Monitoring and Predicting Urban Land Use Change

Applications of Multi-Resolution Multi-Temporal Satellite data

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Abstract— **The ability to map and monitor the spatial extent of the built environment, and associated temporal changes, has important societal and economic relevance. Multitemporal satellite data now provide the potential for mapping and monitoring urban land use change, but require the development of accurate and repeatable techniques that can be extended to a broad range of conditions and environments. We have developed an approach using Landsat imagery, trained with the high resolution data sets, that identifies impervious surface areas (buildings, roads, *etc*) at subpixel resolution. We report on application of the approach over a range of scales, from the local to the entire Chesapeake Bay Watershed (168,000 km^2). We also developed maps of past changes in the built environment, used them to calibrate a spatial predictive model, and generated maps of expected future change under various policy scenarios out to year 2030. We believe these techniques have applicability to a wide range of applications.**

Keywords; land use, sprawl, urbanization, predictive modeling

I. INTRODUCTION

Communities worldwide need data to compensate for and adapt to current growth while planning for expected future change and its impacts on infrastructure, as well as the surrounding environment. Rapid rates of urban land use change, commonly known as suburban sprawl, are now at the forefront of local political disputes. Typically, however, these polarized debates lack adequate information for informed decision making. Satellite data can provide the capability for precisely mapping and monitoring suburban sprawl, i.e., exurban land use change. We have developed a flexible approach to urban/exurban mapping that makes use of Landsat TM/ETM+ imagery and high resolution data (e.g., Ikonos, Quickbird, digital orthophotos and/or planimetric maps). The approach identifies impervious surface area (ISA), including pavement, concrete, and the like, once adequately trained with the high resolution or "field" data sets [1]. ISA is relatively easily detected in Landsat imagery, although substrates with similar spectral properties, such as bare soil in agricultural fields, frequently require additional processing for adequate discrimination and removal. Because ISA is an important variable related to water quality, analyses based on maps produced from this approach have been used to predict, in conjunction with other variables such as riparian forest buffers, the health of small watersheds [2].

II. METHODS: MAPPING THE BUILT ENVIRONMENT

Subpixel estimation of ISA is done by first using the high resolution data (whether imagery or GIS / planimetric) to calculate the proportional impervious cover for each 900m^2 Landsat cell. These data provide the basis for training a regression tree algorithm applicable to the multitemporal Landsat data. The algorithm searches for a dependent variable that, if used to split a population of pixels into two groups, explains the largest proportion of deviation of the independent variable [3]. At each new split the tree is grown until it reaches terminal nodes, each representing a specific range of ISA based on the training information. The regression tree outputs a continuous estimate of ISA (between 0-100%).

Ikonos or QuickBird imagery can be used to develop the training data, and we have produced Ikonos impervious surface maps with very high accuracy (90%+), but because we had planimetric data available for a large (3800 km^2) area, we reserved the Ikonos for independent validation. We then mapped ISA over the entire 168,000 km^2 Chesapeake Bay watershed. ISA was relatively easily detected with the Landsat imagery, but the challenge was discriminating (and eliminating) substrates with similar spectral properties, such as bare soil in agricultural fields. We found leaf-on and leaf-off imagery a minimum requirement for discriminating ISA from bare fields, but multitemporal imagery was even more useful as chances were increased that fields would be observed with some vegetative cover which diverged from ISA features.

III. RESULTS: SUBPIXEL MAPS OF URBANIZATION

The resulting Landsat ISA maps (examples are shown in Figures 1 and 2) had an overall map accuracy of 88%, as assessed with cross-validation, Ikonos and digital orhtophoto images. There was some evidence for systematic commission errors resulting from residual bare or plastic-covered agricultural fields, and beaches [1].

Application of the approach to additional years (1986, 1990, 1996) using just leaf-on and leaf-off TM imagery allowed us to identify areas in the greater Baltimore – Washington DC region that had 10% or more ISA, which was a level sufficient to discriminate even low-density residential development from other land uses. Accurate mapping of changes in these "developed" areas (an example area is shown in Figure 3) permitted us not only to delineate specific projects but also to note the timeframe of their development, and to calculate change rates through time. Whereas rapid development in the region continued throughout the observational period, the highest rates of change occurred between 1986 and 1990.

Other analyses, in addition to the stream health assessments noted earlier [2], have show the land use changes depicted in figure 2 have not been well planned, e.g., they have receded from mass-transit stations and existing development. This characteristic of exurban sprawl often induces greater automobile traffic, higher energy consumption, poorer land use efficiency, and additional stresses on community infrastructure [4].

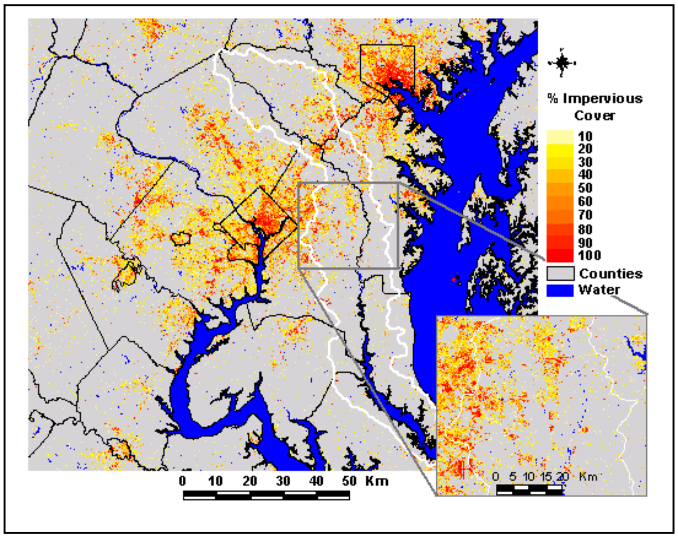

Figure 1. Map of subpixel impervious cover in the Baltimore-Washington DC area, showing not only highly urbanized areas but also lower density residential areas that are more characteristic of exurban sprawl.

IV. Methods: Spatial Predictive Modeling

In order to investigate some of impacts of exurban sprawl we used the time series to calibrate a spatial predictive model of urban change, and generated maps of expected future change under various policy scenarios [5]. The Sleuth cellular automata model [6] was calibrated on a Beowulf PC cluster using a brute force Monte Carlo approach, converging on the rates observed with the multitemporal impervious area observational time series. The model simulates urbanization in four ways, as edge growth, spreading urban centers, road induced growth, and spontaneous growth (i.e., seed areas). Sleuth was then run in a predictive mode out to 2030 assuming three policy scenarios: (i) current trends, (ii) planned growth, (iii) sustainable development. Each had progressively tighter controls on growth, as expressed through exclusion probabilities on different types of resource lands (e.g., parks, riparian buffer zones, etc) and areas targeted for growth (e.g., "attraction to" priority funding areas).

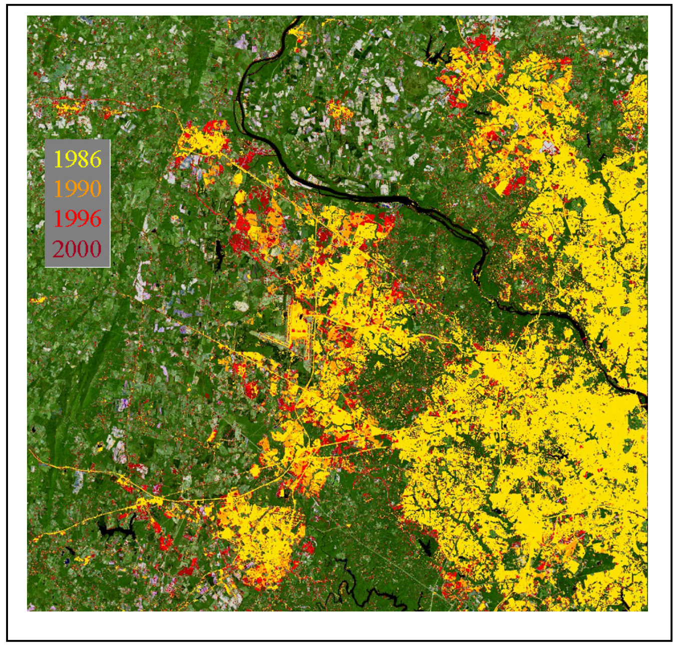

Figure 2. Exurban sprawl in an area of northern Virginia and southwestern Maryland as mapped using impervious surface area estimates from multitemporal Landsat over four years (1986, 1990, 1996, 2000).

V. Results: Impacts of Future Urban Sprawl

Results of the simulations (Figure 4) suggest rates of change under current trends that may be up to ten times past rates, owing to the exponential nature of growth around existing developed areas. An assessment of these changes suggest substantial loss of resource lands (e.g., forests, agriculture) under the current trends scenario compared to more conservative land use policies designed to reduce the impacts of exurban sprawl.

This is the first application of a spatial predictive model, that we are aware of, making use of the fine scale information provided by satellite maps of urban change. Partly this is because ISA maps have not been available in the past at the spatial resolution afforded by the use of very high resolution satellite data (e.g. Ikonos) in conjunction with Landsat, and partly it is because of the substantial computation requirements for calibrating the model over large areas with a small cell size (fine resolution).

Although there are limitations to the model, common to any cellular automata approach, these maps of ISA, exurban change, and predicted future change have proven useful to state and regional agencies tasked with assessing the potential utility of various protective or restorative measures. One example of policy decisions that could benefit from such maps are tax incentives for development in areas that are not valuable resource lands, particularly those areas identified in our maps as having high probabilities of future conversion.

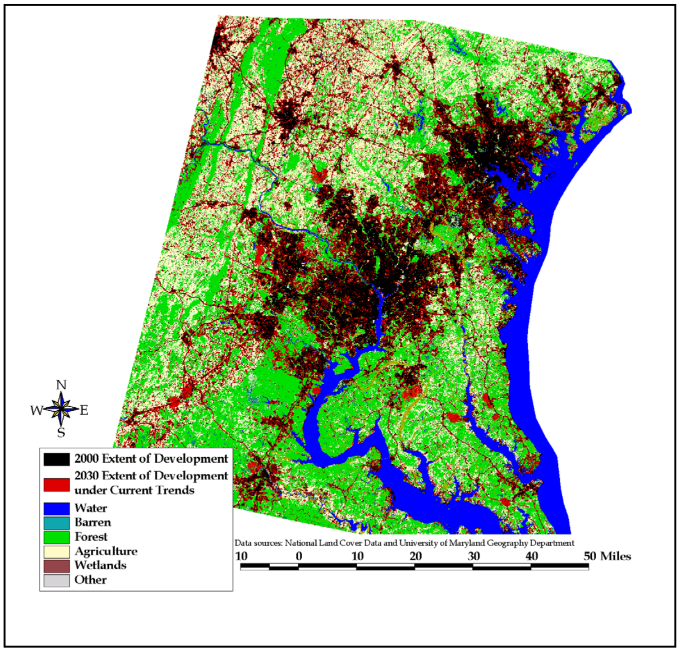

Figure 3. Predictions of future urbanization, as indicted by impervious surface areas, under three policy scenarios. Black areas were developed as of 2000, red areas are predicted change by 2030 under current trends, yellow areas under planned growth, and orange areas under sustainable development.

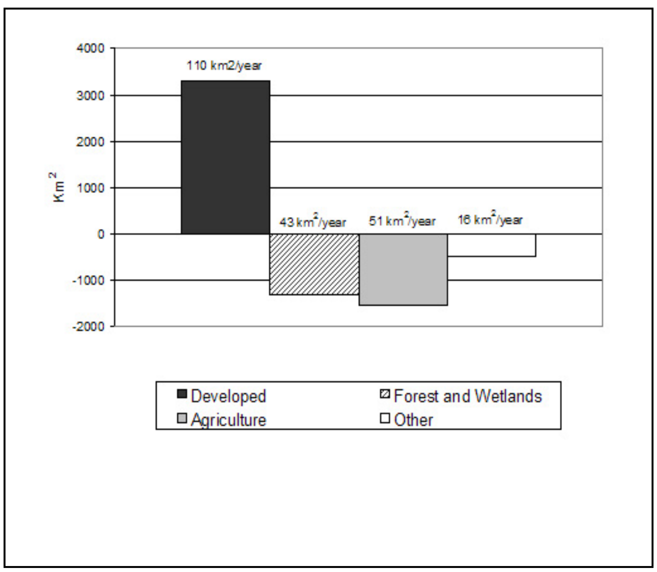

Figure 4. Impact of the "current trends" scenario on resource lands by 2030.

VI. Conclusions

Continued wide availability of affordable Landsat ETM+ imagery (or comparable observational data sets) will ensure valuable continuity in the production of highly accurate maps of the built environment, including subpixel impervious surface area and exurban sprawl maps like those presented here. Similarly, continued advances in very high resolution observational data sets from the commercial sector (e.g., Ikonos and QuickBird) provide valuable synergy with the Landsat data for algorithm and map development, validation of derived products, and extension of information content in regional and national data sets. These land data products provide critical input to resource management and decision support applications, and have substantial societal and economic benefit for community planning and development. One example is the calibration of spatial predictive land use change models, such as that presented here.

Acknowledgment

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