Land use change scenarios for Greater Manchester: analysis and implications for climate change adaptation

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Land use change scenarios for Greater Manchester: analysis and implications for climate change adaptation

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EcoCities is a joint initiative between the School of Environment and Development, at The University of Manchester, and the commercial property company Bruntwood. The project looks at the impacts of climate change and at how we can adapt our cities and urban areas to the challenges and potential opportunities that a changing climate presents.

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Contents

1 Introduction 7

2 Methodology 9

2.1 Calibration 10

2.2 Scenario runs 16

2.3 Methodology caveats 17

3 Recent changes in land cover across Greater Manchester 18

4 Land use change scenarios for GM 22

4.1 Calibration Projection scenario (2050) 22

4.2 The 'long descent' scenario (2050) 28

4.3 The 'upward spiral' scenario (2050) 33

5 Land use scenarios for GM: climate change adaptation implications 39

6 References 47

7 Appendix 1: Metronamica input parameters 50

List of Figures

Figure 1. UMT map (1997) 11
Figure 2. UMT map (2006) 12
Figure 3. Percentage change in area (1997-2006) for 15 UMTs in GM 20
Figure 4. Change in number of 100x100 metre cells (1997-2006) for 15 UMTs in GM 21
Figure 5. Calibration projection scenario (2050) 24
Figure 6. Comparison of % annual change in land cover for 15 UMTs under three scenarios for GM to 2050. 26
Figure 7. Change in number of 100x100 metre cells for 15 UMTs in GM under three scenarios for GM to 2050 27
Figure 8. Long descent scenario (2050) 32
Figure 9. Upward spiral scenario (2050) 38
Figure 10. Synthesis of the 2006 UMT map and three land use scenarios for GM to 2050. 40
Figure 11. Change in urban land cover under three scenarios for GM 42
Figure 12. Change in woodland under three scenarios for GM 43

List of Tables

Table 1. UMT descriptions 13
Table 2. Comparison of land use changes to 2050 under the different EcoCities scenarios 25
Table 3. Comparison of three scenarios for GM against a series of indicators. 41
Table 4. Area demand scenarios to 2050 50
Table 5. Socio-economic figures for population and jobs: calibration input and scenarios to 2050 52
Table 7. Zoning plans – calibration and scenario distinctions 56
Table 8. Constant growth of density 58
Accessibility inputs: calibration and scenarios to 2050 59
Table 9. Formal open space 59
Table 10. Allotments 59
Table 11. High Density Residential 59
Table 12. Medium Density Residential 60
Table 13. Low Density Residential 60
Table 14. Office and Retail 60
Table 15. Town Centre 61
Table 16. Manufacturing and Storage 61
Table 17. Schools and Hospitals 61

Summary

As well as downscaling future climate projections for the UK to the Greater Manchester scale (Cavan 2011), the EcoCities project developed two scenarios, the 'long descent' and the 'upward spiral' (Carter 2011). These draw different narratives of how Greater Manchester may develop over the coming decades based on ten 'drivers of change' identified as important by stakeholders. This paper reports on the outcomes of a research task focused on exploring future land use change over Greater Manchester using the EcoCities scenarios as a framework. We have focused on this issue because evolving land use patterns, and the spatial planning policies that shape them, will influence how the conurbation will adapt to the changing climate.

The research employs the use of Metronamica, a spatial decision support tool designed to assist planners, decision makers and researchers in understanding future land use change. It provides a platform for simulating and assessing potential land use change up to fifty years into the future. By using the EcoCities scenarios as a framework, Metronamica can offer a realistic, albeit not accurate, projection of land use change in the conurbation. Indeed, the research is scenario-based acknowledging that we cannot predict future land use with any degree of accuracy. There are simply too many variables that could influence land use patterns in Greater Manchester over the coming decades.

The results detailed in this report indicate that different land use futures will have contrasting effects on climate change impacts and adaptation responses in Greater Manchester. This demonstrates that when considering adaptation responses, it is vital that attention is paid not just to climate change but also to land use change. These observations will assist the development of adaptation policies and strategies attuned to the importance of current and potential future land use across Greater Manchester.

1 Introduction

We now have a better understanding of how Greater Manchester's (GM) climate may change in the future (Cavan 2011).The risk that a wide range of receptors will be impacted, across the conurbation, by these climatic changes over the coming decades is also recognised (Carter and Lawson 2011). In developing adaptation responses to long-term climate-related risks, it is important to acknowledge and seek to understand not just the dynamic nature of weather and climate, but also evolving socio-economic and political circumstances. These issues have significant potential implications for the development and implementation of adaptation responses. The EcoCities scenarios engage with this debate through putting forward two different future perspectives for GM (Carter 2011), and this report takes these scenarios further by exploring their land use implications.

Complementing the futures dimension of climate change projections with a consideration of changes to the receptors of climate change impacts can encourage more robust long-term adaptation strategies to be developed. This report focuses on changes in land cover in GM, seeing the conurbation itself as the receptor of climate change impacts. Cities and urban areas are dynamic, with land cover evolving over time in response to numerous interacting drivers of change. These drivers include economic growth (and decline), demographic change and politics. Improving understanding of this dynamism is an important, yet under-researched, element of developing adaptation responses. It is broadly acknowledged that spatial planning has a strong role to play in the development of climate change adaptation responses (Blanco and Alberti 2009; Davoudi et al 2010). Processes linked to the development and use of land, which spatial planning influences, have implications for both the nature and severity of climate change impacts and the form and function of adaptation responses.

Blanco et al (2011: 242), in a discussion on the role of urban land in climate change, state that further research is needed into forecasting urban growth through the application of land use change models. They highlight the use of spatial transition models, which include cellular automata and agent based models, as potential approaches for modelling urban growth. This report is focused on a discussion of the application of the Metronamica cellular automata system to model future land use change in GM. The findings of the modelling exercise are discussed in the context of adapting to climate change in the conurbation. The goal of this element of the EcoCities research project is to contribute to the development of a ‘futures perspective’ to adaptation to climate change through offering a scenario-based interpretation of land cover change in GM to complement the scenario-based climate change projections that are available for the conurbation. A further goal has been to work with the Metronamica model, which is designed with the non-expert modeller in mind, to establish whether it is a useful tool to support the exploration of future land use change in GM. Both of these goals have been broadly achieved. Taken together, future projections for climate and land cover now provide a firmer basis to develop long-term adaptation responses to address the potential challenges and opportunities linked to the changing climate.

2 Methodology

Metronamica is a Spatial Decision Support System (SDSS) developed by a Dutch organisation; Research Institute for Knowledge Systems (RIKS). It is designed to support spatial planning decisions at different scales. It uses Constrained Cellular Automata (CCA) to generate dynamic scenarios for land cover change. CCA is now increasingly used as an approach for modelling the simulation of spatial change. CCA dates back to the work of Tobler (1970), who modelled land use change in Detroit. CCA is a cell based model in which individual cells are influenced by the behaviour of surrounding cells, generating a dynamic system of change within a constrained land use map.

Metronamica is most commonly used to enhance understanding of the spatial implications of future land use scenarios. This is useful in policy contexts that require strong justification for longer-term planning decisions. As such it has been by used by government authorities and research groups in various countries around the World (including the Netherlands, Canada, New Zealand, Nigeria), and at various scales (from continents and countries down to cities), to model future land use changes. For example, Metronamica has been used to model urban growth in the Greater Vancouver Regional District (van Vliet et al 2009), to develop future land use scenarios to better understand desertification processes in the Guadalentin watershed in Spain (Kok and van Delden 2009) and to model future urban development scenarios in Lagos, Nigeria (Barredo et al 2004).

At the supra-national level, Metronamica was applied within the PRELUDE project led by the European Environment Agency (Hoogeveen et al, no date). PRELUDE focused on an analysis of the environmental implications of different scenarios for the future of Europe. Narrative scenario storylines were used as the basis of modelling work undertaken using Metronamica, which resulted in dynamic land use model outputs displaying the nature of land use changes in Europe and in selected case study countries (Estonia, Netherlands, Italy) under different future conditions. This has been described as a 'storyline-and-simulation' approach (Alcamo 2001). The application of Metronamica within EcoCities progressed along similar lines as the PRELUDE application, implementing a storyline-and-simulation approach.

Metronamica enables potential future land use change under different scenarios to be visualised and analysed from a spatial perspective. The output of the modelling work undertaken within EcoCities details how land cover could change in GM under several different future scenarios. This method therefore combines creative scenario storylines with a state-of-the-art land use modelling tool to produce an output that can support the development of adaptation responses (particularly linking to land use and spatial planning) within GM.

2.1 Calibration

The application of Metronamica began with the calibration of the model. The calibration process is based around observing actual land use change in the study area (in this case the 10 districts making up GM) and then calibrating Metronamica to model, as realistically as possible, this observed change in land cover. The calibrated model then offers a platform to generate and analyse scenarios for future land use change. Within the EcoCities project, we took land cover maps for 1997 and 2006, which were based on interpretation of aerial photography. These maps can be seen as figures 1 and 2 below. All of the maps within this report are produced within the Metronamica model. The maps follow the urban morphology type (UMT) approach developed within the ASCCUE project (see Handley and Carter 2006; Gill 2006; Gill et al 2007). Table 1 provides descriptions for the 26 different UMT included within the GM Metronamica model.

Figure 1. UMT map (1997)

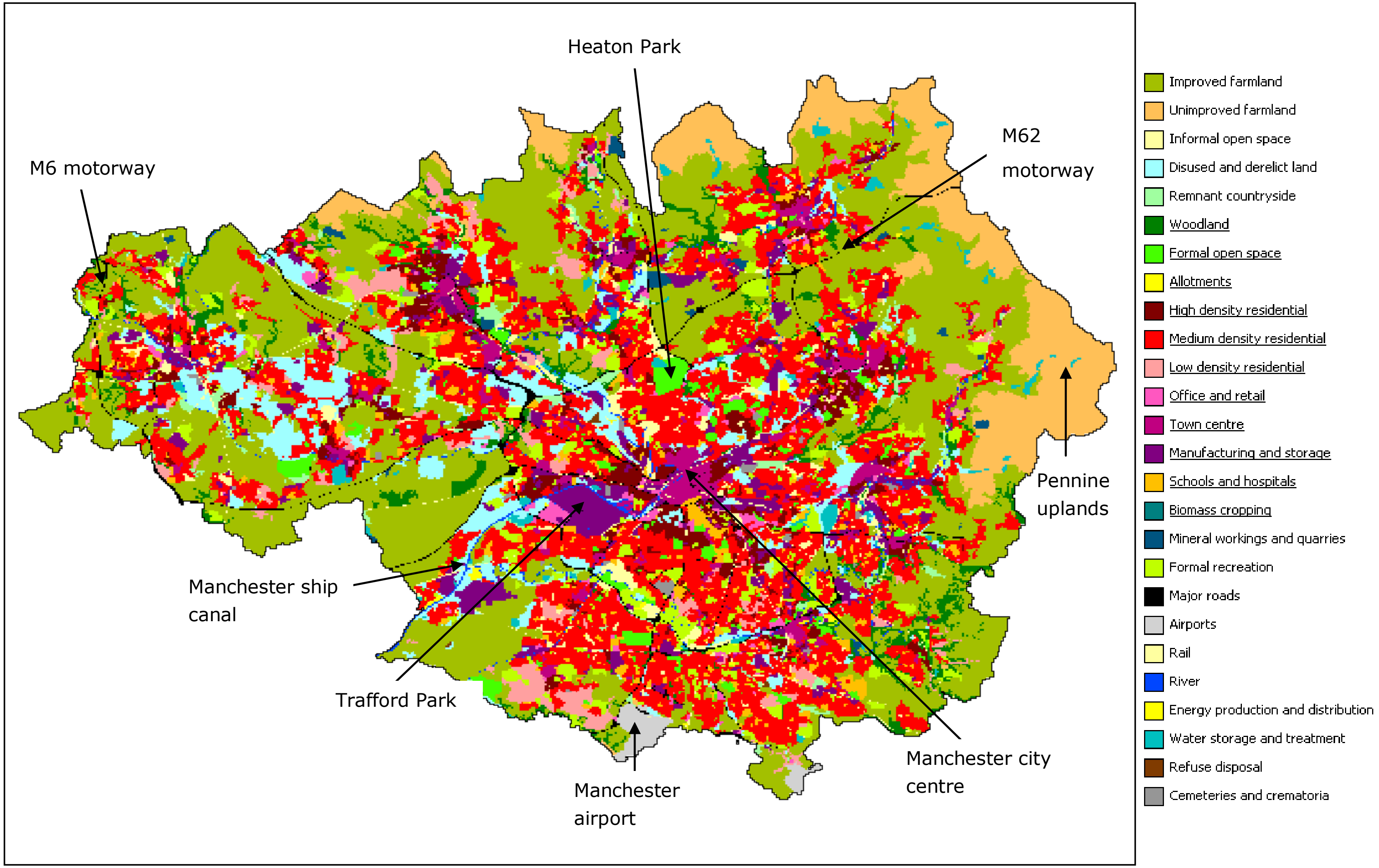


Figure 2. UMT map (2006)

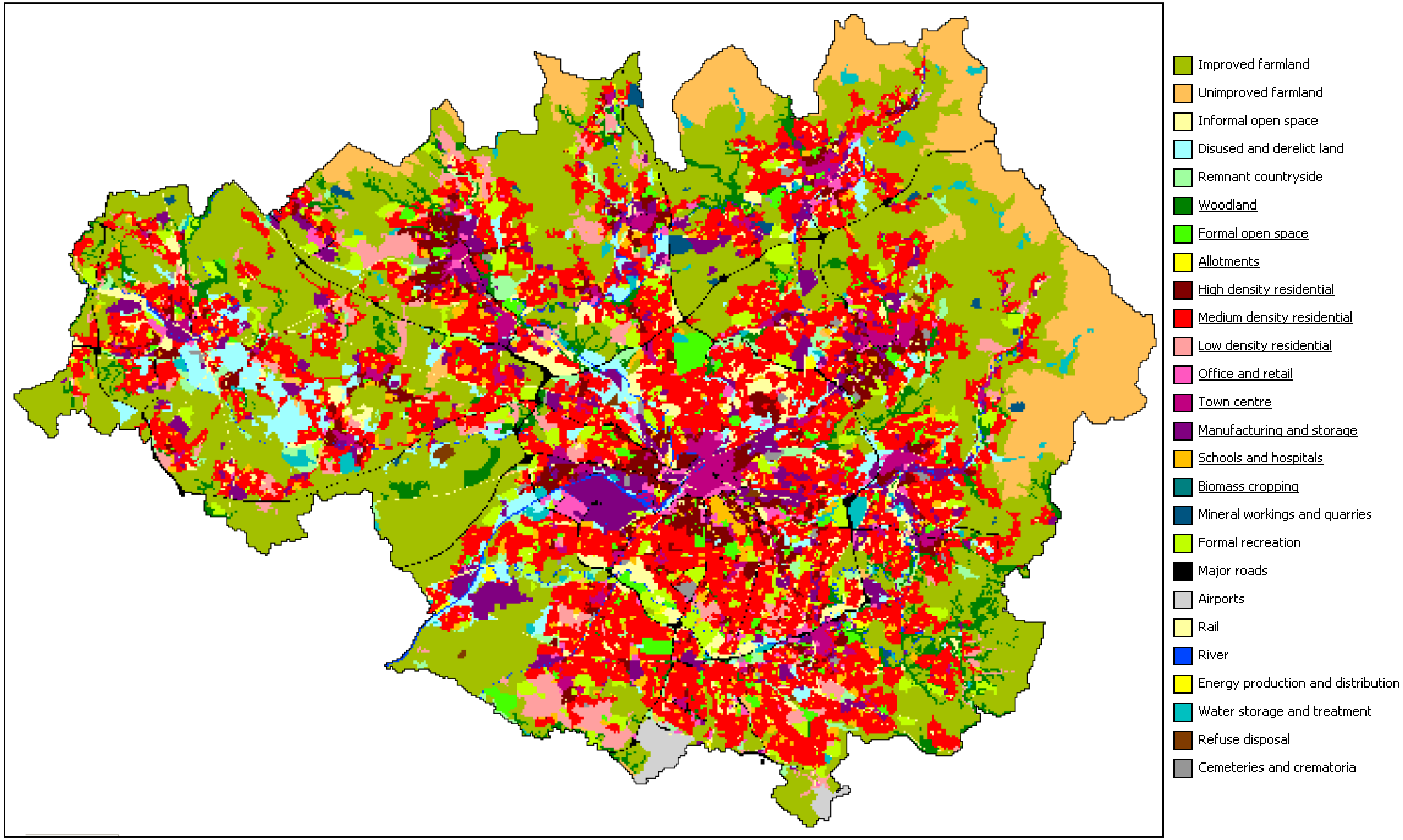


Table 1. UMT descriptions (following Gill 2006)

UMT	Description
Improved farmland	Fields (can contain animals), managed agriculture
Unimproved farmland	Open land with grazing animals
Informal open space	Grassland and woodland, usually on the edges of towns, can be used for informal recreation, include commons, greens, expanses of mown grass
Disused and derelict	Variety of former land uses which have become derelict, lack of management or maintenance, aspect and colour of ground
Remnant countryside	Pockets of countryside surrounded by development, lack of management or maintenance, potential for informal recreation
Woodland	Continuous tree cover
Formal open space	Designed public open space such as parks, gardens and town squares
Allotments	Distinctive rectangular pattern of layout
High density residential	Terraced housing, town houses, or flatted accommodation, with small or no gardens and yards, and few or no opportunities for planting trees
Medium density residential	Larger terraced houses, semi-detached houses, bungalow estates with large front and back gardens, significant numbers of trees
Low density residential	Detached houses, large gardens with lawns and many trees, driveways
Office and retail	Office: Blocks of buildings, no industrial activity, business parks, car parks. Retail: large shopping centres, commercial streets
Town centre	A mixture of retail, offices, and housing
Manufacturing and storage	Manufacturing: Industrial processes, may see chimneys, tanks, pipes, petrochemical activity, large buildings, hard surfaced yards, few locations for trees except round the periphery, site may include regenerated derelict areas. Storage: small buildings including warehouses often with lorries parked outside

Table 1 (cont). UMT descriptions

UMT	Description
Schools and hospitals	Schools: buildings, smaller schools with hard surfaced yards and few green spaces and trees, larger schools with playing fields. Hospitals: often occupy large sites which are heavily planted
Biomass cropping	This new land use was created for the Upward Spiral scenario
Mineral working and quarries	Expanses of bare soil with tyre marks
Formal recreation	Playing fields, sports grounds, playgrounds, golf courses
Major roads	Main roads, motorways, dual carriageways, often incorporating embankments, cuttings, slip roads, and roundabouts
Airports	Large areas of runway, planes
Rail	Tracks and gravel
River	Strips of water, may meander
Energy production and distribution	Gas tanks, electrical installation
Water storage and treatment	Sewage works, reservoirs
Refuse disposal	Landfill sites
Cemeteries and crematoria	Distinctive pattern of mown grass with headstones arranged in grids

Significant input of data (including figures for population and jobs over different time periods, topographical maps, zoning maps and transport network GIS layers) and time are needed to calibrate the model. There are four main components of the model that are worked with during calibration (and subsequent scenario development). Each modelling component addresses different issues that influence the allocation of land uses. They are:

- *Neighbourhood Rules:* Neighbourhood rules determine the relationship between each of the land use types included in the model. Neighbourhood rules cover the persistence of a land use, its propensity to convert to other land uses, and the force of attraction/repulsion that a land use has on other land uses.
- *Accessibility:* Accessibility determines the strength of the influence of transport networks (including roads, motorway junctions, rail and metro stations) on land use location. There are two ways in which transport networks influence land uses within Metronamica; weighting the relative priority of different networks on land use location and determining the distance over which networks influence land use location.
- *Suitability:* Suitability concerns the physical geography of the area and its affect on development potential. In the GM application, suitability was based on slope and elevation data.
- *Zoning:* Zoning applies restrictions or incentives to the development of certain land uses in defined locations. Zoning maps relating to issues including nature conservation, flood risk, and green belts were included in the GM model.

Each component is altered as part of the calibration process in an iterative fashion. After each modelling run, the results are compared against observed changes in land cover and the model is adjusted accordingly to produce land cover results more reflective of actual observed changes.

In addition to the four components described above, model inputs are required on population and jobs figures, which determine the amount of land allocated to residential and other urban land uses. The model also includes an adjustable random co-efficient, put in place to accept randomness and introduce an element of uncertainty into the model. Model input data linked to the calibration process is included in appendix 1.

Constrained cellular automata models such as Metronamica are based around a grid space of cells of equal size (100x100 metres in the case of the GM model). Each cell is allocated to one type of land use. The four key components of the model described above collectively determine whether, at each one-year time step in the model run, the cell will transition to a different land use or will persist in its current state. Further details on Metronamica and the different elements of the calibration process are available within a report from RIKS, the developer of the model (RIKS, no date).

2.2 Scenario runs

After completing calibration, the next step was to use the model as a basis to visualise and analyse the potential land cover changes associated with the EcoCities scenarios. The EcoCities scenarios are reported within a separate document (Carter 2011). The approach taken to the interpretation of the scenarios was based around the method applied by RIKS within the European Environment Agency PRELUDE project (van Delden et al 2005). This involved analysing the narrative scenario storylines to look for elements that linked to land use change and the nature of spatial planning frameworks (that exert a potentially strong influence over land cover change). An assessment was then made of the scenario-based land cover changes to be introduced using the Metronamica model interface to create a visual representation of GM in 2050 under each scenario.

To support the two EcoCities scenarios, the 'long descent' and the 'upward spiral', the Metronamica interface was also set up to project forward a 'business-as-usual' scenario for land use change in GM. Unlike the two EcoCities scenarios (Carter 2011), this scenario was not developed with the input of stakeholders or with consideration to the drivers of change influencing the future growth and development of GM. It therefore does not have a narrative storyline. The scenario simply applies the Oxford Economic future projections for population and jobs in GM in 2032 (Oxford Economics 2010), and continues forward the observed trends in land cover change observed between 1997 and 2006. All of the other settings used to calibrate the Metronamica model (neighbourhood rules, accessibility settings, suitability data and zoning restrictions) are left untouched. Within this report, this is described as the 'calibration projection' scenario. The Metronamica input data for each scenario is provided in appendix 1.

2.3 Methodology caveats

Blanco et al (2011: 243) note that there are weaknesses with spatial transition models (such as Metronamica). These include their significant data requirements and that modelling techniques applied within cellular automata models are not yet mature. There are further specific issues with the Metronamica GM application. There are potential land cover classification errors included within the land cover maps for 1997 and 2006, on which the calibration is based. Also, the cell size (100x100 metres) used for the model allocates one land use to each cell, meaning that land cover details at a fine scale are lost. However, RIKS advise that this cell size is most appropriate for modelling a conurbation the size of GM due to the difficulties associated with modelling at finer scales. This does mean that small-scale changes in land cover of significance for climate change adaptation are lost, such as paving over front gardens, yet it is simply not possible to model such developments within Metronamica.

Acknowledging these weaknesses, Metronamica nevertheless provides a valuable platform to model potential future land cover change in GM. There are, of course, further refinements and additions that could be made to the model in the future. However, it is important to understand that the goal of Metronamica is to model land cover change realistically, not accurately. There is considerable uncertainty over the future growth and development of GM, and it is not possible to determine precisely how the conurbation will change over the coming decades. Instead the goal of this research exercise is, using a scenario-based approach, to better understand possible directions of land cover change and to use this as a platform to consider associated implications for the issue that lies at the heart of the EcoCities project; adaptation to climate change.

3 Recent changes in land cover across Greater Manchester

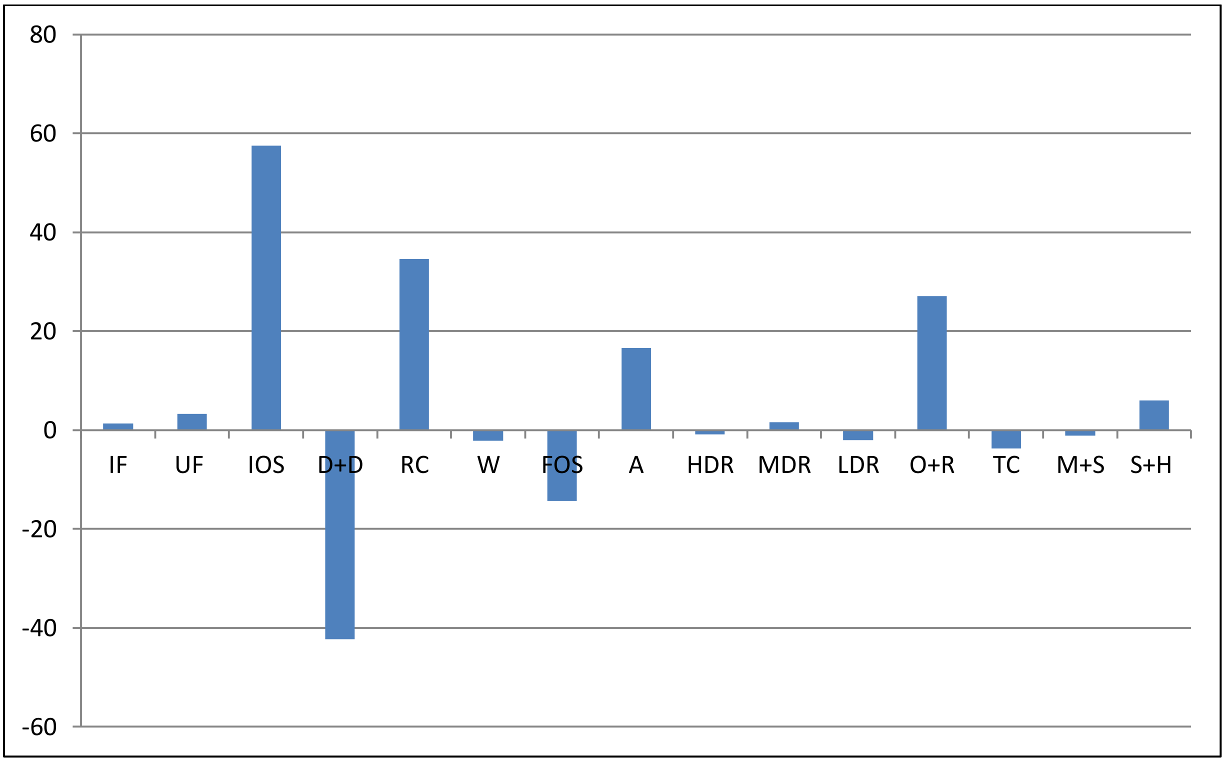
Before considering the outputs of the scenario-based land use projections for GM, the findings of an analysis of recent changes in land cover across the conurbation are presented. This provides a valuable insight into how GM has evolved over recent years. Figures 3 and 4 display data on observed changes in land cover across the 10 districts of GM for the period covering 1997 to 2006. Figure 3 displays percentage change in land cover for the 15 different UMTs that are actively allocated by the Metronamica model. Figure 4 displays data on the change in the number of 100x100 metre grid cells for these UMTs. The data is produced by using Metronamica to compare two UMT maps for GM (figures 1 and 2 display the two maps). Maps were produced by interpreting aerial photography images from 1997 and 2006, based on the approach taken within the ASCCUE project (see Handley and Carter 2006; Gill 2006; Gill et al 2007). It must be acknowledged that there are potential land use type classification errors caused by misinterpretation of aerial photography. Nevertheless, across an area of land the size of GM, the key trends in land cover change observed by this analysis can be relied upon.

Key findings of the 1997–2006 land cover comparison include that the largest percentage growth in land cover is seen for non-urban land uses, namely informal open space and remnant countryside, which increased by 58% and 35% respectively (figure 3). The largest percentage fall in land cover is seen for disused and derelict land and formal open space, which declined by 42% and 14% respectively. However, a different picture emerges when we look at the changes in the number of cells for each land use type between 1997 and 2006 (figure 4). Each 100x100 metre grid square represents 10,000 square metres, or one hectare. For comparison, international football pitches are required to be between 0.62 and 0.82 hectares.

The largest increase in cells was seen for informal open space, with a growth of 1,130 cells. Significant growth (of over 400 cells) was also seen for improved farmland, remnant countryside and medium density residential. Analysis using the Metronamica interface indicates that over half of the growth of informal open space was on land that was previously disused and derelict. The urban land use that saw the largest increase in area, medium density residential, grew most notably at the expense of land previously classified as disused and derelict land, high density residential and schools and hospitals. Office and retail was another urban land use showing significant growth (of 300 cells). Metronamica indicates that this principally took place on land previously classified as disused and derelict, manufacturing and storage and town centre. The largest decline in number of cells was, by far, disused and derelict land with a loss of 2948 cells. The next largest loss was seen for formal open space, where a decline of 339 cells was seen. Analysis using the Metronamica interface suggests that disused and derelict land converted to, in particular, improved farmland, informal open space, remnant countryside, manufacturing and storage and medium density residential. Metronamica also indicates that loss of formal open space was principally driven by conversion to informal open space. Classification errors at the point of interpreting aerial photographs and reduction of maintenance of some areas of formal open space could account for this observed conversion.

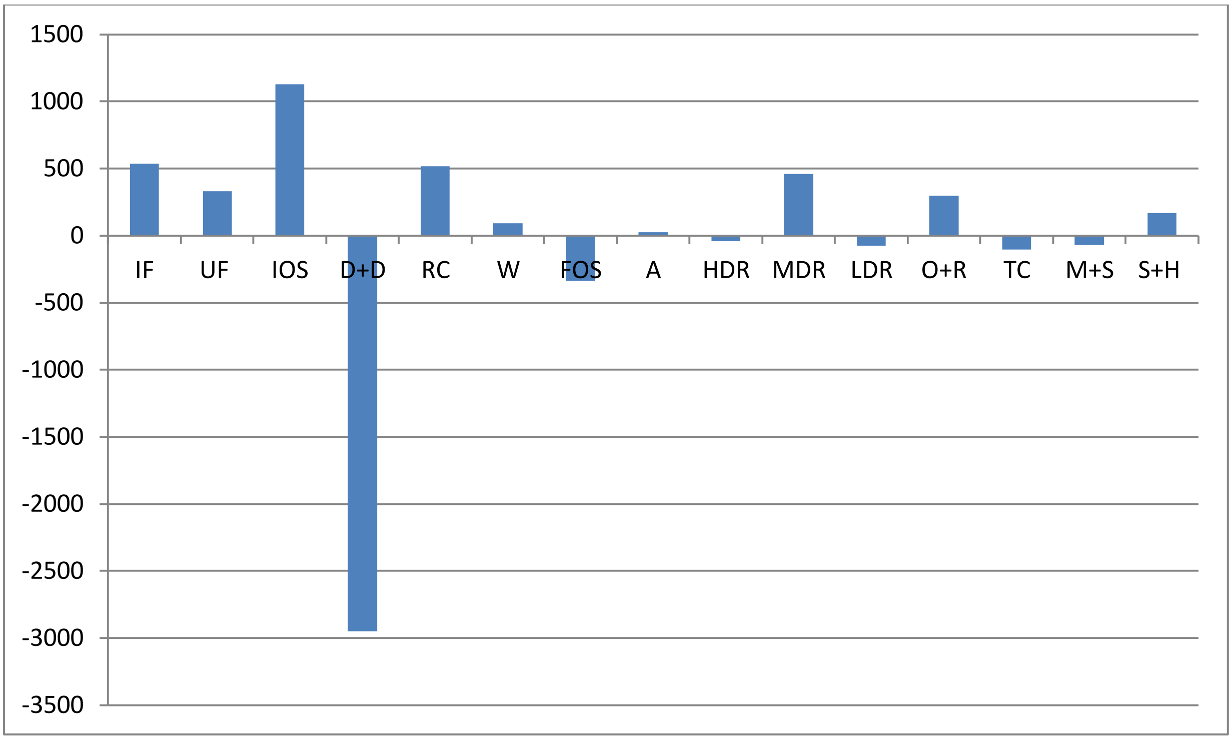
Drawing on this analysis of observed land use change across GM, tentative conclusions can be drawn for the climate change adaptation agenda. Analysis using Metronamica indicated that the development boom that occurred over this period was most visible in the increase of medium density residential and office and retail land cover. A significant amount of this development appears to have occurred on disused and derelict land. Growth in these two key land uses also occurred at the expense of other urban land use types, including high density residential, schools and hospitals and manufacturing and storage. Over the period 1997–2006, the climate change adaptation agenda did not feature strongly in planning and policy making. Hence, it can be assumed that new development generally did not incorporate adaptation responses, such as sustainable drainage systems (SuDS) and green roofs. However, as much of the new development took place on land previously classified as urban, the net effect on adaptive capacity may therefore have been minimal as, effectively, hard surface replaced hard surface. Further, over the nine year period separating the two UMT maps, it is possible that, as a result of the process of natural succession, a proportion of disused and derelict land became covered by grasses, plants, shrubs and small trees. This would account for some of conversion of disused and derelict land to informal open space and remnant countryside. The naturalisation of disused and derelict land in this way brings potential adaptation benefits linked to increasing green cover. These benefits include increasing rainwater infiltration, cooling, enhancing scope for species migration and provision of recreation space. Issues related to the adaptation benefits of brownfield land are covered in an EcoCities dissertation (Polyakova 2011).

Figure 3. Percentage change in area (1997-2006) for 15 UMTs in GM



Key for figure x			
IF: Improved farmland	**RC:** Remnant countryside	**HDR:** High density residential	**TC:** Town centre
UF: Unimproved farmland	**W:** Woodland	**MDR:** Medium density residential	**M+S:** Manufacturing and storage
IOS: Informal open space	**FOS:** Formal open space	**LDR:** Low density residential	**S+H:** Schools and hospitals
D+D: Disused and derelict land	**A:** Allotments	**O+R:** Office and retail	

Figure 4. Change in number of 100x100 metre cells (1997-2006) for 15 UMTs in GM



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D+D: Disused and derelict land	**A:** Allotments	**O+R:** Office and retail	

4 Land use change scenarios for GM

There follows a description and analysis of three land cover scenarios for GM developed within the Metronamica model; the calibration projection, 'long descent' and 'upward spiral' scenarios. The key land cover changes observed for each scenario are described, and the potential implications of these changes for climate change adaptation in GM are considered. For the 'long descent' and 'upward spiral' scenarios, the relationship between the scenario storyline narratives (Carter 2011) and land cover change in GM are outlined, the analysis of which provided the basis for developing these scenarios within the Metronamica model.

4.1 Calibration Projection scenario (2050)

The land cover map for the calibration projection scenario is displayed as figure 5. Table 2 provides a numerical comparison of the land cover characteristics of the 2050 calibration projection map (figure 5) and the 2006 UMT map (figure 2). Figures 6 and 7 chart the data included in table 2. This analysis reveals that over a 44 year period, the general pattern in GM exhibited by the calibration projection scenario is towards a loss of non-urban land uses (particularly formal and informal open space and remnant countryside) and an increase in urban land uses (particularly residential, office and retail and schools and hospitals). There are exceptions, although the only non-urban land use that increases under this scenario is allotments. In terms of urban land uses, a significant decline in manufacturing and storage is seen with town centre also reducing, reflecting a continuation in the decline of the manufacturing sector and the competition that out-of-town shopping centres are placing on the high street.

The land cover trends observed between 1997 and 2006 are clearly ones that point towards urban intensification over time. Projecting these trends forward to 2050, coupled with an expanding population and strong growth in economic sectors including office and retail (as projected by Oxford Economics), leads to an increasingly urbanised GM that has significantly less green cover. These land cover changes have significant implications of the for the adaptation agenda. Given the role that green space has to play in adaptation to climate change impacts (Gill et al 2007), the scenario is not positive for this aspect of adaptation. Loss of land uses including open space, woodland and remnant countryside to the scale projected by this scenario would leave GM with less space for outdoor recreation, less tree cover to provide shade and evaporative cooling functions, and less surface green cover to absorb excessive rainwater.

The period 1997 to 2006 was characterised by a housing development boom, a hollowing out of the manufacturing sector and a growth in the service sector. These changes are clearly reflected in observed land cover changes for this time slice. It is not possible to predict whether or not these trends will persist into the future. Indeed, the financial crisis of 2008, subsequent recession, associated reduction in housing demand and a consumption-squeeze on businesses, points towards a different future; one that aligns more closely to the characteristics of the 'long descent' scenario and not a continuation of the intensive development activity experienced between 1997–2006. It should also be acknowledge that if development activity does re-start to the level seen over this nine-year period, it might be accompanied by more sustainable approaches to the design and location of development, incorporating measures including those that target the reduction of climate change risks. A more intensely urban GM may therefore be one that, by 2050, has adaptation responses more tightly woven into its urban fabric. Nevertheless, the value of running the calibration projection scenario is to demonstrate that, without a more sustainable approach to urban expansion, land use changes of the type seen between 1997 and 2006 would be detrimental to climate change adaptation in GM.

Figure 5. Calibration projection scenario (2050)

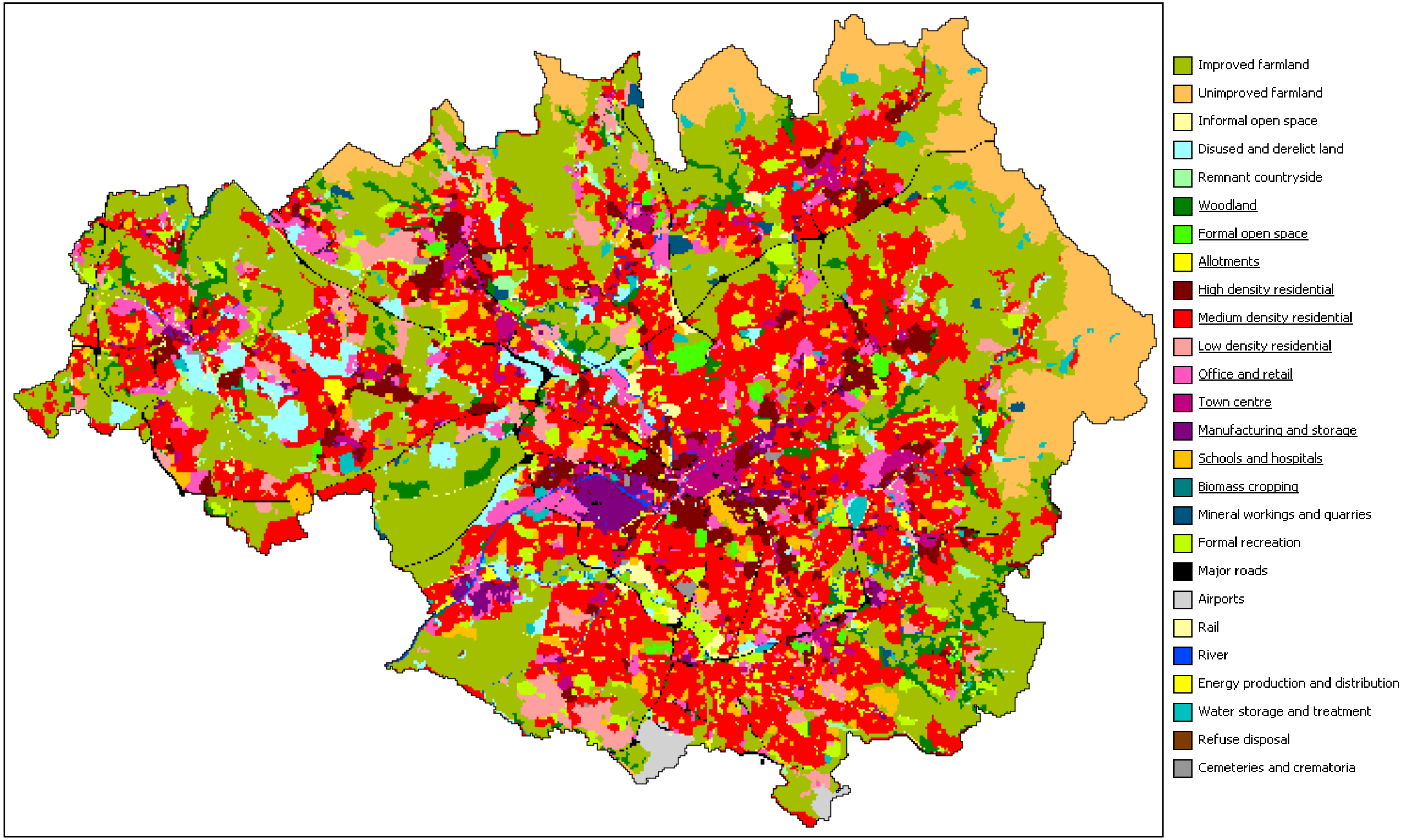
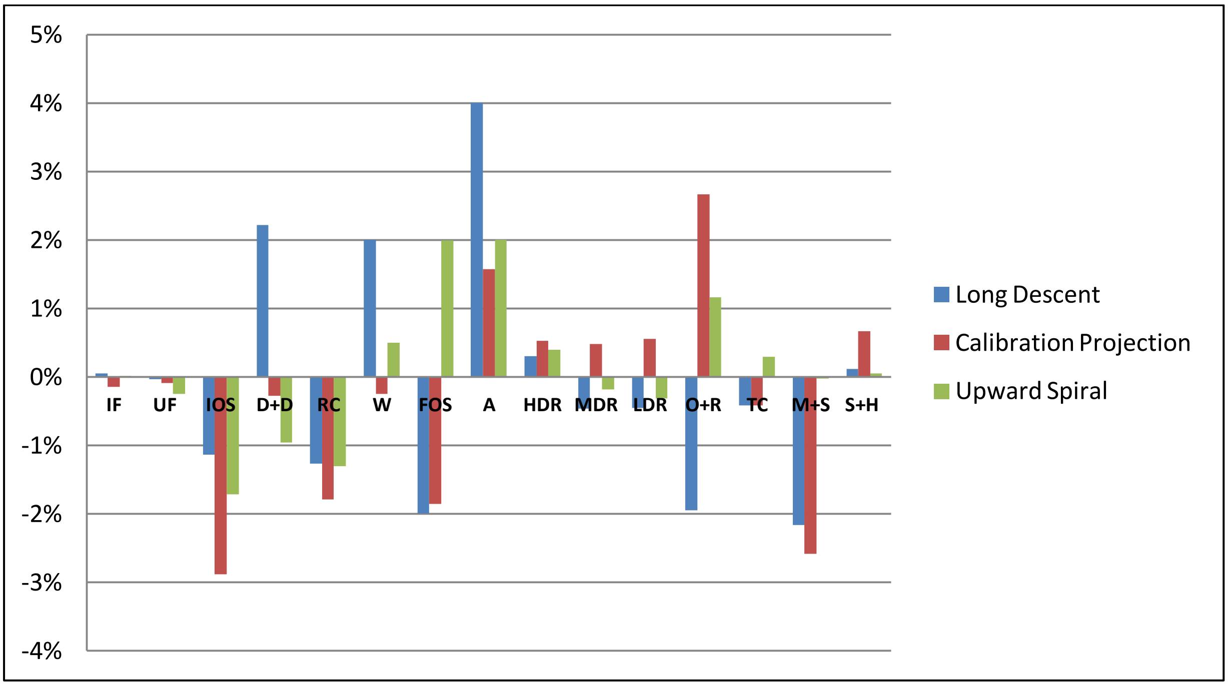


Table 2. Comparison of land use changes to 2050 under the different EcoCities scenarios (each cell is 100x100 metres)

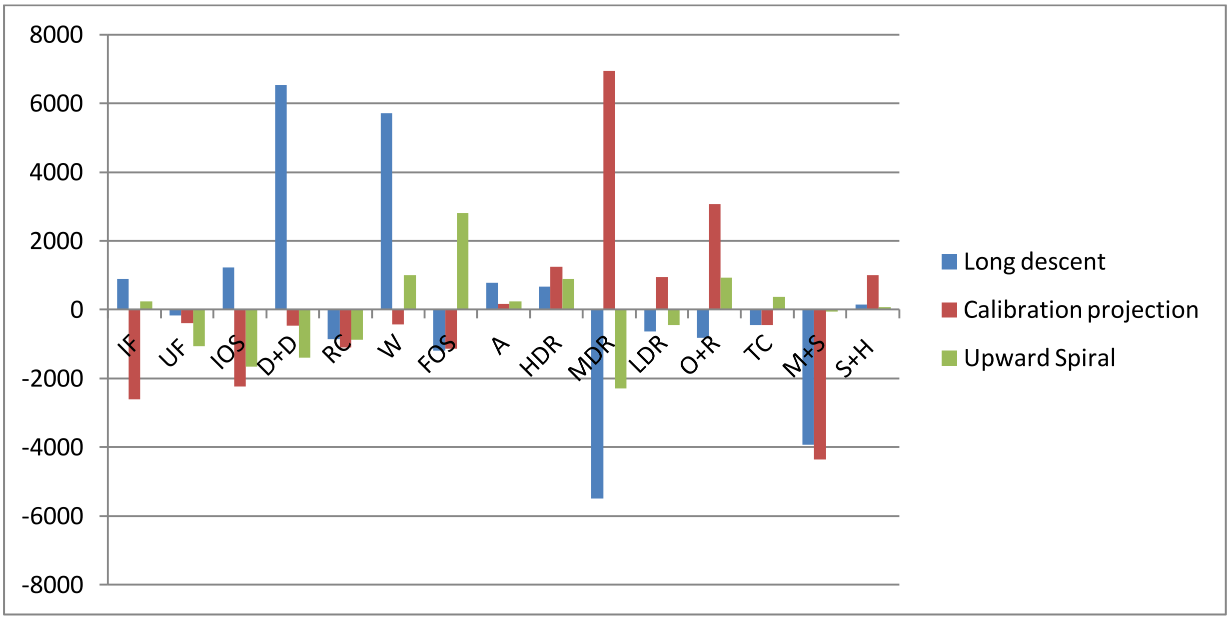
	UMT 2006	**Calibration projection 2050**				**Upward spiral 2050**				**Long descent 2050**			
	Number of cells	Number of cells	Change in number of cells (2006-2050)	% change from 2006	% annual change (2006-2050)	Number of cells	Change in number of cells (2006-2050)	% change from 2006	% annual change (2006-2050)	Number of cells	Change in number of cells (2006-2050)	% change from 2006	% annual change (2006-2050)
Improved farmland	41076	38468	-2608	-6.35	-0.15	41309	233	0.57	0.01	41978	902	2.2	0.05
Unimproved farmland	10373	9981	-392	-3.78	-0.09	9306	-1067	-10.27	-0.25	10212	-161	-1.55	-0.04
Informal open space	3094	855	-2239	-72.37	-2.88	1443	-1651	-53.36	-1.72	1868	1226	-39.63	-1.14
Disused and derelict	4024	3563	-461	-11.46	-0.28	2635	-1389	-34.52	-0.96	10566	6542	162.57	2.22
Remnant countryside	2013	908	-1105	-54.89	-1.79	1130	-883	-43.86	-1.30	1149	-864	-42.92	-1.27
Woodland	4115	3685	-430	-10.45	-0.25	5125	1010	24.54	0.50	9835	5720	139	2.00
Formal open space	2021	885	-1136	-56.21	-1.86	4830	2809	138	1.99	831	-1190	-58.88	-2.00
Allotments	169	336	167	98.82	1.57	404	235	139.01	2.00	949	780	461.54	4.00
High density residential	4760	6008	1248	26.22	0.53	5657	897	18.84	0.39	5429	669	14.05	0.30
Medium density residential	29868	36805	6937	23.23	0.48	27579	-2289	-7.66	-0.18	24381	-5487	-18.37	-0.46
Low density residential	3443	4400	957	27.8	0.56	2997	-446	-12.95	-0.31	2813	-630	-18.3	-0.46
Office and retail	1409	4479	3070	217.89	2.66	2344	935	66.36	1.16	593	-816	-57.91	-1.95
Town centre	2683	2229	-454	-16.92	-0.42	3054	373	13.83	0.29	2229	-454	-16.92	-0.42
Manufacturing and storage	6369	2009	-4360	-68.46	-2.59	6306	-63	-0.99	-0.02	2432	-3937	-61.82	-2.16
Schools and hospitals	2968	3973	1005	33.86	0.66	3034	66	2.22	0.05	3120	152	5.12	0.11

Figure 6. Comparison of % annual change in land cover for 15 UMTs under three scenarios for GM to 2050.



Key for figure x			
IF: Improved farmland	**RC:** Remnant countryside	**HDR:** High density residential	**TC:** Town centre
UF: Unimproved farmland	**W:** Woodland	**MDR:** Medium density residential	**M+S:** Manufacturing and storage
IOS: Informal open space	**FOS:** Formal open space	**LDR:** Low density residential	**S+H:** Schools and hospitals
D+D: Disused and derelict land	**A:** Allotments	**O+R:** Office and retail	

Figure 7. Change in number of 100x100 metre cells for 15 UMTs in GM under three scenarios for GM to 2050



Key for figure x			
IF: Improved farmland	**RC:** Remnant countryside	**HDR:** High density residential	**TC:** Town centre
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D+D: Disused and derelict land	**A:** Allotments	**O+R:** Office and retail	

4.2 The 'long descent' scenario (2050)

The narrative storyline of the 'long descent' scenario can be read in full in an associated EcoCities publication (Carter 2011). The scenario was analysed in order to facilitate its inclusion within Metronamica. This involved considering the associated drivers of land cover change in GM. Particular attention was paid to spatial planning legislation and regulation given its influence over the development and use of land. Based on this assessment of key underlying drivers, an assessment was made of the principal land cover changes to represent within Metronamica to enable a visual interpretation of the spatial implications of the 'long descent' scenario to be developed. The outcomes of this assessment are summarised below, and help to clarify how, under the 'long descent' scenario, land cover could change in GM to 2050.

Drivers of land cover change:

- Global economic growth is sluggish or in decline, with governments unable to recreate the high growth rates seen in the post war years and in the build up to the 2008 financial crisis. As a result there is less inward investment to GM (GM).
- Low economic growth in GM is accompanied by high unemployment. These problems are compounded by GM's peripheral location (in a European context), and that other cities have been more successful in developing progressive policies to secure growth in an era characterised by multiple interacting challenges.
- Demand for goods and services declines, depressing development activity across a range of sectors.
- The unstable economy limits capacity for public and private sector investment in housing, commercial ventures and infrastructure developments.
- Policy makers perceive deregulation as the best way to restart growth.
- Policy makers pay little attention to climate change and environmental resource issues, which nevertheless become increasingly prevalent at the global and GM scale.
- Agricultural systems in key global food producing regions begin to suffer. Coupled with the high price of oil, this increases food prices and incentivises domestic food production.

- Peak oil and accompanying higher fossil fuel prices has implications for sectors that impact on land use, particularly agriculture.
- GM experiences rising population as a result of immigration stemming from overseas climate change and environmental disruption, and declining prospects in GM's hinterlands. Much of the increasing population is absorbed into the existing urban fabric, increasing occupancy rates.
- The values of citizens in many countries around the world remain entrenched within the 'consume and pollute' society. Consequently there is little support for strategy or policy that changes the status quo.
- There is public mistrust in authority, reducing the appetite of policy makers to implement any change-led progressive policy.

Spatial planning legislation and regulation:

- The prevailing deregulatory agenda leads to a weakening of spatial planning policies and processes, which are seen as a break on potential public and private sector initiatives aimed at encouraging growth and employment.
- Zoning policies and environmental legislation are weakened and even repealed in some cases to remove restrictions and costs on new development.
- A top-down central government-led planning policy agenda limits the scope for planning authorities to implement locally relevant policies and measures.
- One non-urban land use that is protected above all others is high quality farmland in recognition of the importance of supporting domestic food production.

Principal land cover changes to represent within Metronamica (including identification of key underlying drivers):

- Industrial farming expands into areas where the landscape is favourable (rising price of imported food).
- Informal urban agriculture in the form of allotments expands, particularly into available land close to residential areas (rising price of imported food).

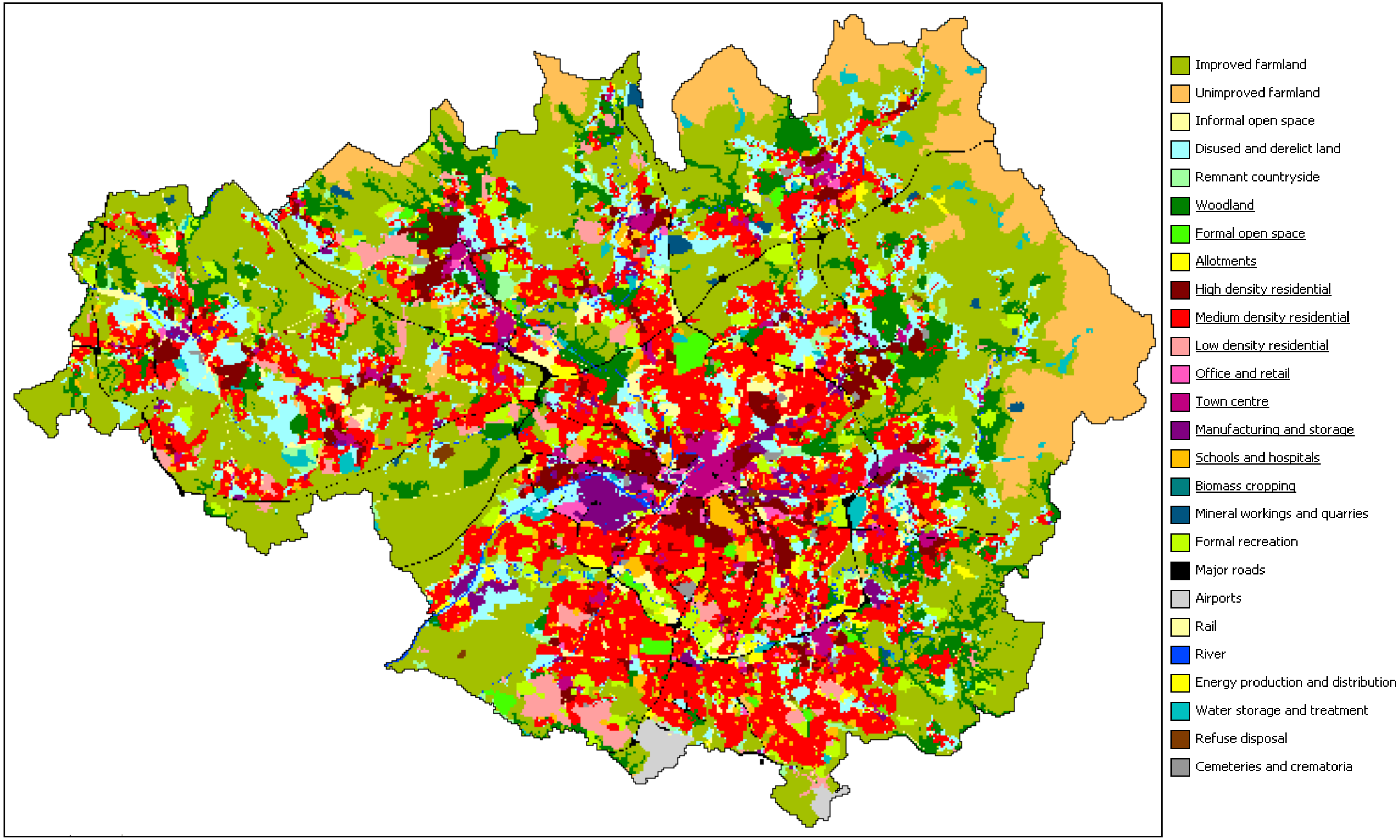
- Locations close to train and metro stations become less attractive for new development (declining public transport services and quality).
- Generally, rates of urban development are slow (poor economic conditions, limited inward investment).
- Some unregulated development takes place sporadically (lack of regulation and enforcement).
- Developers are free to build on previously protected land uses such as greenbelts, floodplains and nature reserves (lack of spatial planning regulations and zoning restrictions, efforts to boost growth and employment).
- Brownfield and greenbelt land with good access to strategic road junctions and routes (motorway junctions, major A-roads) become the prime target for any commercial and residential development that does proceed (car travel remains dominant, declining public transport services and quality).
- There is some new development of high density housing particularly around the urban centres (to accommodate GM's growing population).

Figure 8 offers a visualisation of the 'long descent' scenario as developed within Metronamica. Table 2 provides details of the land cover changes associated with the scenario, and figures 6 and 7 chart the data included in table 2. Land cover changes associated with the 'long descent' scenario point towards a future for GM as a 'shrinking city', with this shrinkage driven by economic decline and associated scaling back of development activity. Shrinking cities are very much a present day issue although recent patterns of urban growth and the notion of the 'urban renaissance' have merely pushed them into the background (Beyer et al 2006). In the 1990s, population numbers in around one quarter of the world's large cities shrank, with most shrinking cities being found in developed industrialised nations (Beyer et al 2006). Key characteristics of the 'long descent' scenario include a reduction in area of urban land uses, and an increase in disused and derelict land and other non-urban land uses. Nevertheless, significant amounts of urban land cover remain, and an increase in high density residential area is seen. This is because the population of GM grows over the course of the scenario. Although much of this growth is absorbed into the existing urban fabric, swelling household densities mean that some new housing is needed. Much of this is high density in nature, where profit margins are greatest for developers.

Generally, urban land cover declines, particularly office and retail and manufacturing and storage, with a reduction in area for these land uses of around 60% in GM to 2050. This stems principally from a break on new developments because of the poor economic circumstances facing the conurbation and the lack of stimulus for consumption. Analysis using Metronamica reveals that the loss of urban land cover is balanced by increases in non-urban land uses, particularly disused and derelict land and woodlands which grow by 6,542 and 5,720 cells respectively. By area, these are the biggest changes in non-urban land cover across the three scenarios by some margin. In common with the characteristics of other shrinking cities, disused urban land gradually becomes covered by vegetation; known in Detroit as the 'urban prairie' where nature fills the void left by urban decline. Within the 'long descent' scenario, this matures over time into woodland. Allotments grow due to the high prices of imported food, with resulting growth in informal urban agriculture.

The 'long descent' scenario raises interesting implications for the climate change adaptation agenda. The scenario is essentially a challenging one in terms of socio-economic indicators. However, the slowing of development activity and the resulting increase in the amount of disused and derelict land (which over time becomes vegetated) and woodland land cover is beneficial, in land use terms, for climate change adaptation. Indeed, this provides more land that offers adaptation functions including recreation, evaporative cooling, rain water infiltration and biodiversity conservation. Assessed simply in adaptation terms, an urban area with such land cover characteristics has clear advantages over another location where there is a predominance of hard surfacing and a lack of green cover. However, adaptive capacity is influenced by much more than land cover, and many of the elements of the 'long descent' scenario are detrimental to adaptive capacity from a broader perspective. These issues are discussed in greater detail in section 5.

Figure 8. 'Long descent' scenario (2050)



4.3 The 'upward spiral' scenario (2050)

The full 'upward spiral' scenario story line can be read in an associated EcoCities publication (Carter 2011). The 'upward spiral' scenario was assessed in the same way as the 'long descent' scenario to enable a visualisation of the associated land cover changes using Metronamica. Key drivers of land cover change, with a specific focus on spatial planning legislation and regulation, are summarised below. The specific land cover changes linked to this scenario are also outlined.

Drivers of land cover change:

- There is increasing awareness of climate change issues, and the need to develop adaptation responses, amongst a range of stakeholder groups. With the impacts of climate change being felt more keenly as time passes, the adaptation response develops.
- The greater level of environmental awareness amongst citizens strengthens political resolve to implement responsive land use policy.
- Policies and strategies are developed to encourage sustainable growth, with greater attention to environmental 'limits to growth'.
- There is broad policy support for climate change mitigation and adaptation action at the global and GM level, with policy makers acting on the findings of research into climate change causes and impacts.
- The need to adapt infrastructure to the changing climate is recognised within the public sector and by private sector.
- Adaptation responses such as sustainable drainage systems and green roofs, become commonplace across GM. Indeed, green infrastructure is increasingly seen as 'critical infrastructure' and protected and enhanced as such.
- The buoyant economy globally and in GM supports steady growth, which provides capital to invest in new climate resilient infrastructure.
- GM's growing population spurs development activity, both residential and commercial. Developers are also encouraged by a clear policy framework and consumer demand for commercial and residential properties.
- Infrastructure owners and providers actively support steps to 'climate proof' existing and proposed infrastructure.

- Carbon pricing has a number of implications for land use. These include changing transportation choices, raising demand for local recreation and local holidays, strengthening the competitiveness of renewable energy schemes and increasing demand for carbon sequestration projects.
- Climate change impacts in other parts of the world influence food security nationally and in GM.
- There is more demand for recreation opportunities in urban areas and the city's hinterlands.

Spatial planning legislation and regulation:

- Strong spatial planning frameworks tightly define policies and principles regulating the development and use of land in the city.
- Spatial planning regulations restrict sprawling development through zoning approaches and the promotion of densification of existing settlements.
- Land use policies are developed to support moves to a 'low carbon economy' supporting agendas such as public transport, renewable energy and local agriculture.
- Planning policies protect landscapes that provide climate change adaptation functions such as floodplains, urban parks, woodland along river corridors, greenbelt, absorptive soils and upland areas for rainwater retention.
- GM is given a clear remit from national government to develop locally relevant spatial planning policy initiatives to deliver goals that are most appropriate for the city.
- GM spatial planning policy provides certainty to businesses looking to invest a city that is becoming increasingly resilient to the impacts of climate change.
- The planning system becomes an enabler of a 'sustainability transition'.

Nature of land cover change to represent within Metronamica (including a consideration of key underlying drivers):

- Multifunctional development activity is concentrated in existing urban areas leading to densification and urban infill, especially around public transport nodes (greenhouse gas (GHG) mitigation, improving quality of life in urban areas, reducing urban sprawl, congestion charge, incentivised business parks).

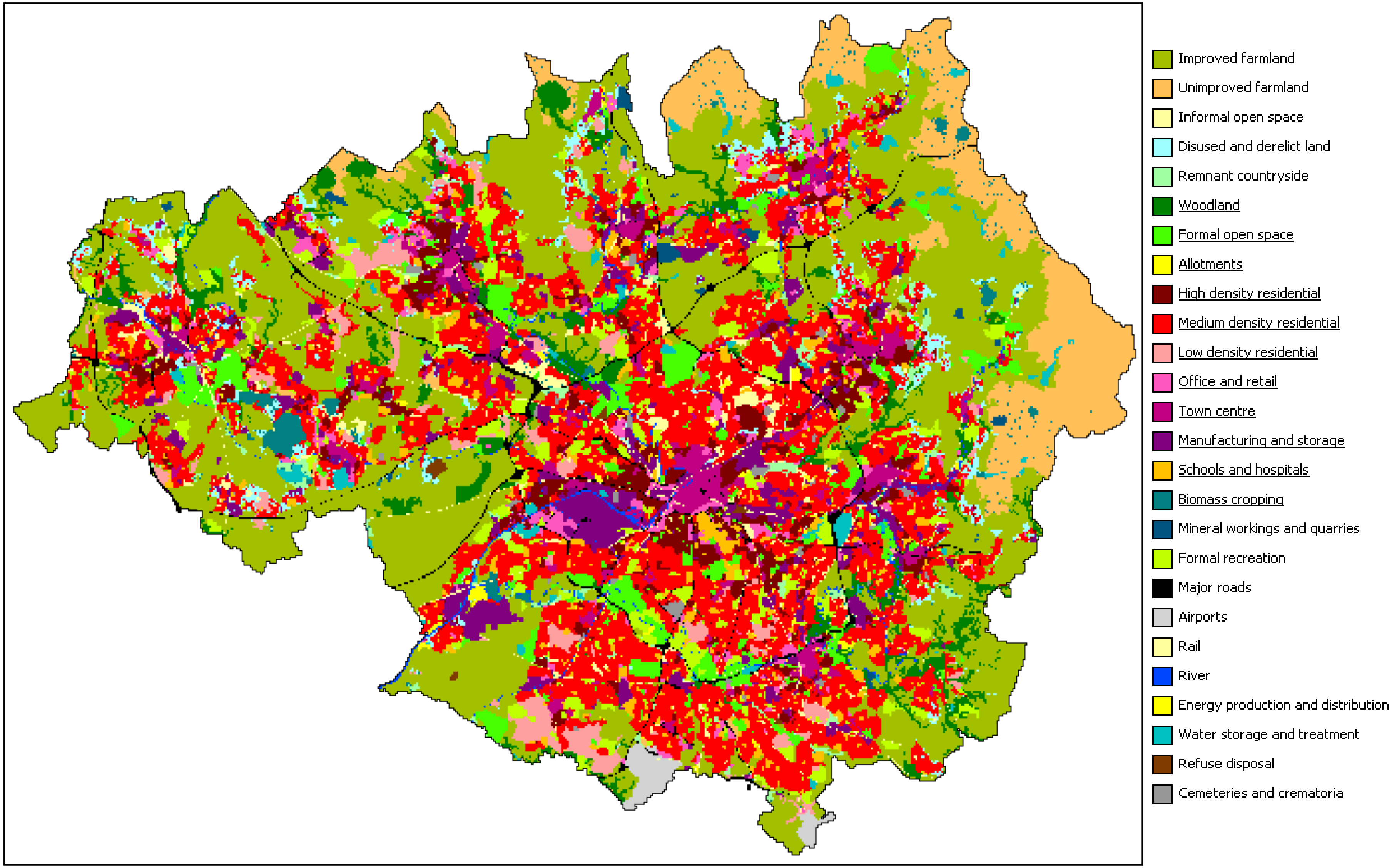
- High density housing increases, particularly in urban cores and close to public transport nodes (GHG mitigation, reducing urban sprawl, investment in public transport, rising oil prices, congestion charge).
- Commuter hubs in the urban fringe expand where well connected to public transport, particularly train and tram lines (information and communication technology growth, GHG mitigation, investment in public transport, rising oil prices).
- There is a loss of retail and office space in peripheral locations, particularly where they are not well served by public transport (rising oil prices, congestion charge, move away from car dominated transport mix).
- Zoning policies encourage new development to take place on areas of brownfield land close to existing development (protection of landscapes providing ecosystem service functions, densification policy, incentivised business parks).
- Existing high quality farmland is protected, with expansion of farmland where this is appropriate (rising cost of imported food).
- Allotments close to residential areas are protected and expanded (rising cost of imported food, increased public interest in environmental issues).
- Existing woodland is protected across GM, and enhancement of woodland is encouraged in some areas (biodiversity conservation, climate change adaptation, recreation, carbon sequestration).
- Biomass cropping emerges in urban areas and the hinterlands of the city on land that is not providing other important functions (rising cost of fossil fuels, promotion of renewable energy, greenhouse gas mitigation).
- Development is restricted in upland areas around the city (nature conservation, recreation, carbon sequestration, space for wind farms).
- Green infrastructure (of all forms) is protected and enhanced, particularly in densely populated urban areas (demand for recreation, demand for higher quality of life in urban areas, climate change adaptation, biodiversity conservation).
- Distinctive local natural landscapes are protected (recreation potential and biodiversity value).

‘Upward spiral’ is a scenario in which GM grows, both in terms of population and economic strength. There is, however, a greater emphasis on principles of environmental sustainability to guide decisions and actions linked to the growth and development of the conurbation. In land use terms, this is linked to processes including densification to reduce greenhouse gas emissions, and the protection of landscapes that provide climate change adaptation and broader ecosystem service functions. Figure 9 provides a visualisation of the ‘upward spiral’ scenario. Table 2 includes details of the land cover changes associated with the scenario, and figures 6 and 7 chart the data included in table 2. This analysis reveals that although some urban land uses shrink, notably medium and low density residential areas, the general trend is towards an increase in urban land cover, especially high density residential and office and retail. More significant, in terms of area of land cover, are the changes in non-urban land uses. Formal open space, which increases by 138% in area adding 2,806 cells, is particularly prominent. By area, woodland also grows considerably adding 1,010 cells by 2050.

Within this scenario, more land is converted into non-urban land that provides recreation opportunities, including formal open space and allotments. In order to accommodate these changes in the fabric of the conurbation some land use types decline in cover between 2006 and 2050. Metronamica analysis of the ‘upward spiral’ scenario highlights, for example, that much of the increase in formal open space is seen at the expense of disused and derelict land and informal open space. Smaller amounts of other land use are also lost to formal open space, such as medium density residential and remnant countryside. Of the non-urban land uses, informal open space and derelict and disused land see the largest declines in area, being replaced by growing urban land uses such as high density residential and office and retail. Of the urban land uses, the largest declines in area are seen for medium density residential (loss of 2289 cells) and then low density residential (loss of 446 cells). This reflects the policy of densification followed within the ‘upward spiral’ scenario, and the development of housing closer to public transport nodes.

In the context of climate change adaptation, the land use changes associated with the ‘upward spiral’ scenario have several broad consequences. The adaptation implications of increases in urban area are dependent on the design and location of the development that takes place. The EcoCities Metronamica model, which works on 100x100 metre grid cells, cannot visualise small scale changes to urban form, such as tree planting or the conversion of small patches of hard surface to managed green space. Indeed, it would not be possible or realistic to model such small scale changes in urban land cover. However, in the spirit of the 'upward spiral' scenario, and the strong spatial planning legislation and regulations that this scenario implies, it can be taken that new development is of a type that builds in adaptation responses. Despite the increases in land uses including formal open space and woodlands, under this scenario, there is less green cover in GM in 2050 than there was in 2006 due to the loss of land uses such as unimproved farmland, informal open space and remnant countryside. This would has negative consequences for adaptation to risks linked to the changing climate including flooding, heat stress and species loss.

Figure 9. 'Upward spiral' scenario (2050)



5 Land use scenarios for GM: climate change adaptation implications

The underlying motivation for taking a futures perspective to the consideration of land cover change in GM has been to explore, using scenarios, how changes to the conurbation might affect climate change impacts and adaptation responses. The drivers of change on the future growth and development of the city, as expressed within the scenarios, will influence the nature of the built environment and land cover with important implications for the adaptation agenda. The Metronamica model has provided a platform for visualising and analysing the land use implications of the scenarios developed within the EcoCities project (Carter 2011). The preceding discussion highlighted land use changes, and associated climate change adaptation implications, arising from three different land use futures for GM. This section focuses on a comparative assessment of the three scenarios in this respect.

Figure 10 juxtaposes the three land cover scenarios for 2050, and the 2006 UMT map. At the most broad brush level, a basic visual analysis highlights several key differences between the scenarios for 2050 in comparison to the current land cover characteristics of GM. The calibration projection is clearly the most intensely urban of the scenarios, with the 'long descent' scenario emerging as the least urbanised scenario. 'Long descent' also leads to the highest amount of green cover, woodland for example. 'Upward spiral' stands somewhere in between the calibration projection and 'long descent' in terms of the intensity of urbanisation processes and resulting amounts of green cover. Table 3 compares the three scenarios against a series of indicators produced using the Metronamica interface and confirms these differences in land cover between the scenarios. Figure 11 maps one of the indicators visually; the change in the amount of urban area for each scenario. It is here that the amount of urbanisation associated with the calibration projection becomes starkly apparent. Figure 11 also demonstrates that, in the 'upward spiral' scenario, where new urban land is developed this tends to cluster whereas under the 'long descent' scenario new urban development is more dispersed. This reflects the outcome of the densification policy that runs through 'upward spiral'. Figure 12 maps the change in woodland cover across the three scenarios. This provides a useful counterpoint to the mapping of urban land cover (figure 11), and demonstrates that the more intensely urban the scenario, the less woodland cover is seen.

Figure 10. Synthesis of the 2006 UMT map and three land use scenarios for GM to 2050.

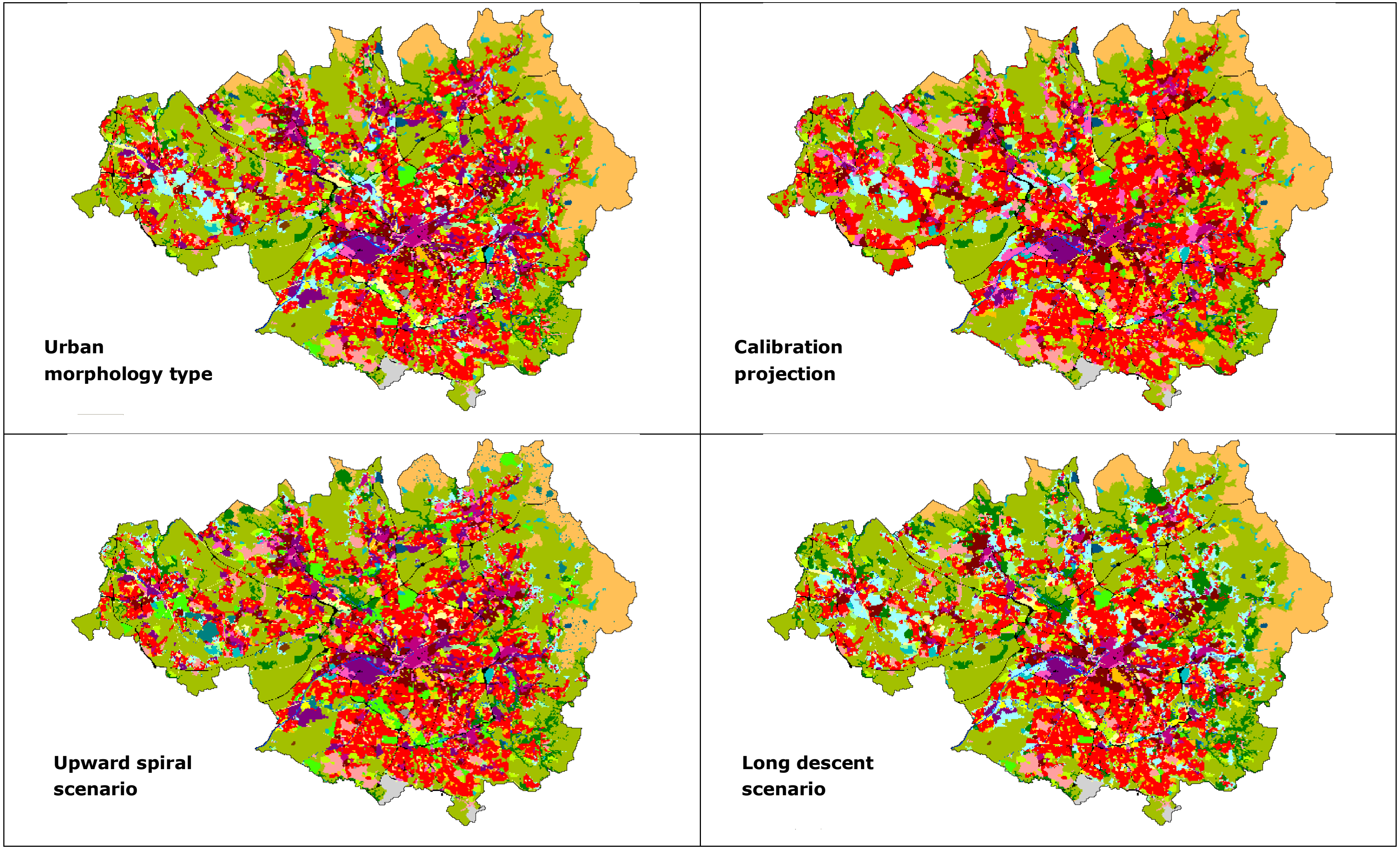


Table 3. Comparison of three scenarios for GM against a series of indicators.

Indicator	Calibration Projection (2050)	Upward Spiral (2050)	Long Descent (2050)
Soil sealing (100x100 metre cells)	67,676	58,664	48,690
Urban disappeared (100x100 metre cells)	846	3,120	12,496
Urban appeared (100x100 metre cells)	9,893	2,591	1,993
Deforestation (100x100 metre cells)	974	458	97
Aforestation (100x100 metre cells)	451	1,468	5,817
Average distance from residential to recreation (km)	0.63	0.36	0.49
Average distance from residential to work (km)	0.44	0.32	0.38

Figure 11. Change in urban land cover under three scenarios for GM

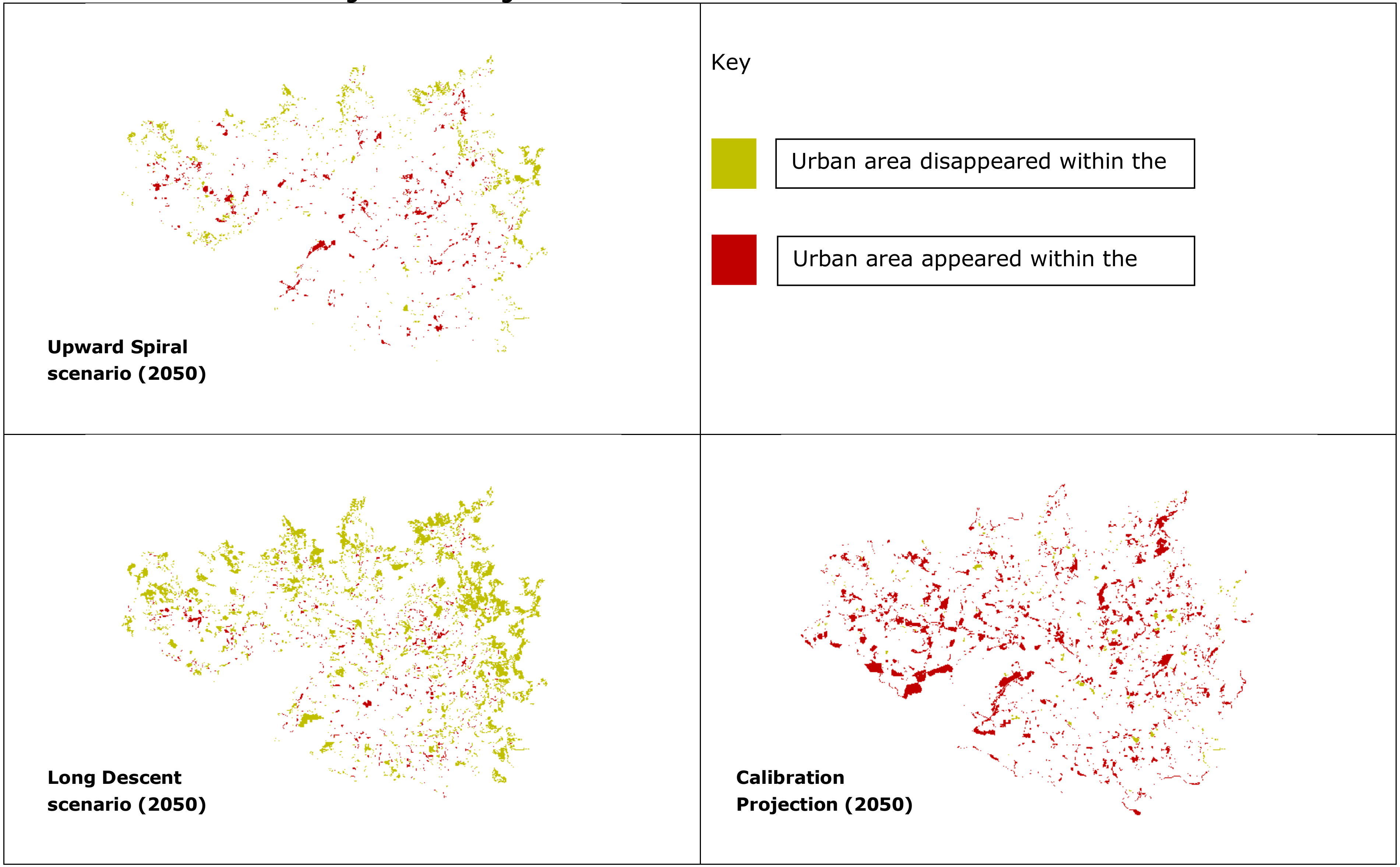
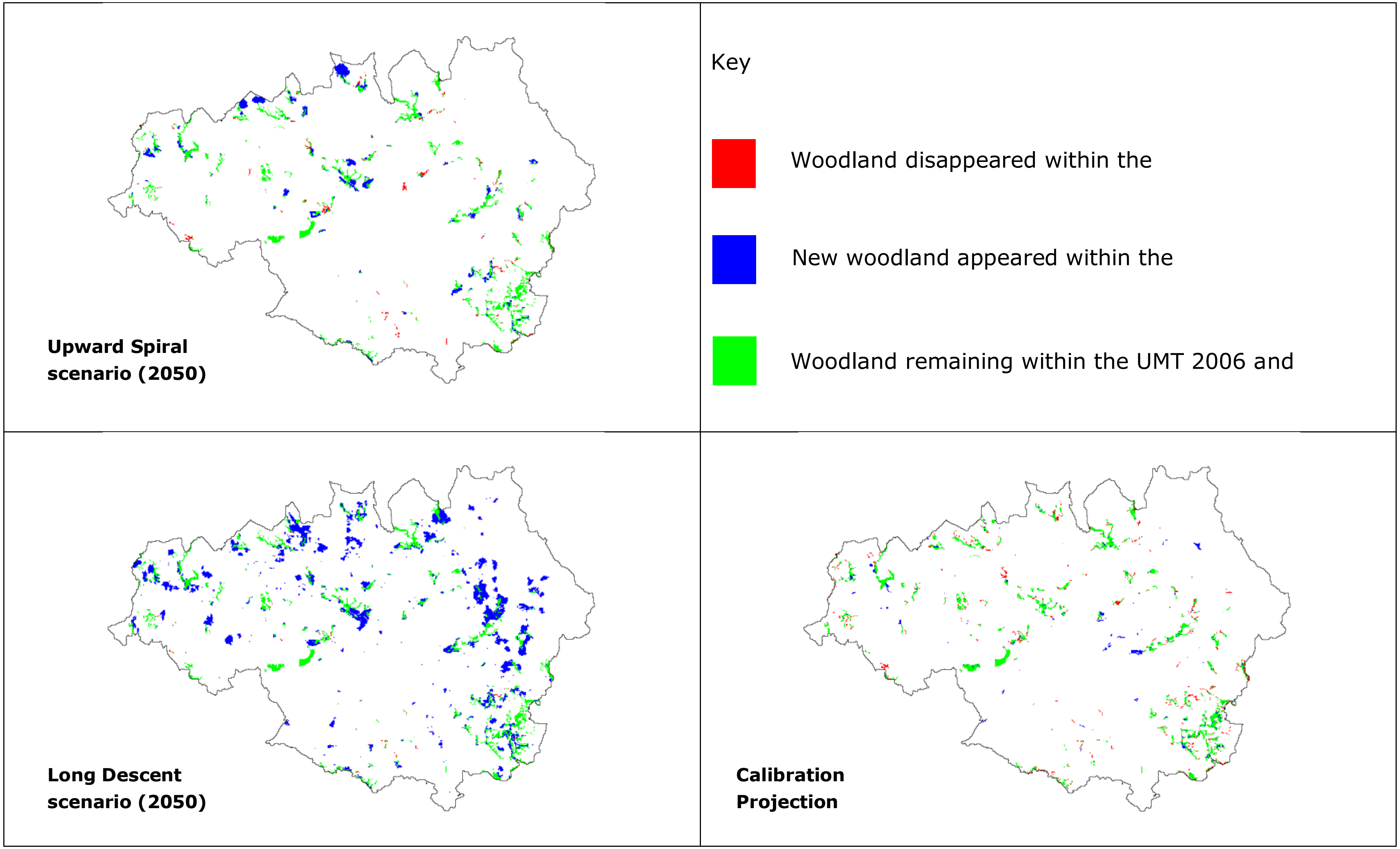


Figure 12. Change in woodland under three scenarios for GM



Some of the most prominent adaptation implications of each scenario have been highlighted in the preceding discussion (section 4). This comparative assessment, using quantitative indicators and maps developed within the Metronamica interface, indicates that different land use futures have contrasting effects on climate change impacts and adaptation responses in GM. This demonstrates that when considering adaptation responses, it is vital that attention is paid not just to the changing climate but also to land use change. This is because risks emerge at the interface between human and climatic interactions, for example concerning decision to develop in areas prone to escalating flooding or where urban intensification compounds the urban heat island effect within a warming climate. As a result, 'upward spiral', which is a positive scenario in many respects, has land use implications that are potentially more detrimental to impacts and adaptation that the 'long descent' scenario. This is certainly the case when the calibration projection and 'long descent' scenarios are compared.

However, it is important to emphasise that the adaptive capacity of a conurbation such as GM depends on much more than land cover characteristics. Adaptive capacity has been defined as: '…the ability or potential of a system to respond successfully to climate variability and change' (Adger et al 2007: 727). Adaptive capacity is determined by: 'the characteristics of communities, countries and regions that influence their propensity or ability to adapt' (IPCC 2001: 18). It has been established that these characteristics have dimensions that are generic, and also those that are specific to the particular climate change risk that is being explored (Adger et al 2007). Further, as noted by Alberini et al (2006: 124): '…assessment of adaptive capacity depends crucially on the time and geographical scale of reference.'

Generic factors determining adaptive capacity have been identified as including (Adger et al 2007; Alberini et al 2006; Brooks et al 2005; Haddad 2005; Smit and Wandel 2006; Vincent 2006; Yohe and Tol 2002):

- Income levels, and of equality in the distribution of income.
- Availability of, access to and distribution of resources.
- Availability and access to information [on climate change impacts and potential adaptation responses].
- Technological capacity and the range of technological options available for adaptation.

- Environmental factors [availability and quality of land, water, raw materials, biodiversity etc].
- Infrastructure quality and provision.
- Awareness and perception of climate change risks.
- Organisational and institutional capacity to implement adaptation responses
- The quality and transparency of decision making processes.
- The ability of society to act collectively to develop and implement adaptation responses.
- Human capital (including factors such as skills and education).

It is recognised that key adaptation concepts, including adaptive capacity and vulnerability, evolve over time (Adger et al 2007; Smit and Wandel 2006). As noted by an IPCC report: 'Adaptive capacity can vary over time and is affected by multiple processes of change' (Adger et al 2007: 731). The ability of a system to cope with changes in climate variables and evolving patterns of extreme weather events will be influenced by future social, technological, economic, environmental, political and value-based drivers of change.

The changes in land cover that GM will experience over the coming decades are impossible to predict. Land cover characteristics are one, albeit highly significant, element of how able the conurbation will be to adapt to the changing climate that it faces. Through the use of scenarios and land use modelling, this research has demonstrated that future land cover patterns in GM will vary depending on the outcomes of a complex interplay between different local and global drivers of change. These drivers will in turn influence the nature of other determinants of adaptive capacity, such as the generic factors listed above. Developing an enhanced appreciation of the implications of uncertain chains of cause and effect between different determinants of adaptive capacity is a crucial stage in developing planning and policy making responses to climate change impacts. This issue is addressed in an associated EcoCities working paper (Ravetz 2012) which, when considered in tandem with this report on future land use change, highlights that there is a need to deepen and lengthen the consideration of adaptation to climate change in GM.

The researchers involved in this task are not modelling experts. However, Metronamica is designed as a system to be applied by researchers and practitioners to support spatial planning and land use development. The goals of this particular exercise have been to raise awareness of the implications of future land cover change for climate change adaptation, and also to look at the potential of the Metronamica model to support planning for the changing climate in GM. These goals have both been achieved, yet further work could be undertaken to advance them further. This could involve the inclusion of new data layers (e.g. agricultural land classification, soil type data) within the model, working with the outputs of the land use scenarios within the STAR tools to look at their implications for surface temperature and rain water runoff, and the development of probability-based maps to display the results of the scenarios. Also, although the focus of the EcoCities project has been on adaptation to climate change, the outputs of the GM Metronamica model could be used to investigate other agendas such as transport or regeneration.

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7 Appendix 1: Metronamica input parameters

Table 4. Area demand scenarios to 2050 (based on changes from observed trends in land cover change)

Variable	% change 1997-2006 in cells	Upward Spiral Scenario	Long Decent Scenario
Area of woodland	1997: 4208 2006: 4115 Change: -0.25%/yr	**Reversal** in observed trend (0.5% annual increase). Protection and enhancement of woodland for recreation, biodiversity, carbon sequestration etc.	**Reversal** of observed trend (2% annual increase). Weaker spatial planning leads to loss of some woodland to residential development. However, natural succession leads to significant increase in woodland on sites that have become derelict, driving increase in woodland over time.
Area of formal open space	1997: 2360 2006: 2021 Change: -1.86%/yr	**Reversal** in observed trend (2% annual increase). Greater public demand for outdoor recreation, with corresponding investment by the government and private sector in parks, gardens, golf courses etc.	**Increase** of observed trend (2% annual decrease). There is less public sector investment in parks, sports facilities etc. There is no protection from development. Lack of maintenance leads to some conversion to woodland and informal open space.
Area of allotment	1997: 145 2006: 169 Change: +1.58%/yr	**Increase** of observed trend (2% annual increase). Factors including the higher price of imported food and increased public demand for outdoor recreation stimulate growth.	**Strong increase** of observed trend (4% annual increase). The higher price of imported food and the general decline in availability of many foodstuffs spurs growth in informal agriculture.
Area of town centre	1997: 2785 2006: 2683	**Reversal** of observed trend (0.5% annual increase). The growing economy invigorates town centres, stimulating new development.	**Continuation** of observed trend (0.42% annual decrease). Reduced demand for goods and services stemming from poor economic

Table 4 (cont). Area demand scenarios to 2050

Variable	% change 1997-2006 in cells	Upward Spiral Scenario	Long Decent Scenario
	Change: -0.42%/yr	Out of town shopping centres decline due to the high price of fuel and poor public transport connections. Coupled with densification policy, this supports steady town centre growth.	conditions causes closure of businesses in the retail and entertainment sectors.
Area of extra 1 (biomass cropping)	50 cells in 2015. 15% annual growth to 2025, followed by 7.5% annual growth to 2050.	**Increase** in land cover. Increasing demand for local renewable energy and climate change mitigation targets usher in biomass cropping as an important source of energy.	**NA** biomass cropping does not emerge in this scenario.

Table 5. Socio-economic figures for population and jobs: calibration input and scenarios to 2050

Variable	Calibration	Oxford Economics projection to 2032	Upward Spiral Scenario	Long Descent Scenario
Total GM population	1997: 2522000 2006: 2554200	2875700 (0.46% annual increase)	**Continuation** in projected trend: 0.46% annual increase. Factors including the high cost of fuel, the concentration of housing and employment opportunities in urban centres and steady economic growth maintain increase in population growth.	**Increase** in projected trend: 0.54% annual increase. Immigration from overseas and GM's hinterland, driven by issues including climate disruption, environmental change, and perceived economic opportunities, stimulates strong growth.
Population in high density housing	1997: 840667 2006: 851400	Not available	**Strong growth** (0.85% annual increase). Rising population and policies to densify of existing urban areas, particularly around public transport nodes, stimulates high density growth. Housing developers also have capacity to invest in appropriate schemes.	**Strong growth** (1% annual increase). New development that does take place tends to be high density housing. New residents invariably move into high density housing. Returns to developers are highest in this type of housing.
Population in medium density housing	1997: 840667 2006: 851400	Not available	**Low growth** (0.30% annual increase). Rising population and policies to increase densification of existing urban areas, particularly around public transport nodes, lead to some medium density growth. Housing developers also have capacity to invest in appropriate schemes.	**Low growth** (0.27% annual increase). Poor economic conditions reduce demand for housing. Developers do not have significant capital to invest in new housing schemes. Some housing growth takes place in the more affluent suburbs. Sporadic development takes place in some areas.
Population in low density housing	1997: 840667 2006: 851400	Not available	**Low growth** (0.17% annual increase). High fuel prices and government policy rewarding growth in high density housing creates results in less growth in low density housing. Some growth takes place in areas supported by train and metrolink access.	**Low growth** (0.27% annual increase). Poor economic conditions reduce demand for housing. Developers do not have significant capital to invest in new housing schemes. Some housing growth takes place in the more affluent suburbs. Sporadic development takes place in some areas.
Jobs in retail and	1997: 287900 2006: 414900	640100 (1.68% annual	**Continuation** in projected trend: 1.68% annual increase. The buoyant economy and rising	**Decrease** in projected trend: 1.49% annual decrease. Sluggish and declining economic growth in

Variable	Calibration	Oxford Economics projection to 2032	Upward Spiral Scenario	Long Descent Scenario
office		increase)	population maintains demands for goods and services, and hence supports continuing growth in retail and office jobs.	GM, coupled with rising unemployment and consequent reduced demand from consumers, leads to a decline in jobs in this sector.
Jobs in manufactur -ing and storage	1997: 286700 2006: 211200	143100 (1.49% annual decrease)	**Reduction** in projected trend: 0.49% annual increase. Growth in the economy spurs a manufacturing revival, particularly in the low carbon, high-tech and 'green' sectors.	**Continuation** in projected trend: 1.49% annual decrease. Sluggish and declining economic growth in GM cements the downward trend in employment and production within the manufacturing sector.
Jobs in health and education	1997: 211200 2006: 242200	274800 (0.49% annual increase)	**Continuation** in projected trend: 0.49% annual increase. The buoyant economy and increase focus on social welfare and equality encourages government spending on public services.	**Decrease** in projected trend: 0.1% annual increase. Sluggish and declining economic growth in GM reduces the capacity of the government to fund public services. The private sector does not have the capacity to fill the gap.

Table 6. Population figures for Greater Manchester: scenario input data

	2006	% annual growth from 2006	2020	2032	2050
Long Decent					
Population in high density	851400	1	978662	1102781	1319089
Population in medium density	851400	0.27	884154	913230	958646
Population in low density	851400	0.27	891408	922084	959436
Upward Spiral					
Population in high density	851400	0.85	958509	1043171	1235587
Population in medium density	851400	0.30	887865	914863	971348
Population in low density	851400	0.17	877327	893583	918817
Calibration Projection					
Population in high density	851400	0.46	851400	959304	1041917
Population in medium density	851400	0.46	851400	959304	1041917
Population in low density	851400	0.46	851400	959304	1041917

Notes on socio-economic figures for population and jobs (Tables 5 and 6)

- Decline in jobs in economic sectors: Over recent decades there has been a decline in people employed in the manufacturing sector. The Oxford Economics projections for GM demonstrate that this is set to continue, at an annual rate of decline of 1.49%. The figure of a 1.49% annual decline is taken as a proxy value for a declining sector.
- Increase in jobs in economic sectors: Two of the three sectors represented in the Metronamica model saw increases in jobs over the period 1997-2006, and are projected to see further employment growth to 2031 according to the Oxford Economics model. Strong annual growth is projected for jobs in retail and office (1.68%) and moderate growth in the health and education sector (0.49%).
- The population in the three different housing density classes are simply taken as one third of the total GM population at 2006. Data was not available to match the population figures with the different residential density classes used within the Metronamica model. For the calibration projection, the 0.46% annual increase in population in the three different housing classes to is based on one third of projected population growth to 2032 being accommodated in each type of housing.
- Jobs data comes from the Oxford Economics 2010 report. Figures for distribution are taken for storage. Figures for banking and finance, insurance, other finance, business services, real estate activities, computer related activities, legal and accounting services, advertising, labour recruitment, other business services and public administration are taken for office.

Table 7. Zoning plans – calibration and scenario distinctions

Plan	Calibration				Upward Spiral Scenario					Long Decent Scenario			
	U	***W***	***FO***	***A***	***U***	***W***	***FO***	***A***	***BC***	***U***	***W***	***FO***	***A***
Greenbelt (afforestation)	SR	WR	A	A	SR	AS	AS	A	AS	U	U	U	U
Greenbelt (deforestation)	SR	WR	A	A	SR	AS	AS	A	AS	U	U	U	U
Greenbelt (forest)	SR	A	A	A	SR	AS	AS	A	AS	U	U	U	U
Urban park	AR	WR	SR	WR	AR	AR	AR	AR	AR	U	U	U	U
Local nature reserve	AR	WR	SR	WR	AR	AR	AR	AR	AR	U	U	U	U
Sites of biological importance	AR	WR	SR	WR	AR	AR	AR	AR	AR	U	U	U	U
Woods for people	SR	AS	SR	WR	AR	AS	AR	AR	AR	U	U	U	U
Brownfield	WS	A	A	A	AS	A	A	AS	A	U	U	U	U
National nature reserve	AR	WR	SR	AR	AR	AR	AR	AR	AR	U	U	U	U
Ex quarries	A	A	U	A	A	AS	AS	A	AS	U	U	U	U
Joint waste plan landfill	A	A	U	A	SR	AS	AS	AR	AS	U	U	U	U
Flood zone 3	U	A	A	A	SR	AS	AS	AS	AS	U	U	U	U
Flood zone 2	U	A	A	A	SR	AS	AS	AS	AS	U	U	U	U
Joint waste plan MS2	U	A	U	A	SR	SR	SR	SR	SR	U	U	U	U
Quarry extension	U	A	U	U	SR	SR	SR	SR	SR	U	U	U	U
Surface water flooding over 1m	U	A	A	U	SR	AS	AS	AS	AS	U	U	U	U
LU 2006 improved farmland	NA	NA	NA	NA	WR	WR	WR	WR	WR	WR	WR	WR	WR
LU 2006 unimproved farmland	NA	NA	NA	NA	A	WS	WS	WS	WS	U	U	U	WS
LU 2006 informal open space	NA	NA	NA	NA	A	WS	WS	WS	WS	U	U	U	WS

Table 7 (cont). Zoning plans – calibration and scenario distinctions

Plan	Calibration				Upward Spiral Scenario					Long Decent Scenario			
	U	***W***	***FO***	***A***	***U***	***W***	***FO***	***A***	***BC***	***U***	***W***	***FO***	***A***
LU 2006 disused and derelict land	NA	NA	NA	NA	WS	WS	WS	WS	WS	U	U	U	WS
LU 2006 remnant countryside	NA	NA	NA	NA	A	WS	WS	WS	WS	U	U	U	WS
LU 2006 woodland	NA	NA	NA	NA	WR	U	WR	WR	WR	U	U	U	WS
LU 2006 formal open space	NA	NA	NA	NA	WR	WR	U	WR	WR	U	U	U	WS
LU 2006 allotments	NA	NA	NA	NA	WR	WR	WR	U	WR	WR	WR	WR	U
LU 2006 high density residential	NA	NA	NA	NA	A	WR	WR	WR	WR	U	U	U	WR
LU 2006 medium density residential	NA	NA	NA	NA	A	WR	WR	WR	WR	U	U	U	WR
LU 2006 low density residential	NA	NA	NA	NA	A	WR	WR	WR	WR	U	U	U	WR
LU 2006 office and retail	NA	NA	NA	NA	A	WR	WR	WR	WR	U	U	U	WR
LU 2006 town centre	NA	NA	NA	NA	A	WR	WR	WR	WR	U	U	U	WR
LU 2006 manufacturing and storage	NA	NA	NA	NA	A	WR	WR	WR	WR	U	U	U	WR
LU 2006 schools and hospitals	NA	NA	NA	NA	A	WR	WR	WR	WR	U	U	U	WR
LU 2006 biomass cropping	NA	NA	NA	NA	WR	WR	WR	WR	U	U	U	U	U

Key for the zoning plans table	WS: weakly stimulated – development broadly supported but not actively encouraged
U: Urban including high, medium and low density residential, office and retail, town centre, manufacturing and storage, schools and hospitals	A: allowed – no restrictions on or encouragement of development
W: woodland	WR: weakly restricted – some limitations on development
FO: formal open space	SR: strictly restricted – very limited development permitted
A: allotments	AR: absolutely restricted – no development permitted under any circumstances
AS: actively stimulated – development strongly encouraged	U: unspecified - no influence, with no policy relating to this relationship.

Table 8. Constant growth of density

Constant growth of density is a value inputted into the Metronamica interface, and concerns the average floor space per employee/resident. Where this value is above 1, floor space declines for the specified landuse over the modelling period. Where this value is less than 1, floorspace increases for the specified landuse over the modelling period. The constant growth of density value applies a multiplier each year, so a value of 1.01 will lead to a 1% decline in floor space per job or resident per year in each cell. This will lead to a decline in the number of cells taken by the specified land use.

Variable	Calibration (1997-2006)	Upward Spiral (2006-2050)	Long Decent (2006-2050)
Population (high density)	1	1.005 – government promotes densification policies, particularly in high density residential areas. This supports carbon reduction targets. Restoration and retrofit leads to less new build. Where development in outlying areas is lost, this gradually becomes natural land.	1.0075 - more people living per dwelling. Less new development taking place. Where new development takes place this is high density as developer profits are higher. Some existing development becomes derelict.
Population (medium density)	1	1.005 – government promotes densification policies to reduce urban sprawl. Where development in outlying areas is lost, this gradually becomes natural land.	1.0075 - more people living per dwelling. Less new development taking place. Some existing development becomes derelict.
Population (low density)	1	1.005 – government promotes densification policies to reduce urban sprawl. Where development in outlying areas is lost, this gradually becomes natural land.	1.0075 - more people living per dwelling. Less new development taking place. Some existing development becomes derelict.
Retail and Office	0.99 – calibration period was characterised by intensive development of retail and office space.	1.005 – densification policy also influences retail and office space. Where development in outlying areas is lost, this gradually becomes natural land.	1.0075 – as development activity is low, new businesses tend to take over unused space rather than building new shops or offices. Jobs in this sector decline. Some existing development becomes derelict.
Manufacturing and Storage	0.99 – calibration period was during a time of steady economic growth. Storage facilities in particular expanded.	1.005 – move to high tech industries that have a smaller footprint. New industry takes over disused space. Where development in outlying areas is lost, this gradually becomes natural land.	1.0075 - Jobs in this sector decline and demand for goods and services falls, slowing development. Some existing development becomes derelict.
Health and Education	1	1.005 – increased investment in public services leading to growth in schools and hospitals – however these often expand on and develop existing sites	1 – there is little investment in public services, and hence development activity is low. Jobs in this sector decline.

Accessibility inputs: calibration and scenarios to 2050

Table 9. Formal open space

Infrastructure type	Calibration		Upward Spiral		Long decent	
	Distance Decay	Weight	Distance Decay	Weight	Distance Decay	Weight
A-Roads	12	1	12	0.5	NA	NA
Motorway Junctions	12	0.5	12	0.5	NA	NA
Railway Station	20	0.8	25	1	NA	NA
Metrolink Station	20	0.8	25	1	NA	NA

Table 10. Allotments

Infrastructure type	Calibration		Upward Spiral		Long decent	
	Distance Decay	Weight	Distance Decay	Weight	Distance Decay	Weight
A-Roads	3	1	10	0.5	10	0.5
Motorway Junctions	12	0.5	10	0.5	10	0.5
Railway Station	20	0.8	20	1	10	0.5
Metrolink Station	20	0.8	20	1	10	0.5

Table 11. High Density Residential

Infrastructure type	Calibration		Upward Spiral		Long decent	
	Distance Decay	Weight	Distance Decay	Weight	Distance Decay	Weight
A-Roads	3	1	5	0.25	10	1
Motorway Junctions	10	0.25	5	0.25	10	1
Railway Station	6	0.5	10	1	6	0.25
Metrolink Station	6	0.5	10	1	6	0.25

Table 12. Medium Density Residential

Infrastructure type	Calibration		Upward Spiral		Long decent	
	Distance Decay	Weight	Distance Decay	Weight	Distance Decay	Weight
A-Roads	6	1	8	0.25	15	1
Motorway Junctions	15	0.25	8	0.25	15	1
Railway Station	8	0.5	15	1	12	0.25
Metrolink Station	8	0.5	15	1	12	0.25

Table 13. Low Density Residential

Infrastructure type	Calibration		Upward Spiral		Long decent	
	Distance Decay	Weight	Distance Decay	Weight	Distance Decay	Weight
A-Roads	5	0.6	10	0.5	20	1
Motorway Junctions	8	0.4	10	0.5	20	1
Railway Station	12	0.25	20	1	20	0.25
Metrolink Station	12	0.25	20	1	20	0.25

Table 14. Office and Retail

Infrastructure type	Calibration		Upward Spiral		Long decent	
	Distance Decay	Weight	Distance Decay	Weight	Distance Decay	Weight
A-Roads	12	0.6	5	0.25	6	1
Motorway Junctions	12	0.4	5	0.25	6	1
Railway Station	15	0.25	10	1	15	0.25
Metrolink Station	15	0.5	10	1	15	0.25

Table 15. Town Centre

Infrastructure type	Calibration		Upward Spiral		Long decent	
	Distance Decay	Weight	Distance Decay	Weight	Distance Decay	Weight
A-Roads	3	1	5	0.25	6	1
Motorway Junctions	15	0.5	5	0.25	6	1
Railway Station	4	0.5	10	1	15	0.25
Metrolink Station	6	0.25	10	1	15	0.25

Table 16. Manufacturing and Storage

Infrastructure type	Calibration		Upward Spiral		Long decent	
	Distance Decay	Weight	Distance Decay	Weight	Distance Decay	Weight
A-Roads	20	1	12	0.5	6	1
Motorway Junctions	15	0.8	12	0.5	6	1
Railway Station	15	0.25	25	1	15	0.25
Metrolink Station	15	0.25	25	1	15	0.25

Table 17. Schools and Hospitals

Infrastructure type	Calibration		Upward Spiral		Long decent	
	Distance Decay	Weight	Distance Decay	Weight	Distance Decay	Weight
A-Roads	15	0.4	8	0.5	12	1
Motorway Junctions	15	0.3	8	0.5	12	1
Railway Station	20	0.25	15	1	12	0.25
Metrolink Station	20	0.25	15	1	12	0.25