Spatial Predictive Modeling and Remote Sensing of Land Use Change in the Chesapeake Bay Watershed

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I. INTRODUCTION

Land use change in developed countries largely takes the form of conversion of land from agriculture and forests to residential use. In the U.S. the spatial pattern of this conversion has tended to be one of increasingly fragmented, low density development, popularly called “sprawl.” Because it generally occurs in areas well outside urban centers, low density sprawl will generally be serviced by septic fields rather than sewage treatment plants, increasing per capita nutrient loadings and fecal coliform discharges into the aquatic environment. In addition, this spatial pattern can be expected to have consequences for carbon sequestration as vegetative cover is lost and for carbon emissions because of the higher level of vehicle miles traveled as a result of a dispersed population.

The impact of development on the environment will be dependent on both the spatial form development takes and on the type of land use it replaces. Our project maps, models and predicts spatial patterns of land use change in the central Maryland portion of the Chesapeake Bay Watershed. The study area provides an excellent opportunity to model the spatial patterns of sprawl, because it is representative of a set of conditions generally prevalent in much of the U.S. and has clear links to water quality in the Chesapeake Bay itself.

II. PROJECT GOALS

- Map and monitor changes in impervious surfaces (the built environment) using multi-scale satellite imagery (Ikonos and Landsat).
- Develop agent-based micro-economic models of land use change over time, focusing on low density development at the urban-rural fringe.
- Develop techniques to initialize variables in micro-economic model with impervious surface data derived from Landsat imagery.
- Test agent-based economic models that use Landsat and economic data against a cellular automata model that is driven by Landsat data alone.

III. MAPPING THE BUILT ENVIRONMENT

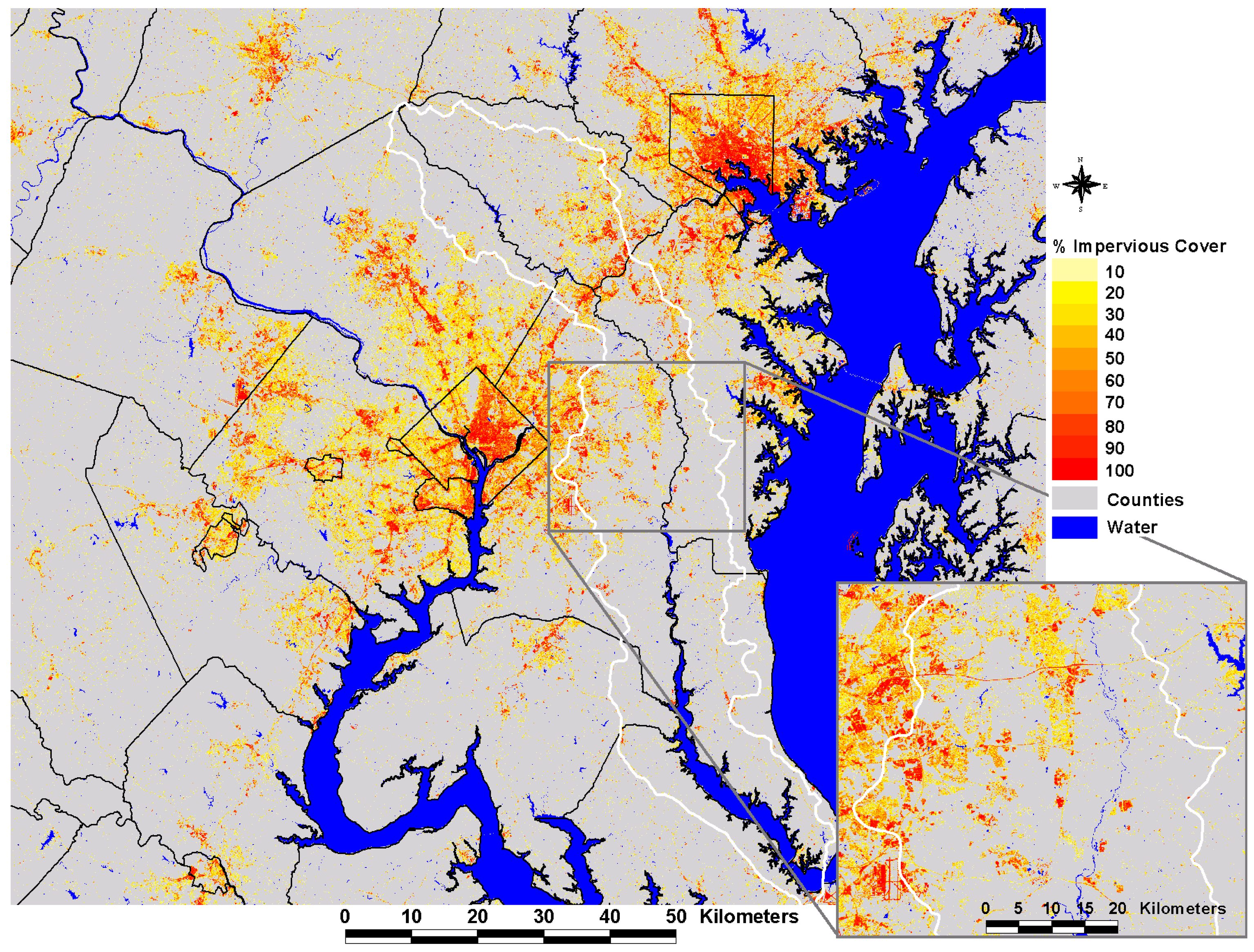

Figure 1: Impervious surfaces (%) in the Washington, DC-Baltimore area, 2000
A specific indicator of urbanization and residential sprawl is the amount of impervious surface area created through time. This sub-pixel map of impervious surfaces in the Baltimore – Washington metropolitan area was developed using a decision tree algorithm trained with planimetric data of Montgomery County, MD to classify a multi-temporal series of Landsat ETM+ imagery. The Patuxent watershed is outlined in white.

IV. MONITORING CHANGE

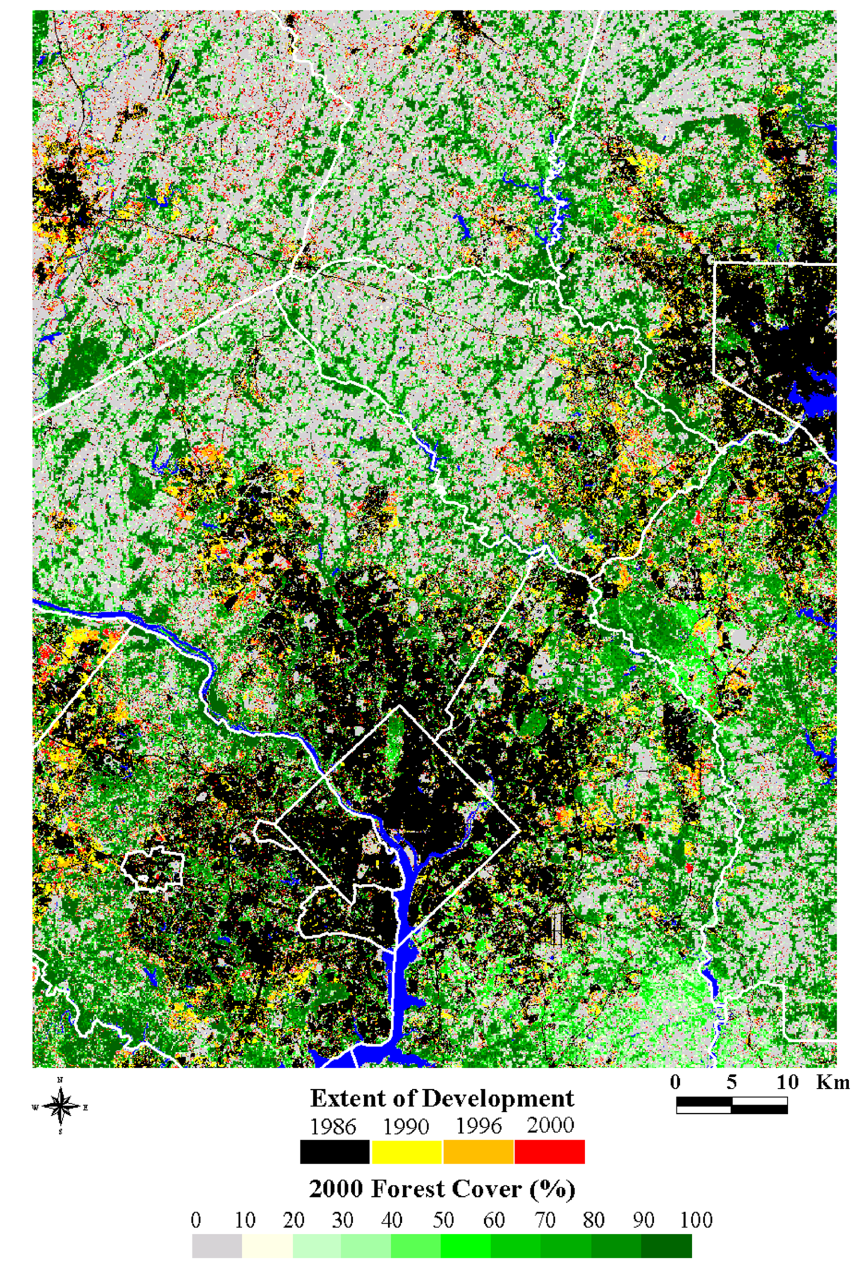

Figure 2: Change in the extent of developed land, 1986-2000 in the Washington, DC-Baltimore area
Techniques that were developed to map impervious surfaces were applied to historic Landsat TM imagery to map changes in the extent of developed land.

V. AGENT-BASED MICRO-ECONOMIC MODELING OF LAND USE CHANGE

- Estimates parameters of optimal timing and density decisions made by parcel owners who are facing market and regulatory constraints.
- Rules governing optimal timing of development:

Net one-time returns from development exceed present value of foregone returns from undeveloped use:

$$d(T)[P(T)-C(T)]-\sum_{t=0}^{\infty} A(T+t)d^{T+t} > 0$$

Net returns from developing in T exceed the present value of returns from waiting another period to develop:

$$d(T)[P(T)-C(T)] > d\{d(T)[P(T+1)-C(T+1)+A(T)$$

d= optimal density of development;
P=returns from selling developed lot;
C=cost of conversion per lot;
A=one period returns from undeveloped use;
T=optimal development time

- Increased fragmentation of land uses and growth in low density residential uses requires improved methods of predicting spatial patterns of change. Our work takes advantage of parcel level geocoded data, specifically recognizes heterogeneity in space, and incorporates spatial interactions of land use change. In this project we develop and apply this spatially explicit modeling approach, and link it with more conventional models that explain the amount of new development.

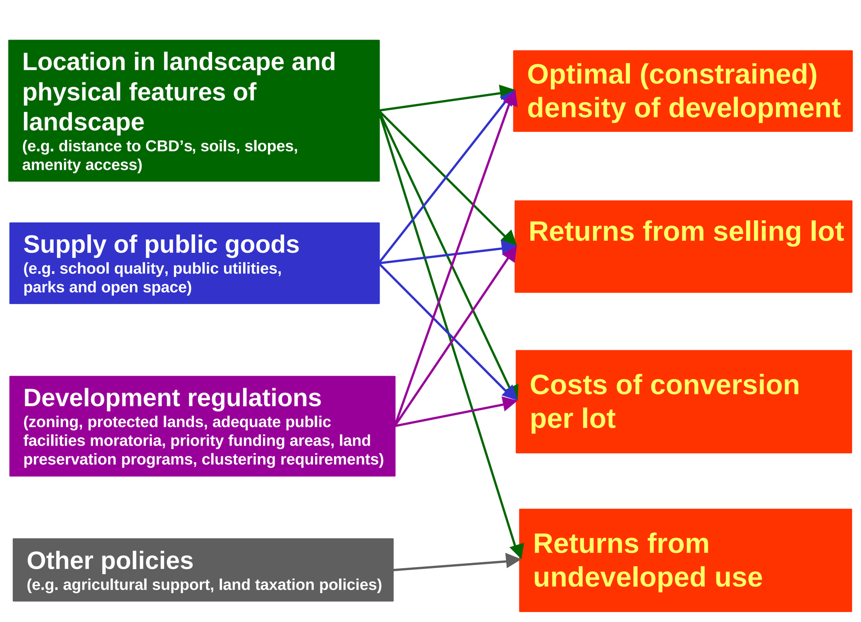

Figure 3: Factors that affect the economics of land conversion

VI. MODELING LAND USE CHANGE – THE CELLULAR AUTOMATA APPROACH

- The SLEUTH cellular automata for modeling urban land use change was applied to the Washington, DC-Baltimore region. The model was calibrated using a time series of historic urban development (Figure 2), and growth was projected into the future assuming three different policy scenarios: current trends, managed growth and sustainable. Regulatory policies were incorporated into the model using “excluded layers” that alter the probability of a cell becoming developed.

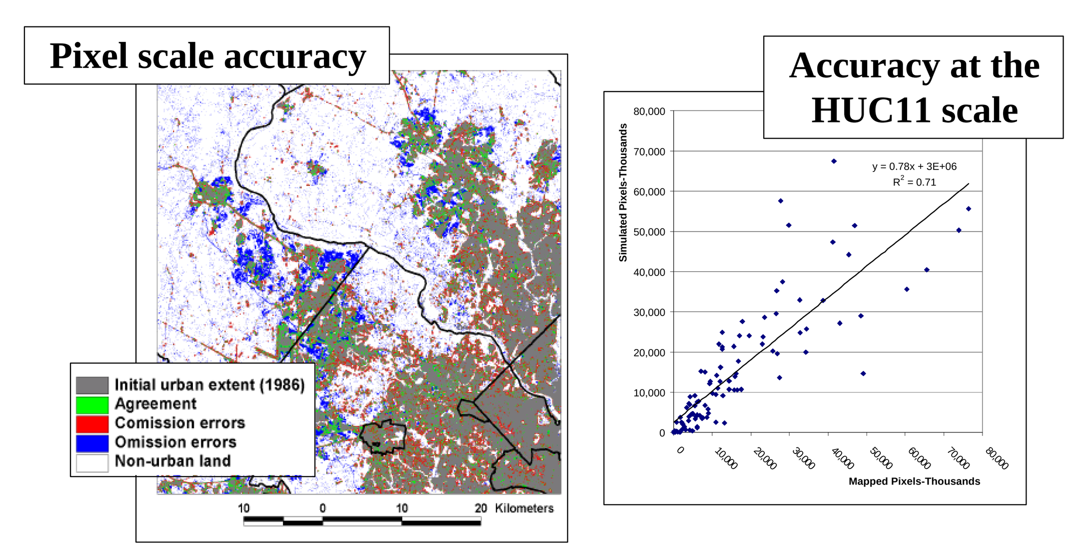

Figure 4: Accuracy of the SLEUTH cellular automata
At the pixel scale, accuracy is quite poor. However, the model performs well at broader spatial scale, such as the HUC 11 watershed scale.

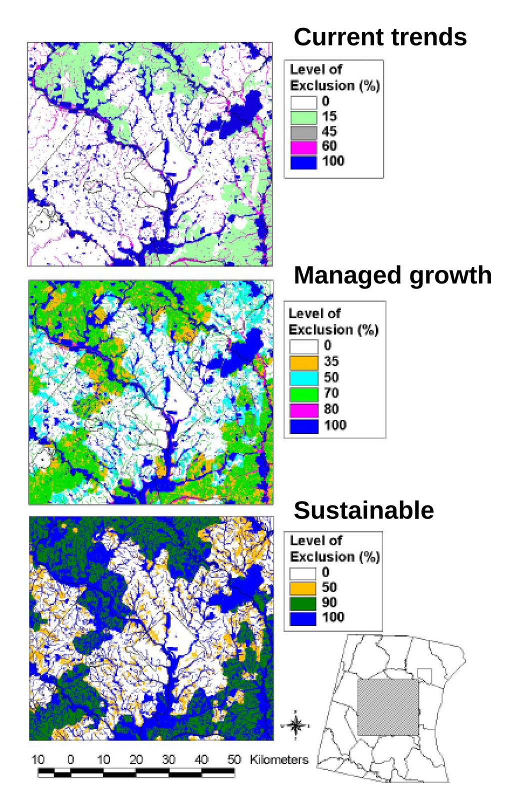

Figure 5: Excluded layers used to simulate impacts of regulatory policies on land cover change

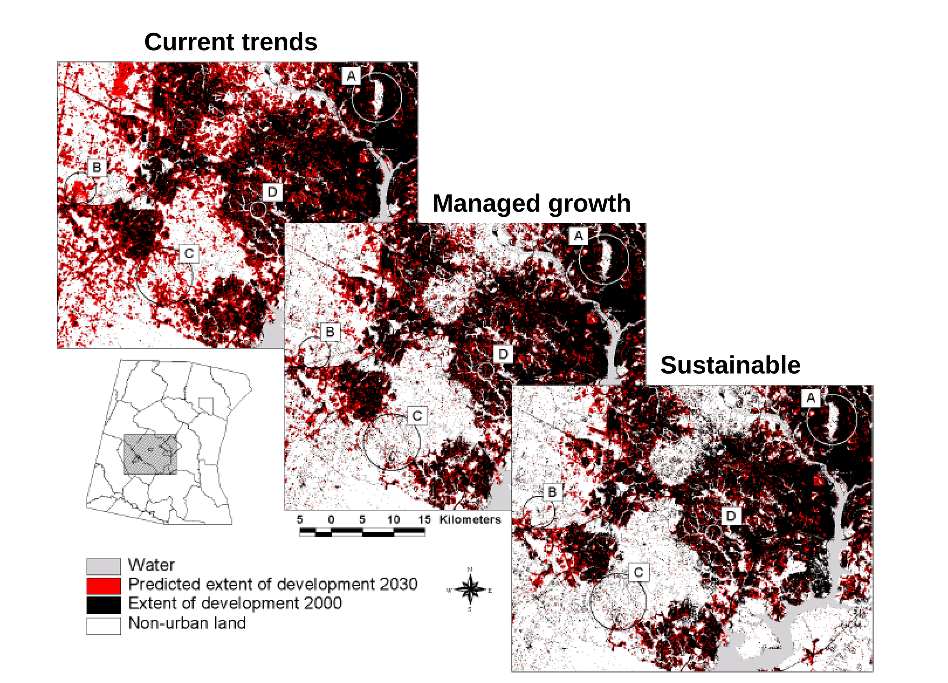

Figure 6: 2030 predictions for each policy scenario
The effect of protection placed on parks is shown at A. An area that was seeded with new development in the current trends scenario is shown at B. The effect of the smart growth areas is shown at C, which experiences development only in the current trends scenario. The effect of increasing protection on streams in the ecologically sustainable scenario is shown at D.

VII. COMPARISON OF MODELING TECHNIQUES FOR MONTGOMERY COUNTY, MD

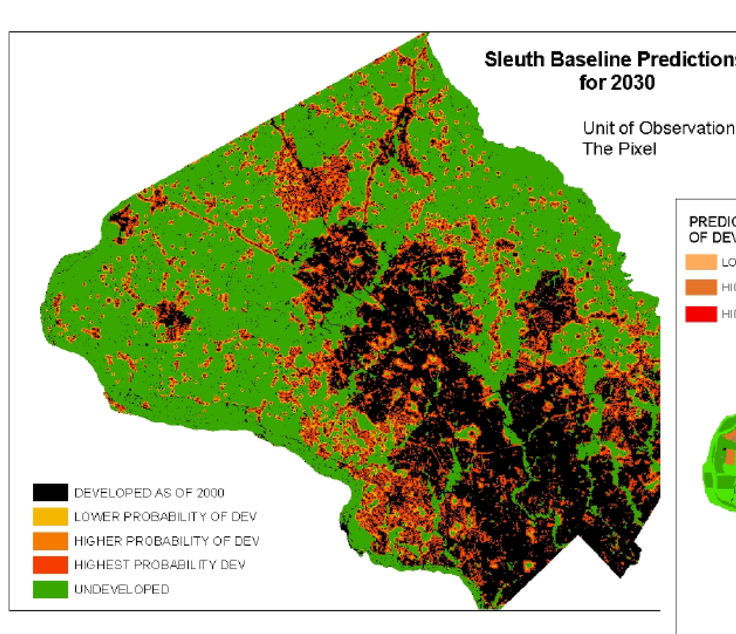

Figure 7: Forecasting output of SLEUTH model reflecting probability of development from year 2000 to year 2030 under baseline conditions.

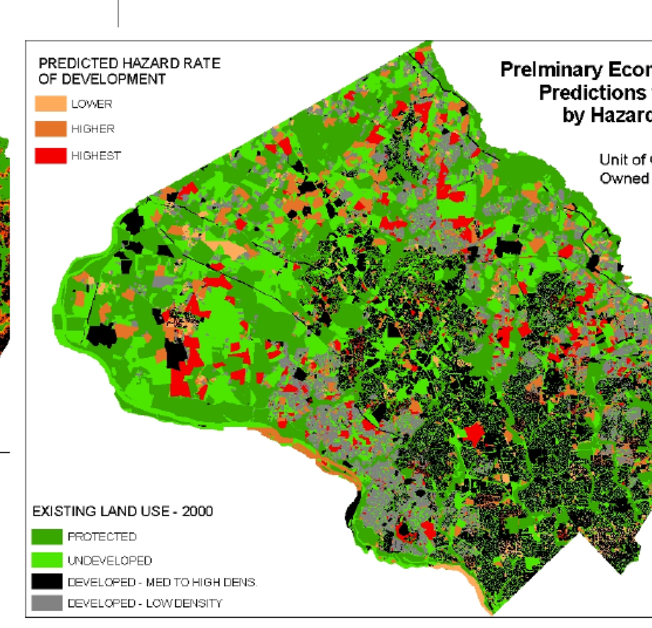

Figure 8: Forecasting output from economic model reflecting hazard rates of subsequent development beyond the year 2000.

Figure 9: Forecasting output from the economic model in which parcels are predicted to be developed in order of their likelihood until sufficient land is developed to accommodate forecasted new households by year 2030.

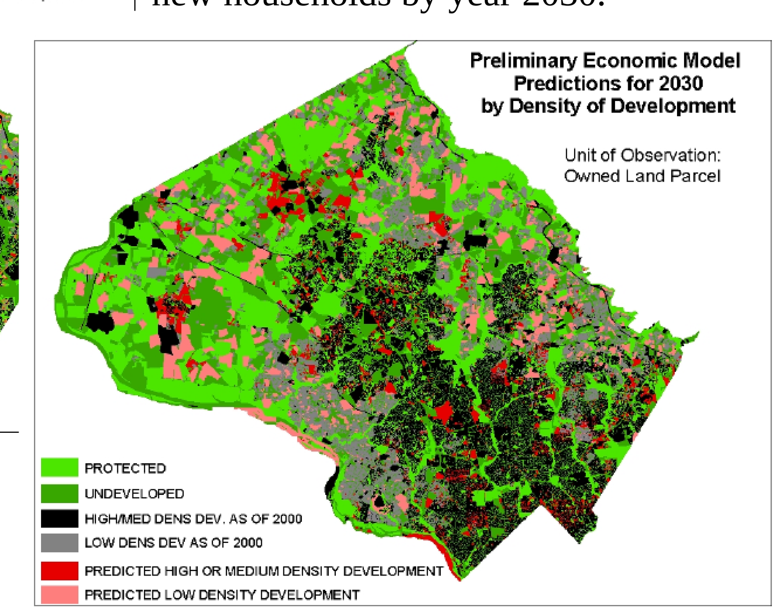

Table 1: Comparison of three approaches to urban modeling

	Build-Out Analysis	Cellular Automata Modeling (e.g. Sleuth)	Economic Modeling
Unit of Observation	Transportation Analysis Zone	Cell in landscape	Privately owned parcel of land
Nature of Approach	Accounting procedure	Pattern-based	Process-based
Nature of land use change process	Deterministic process dictated by regulations	Stochastic process regulated by conceptually simple transition rules. SLEUTH employs “slope”, “spread”, “breed”, “dispersion”, and “road gravity” coefficients	Stochastic model of behavior of land owners (choosing optimal timing of development and optimal density of development)
“Driving Forces”	Current maximum density allowed by zoning	State of current land cover, physical features of the landscape, user-defined areas that are protected from development.	Value of land in undeveloped use, value of land in developed uses, and conversion costs. All are functions of: current land cover, physical and locational features, public goods provision, and relevant regulations
Analytical Method	GIS overlays	Cellular automata models that simulate cell changes by an iterative calibration process using observed cell changes	Discrete choice or hazard model analysis to test hypotheses and calibrate parameter estimates for forecasting
Data required	Current zoning in GIS form	Landsat data for at least 4 points in time; road networks for 2 points in time; excluded layers for calibration and predictive scenarios	Parcel level data including locations of parcels, GIS data on physical features, regulations, public goods, land cover
Source of growth pressure information	“Small area” population forecasts	Historic rates and patterns of development	Model of housing starts as function of regional economic projections