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# Designing and implementing a regional urban modeling system using the SLEUTH cellular urban model

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ABSTRACT

This paper presents a fine-scale (30 meter resolution) regional land cover modeling system, based on the SLEUTH cellular automata model, that was developed for a 257000 km$^2$ area comprising the Chesapeake Bay drainage basin in the eastern United States. As part of this effort, we developed a new version of the SLEUTH model (SLEUTH-3r), which introduces new functionality and fit metrics that substantially increase the performance and applicability of the model. In addition, we developed methods that expand the capability of SLEUTH to incorporate economic, cultural and policy information, opening up new avenues for the integration of SLEUTH with other land-change models. SLEUTH-3r is also more computationally efficient (by a factor of 5) and uses less memory (reduced 65%) than the original software. With the new version of SLEUTH, we were able to achieve high accuracies at both the aggregate level of 15 sub-regional modeling units and at finer scales. We present forecasts to 2030 of urban development under a current trends scenario across the entire Chesapeake Bay drainage basin, and three alternative scenarios for a sub-region within the Chesapeake Bay watershed to illustrate the new ability of SLEUTH-3r to generate forecasts across a broad range of conditions.



## 1. Introduction

The objective of this paper is to describe a regional urban land cover modeling system that was developed for the Chesapeake Bay watershed, which is located in the eastern United States (Fig. 1). We developed a fine-scale (30 meter × 30 meter or 0.09 hectare cell size) regional modeling system, based on the SLEUTH urban land-cover change model (Clarke, Hoppen, & Gaydos, 1997; US Geological Survey, 2007) and applied it to forecast growth up to the year 2030 for the Chesapeake Bay watershed (CBW) and adjacent counties, an area covering 257,000 km$^2$.

SLEUTH is one of a class of models known as cellular automata (CA), where the land surface is conceptually divided into cells using a regular grid. SLEUTH then associates with each cell an automaton, an entity that independently executes its own state-transition rules, taking into account the states of the automata associated with nearby cells. Given its success with regional scale urban simulation, its ability to incorporate different levels of protection for different areas, the relative ease of computation and implementation, and the fact that it is public domain software, we adopted the SLEUTH model (Clarke et al., 1997; Clarke & Gaydos, 1998) to form the basis for this work. SLEUTH incorporates spatial data through a link with geographic information systems (GIS) and, like many recently developed CAs (e.g. Van Vliet, White, & Dragicevic, 2009), relaxes many of the assumptions of classic CA theory, such as homogeneity of space, uniformity of neighborhood interactions, and universal transition functions, to more realistically simulate real urban systems. Because they are interactive, modified CA models like SLEUTH are attractive in applied settings as planning tools (Batty, 1997). Potential outcomes can be visualized and quantified, the models can be closely linked with GIS, and raster based spatial data derived from remote sensing platforms can be easily incorporated into the model.

The utility of CA models for simulating complex systems, including urban systems, has been well documented (Couclelis, 1997; O'Sullivan & Torrens, 2000; Silva & Clarke, 2005; Torrens, 2006; Torrens & O'Sullivan, 2001; Van Vliet et al., 2009). For regional scale modeling, CA models have proven to be effective platforms for simulating dynamic spatial interactions among biophysical and socio-economic variables associated with land-cover change (White & Engelen, 1997). For example, Li and Liu

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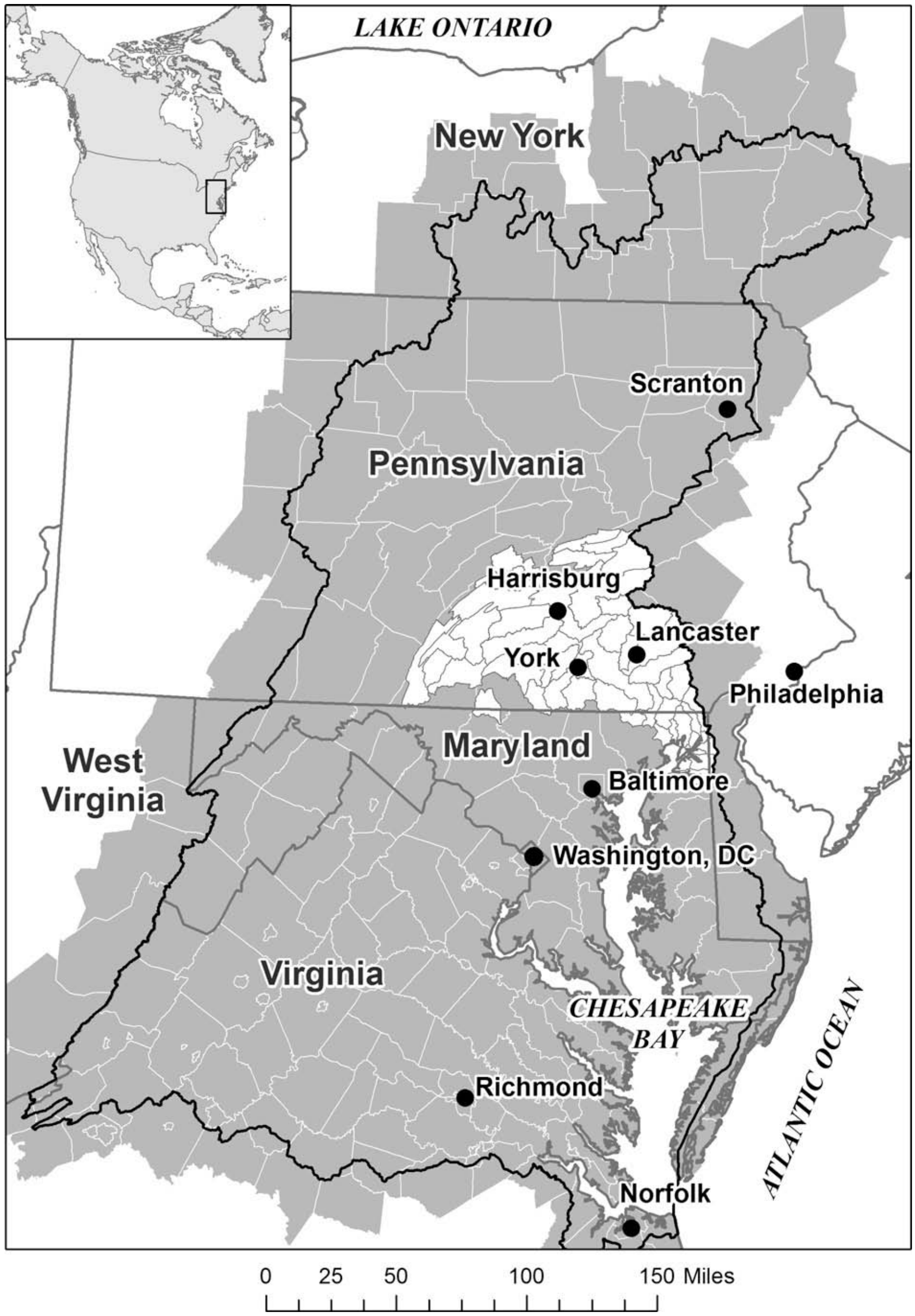


**Fig. 1.** Study area. The Chesapeake Bay drainage basin is outlined in black. Our study area, shown in gray, includes all the counties that are contained within or that intersect the watershed boundary. The small watersheds colored white in southeast Pennsylvania represent a case study area that will be presented in this paper.

(2006) develop a modeling approach that relaxes traditional CA transition rules with case-based reasoning and explicitly accounts for the influence of proximity and distance between urban clusters. They have used this CA modeling system to accurately simulate fine-scale (30 m × 30 m) urbanization patterns and interactions between hierarchically organized urban centers in the Pearl River Delta in southeastern China, an area of over 41,000 km$^2$. Most notably, Soares-Filho et al. (2006) use the SimAmazonia CA modeling system to integrate factors driving deforestation in the Amazon basin, including market forces, road construction, and government regulations. SimAmazonia was applied over a very large region, more than 8 million km$^2$ at a resolution of 1 km × 1 km cells.

We addressed two main challenges in this work. First, because of the size of the watershed and the fine grain of the analysis, application of the model posed significant logistical and computational challenges; this application required more memory than any previously published analysis of which we are aware. Second, urbanization patterns and patterns of urban land-cover change are extremely heterogeneous across the watershed (Jantz, Goetz, & Jantz, 2005). In overcoming these challenges, this application represents a significant contribution to the software infrastructure for simulation of urban growth and the development of decision support tools for regional ecosystem management. This work was undertaken in close partnership with the Chesapeake Bay Program, providing a direct link between the science of land-cover change modeling and applications for ecosystem management.

The US Environmental Protection Agency has listed the Chesapeake Bay as impaired due mainly to non-point source loads of