NASA LCLUC Program

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

Principal Investigators

Prof. Nancy Bockstael
Dept. of Agricultural and Resource Economics, University of Maryland, College Park, MD 20742 Email: nancyb@arec.umd.edu, Tel. 301-405-1263

Dr. Scott J. Goetz
Dept. of Geography, University of Maryland, College Park, MD 20742
Email: sgoetz@geog.umd.edu, Tel: 301-405-1297, Fax: 301-314-9299

I. Overview

We are modeling the processes by which increasing demand for developed land uses, brought about by changes in the regional economy and the socio-demographics of the region, is translated into a changing spatial pattern of land use. Our study focus is a portion of the Chesapeake Bay Watershed where the spatial patterns of sprawl represent a set of conditions generally prevalent in much of the U.S. Working in the region permits access to (i) a time-series of multi-scale and multi-temporal (including historical) satellite imagery and (ii) an established network of collaborating partners and agencies willing to share resources and eager to utilize developed techniques and model results. In addition, a unique parcel-level tax assessment database exists for the Maryland portion of this region that makes it possible to establish an historical cross-sectional, time-series database of parcel level development decisions. Predictions of future land use change will permit scenario analyses of future carbon dynamics as well as nutrient loadings into the Chesapeake Bay tributaries. It will also provide critical quantitative insight into the impact of alternative land management and policy decisions, since one of the states in the region (Maryland) is a leader in adopting "Smart Growth" policies which are aimed at curbing sprawl development. Our technical approach includes three components: (i) spatial econometric modeling of the development decision, (ii) advanced remote sensing of suburban change and residential land use density, including comparisons of past change from Landsat analyses and more traditional sources, and (iii) linkages between the two through variable initialization and supplementation of parcel level data.

Key words:
Research Fields: Change detection, Land use modeling, Socioeconomics, Urbanization
Geographic Area/Biome: North America
Remote Sensing: IKONOS, Landsat
Methods/scales: Agent modeling, Local to Regional Scale

II. **Questions, Goals, Approaches, Accomplishments**

Science Questions

Our research project incorporates a number of the NASA LCLUC program's stated research priorities, including socioeconomic "drivers" as "*forcing factors*" of land use change, land cover conversion and land-use intensification as *responses and consequences* of land use change, agent-based models as simulators of the *processes and implications* of land use change, and multi-sensor remote sensing as part of the *techniques and methods* to monitor land use change. For example, we are mapping and monitoring urbanization in the study region using innovative remote sensing techniques while also, from a completely different perspective, spatially modeling the land use change decision at the individual property owner level. Later stages of the project will consider the fusion of these approaches and possible consequences of observed and predicted change.

- Social science (50%), Remote sensing research and applications (50%)

GOFC themes (50%), Socioeconomics (50%)

Approach / Methods

The overall approach of the project for year one was to develop and use remote sensing data sets and algorithms to map observed rates of change and to apply these to the calibration of a predictive model with no inherent economic components in order to simulate predictions of future changes under "current trends" and alternative land management practices as a strawman for eventual comparison to the agent-based microeconomic model. First year work on the latter model involved the construction of a geocoded, cross-section, time-series database of parcel level historical development decisions for nine counties in central Maryland, the compilation of all relevant zoning regulations for these counties, and the acquisition of additional geocoded data associated with the parcels. A preliminary analysis of the development decision using data for one county highlighted additional data needs that are now being addressed. We have overcome a number of substantial challenges in this process and have thus made good progress. Comparisons between the simple predictive model and the agent-based model can soon be made to provide insight into the mechanisms required to spatially model land use change and to consider ways in which integration of remote sensing output into the agent-based modeling can provide some of the variables needed to accurately model the processes by which land use change occurs.

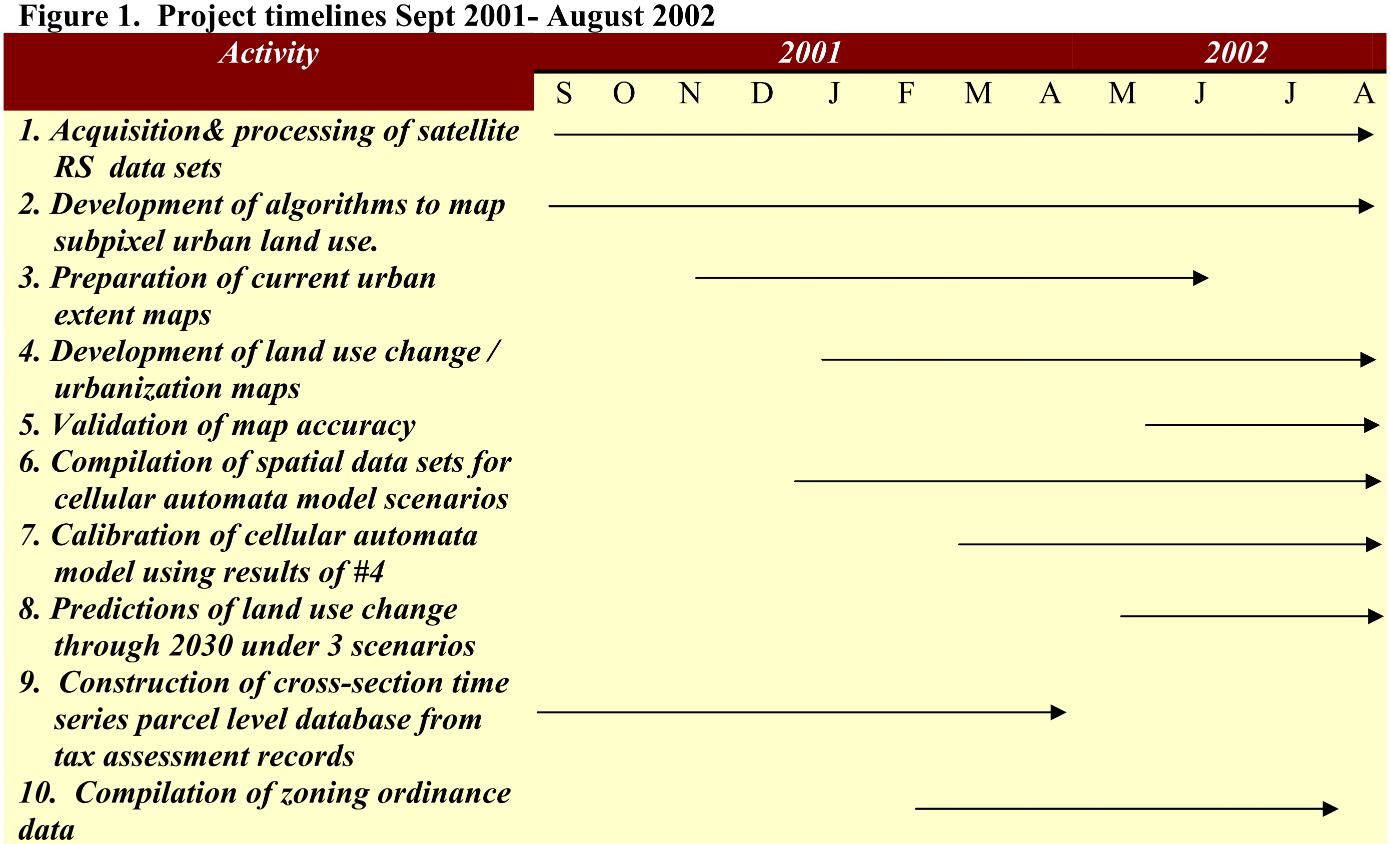
Goals & Accomplishments

The goals for this first year were to initiate the remote sensing and spatial modeling components of the project (outlined in Figure 1). The remote sensing (RS) analysis required acquistion and processing of GIS data sets, Ikonos and Landsat imagery, their georectification and radiometric normalization, and algorithm development to map continuous subpixel estimates of urban / residential land use. These were then used to produce maps of current and past urban extent in the region, and assess map accuracy. A relatively simplistic (cellular automata) approach to spatially modeling urbanization was then calibrated using the observed rates of land use change (derived from RS), and the model run to project future scenarios out to the year 2030. This approach set a baseline from which more explicit and mechanistic models of land use change, based on agent microeconomic decisions at the parcel level, could later be compared.

The agent-based model required the construction of a historical database of parcels. Maryland's Assessment and Taxation Division records data on every land parcel in the county and includes a legal description of the parcel, its zoning, size, current use and the date on which it was recorded as a parcel (and in 1996 the Office of Planning began digitizing the centroids of each of these parcels). The database is continually overwritten, however, and includes only limited information that directly relates a parcel in one year to its antecedents in previous years if the parcel was developed from a larger parcel or set of parcels. Snapshots of the database were acquired for 1993, 1995, 1997 and 2001 and, using a variety of clues, the origins of parcels that appear in 2001 were traced back to 1993 to yield a cross-section, time series data set of developable parcels and development outcomes for 8 years of activity.

Human land use decisions are affected by regional growth but also by features of the landscape (manmade and natural) that affect the value of different parcels in alternative uses and by public policies that constrain development. Landscape features such as computing distances, proximity to positive amenities, etc. and land use regulations and incentives including zoning (which governs maximum densities, minimum lot sizes, mandatory or optional clustering), adequate public facilities moratoria, development fees, agricultural preservation opportunities, new Priority Funding Areas (established under Smart Growth legislation) etc. have been recorded in digitized form and linked to the individual parcels. In this regard, a major effort was undertaken to extract from the nine counties' ordinances all relevant zoning information.

Figure 1. Project timelines Sept 2001- August 2002



11. Mapping of land use regulations	⟶
12. Estimation of preliminary test model	⟶

III. Progress and Next Steps

New Products

- Subpixel urban / residential land use for Baltimore-Washington region (2000) (Figure 2). Overall map accuracy was ~95%.
- Subpixel urban / residential land use maps for four time periods (1986, 1990, 1996, 2000), depicting observed land use change for a portion of the study area (Figure 3).

New Potential

- A cellular automata approach for predicting land use change applied over a large area at fine resolution by calibrating the model with accurate maps of past land use change derived from subpixel maps based on Ikonos and Landsat imagery (Figure 4). This is, to our knowledge, the first attempt to predict land use change at fine resolution over an area this size.
- An agent-based modeling approach, based on parcel level historical data constructed for a domain covering approximately 4000 sq. miles. This is a uniquely comprehensive, micro-level, digitized database of human decisions and government policies.

Next Steps

- Further development of urban extent maps for additional years between 1986-2002.
- Testing of methods to map residential density, particularly low-density areas at the exurban fringe.
- Testing of agent-based microeconomic models using data sets compiled this first year.
- Resolution of some spatial econometrics problems (notably identification problems and spatial autocorrelation in discrete choice models) that will arise in estimation of the agent-based microeconomic model.
- Comparison of cellular automata model predictions with microeconomic model and analysis of model constraints.
- Integration of remote sensing output into agent-based model to improve measurement of important variables.
- Submission of manuscripts describing the results thus far.

IV. Conclusions

Good progress was made preparing needed remote sensing and applying these to map past land use change, calibrate a high resolution, but naïve spatial predictive model of future land use change, and predict future land use of the study domain out through the year 2030. Progess was also made constructing the GIS and parcel-level data sets needed for an agent-based economic model of development decisions, in which exogenous landscape factors and public sector policies are taken into account. The results from the naïve cellular automata model (Figures 2-4) will next be compared with the agent based model and methods developed to integrate results to more realistically and accurately predict future changes, and to explore methods by which remote sensing can be used with an agent-based microeconomic model. Several peer-reviewed publications addressing various components of the projects results thus far have been initiated and are planned for publication over the coming year.

Figure 2. Observed land use in the Baltimore – Washington region mapped with a subpixel algorithm and Landsat imagery. Warm colors (red and green) are densely built areas, and cooler colors (blues) are residential areas.

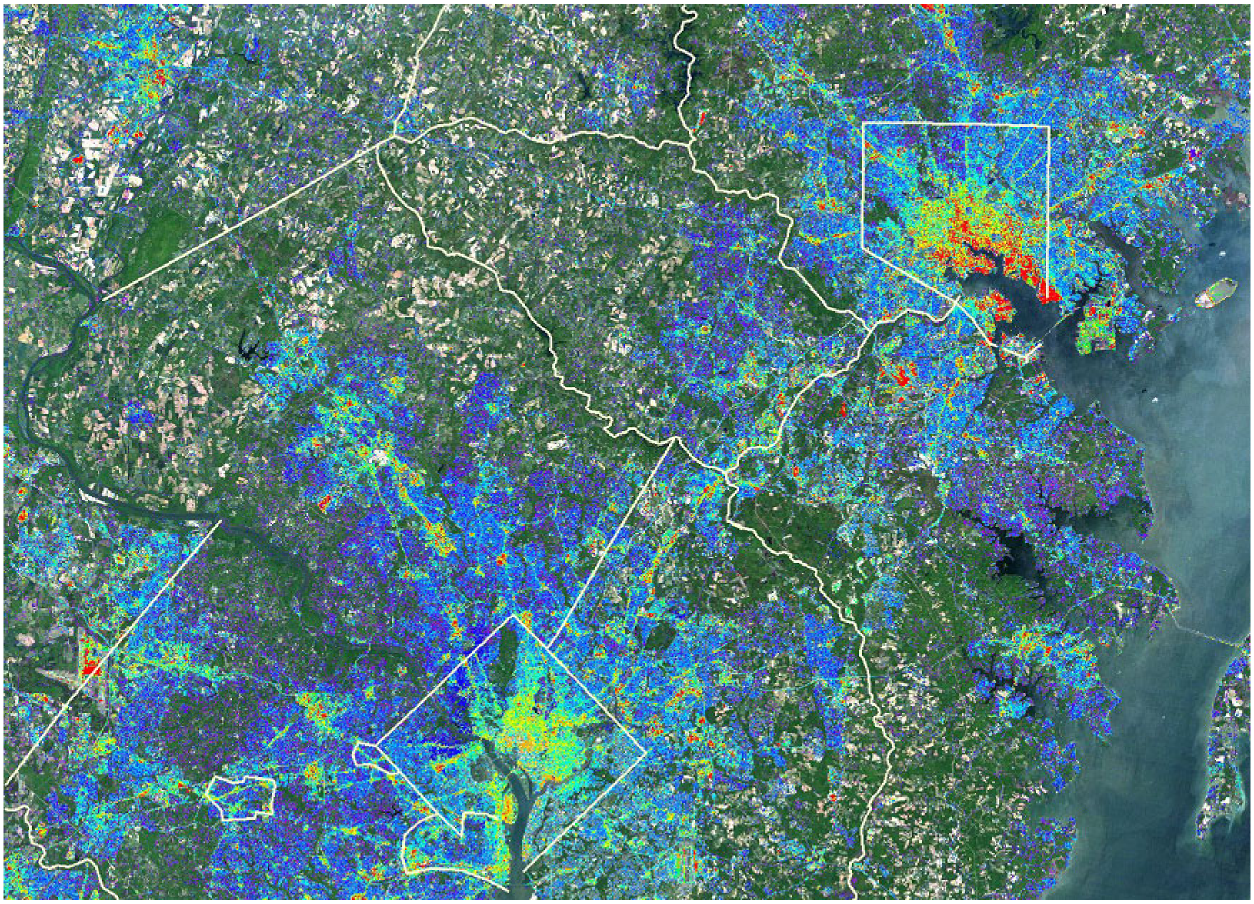


Figure 3. Land use change in a portion of Montgomery county Maryland and Fairfax county Virginia derived from subpixel estimates of urban extent using Landsat imagery.

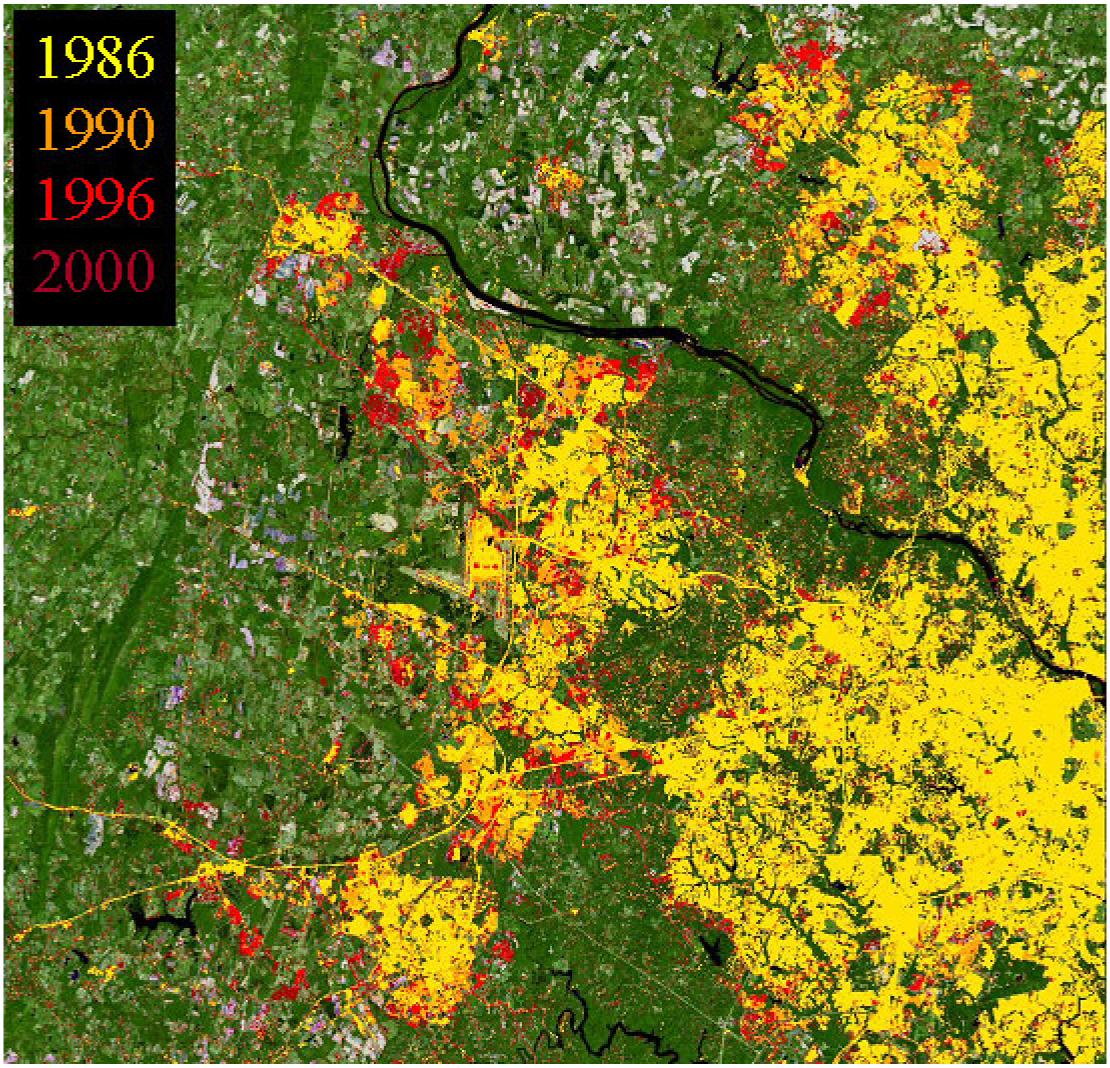


Figure 4. Predicted land use change in a portion of the study region, under three different land management scenarios, based on a cellular autonoma model calibrated with a time series of urban extent mapped with a subpixel algorithm and Landsat imagery. Blue depicts areas that have a 95% probability of change under stringent land management controls (ecologically sustainable), yellow depicts areas that will change under a managed growth scenario (plus all blue areas), and red depicts change under current trends (plus the areas under both managed scenarios).