# Exploring Cities Water Future Infrastructure

**Arlex Sanchez Torres, Roland Price, Zoran Vojinovic***

Department of Hydroinfomatics and Knowledge Management
UNESCO-IHE
Netherlands

## Abstract

Cities around the world are currently facing considerable pressure to cope with urban development and economic growth. Urban planning is therefore very important to improve the effectiveness of the investments and interventions that take place in the urban system. The proposed approach aim at the integration of agent based models with physically based hydraulic models of the networks to determine the water infrastructure and performance in delivering adequate water services in the future and how this can shape the urban development process.

The integration of these models allows the exploration of several planning scenarios to asses the impact of certain actions, policies, regulations and to explore several urban futures. The expected result is a new approach for urban water infrastructure planning which help water companies and municipalities to have a dynamic planning tool to improve the effectiveness of their investments and to be more environmentally efficient.

## 1 Background

Cities around the world are currently facing considerable pressure to cope with urban development and economic growth. On the one hand urban infrastructure is aging and there is a rapid growth of population while economic resources are in short supply. Under such circumstances urban planning is very important to improve the effectiveness of the investments and interventions that take place in the urban system.

Cities can be considered as complex systems based on their characteristics of emergence, self-similarity, self-organization and non-linear behaviour of land use changes with time; see Batty and Langley, (1994). The use of tools that can help in understanding these characteristics are important to gain knowledge about the patterns and mechanisms behind urban dynamics. Cellular automata models are built and used to represent the same phenomena or characteristics in several disciplines of sciences.

* *Corresponding Author: z.vojinovic@unesco-ihe.org*

Integrated urban water management is a challenging issue that aims at the sustainable use of the water resources. The current practices in the sector are leading towards a crisis that is calling for innovative thinking and the adoption of new strategies including integrated thinking and planning. There is also a need to develop tools that allow such integration.

In the literature there are a number of attempts to model the urban landscape and the changes in land use for future development according to scenarios. The Moland framework is an example of such a model that has been successfully applied and calibrated to real life cases in Europe and different cities around the world, as presented by Barredo et al, 2003, Engelen et al, 2007, van Vliet and van Delden, 2008, among others.

## 2 Modelling Approach

In the modelling framework of this research the idea is to use the outcomes of Metronamica and to incorporate relevant information from the urban water related infrastructure. In particular, the objective is to design the water distribution and drainage networks in the urbanising areas of a city based on the characteristics of the existing networks, and to rehabilitate the existing networks such that the whole urban water system is sustainable into the future.

The main components the modelling approach are:

- A regional model: for the distribution and allocation of land use demand.
- Cellular model: Computes the potential of land use change.
- A numerical model: that describes the performance of the water systems (water distribution).

A reverse engineering model: that takes the predicted new developments land uses to asses the layout of the water services networks in such a way that the water services accessibility maps can be updated and create dynamic conditions that are incorporated in the simulation loop.

Within the cellular automata model there will be six elements that determine if a cell changes its land use state in a particular time step: 1. Physical suitability map: This is a map per land use based on factors such as elevation, slope, soil quality and stability, agricultural capacity, etc. 2. Zoning or institutional suitability: this is also a map per land use category based on master plans and planning documents. Incorporate buffer zones, valuable protected zones, etc. 3. Accessibility: it is a map calculated based on the easy access to the transportation network. 4. Water supply accessibility map: It's a map that considers the relative to the easy access to the pipe networks and the level of service. This map is updated at certain time steps when the reverse engineering model is run. 5. Urban drainage flooding risk map: It's a map that considers the easy access to the pipe networks and the risk of flooding. This map is updated at certain time steps when the reverse engineering model is run. 6. Transition rules: For each land-use function, a set of rules determines the attraction or repulsion of each cell and land use function present in the neighbourhood.

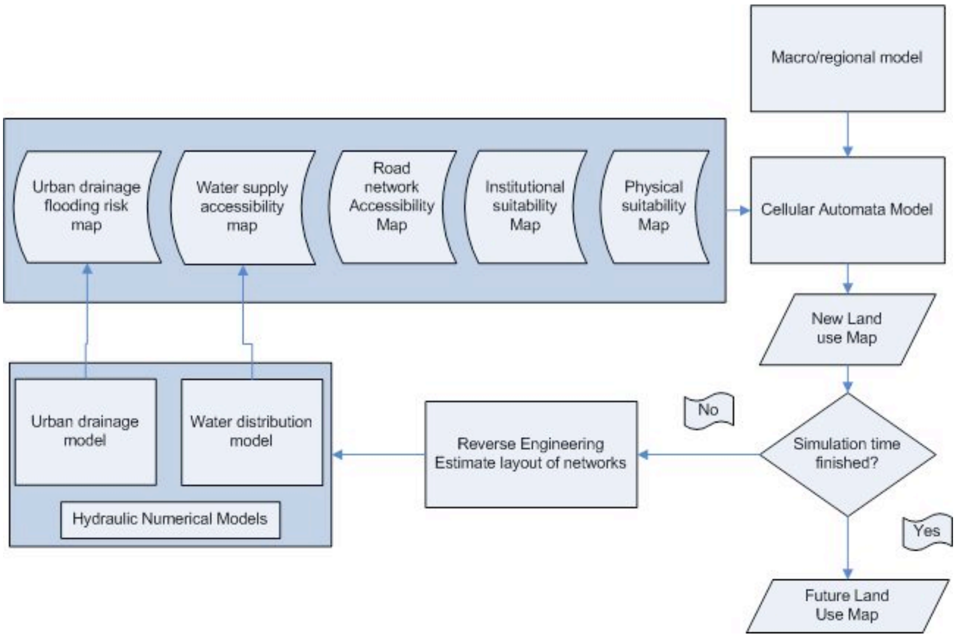
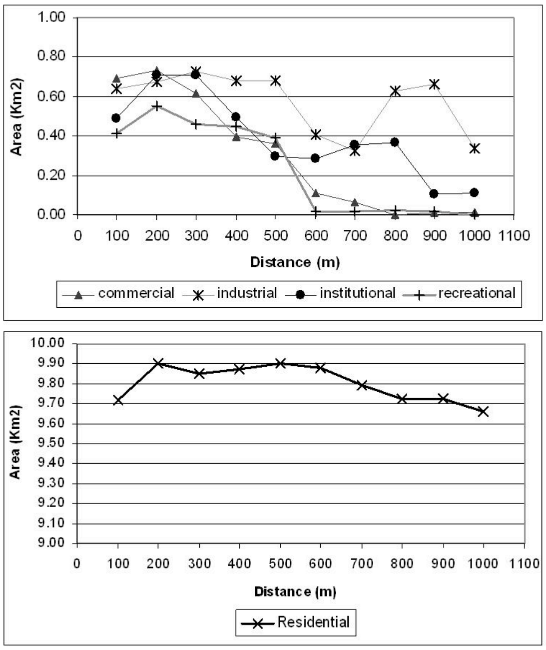



Figure 1 A simulation loop within the framework

## 3. Results

A case study using the Metronamica cellular automata environment was devised to model the land use changes in a municipality in Colombia. New tools have been developed to route the water mains through the new areas according to land use. But before the simulation can be done, the existing infrastructure has to be connected to the new network and the impact of the provision of water-related services to the new network has to be assessed.

The new tool correlates the layout of the existing infrastructure with the land use. For this purpose corridors along the main pipes of the existing water network are defined (for pipes with a diameter bigger than 356 mm). Each corridor is 100 meters wide (with a total of 10 corridors). The intercepted area per land use category is then plotted to analyse the area as a function of distance from the water mains.




(a) (b)

Figure 1.2 Distribution of the intercepted area per land use along the main pipes

Figure 1.2 (a) shows the distribution of the areas from the main pipes for residential land use. It is quite homogenous and uniformly distributed. This implies that this land use does not give much information on the location of the pipes. However, for the commercial, institutional and recreational land uses there is a significant change in the distribution of area, which decreases rapidly after 400-500 metres; see Figure 1.2 (b). For industrial land use the pattern is not very conclusive since this happens to be more sensitive to the cell size used for the analysis. It is interesting to observe therefore that the commercial land use can help in the positioning of the pipes or layout of the network. Commercial and industrial activities are drivers of economic growth and urbanization and it seems that there is a spatial correlation with the main pipes of the water distribution network. This knowledge can be used in conjunction with the results of the CA model to position pipes in future urbanising areas and to assess the performance of the new system and its influence on the urban development.

An approach to define the layout of the network from land use has been developed. It consists of doing a cluster analysis of the new commercial land cells (using a version of the k-means clustering algorithm), determining the centroids of the main clusters, and then using a simple three point algorithm to determine the direction and position of the pipes based on a distance rule algorithm. This approach seems to reproduce a good pattern for the existing distribution network, see figure 1.3.

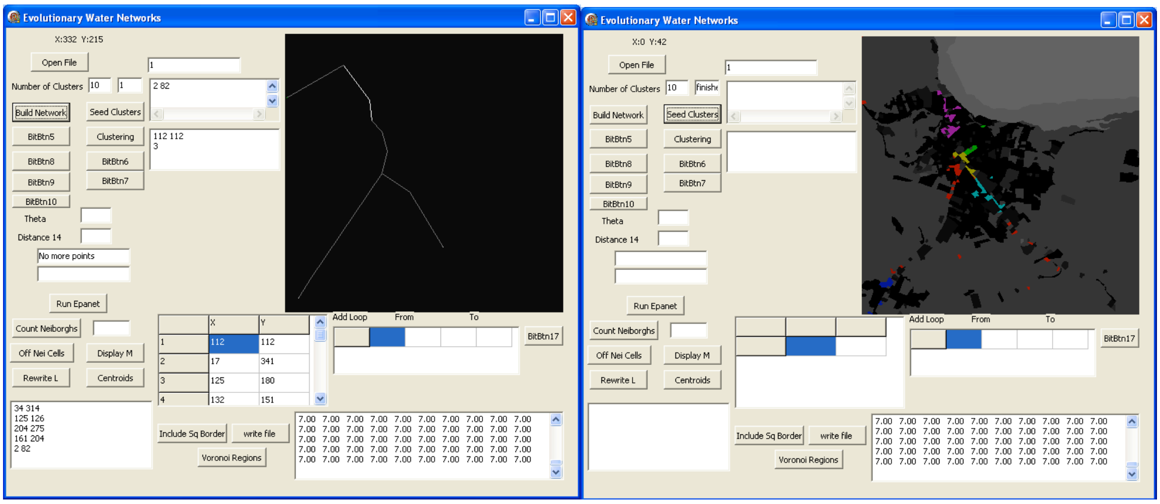



Figure 1.3 Screenshot of the software to determine the layout of the network

Figure 1.3 shows the application of the cluster approach to the main pipes for the water distribution network in the case study. The centroids of the clusters were used to derive the network layout. An algorithm to assign and distributed the estimated water demand per land use was also implemented based on the Voronoi diagram. With this information an automate tool can generate the input file to model the estimated network layout in Epanet 2.0. To dimension the pipes a connection with the NSGA II was made. The NSGA II assigns randomly diameters from a catalogue with 20 commercial diameters available. The problem of sizing the pipes is tackle as an optimization problem using two objective functions. The used objective function is the capital investment cost of the pipes and the number of nodes that do not fulfilled the critical pressure condition of 15 m. for this case.

The approach looks promising since it can resemble the original layout of the existing system. Next steps include the inclusion of other land use information, and to establish some indicators of fitness for the approach. The aim is to develop a complete modelling framework to determine the optimal way of defining the water distribution networks in urbanising areas using different future scenarios.

The expected result is a new approach for urban water infrastructure planning which help water companies and municipalities to have a dynamic planning tool to improve the effectiveness of their investments and to be more environmentally efficient.

## Reference

Barredo J., Kasanko M., McCormick N., Lavalle C. (2003). Modeling dynamic spatial processes: simulation of urban future scenarios through cellular automata. Journal of Landscape and urban planning. Vol 64. pp 145-160. Elsevier Science.

Batty M and Longley P. (1994). Fractal Cities. A geometry of form and function. Academic Press. London, UK.

Engelen G., C. Lavalle , J.I. Barredo, M. va n de r Meulen and R. White. (2007). The Moland modeling framework for urban and regional land-use dynamics. In: Modeling Land Use change: Progress and applications. Edited by Koomen Eric, Stillwell John, Bakema Aldrik, Scholten Henk J. Springer. The Netherlands.

Van Vliet J., and Van Delden H. (2008). An activity based cellular automaton model to simulate land use changes. International Congress on Environmental Modelling and Software. (iEMSs). Barcelona, Spain