018530 - SWITCH

Sustainable Water Management in the City of the Future

Integrated Project

Global Change and Ecosystems

Deliverable D1.2.11 (WP 1.2)
Modeling Results : Case Study of Birmingham, UK
City water future for Birmingham

Due date of deliverable: M60

Actual submission date: M60

Start date of project: 1 February 2006

Duration: 60 months

Revision [Final]

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Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission	
CO	Confidential, only for members of the consortium (including the Commission Services)	

SWITCH Deliverable Briefing Note Template

SWITCH Document

Deliverable D1.2.11

Modeling Results : Case Study of Birmingham, UK

Audience

The document was prepared for an audience both inside and outside the SWITCH consortium. For consortium members it gives an overview on how a cellular automata model for the city of Birmingham in the UK was built and use to model the growth of the city. The results presented here are part of an on-going PhD research that aims to use agent based technology applied in urban water management. The model will be integrated with an existing urban drainage model for the city that has been simplified and setup in SWMM 5.0. External audience consists of mainly academic fellows that are currently working on similar subjects.

Purpose

The purpose of the document is to review the progress in the implementation of land use change models with cellular automata models and the integration with urban drainage computational engines to explore the cities' future drainage infrastructure development.

Background

This document contributes to the SWITCH approach proposed during the project. The document is a step towards the development of a set of tools to evaluate city's future scenarios of development.

Potential Impact

The document presents the results of the on-going research work that aim to contribute to the development of a new approach for urban drainage infrastructure planning and design which help water companies and municipalities to improve the effectiveness of their investments and contributes to the sustainability of the systems.

Issues

Not applicable

Recommendations

The document consists of a description of the application of the Dinamica Ego software to model the growth of the city of Birmingham and the potential of integration with a traditional urban drainage modeling engine.

Table of Content

Case of Study of City water future for Birmingham

Summary

The rapid urbanisation and population growth; creates the need for better planning and management of the urban infrastructures. Urban drainage system is one of the vital services needed for any urban area and modelling it is a challenge because the changing conditions of its hydrology in the future. Generating urban drainage network using agent-based models can provide the network distribution plan on the new developed urban areas depending on the existing system. The urban area growth and expansion is modeled by using cellular automata model of land use change. The Dinamica Ego software is used for this purpose.

Introduction

Cities can be considered as complex systems considering their characteristics of emergence, self-similarity, self-organization and non-linear behavior of land use changes with time, Batty and Langley, 1994. The use of tools that can help in the understanding of the above–mentioned characteristics are important to gain knowledge about the patterns and mechanisms behind urban dynamics. Agent-based models are built and used to represent the same phenomena or characteristics in several disciplines of sciences. For modeling land use changes and urban planning, some interesting aspects used in this technique are the representation of the environment (can be done in two or three dimensions), the integration with GIS and temporal – space variables and the interaction between the agents and the agents with the surrounding environment.

Traditionally urban planning and development have been done based on the formulation and execution of master plans for a fix period of time. These plans normally include projections of the population growth, the demand for future services, the land use changes, etc. Master plans normally end up in bookshelf, and this approach is showing to be ineffective and very often those plans are not fulfilled. As a result the goals are lost, some areas and sectors inside the cities are developed without any control. This is particularly interesting in urban areas in developing countries due to several reasons including unexpected events such as migration, natural disasters, economic factors, etc

Urban infrastructures are vital for any new urbanised area. In order to attain these infrastructures, prepared plans need to be available to connect the newly developed infrastructure with the existing one. Accordingly, many modellers are concerned with implementing integrated approaches; improve urban planning and decision support systems. Several researches in previous years focused on the water and electric powers networks simulations .In their simulations; they used growth patterns using geographically based urban growth models to have infrastructure distribution patterns. These patterns can help planners and decision-makers at the city level to understand future scenarios of city expansion foresee bottlenecks and suggest possible solutions. The lack of urban water infrastructures network distribution models leads to the necessity to develop a new approach to generate these models for future urban planning.

Agent based models, including cellular automata has been used and tested in several cases for land use changes modeling, including urban dynamics. The results of those models have successfully probe that the application of ABM and CA for land use changes modeling is possible and that the outcome of the models are similar of what is observed in reality.

Objective of the study

The objective of this case study is to describe the ongoing research results that aim to contribute the development of a framework for the evolution of urban drainage networks. This purposed framework will be used to determine the optimal distribution of urban drainage network in new developed areas and its relation to the existing system. This frame work will be functioned on the City of Birmingham. The frame work will give a prediction of the current drainage network extension depending on the future land use changes.

Methodology

The framework for the evolution of urban drainage networks consist of doing a spatial analysis to find characteristics that connects the land use pattern distribution of an urban area with the properties of the urban drainage system. The interaction between agent based algorithm and the cellular automata model for urban growth will define a new approach to explore scenarios of future growth and urban dynamics were water is at the center. The proposed framework is presented in below figure 1.

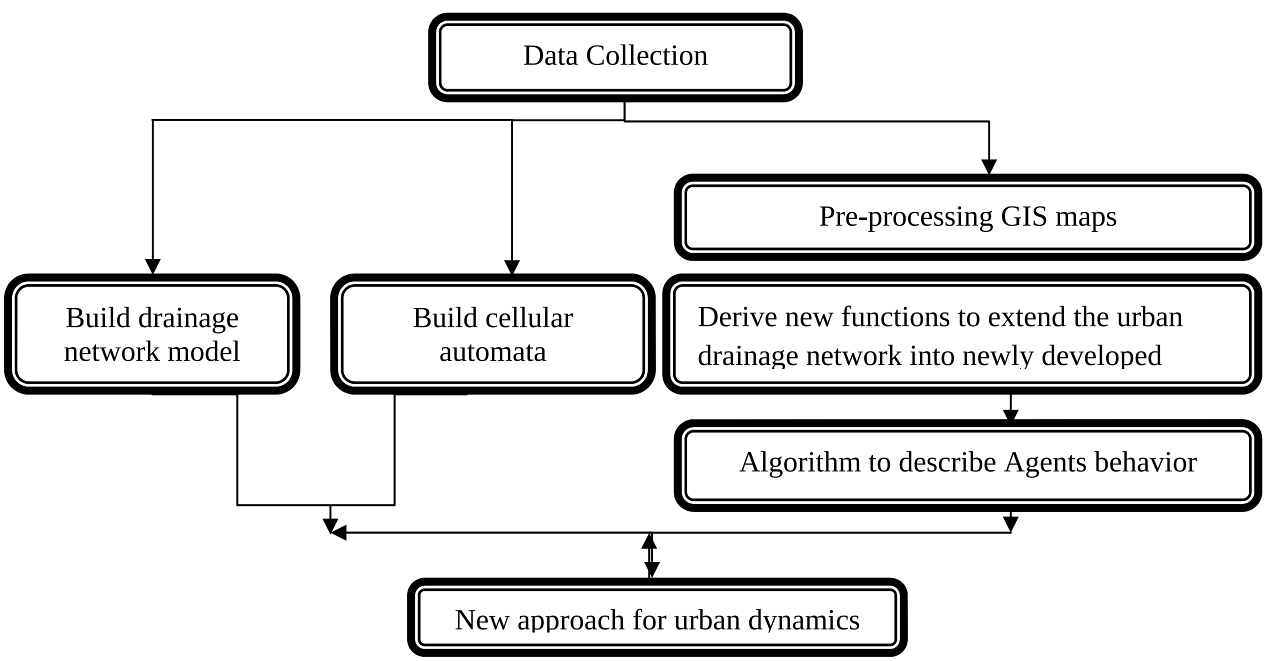


Figure 1. General methodology

In this study, DINAMICA software is used as a simulation platform for our urban dynamics model. DINAMICA employs, as input, a set of maps, including the initial and final map of land use, also known as landscape maps, considering that a landscape could be viewed as a bi-dimensional ar-ray of land use types; the sojourn time map that keeps track of the time since the last change, and two sets of ancillary maps: the static and dynamic variables, the latter named so because they are updated by the model iteration. These two sets of variables control the location of changes (Fig. 2). These variables are combined by summing their Weights of Evidences (Goodacre et al. 1993; Bonham-Carter, 1994 and Soares-Filho et al. 2005), to produce a transition probability map, which depicts the most favourable areas for change (Soares-Filho et al. 2002, 2004 and 2005). Weights of Evidence consists of a Bayesian method, in which the effect of each spatial variable on a transition is calculated independently of a combined solution.

The only assumption for the Weights of Evidence method is that the in-put maps have to be spatially independent. A set of measures can be used to assess this assumption, such as the Cramer test and the Joint-Uncertainty Information (Bonham-Carter 2004). Correlated variables must be disregarded or combined into a third that will be used in the model. As a result, the spatial relationships calculated by Weights of Evidence method are used to parameterize and calibrate the simulation model with respect to the spatial configuration of changes.

Another component of the model, the transition function, operates on the probability maps, and is constrained by the quantity of changes specified as input for each transition. This function draws the higher probability cells, after having ranked them in a vector file. The quantities of changes are determined a priori through the calculation of a historical transition matrix. The transition matrix describes a system that changes over discrete time increments, in which the value of any variable in a given time period is the sum of fixed percentages of the value of the variables in the previous time period.

DINAMICA uses as a local CA rule, a transition engine composed of two complementary transition functions, the Expander and the Patcher (Soares-Filho et al. 2002). DINAMICA splits the cell selection mechanism into these two processes. The first process is dedicated only to the expansion or contraction of previous patches of a certain class, and it is called Expander. The second process is designed to generate or form new patches through a seeding mechanism, and it is called Patcher. For each transition, the percentage of transitions executed by the Expander function in relation to Patcher must be defined. The Patch Isometry is a number varying from 0 to 2. The patches assume a more isometric form as this number increases. The size of new patches and expansion fringes are set according to a lognormal probability distribution. Therefore, it is necessary to specify the parameters of this distribution represented by the mean and variance of the patch sizes to be formed.

As the quantity of changes is passed as fixed parameter to the model, its validation considers only the spatial locations of the changes. This is the last procedure before the

model can be used for prognosis. It consists of a comparison between the model results and a reference map, in this case, the land use map at the simulation final time. To date, there are several map comparison techniques that have gained prominence as they apply multiple resolution windows to asses the spatial match between two maps, e.g. Costanza (1989), Pontius (2002), Power et al. (2001) and Hagen (2003). Nonetheless, there is neither consensus about which technique yields the most appropriate validation, nor what fitness value should be taken as a threshold to accept or reject the model. Of these techniques, the fuzzy comparison method by Hagen (2003) was adapted to be used in Dinamica, named therein as the "Reciprocal Similarity". This method employs a decay exponential function with the distance to weight the cell state distribution around a central cell. Generally, one can say that a simulated map presents good result when it has a fitness value higher than the one obtained through a comparison between the final and initial maps. (Hagen 2003).   Figure 2 shows the required steps to set-up the cellular automata model of land use change within Dinamica Ego.

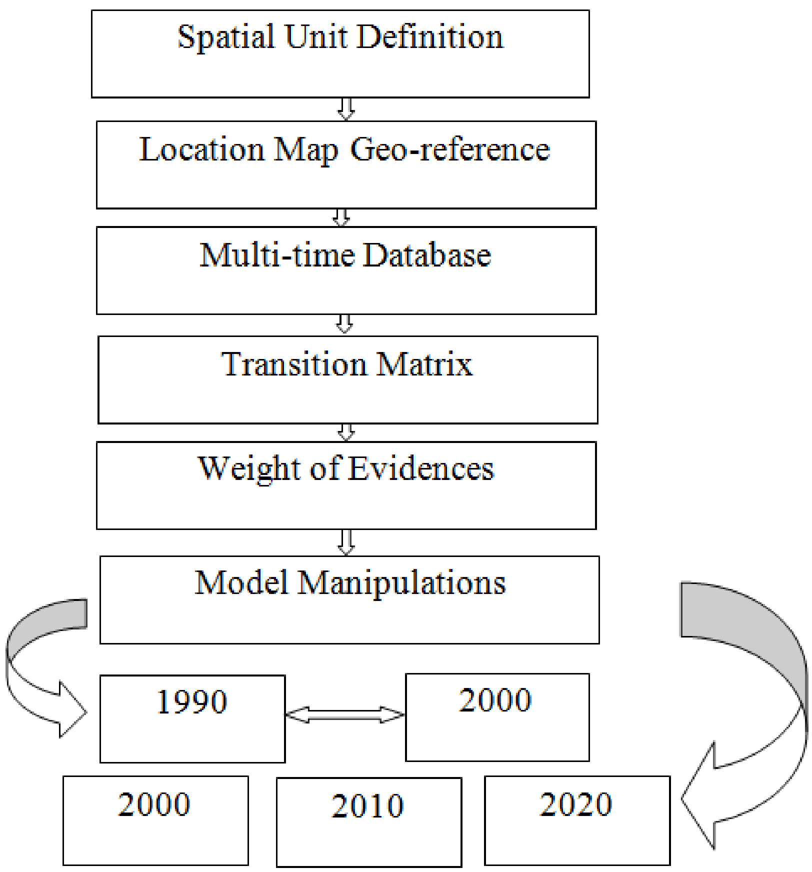


Figure 2. Steps to build the land use change model in dinamica

The study area: city of Birmingham

City of Birmingham is a located in the West Midlands county of England. The city total area equals to 267.77 km2 .The main Birmingham plateau can be subdivided into smaller units separated by rivers , and have ranging level from 150–300 m above sea level. North of the River Tame is the low Sutton Plateau which lies west of Sutton Coldfield town centre between Aldridge and Hamstead in the west and Bassetts Pole to Tyburn in the east. On its western edge a ridge runs from Shire Oak to Queslett where it rises up to the prominent landmark of Barr Beacon. The West Bromwich-Harborne plateau is a similar low plateau lying south of the River Tame, west of the River Rea. On the low eastern edge of this plateau was founded the tiny Anglo-Saxon settlement of Birmingham. To the south is the higher ground of the Sedgley-Northfield Ridge which marks part of the main English watershed.

Birmingham is the most populous British outside London, with a population of 1,028,700 (2009 estimate). Birmingham is the United Kingdom second most populous Urban Area with a population of 2,284,093 (2001 census). The city is facing a rise in population growth as the rate of population increase from the year 2000 to year 2010 is 4.2 % (2010 census).

The Urban Growth Model

This study aims to contribute to the development of an approach to integrate urban water networks with a cellular automata model. The result will be a spatial planning and visioning tool that can be used by professional staff at the local municipalities to generate, run and test different scenarios for several policy strategies addressing the sustainability of the water services and resources

The idea in this case study is to focus at the level of the city and the impact of the urbanization processes in the environment, in particular the water resources. Table 1, provides an indication of the main characteristics of the model.

Table 1. Characteristics of the urban model

Characteristics	Description
Spatial Resolution	100 m. or less, focus is on the urban sub-catchments.
Cellular Automata Engine	Dinamica
Set of States (cells)	Industrial, commercial, residential (2-3 subcategories).
Neighborhood	Moore or Circular, it has an important effect as described by Chen et al,2003.
Transition Rules	Probability functions.
Temporal Resolution	Year (visioning, scenario planning and assessment)
Initial Conditions	Derived from maps at a giving year. Depends on availability.
Case studies	Birmingham, UK
Agents	Urban drainage network extenders

Building the Cellular Automata Model of Urban Growth

Setting the input Database

The focus of the case study is the municipal area of Birmingham in the United Kingdom. For this a set of input maps were provided by the partners of the learning alliance in Birmingham. The maps contained the boundaries of the modeled area, the areas that are served by Severn Trend in terms of urban drainage and land use maps, derived from different sources in the UK.

The Dinamica model requires two set of maps for land use, for this particular case the land use maps corresponding to the Corine Dataset from the European Spatial Agency were used. The maps correspond to the land use classification for the years 1990 and 2000. The corine land use classes were regrouped into 6 classes that will be modelled. Table 2 presents the corine classes and the reclassification done to this case study.

Figure 2 presents the selected modeled area that includes Birmingham.

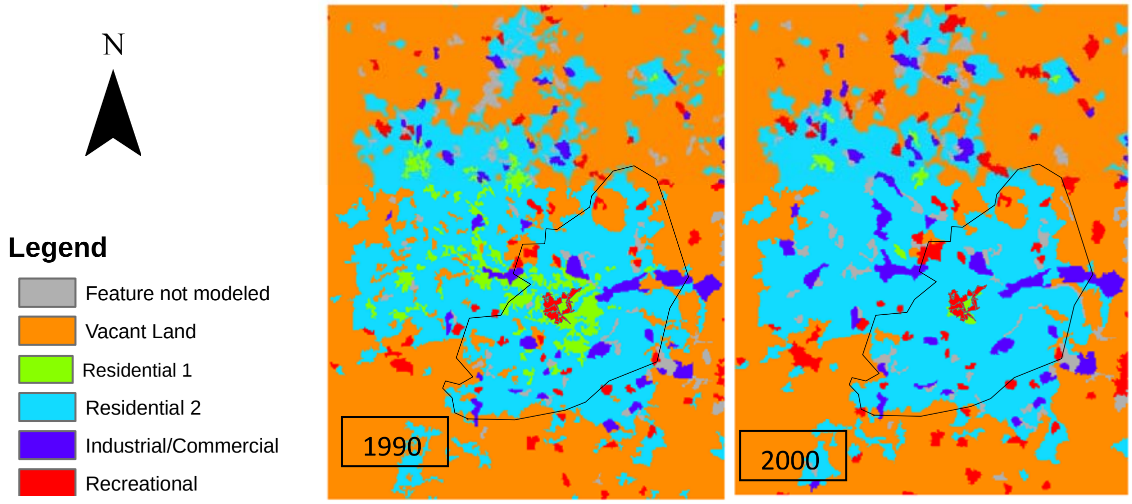


Figure 2. Modeled Area and Land Uses

Table 2. Classes used in the modeled area of Birmingham.

Corine Classification				Dinamica Ego	
Code	**Level1**	**Level2**	**Level3**	**Legend**	**Reclass To Dinamica**
1	Artificial surfaces	Urban fabric	Continuous urban fabric	Residential 1	2
2	Artificial surfaces	Urban fabric	Discontinuous urban fabric	Residential 2	3
3	Artificial surfaces	Industrial, commercial and transport units	Industrial or commercial units	commercial&industrial	4
4	Artificial surfaces	Industrial, commercial and transport units	Road and rail networks and associated land	Transportation	0
6	Artificial surfaces	Industrial, commercial and transport units	Airports	Airport	0
7	Artificial surfaces	Mine, dump and construction sites	Mineral extraction sites	Construction	0
8	Artificial surfaces	Mine, dump and construction sites	Dump sites	Construction	0
9	Artificial surfaces	Mine, dump and construction sites	Construction sites	Construction	0
10	Artificial surfaces	Artificial, non-agricultural vegetated areas	Green urban areas	Parks	0
11	Artificial surfaces	Artificial, non-agricultural vegetated areas	Sport and leisure facilities	recreation	5
12	Agricultural areas	Arable land	Non-irrigated arable land	VacantLand	1
16	Agricultural areas	Permanent crops	Fruit trees and berry plantations	VacantLand	1
18	Agricultural areas	Pastures	Pastures	VacantLand	1
20	Agricultural areas	Heterogeneous agricultural areas	Complex cultivation patterns	VacantLand	1
21	Agricultural areas	Heterogeneous agricultural areas	Land principally occupied by agriculture, with significant areas of natural vegetation	VacantLand	1
23	Forest and semi natural areas	Forests	Broad-leaved forest	VacantLand	1
24	Forest and semi natural areas	Forests	Coniferous forest	VacantLand	1
25	Forest and semi natural areas	Forests	Mixed forest	VacantLand	1
26	Forest and semi natural areas	Scrub and/or herbaceous vegetation associations	Natural grasslands	VacantLand	1
27	Forest and semi natural areas	Scrub and/or herbaceous vegetation associations	Moors and heathland	VacantLand	1
29	Forest and semi natural areas	Scrub and/or herbaceous vegetation associations	Transitional woodland-shrub	VacantLand	1
31	Forest and semi natural areas	Open spaces with little or no vegetation	Bare rocks	VacantLand	1
41	Water bodies	Inland waters	Water bodies	Water	0

In order to have the set of spatial data, the following maps were processed using ArcGis 9.3

1. Roads Map for the city of Birmingham (Open Street Map)

   Main trunks, MotorWays, Primery Roads, Secundary Roads, Rail Network

2. Terrain Map the city of Birmingham - DTM (http://srtm.csi.cgiar.org)

   Digital elevation model and Derived Slope MapDrainage Network of the current system

   As provided by Severn Trend in the framework of the learning alliance.

3. The city land marks and water ways. (Open Street Maps)

   Main Rivers, Main Canals.

These maps were processed in ArcGis for two purposes according with the proposed methodology. First of all, Dinamica Ego works with raster maps, therefore all the maps have to be transformed to raster. It is very important that all of them are projected in the same coordinate system, so that they overlay exactly one on top of the other. The cell size has to be the same. In other words, we have a set of matrices of the same size. The second processes done with the maps in Arcgis 9.3 is a spatial analysis using corridors along the main collectors of the drainage network to try to find out relation between the distribution of land use and the proximity to the sewer pipes. Figure 3 Presents the collection of input maps used to setup the model.

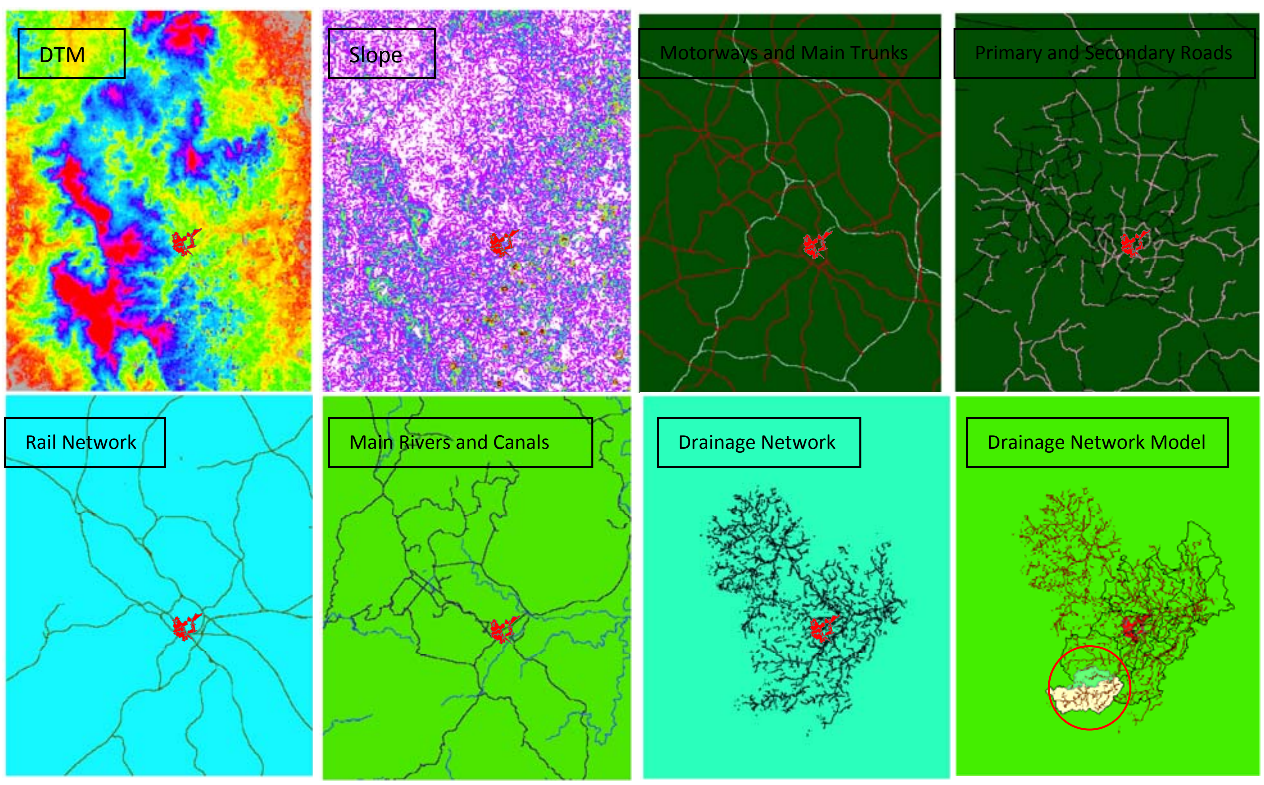


Figure 3. Input Map DataSet

The spatial resolution of the cells is 100 by 100 meters, all maps were projected to the ETRS_1989_LAEA coordinate system.

The model is built as a set of steps that follow a workflow schema. To achieve each step a chart of relation between functors is dragged and links between them are created according to their relations, for example: to change the format of a input file, the workflow presented in figure 4 is followed. a functor load map is directly linked to calculate new map which is directly linked to save the new map with the desire format.

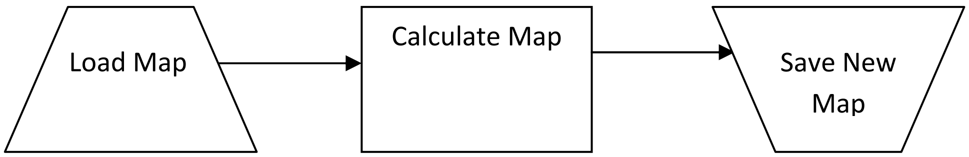


Figure 4. Example of workflow to change a map format

In order to build the land use change model, the following five setup steps where followed:

1- Calculating transition map: By inputting the two land use maps (1990 /2000), A transition matrix (single step /multi step) is created to calculate percentage of change between different land uses.

Cells per category (initial landscape):

1	92360
2	6032
3	51934
4	4501
5	3280

Cells per transition:

From \ To	1	2	3	4	5
1	XXXX	1	6157	634	2374
2	40	XXXX	4465	723	2
3	3959	231	XXXX	982	405
4	137	--	646	XXXX	7
5	206	--	274	9	XXXX

Single Step Transition Matrix:

From \ To	1	2	3	4	5
1	XXXX	0.0000108	0.0666631	0.0068644	0.0257038
2	0.0066313	XXXX	0.7402188	0.1198607	0.0003316
3	0.0762314	0.0044480	XXXX	0.0189086	0.0077984
4	0.0304377	--	0.1435237	XXXX	0.0015552
5	0.0628049	--	0.0835366	0.0027439	XXXX

Multi Step Transition Matrix:

From \ To	1	2	3	4	5
1	XXXX	--	0.0348213	0.0035071	0.0136704
2	--	XXXX	0.5624776	0.0900277	--
3	0.0402002	0.0034140	XXXX	0.0099755	0.0038869
4	0.0147155	--	0.0773488	XXXX	0.0005756
5	0.0326221	--	0.0441761	0.0012019	XXXX

A single transition matrix means that the time step used is 10 years for our case. To calculate a multiple step transition matrix the estimated transition rates per transition are computed based on the time steps that are input in the model. For example if the time steps are selected as 10 then the rates in the multiples step transition matrix are yearly based.

2- Calculating ranges to categorize gray tone variables: In this stage weights of evidence are calculated to produce transition probability map, Fig 5 shows the creation of the probabilities map and the weight of evidence role. The inputs of this stage are the old/new land uses maps and the calculated static maps.

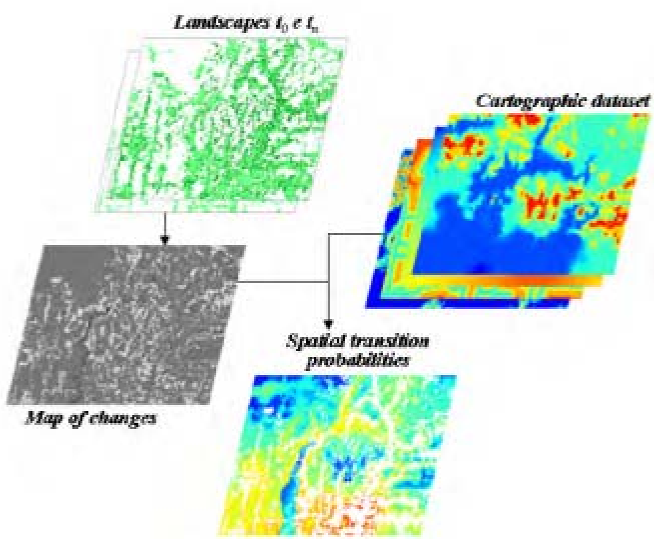


Figure 5. Workflow to calculate the probability maps of change.

In this step a Cube of raster maps are input as variables to calculate the weights of evidence skeleton. The raster maps are consider as static variables in the model since they do not change during the simulation. The continue variables are categorized in intervals following a set of buffers along the main features. Figure 6 shows an example of a distance map from the main trunks.

In a similar way the distance from the modeled land uses are also computed and are consider dynamic variables since they change during every time step within the simulation.

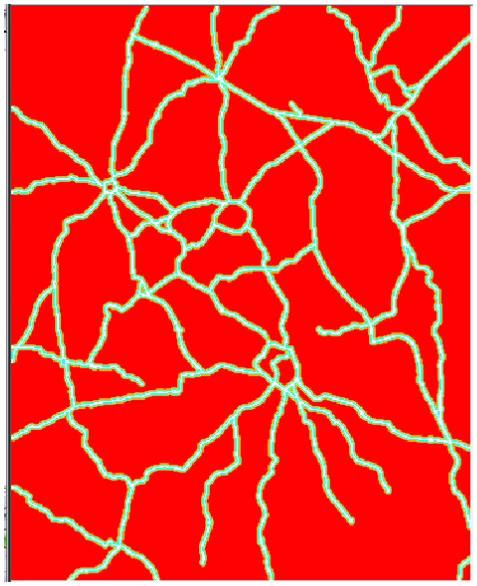


Figure 6. Distance from the main trunks in the Cube of Maps

3- Calculating weights of evidence coefficients: In these weights of evidence coefficients are calculated. As an example figure 7 shows that for the transition from the land use category 2 to the land use category 4. The map distance from the main sewers is significantly important within the first 400 meters. the contrast indicator measure if the specific variable has an influence of attraction)if the indicator is positive) or repulsion (if the indicator is negative). this can be better seeing in figure 8.

Transition: 2->4 Variable: MapStaticM3/D_MSewers

Range	Possible Transitions	Executed Transitions	Weight Coefficient	Contrast	Significant?
0 <= v < 200	551	264	-0.102366	-0.212872	no
200 <= v < 300	212	85	-0.420369	-0.524042	yes
300 <= v < 400	55	16	-0.909806	-0.956538	yes
400 <= v < 500	27	9	-0.71198	-0.729866	no
500 <= v < 600	15	3	-1.40513	-1.42259	yes
600 <= v < 700	11	0	~ 0	-0.0211343	no
700 <= v < 1300	20	3	-1.75343	-1.78067	yes
1300 <= v < 1400	8	8	~ 0	0.0150379	no
1400 <= v < 10100	163	148	2.27033	2.56453	yes
	1062	536			

Figure 7. Weights of Evidence example

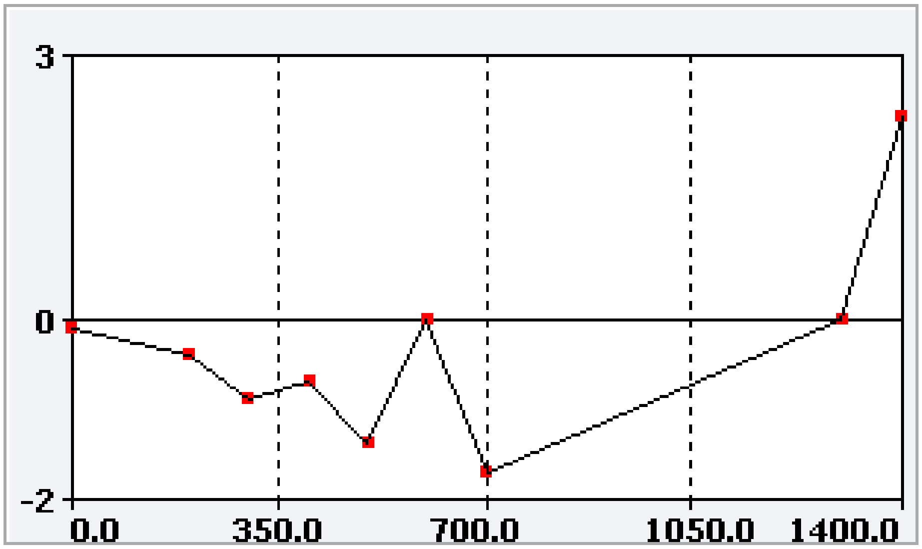


Figure 8. Weights of Evidence graph for transition 2 to 4, variable distance to main sewers.

4- The fourth step corresponds to a statistical test of significance between all the variables in the model. This is done to see if there is a high correlation between any pair of maps. If this happen then it means that one of the maps is redundant and therefore not needed in the simulation. The outcome of this test is that all the maps used to build the model are independent and can be used. figure 9 shows an example of the result window that is obtained by running the test.

Transition: 2->4

		Crammer			Entropy	
First Variable	Second Variable	Chi^2	Crammer*	Contingency	Joint Entropy	Joint Information* Uncertainty
MapStaticM3/D_Canals	MapStaticM3/D_MRivers	14728.8	0.0786558	0.291411	4.49735	0.0202522
MapStaticM3/D_Canals	MapStaticM3/D_MSewers	14898.6	0.0989092	0.298517	3.71437	0.0269561
MapStaticM3/D_Canals	MapStaticM3/D_MTrunks	2518.11	0.0572331	0.126942	3.64842	0.00439232
MapStaticM3/D_Canals	MapStaticM3/D_MotorWays	2726.24	0.0338887	0.130134	4.62421	0.00380734
MapStaticM3/D_Canals	MapStaticM3/D_PrimaryRoads	13010.6	0.0831766	0.276868	4.24584	0.0193111
MapStaticM3/D_Canals	MapStaticM3/D_Rails	13698.1	0.076296	0.28338	4.63206	0.0178198
MapStaticM3/D_Canals	MapStaticM3/D_SecundaryRoads	7929.32	0.0714122	0.220278	4.4242	0.0113578
MapStaticM3/D_Canals	MapStaticM3/Elevation	7047.8	0.0936219	0.204903	3.70547	0.0121361
MapStaticM3/D_Canals	MapStaticM3/slope	482.367	0.0344979	0.0596457	2.72283	0.00132564
MapStaticM3/D_MRivers	MapStaticM3/D_MSewers	12284.6	0.0892085	0.271506	3.61125	0.024948
MapStaticM3/D_MRivers	MapStaticM3/D_MTrunks	1505.62	0.0439603	0.0978268	3.53122	0.00268066
MapStaticM3/D_MRivers	MapStaticM3/D_MotorWays	5265.07	0.0439254	0.17821	4.48875	0.00690304
MapStaticM3/D_MRivers	MapStaticM3/D_PrimaryRoads	6647.9	0.0590578	0.200431	4.15305	0.0102539
MapStaticM3/D_MRivers	MapStaticM3/D_Rails	9547.1	0.0632798	0.238037	4.52218	0.0128006
MapStaticM3/D_MRivers	MapStaticM3/D_SecundaryRoads	9180.76	0.0763226	0.234616	4.29898	0.0133081
MapStaticM3/D_MRivers	MapStaticM3/Elevation	22116.4	0.164695	0.345581	3.53126	0.0393684
MapStaticM3/D_MRivers	MapStaticM3/slope	701.796	0.04133	0.071403	2.61254	0.00200965
MapStaticM3/D_MSewers	MapStaticM3/D_MTrunks	10112.2	0.116213	0.251507	2.75096	0.0236758
MapStaticM3/D_MSewers	MapStaticM3/D_MotorWays	23262.9	0.123025	0.362568	3.67722	0.0414255
MapStaticM3/D_MSewers	MapStaticM3/D_PrimaryRoads	20594	0.116161	0.344806	3.30967	0.0402945
MapStaticM3/D_MSewers	MapStaticM3/D_Rails	16497.5	0.104027	0.312489	3.71283	0.0313426
MapStaticM3/D_MSewers	MapStaticM3/D_SecundaryRoads	44080.9	0.170663	0.474934	3.41818	0.0822879
MapStaticM3/D_MSewers	MapStaticM3/Elevation	32611.1	0.204367	0.415637	2.74208	0.0747762
MapStaticM3/D_MSewers	MapStaticM3/slope	532.515	0.0367337	0.0634963	1.86573	0.00209117
MapStaticM3/D_MTrunks	MapStaticM3/D_MotorWays	3813.37	0.0700434	0.154735	3.60852	0.00658683
MapStaticM3/D_MTrunks	MapStaticM3/D_PrimaryRoads	1319.59	0.0414196	0.0922224	3.27926	0.00262252
MapStaticM3/D_MTrunks	MapStaticM3/D_Rails	8398.81	0.104484	0.227507	3.63573	0.0144818
MapStaticM3/D_MTrunks	MapStaticM3/D_SecundaryRoads	12143.3	0.126112	0.27141	3.40425	0.020811
MapStaticM3/D_MTrunks	MapStaticM3/Elevation	1317.88	0.0408542	0.0909739	2.70754	0.00317648
MapStaticM3/D_MTrunks	MapStaticM3/slope	118.053	0.0172251	0.0298215	1.72776	0.000528256
MapStaticM3/D_MotorWays	MapStaticM3/D_PrimaryRoads	3384.57	0.0422032	0.144658	4.24898	0.00491814
MapStaticM3/D_MotorWays	MapStaticM3/D_Rails	7967.65	0.0579106	0.21885	4.61516	0.0100007
MapStaticM3/D_MotorWays	MapStaticM3/D_SecundaryRoads	3249.74	0.0454769	0.142346	4.40435	0.00468903
MapStaticM3/D_MotorWays	MapStaticM3/Elevation	13899.8	0.130766	0.280649	3.64506	0.021095
MapStaticM3/D_MotorWays	MapStaticM3/slope	317.223	0.0278333	0.0481528	2.69901	0.000843169
MapStaticM3/D_PrimaryRoads	MapStaticM3/D_Rails	13416.3	0.084418	0.280677	4.24944	0.020822
MapStaticM3/D_PrimaryRoads	MapStaticM3/D_SecundaryRoads	8687.36	0.0747069	0.229915	4.0488	0.0138487
MapStaticM3/D_PrimaryRoads	MapStaticM3/Elevation	7554.01	0.0968806	0.211721	3.32735	0.014015
MapStaticM3/D_PrimaryRoads	MapStaticM3/slope	388.598	0.0309501	0.0535303	2.36168	0.00125297
MapStaticM3/D_Rails	MapStaticM3/D_SecundaryRoads	13510.9	0.0931722	0.282624	4.41086	0.0191642
MapStaticM3/D_Rails	MapStaticM3/Elevation	5633.17	0.0836584	0.183876	3.71765	0.0105012
MapStaticM3/D_Rails	MapStaticM3/slope	357.285	0.0296736	0.0513284	2.73763	0.00094991
MapStaticM3/D_SecundaryRoads	MapStaticM3/Elevation	13088.9	0.128014	0.275196	3.4595	0.0241581
MapStaticM3/D_SecundaryRoads	MapStaticM3/slope	293.522	0.0270022	0.0467182	2.51811	0.000880125
MapStaticM3/Elevation	MapStaticM3/slope	1918.81	0.067913	0.116823	1.79942	0.00635307

Figure 8. Test of correlation between pairs of maps.

5- Setup and run the land use change simulation model: In this stage the input is the old/new land use maps and the new weights of evidence coefficients and the transition matrix. The outcome of the model is the simulated map of year 2000. This model is using so far the Functor patcher which can create new seeds and start new clusters of land uses in new areas in accordance with the probability map. the model will be extended to use the functor expander than can continue the growth of existing clusters of land use. The calibration parameters are meanly the size of the patches to be created the variance and the isometry. these are all parameters in the patcher functor. The other parameter that has a strong influence is the size of the neighborhood use for the local interaction of the cellular automata. So far, the Moore neighborhood has been tested and the extended Moore scheme will be evaluated in the near future . Figure 10 shows the workflow of the dynamic model.

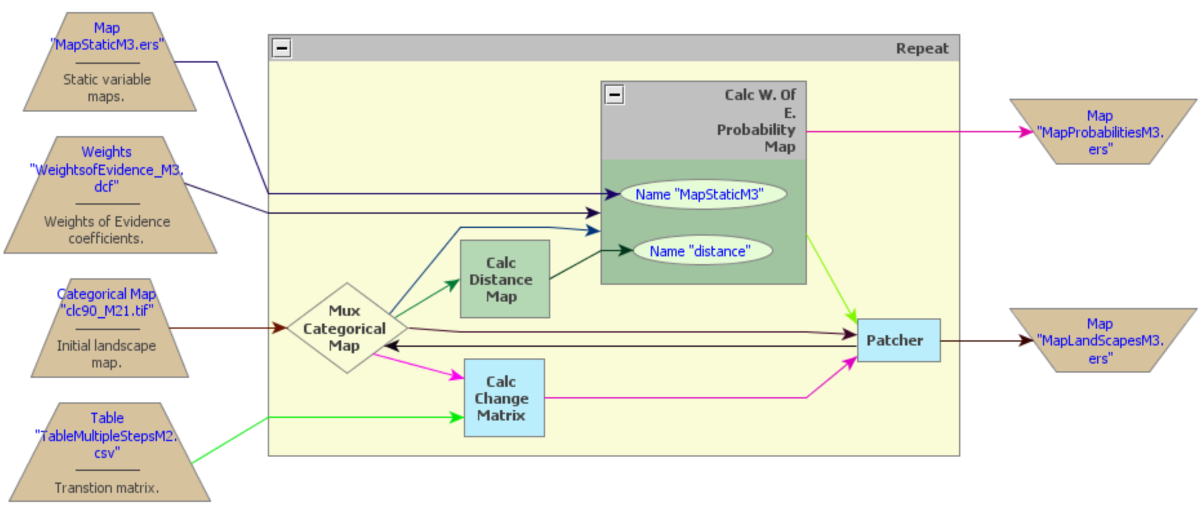


Figure 10. Workflow of the land use change model.

Figure 11 shows the input map of land use for year 1990, the simulated land use map for year 2000, the land use map of year 2000.

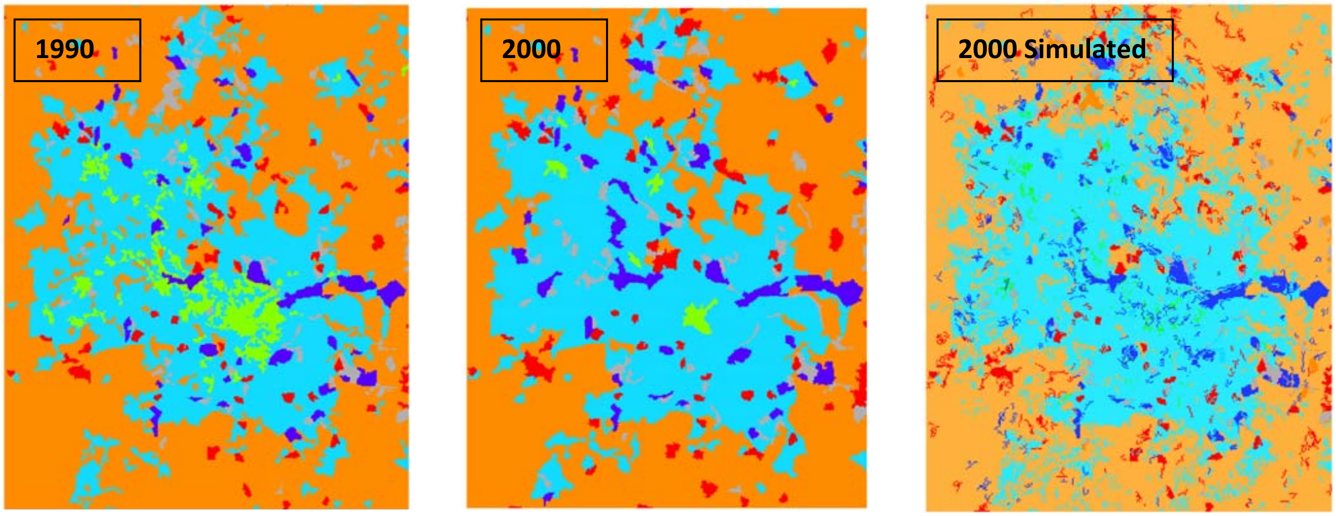


Figure 11. Simulated land use for year 2000.

Calibration and Validation of the land use model

A setup for the model calibration is created as shown in figure 12. This check compares the real land use of the years 1990 and 2000 , then compare them to the result of comparison of the land use maps of real 1990 and the simulated 2000.That is to check the similarity between the actual land use map of year 2000 and the simulated map of the year 2000.A new map will be created called the similarity map, as presented in figure 13.We can compare visually the similarity between actual and simulated land use. But also the software creates a similarity map to check the contest between the two .The similarity map consists of three colors illustrating the spatial fit of the simulation. The red color show high fit, the yellow color show moderate fit and the blue color show poor fit.

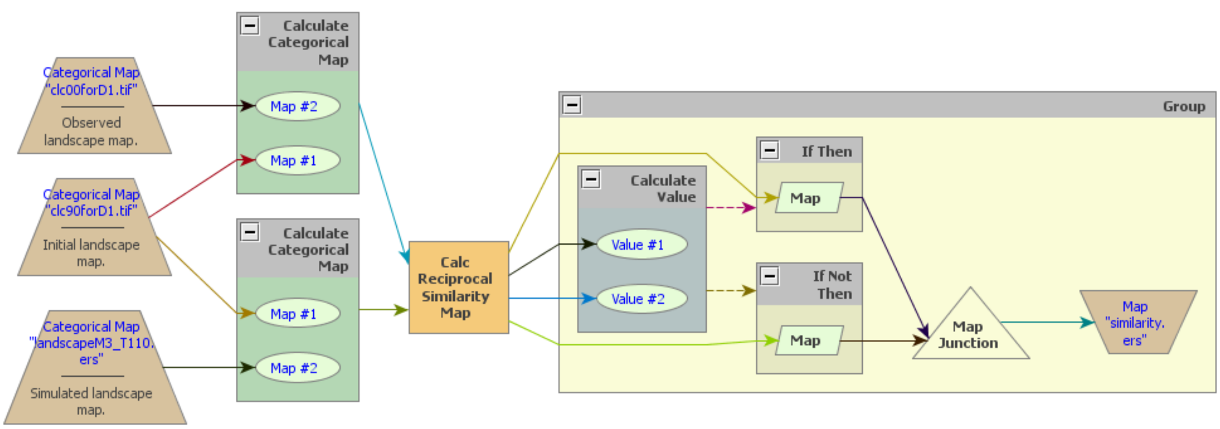


Figure 12. Model to calculate the similarity map.

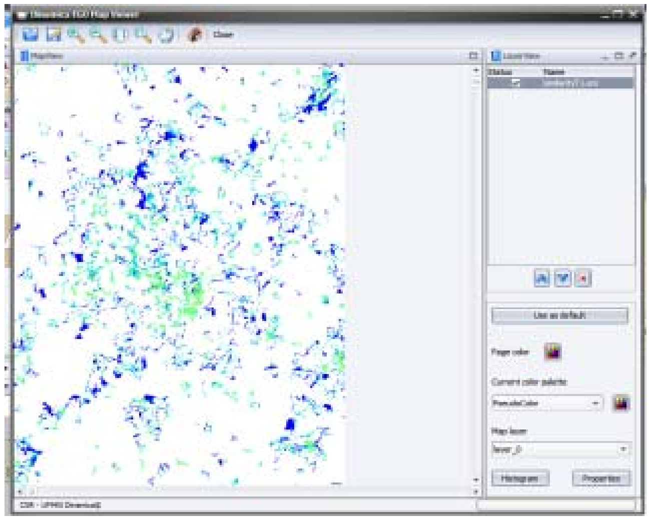


Figure 13. Similiraty Map

In addition, two mean values of validation are calculated when running the calibration model. These mean values show the similarity percentage between the simulated map and the real map, also the simulated map and the result of comparing year 1990 and year 2000 maps. The higher the percentage of mean values the best the simulation. By changing the simulation parameters will produce new land use map, this land use map will be the input for the new calibration simulation. New similarity map will be produced also new mean values. The best mean value and similarity mean will decide the final parameters for Birmingham model.

Running simulation calibration trials were taken place inorder to find the best similarity fit, and the best parameters for the Birmingham model as shown in table 3.The parameters modified in the tables are the patcher values (mean/variance/isometry), prune value and the window size .Matrix of transition function parameters consisting of mean patch size, patch size variance, and isometry. By varying these parameters, various spatial patterns can be reproduced. The prune value is a factor multiplies the expected number of cells to be changed to set the quantity of possible cells, based on their spatial probability, that take part in the selection mechanism of new patch nuclei. Window size corresponds to the neighborhood search window, and it gives the size for square window (columns * rows) and the values starts from 3*3.

As shown in table 3 the best two mean values till now are equal to 52 % and 50%.These values occur at patcher values (03/00/00) with prune value 10 and window size 5*5.Thus, this mean calibration values are not satisfying .The model needs to be run for more times to investigate the effectiveness of the parameters on the calibration results.

Table 3. Run test to calibrate the model

Trial	Patcher(M/V/S) from	To	Mean 1	Mean 2	
1		01/00/00	0.035	0.0066	Search window size :3*3 and Prune Value:10
2		02/00/00	0.036	0.0076	
3		03/00/00	0.51	0.49	
4		04/0/0	0.506	0.48	
5		05/00/00	0.502	0.48	
6		10/0/0	0.046	0.009	
7		01/01/01	0.52	0.47	
8	03/00/00	03/01/00	0.506	0.48	
9		03/00/0.5	0.507	0.48	
10		03/00/1	0.511	0.488	
11		03/00/1.5	0.034	0.006	
12		03/00/2	0.50	0.48	
13	03/00/1	03/01/01	0.511	0.493	
14		03/02/01	0.513	0.494	
15		03/03/01	0.507	0.494	
16		03/04/01	0.509	0.494	
17		03/05/01	0.502	0.488	
18		03/10/01	0.501	0.492	
	Patcher(M/V/S)	search window	M1	M2	Prune Value:10
19	01/00/00	5*5	0.525	0.48	
20	02/00/00	5*5	0.28	0.65	
21	**03/00/00**	**5*5**	**0.52**	**0.50**	
22	04/0/0	5*5	0.509	0.496	
23	05/00/00	5*5	0.038	0.0079	
25	10/0/0	5*5	0.04	0.008	
26	03/01/00	5*5	0.512	0.483	
27	Patcher(M/V/S)	prune	M1	M2	Search window size :5*5
28	01/00/00	8	0.521	0.499	
29	02/00/00	8	0.514	0.499	
30	03/00/00	8	0.513	0.499	
31	01/00/00	12	0.5277	0.465	
32	02/00/00	12	0.515	0.499	
33	03/00/00	12	0.527	0.485	

The drainage system

In 2010, Birmingham was ranked as the 55th-most livable city in the world. Birmingham is one of the biggest industrial cities in England. The water services in the city serves the domestic and the industrial needs; the city council is now adopting the policy of having future development management plans with the calls to have better resources management plans for the city.

Birmingham main water supply has been imported through a 118 km pipeline from the Elan Valley in South Wales. After use by households and industry, this water is treated and then discharged into the city's water courses. Leakage of the imported water from the supply and wastewater systems has contributed to the city's rising groundwater table and has increasingly posed risks to property. Obviously the impacts influencing the planning of the future water systems in Birmingham are the increase of ground water level, high risks of flooding at raining time and miss coordination of planning relating to water and other services.

Setting the drainage system model

In order to plan for the future urban drainage network, it was initially to study the current network. The urban drainage system for the city is combined network.   A previous was set in the InfoWorks CS program, that model was exported to the EPA-SWMM model .The SWMM model for the imported network is shown in Fig.14.

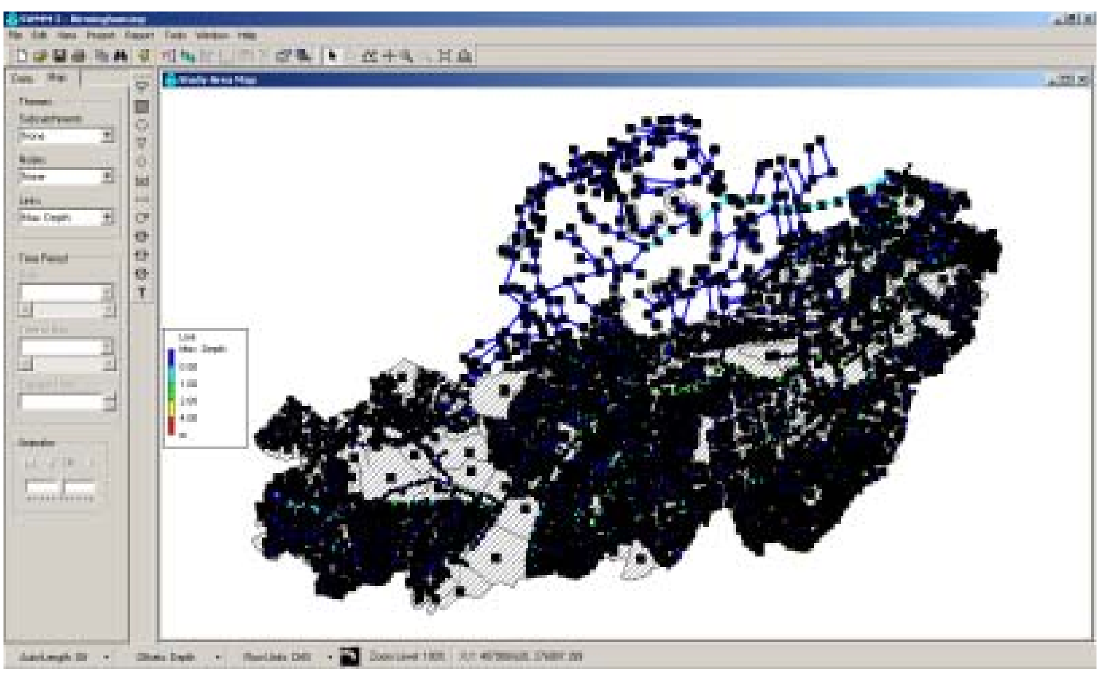


Figure 14. The Original Drainage Network of Birmingham

The original model description stated in Table 4:

Subcatchments	Junction Nodes	Outfall Nodes	Conduit Links	Orifice links	Weir Links	Outlet Links
2796	6367	41	6333	49	18	1

The original network as shown in figure 14 have 6333 conduit links ,6367 junction nodes and 2796 subcatchments . The l pipe diameters varied from 0.225 m to 5.25m.The model is for catchment in Birmingham with total area 3900 ha and total population 143184 habitants. It was necessary to simplify that model to analyze the model performance, monitor the network and the future network expansion.

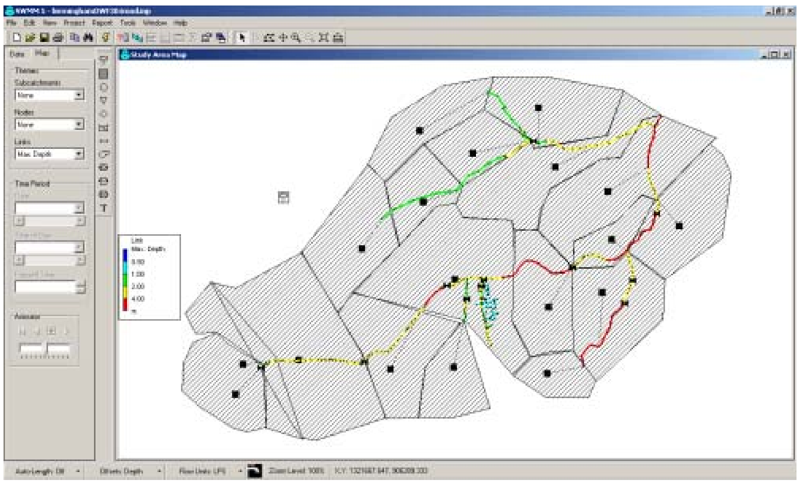


Figure.15 The Drainage Network of Birmingham After Simplification

The new model description shown in Table 5:

Subcatchmnets	Junction Nodes	Outfall Nodes	Conduit Links	Orifice links	Weir Links	Outlet Links
18	380	2	345	13	7	1

The new model was simplified by taking in consideration the larger pipe diameter and the direction of the drainage flow. The main pipe lines of the catchment were kept and the secondary pipes were deleted. Pipes with diameters less than 1m where deleted. The new network pipe diameters varies from 1 m to 5.25 m .The number of conduit links was decreased from 6333 to 345 accordingly the unconnected nodes were deleted to have 380 junction nodes instead of 2796. The subchatchments were redefined to reduce them from 2796 to 18 subcatchments within our catchment area, allocated in SWMM model and

new outfalls were assigned to each subcatchment. Illustrated in Fig.15 the model after simplification.

The comparisons between the simplified and the original model were done to the analyze subcatchment areas, population number and locations. Populations were assigned to the new subcatchmnets according to the intersection between original and new subcatchmnets. Total area used for the new Subcatchments equal to the original subcatchments area.

The model was tested and run for four different rainfall data sets. These data for two return periods equal to 5 and 30 years. For each return period there are two available rainfall events for 30 minutes and 60 minutes duration. Shown in figure 16, 17 , 18, and 19 the four rain fall events.

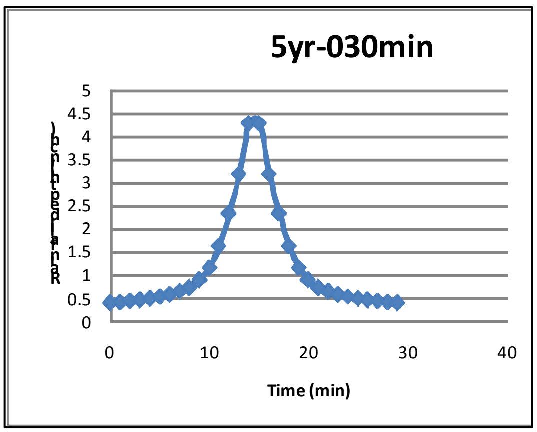


Figure 16. Rainfall event 5 years return period and 60 minutes duration .

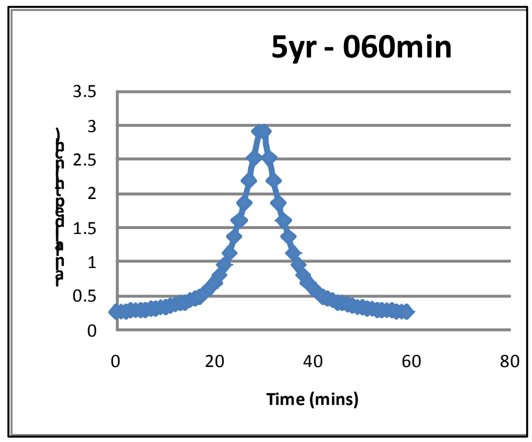


Figure 17. Rainfall event 5 years return period and 30 minutes

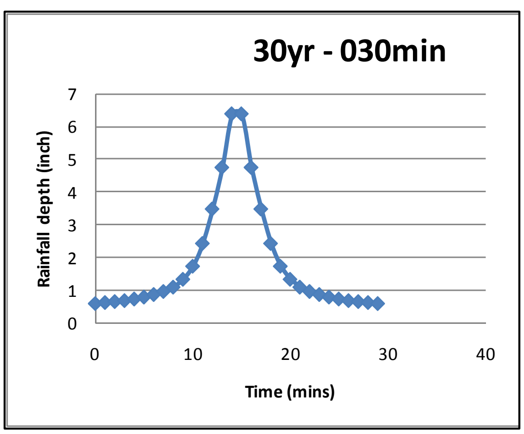


Figure 18. Rainfall event 30 years return period and 30 minutes duration.

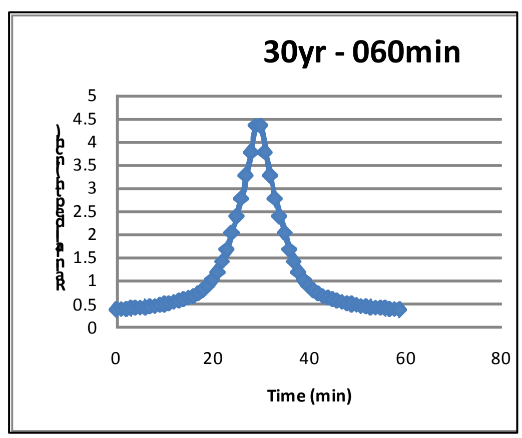


Figure 19. Rainfall event 30 years return period and 60 minutes duration.

The effect of dry weather flow effect was taken in the simulation, DWF pattern was calculated the average of 28 DWF patterns exported from the InfoWorks model, the DWF pattern is shown Figure 20.

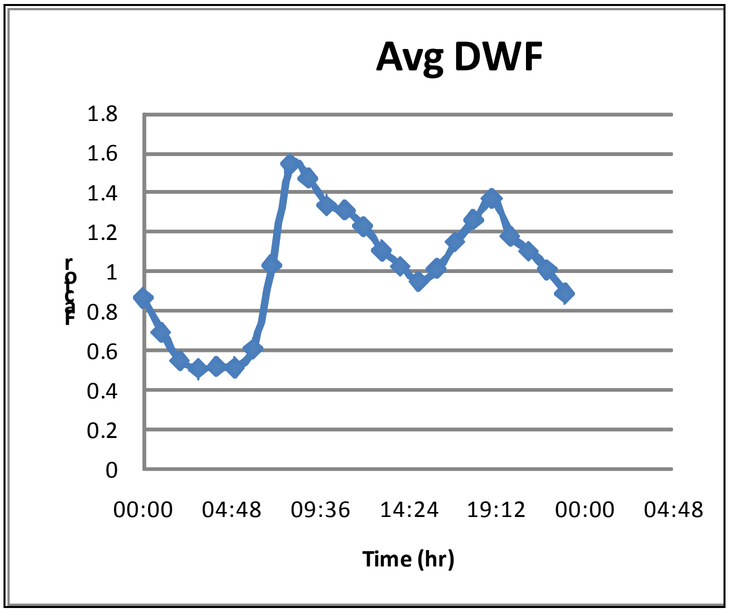


Figure 20. Dry Weather Flow pattern for 24 hours

Running the model (First Trial Run)

1-Two runs for return period 5 years using simulation time 1 day:

30 minutes rainfall event

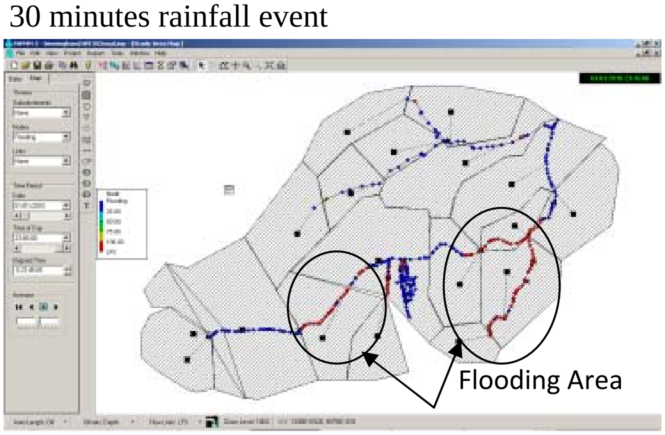


Figure 21. Drainage network flood map for rainfall event 5 years /30 minutes.

60 minutes rainfall event

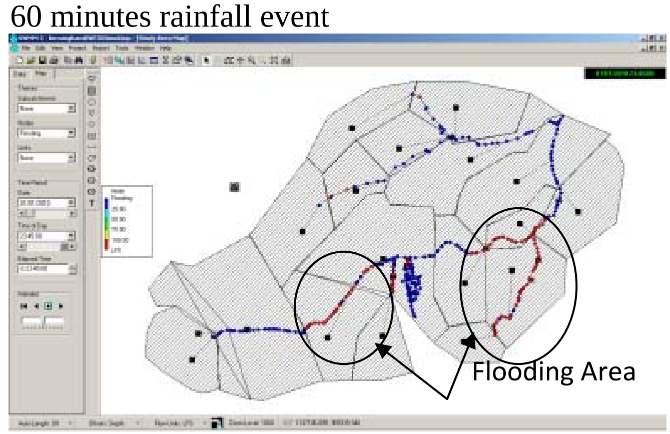
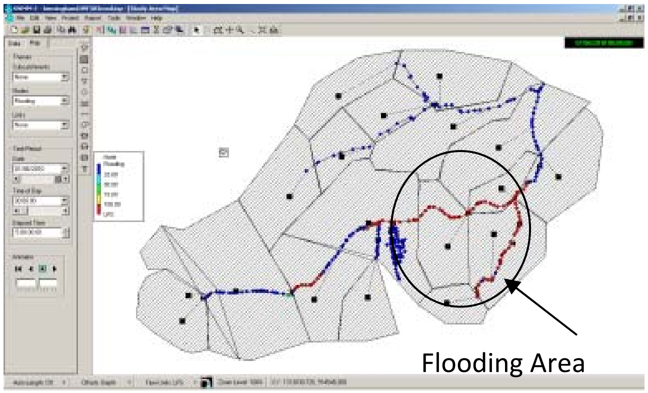


Figure 22.Drainage network flood map for rainfall event 5 years /60 minutes .

2- Two runs for return period 30 years using simulation time 5 day:

30 minutes rainfall event

60 minutes rainfall event



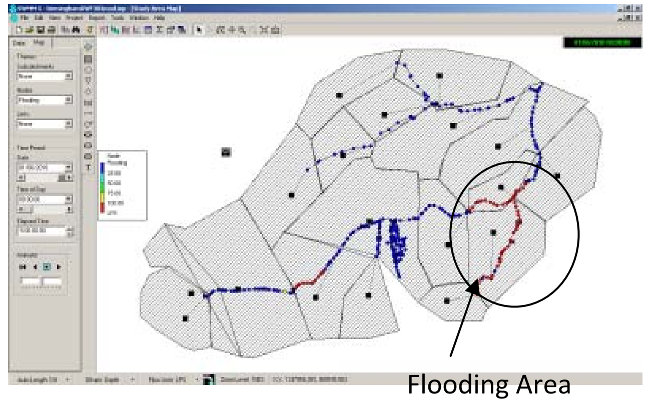


Figure 23. Drainage network flood map for rainfall event 30 years /30 minutes.

Figure 24. Drainage network flood map for rainfall event 30 years /60 minutes.

From the previous figures we see there is urban drainage flooding in the simplified sewer system for this four simulation trials. The flooded area is always at the same location at the lower middle part of the catchment, shown in figure 25 the max flood in the middle of the catchment . The initial four runs were to test the simplified model and to have better understanding for the network. Upsizing the drainage network will lead to overcome this flooding occurring, also by changing the model parameters.

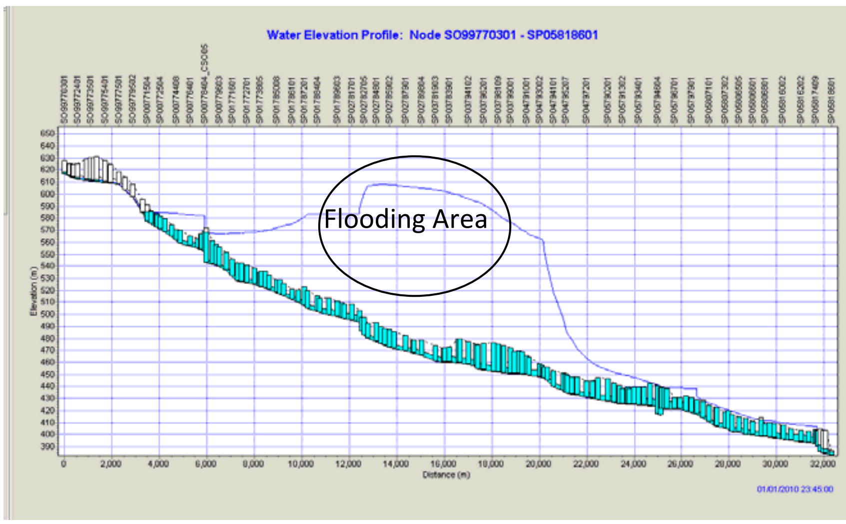


Figure 25. Longitudinal profile of the flood at 5 years /30 minutes .

This model will be the basic drainage network for the current drainage system in Birmingham city catchment. The model was exported to GIS model to verify the location of the network within the Birmingham city and to identify the land uses in the study catchment.

Conclusion

The present work shows that the approach based on the use of cellular automata algorithms in combination with hydraulic modeling tools can produce useful information that can be used in evaluating different urban growth scenarios.

Further work will continue to enhance the present work within the framework of the PhD research.

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