at the raw data. Table 12 shows the weightings which were extracted from the model. The soil codes represented in Table 12 could not be determined or matched to the Soil datasets obtained from the EPA.

Table 12 - Suitability weights for Soil

Soil Code	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Arable	5	0	10	10	9	7	6	5	5	5	4	3	1	0
Pasture	5	0	10	10	9	8	7	7	7	7	6	5	3	1
Het. Agric	5	0	10	10	9	7	6	6	6	6	5	4	2	0
Forest	5	0	10	10	10	9	9	8	7	6	4	3	2	2
Semi-Natural	5	0	10	10	10	10	10	10	10	10	10	10	10	10
Wetlands	5	0	2	3	4	4	5	6	7	8	9	9	10	10
Abandoned	5	0	10	10	10	10	10	10	10	10	10	10	10	10
Res. Con. Dense	5	0	10	10	10	10	10	10	10	9	7	5	3	1
Res. Med. Dense	5	0	10	10	10	10	10	10	10	9	7	5	3	1
Res. Disc. Dense	5	0	10	10	10	10	10	10	10	9	7	5	3	1
Res. Disc. Sparse	5	0	10	10	10	10	10	10	10	9	7	5	3	1
Industry	5	0	6	4	10	3	10	4	10	2	7	5	3	1
Commerce	5	0	10	10	10	10	10	10	10	9	7	5	3	1
Services	5	0	10	10	10	10	10	10	10	9	7	5	3	1
Port	5	0	10	10	10	10	10	10	10	10	10	10	10	10

Table 13 - Suitability weights for Elevation

Elevation	< 2.5	2.5 - 5	5 – 10	10 - 25	25 - 50	50 - 100	100 - 250	250 - 500	> 500
Arable	6	8	10	10	10	10	8	6	2
Pasture	8	9	10	10	10	10	8	6	4
Het. Agric	6	8	10	10	10	10	8	6	2
Forest	10	10	10	10	10	10	10	10	10
Semi-Natural	10	10	10	10	10	10	10	10	10
Wetlands	10	10	10	10	10	10	10	10	10
Abandoned	10	10	10	10	10	10	10	10	10
Res. Con. Dense	9	10	10	10	10	9	8	4	1
Res. Med. Dense	9	10	10	10	10	9	8	4	1
Res. Disc. Dense	9	10	10	10	10	9	8	4	1
Res. Disc. Sparse	9	10	10	10	10	9	8	4	1
Industry	9	10	10	10	10	9	8	4	1
Commerce	9	10	10	10	10	9	8	4	1
Services	9	10	10	10	10	9	8	4	1
Port	10	10	6	1	0	0	0	0	0

Table 14 - Suitability weights for Slope

Slope	<1	1 - 1.5	1.5 - 2.5	2.5 - 5	5 - 7.5	7.5 - 10	10 - 15	15 - 25	> 25
Arable	10	9	8	6	4	3	2	1	0
Pasture	10	10	9	8	7	6	4	2	0
Het. Agric	10	9	8	6	4	3	2	1	0
Forest	10	10	10	10	9	9	9	8	8
Semi-Natural	10	10	10	10	10	10	10	10	10
Wetlands	10	10	10	9	7	5	3	1	0
Abandoned	10	10	10	10	10	10	10	10	10
Res. Con. Dense	10	10	10	9	8	5	2	1	0
Res. Med. Dense	10	10	10	9	8	5	2	1	0
Res. Disc. Dense	10	10	10	9	8	5	2	1	0
Res. Disc. Sparse	10	10	10	9	8	5	2	1	0
Industry	10	10	10	9	8	5	2	1	0
Commerce	10	10	10	9	8	5	2	1	0
Services	10	10	10	9	8	5	2	1	0
Port	10	10	10	6	3	2	1	0	0

Table 15 - Suitability weights for Aspect

Aspect	<1	1 - 1.5	1.5 - 2.5	2.5 - 5	5 - 7.5	7.5 - 10	10 - 15	15 - 25	> 25
Arable	7	8	9	10	10	10	9	8	10
Pasture	7	8	9	10	10	10	9	8	10
Het. Agric	7	8	9	10	10	10	9	8	10
Forest	7	8	9	10	10	10	9	8	10
Semi-Natural	7	8	9	10	10	10	9	8	10
Wetlands	7	8	9	10	10	10	9	8	10
Abandoned	7	8	9	10	10	10	9	8	10
Res. Con. Dense	7	8	9	10	10	10	9	8	10
Res. Med. Dense	7	8	9	10	10	10	9	8	10
Res. Disc. Dense	7	8	9	10	10	10	9	8	10
Res. Disc. Sparse	7	8	9	10	10	10	9	8	10
Industry	7	8	9	10	10	10	9	8	10
Commerce	7	8	9	10	10	10	9	8	10
Services	7	8	9	10	10	10	9	8	10
Port	7	8	9	10	10	10	9	8	10

Appendix D: Transport zones in GDR

County ID	County	Zone Name	Zone Code
0	Outside of model area	Outside area	0
1	Louth County	St. Mary's	5
1	Louth County	Drogheda	2
1	Louth County	Ardee	1
1	Louth County	Dundalk Rural	3
1	Louth County	Dundalk Urban	4
2	Meath County	Kells Urban	9
2	Meath County	Navan Urban	11
2	Meath County	Trim	13
2	Meath County	Dunshaughlin	7
2	Meath County	Kells Rural	8
2	Meath County	Slane	12
2	Meath County	Navan Rural	10
2	Meath County	Drumone-Old Castle	6
3	Dublin City	North Inner City	21
3	Dublin City	Doneghmede	20
3	Dublin City	Ballymun-Finglas	16
3	Dublin City	Cabra-Glasnevin	17
3	Dublin City	Clontarf	18
3	Dublin City	Artane-Whitehall	14
3	Dublin City	Ballyfermot-Drimnagh	15
3	Dublin City	South-East Inner City	23
3	Dublin City	South-West Inner City	24
3	Dublin City	Pembroke-Rathmines	22
3	Dublin City	Crumlin-Kimmage	19
3	South Dublin	South Dublin	29
3	Dun Laoghaire-Rathdown	Dun Laoghaire-Rathdown	26
3	Fingal	Balbriggan	25
3	Fingal	Mulhuddart-Castleknock	27
3	Fingal	Sword-Howth-Malahide	28
4	Kildare County	Athy Urban	31
4	Kildare County	Naas Urban	36
4	Kildare County	Athy Rural	30
4	Kildare County	Celbridge	33
4	Kildare County	Carbury	32
4	Kildare County	Naas and Droichead Nua Rural	35
4	Kildare County	Droichead Nua	34
5	Wicklow County	Arklow Urban	38
5	Wicklow County	Bray Urban	41
5	Wicklow County	Wicklow Urban	44
5	Wicklow County	Baltinglass	39
5	Wicklow County	Greystones	42
5	Wicklow County	Bray Rural	40
5	Wicklow County	Arklow Rural	37
5	Wicklow County	Wicklow Rural	43

Appendix E: Cell numbers and activity density values within residential land use types in the GDR.

County	Classes	Cell number			Activity Density		
		1990	2000	2006	1990	2000	2006
Louth	Res. Continuous Dense	0	0	0	0.0	0.0	0.0
	Res. Medium Dense	0	0	0	0.0	0.0	0.0
	Res. Discontinuous	212	265	319	174.0	192.4	222.2
	Res. Discon. Sparse	273	336	466	138.4	104.7	83.0
	Industry	72	105	115	134.3	125.5	158.6
	Commerce	33	41	50	184.9	222.9	299.4
	Services	26	30	31	197.8	277.0	391.3
Meath	Res. Continuous Dense	0	0	0	0.0	0.0	0.0
	Res. Medium Dense	0	0	0	0.0	0.0	0.0
	Res. Discontinuous	149	268	462	279.4	199.7	185.6
	Res. Discon. Sparse	414	414	561	184.9	200.7	148.5
	Industry	47	71	103	210.4	243.5	301.4
	Commerce	26	27	39	175.2	321.8	607.5
	Services	36	36	36	106.3	202.3	493.1
Dublin	Res. Continuous Dense	24	24	30	519.2	1349.5	1585.5
	Res. Medium Dense	65	68	83	1503.3	2141.7	2594.7
	Res. Discontinuous	3511	3925	4341	407.0	379.1	362.7
	Res. Discon. Sparse	405	481	556	151.3	130.7	102.2
	Industry	497	735	889	240.5	213.5	177.0
	Commerce	217	268	291	683.6	783.3	804.0
	Services	418	427	460	232.1	312.9	317.4
Kildare	Res. Continuous Dense	0	0	0	0.0	0.0	0.0
	Res. Medium Dense	0	0	0	0.0	0.0	0.0
	Res. Discontinuous	247	405	483	251.1	215.8	216.5
	Res. Discon. Sparse	394	526	811	121.3	115.2	105.5
	Industry	92	148	180	129.7	150.2	186.8
	Commerce	42	48	54	154.7	267.2	540.7
	Services	50	50	52	127.9	215.8	433.4
Wicklow	Res. Continuous Dense	0	0	0	0.0	0.0	0.0
	Res. Medium Dense	0	0	0	0.0	0.0	0.0
	Res. Discontinuous	214	267	309	230.1	210.2	198.7
	Res. Discon. Sparse	388	486	635	142.3	122.5	114.0
	Industry	65	86	84	137.8	161.2	231.6
	Commerce	24	33	38	252.7	297.6	523.3
	Services	15	20	20	257.6	335.0	667.5

Appendix F: Census and Place of Work Surveys occupational categories grouped in MOLAND activity categories

MOLAND Category	Census Occupational Group	POWSAR and POWCAR Groups
Industrial	Electrical trades workers Engineering and allied trades workers Textile, clothing and leather workers Food, drink and tobacco production workers Chemical, paper, wood, rubber, plastics and printing workers Other manufacturing workers Building and construction workers Communication, warehouse and transport workers Scientific and technical occupations	Manufacturing, mining, quarrying, electricity, gas and water Construction Transport, storage and communications
Commercial	Managers and executives Clerical and office workers Sales occupations Business and commerce occupations Computer software occupations	Commerce
Services	Health and related workers Social workers and related occupations Religious occupations Other professional workers Personal service and childcare workers Teachers Central and local government workers Garda Siochana Army occupations	Public administration and defence Education, health and social work Professional services