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Satellite Maps Show Chesapeake Bay Urban Development

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The extent, density, and configuration of the built environment—such as buildings, roads, parking lots, and other materials constructed for human use—have an impact on a wide range of biogeochemical and hydrological processes. These built areas, which are impervious to water infiltration, modify hydrology through the combined influence of increased peak flows, reduced base flows, flashier stream hydrographs (decreased lag times between storm events and peak discharge), and changes in bank and streambed erosion [*Nilsson et al.*, 2003]. Additionally, increasing impervious cover has long been known to amplify point source pollution discharges into streams, including chemical runoff from parking lots and roads [*Schueler,* 1994].

Two maps of the built environment, expressed in terms of impervious surface area, have been derived for areas that encompass the 168,000-square-kilometer Chesapeake Bay watershed (Figure 1), a region that has been highly altered by human land use [*Goetz et al.*, 2004; *Jantz et al.*, 2005]. One map was developed for the region at fine (30-square-meter) spatial resolution, and the other covers the extent of the conterminous United States at one-square-kilometer resolution [*Elvidge et al.*, 2004]. A finer-resolution regional map was used to assess the quality of the national map, demonstrating the utility the latter map for a range of applications related to monitoring land transformation and assessing watershed impacts.

Regional and National Maps of the Built Environment

The regional map was derived for the year 2000 using 60 multitemporal Landsat Enhanced Thematic Mapper Plus (ETM+) images, each rectified for a variety of geometric and radiometric discontinuities [*Goetz et al.*, 2004]. The map contains subpixel information on the proportion of each 30-meter (900-square-meter) pixel that is occupied by impervious cover, ranging from approximately 10 percent for low-density residential development to nearly 100 percent in intensively developed commercial and industrial areas. The extent of impervious cover represented in the map was validated using higher-resolution imagery, with overall accuracy approaching 90 percent [*Jantz et al.*, 2005]. This map is currently being used in the Chesapeake Bay Program restoration effort as one of the key drivers of a community watershed model, and related baseline mapping and monitoring activities (http://www.chesapeakebay.net).

The national map was derived using Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS) imagery, which has the unique capability of detecting low levels of visible and near-infrared radiance at night. These data were processed to create a map of the percent of impervious surface cover at one–square-kilometer resolution for the United States [*Elvidge et al.*, 2004] by augmenting the OLS imagery with a vector road database and urban cover classes derived from a circa-1990 National Land Cover Database (NLCD) map at 30-square-meter resolution [*Vogelmann et al.*, 2001]. High-resolution aerial

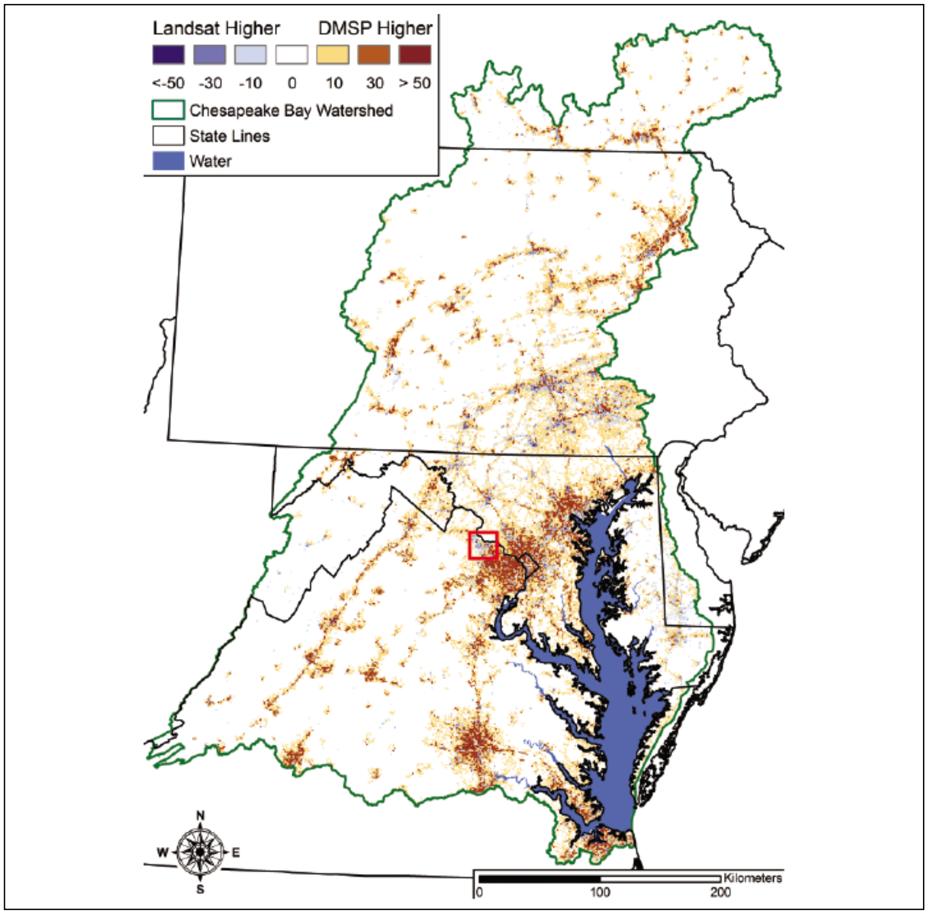

Fig. 1. Differences in impervious surface estimates between the national (DMSP-NLCD) and regional (ETM+) maps across the 168,000-square-kilometer Chesapeake Bay watershed. The regional map was aggregated to match the one-square-kilometer resolution of the national map. The red box encompasses an area shown in more detail in Figure 2.

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photographs were used to provide calibration of a linear regression model in which the impervious cover estimates from photos were predicted from the combined OLS, land cover, and roads data sets. Root-mean-square error in the linear model used to generate the map was 11.3 percent, for observed values ranging between 0 and 90 percent [*Elvidge et al.*, 2004].

The latter map provides a unique view of the built environment across the nation, from which additional useful information relevant to watershed loadings can be derived. For example, the map was recently used with climate data and fertilizer inputs to estimate water and carbon budgets of residential lawns [*Milesi et al.,* 2005].

Table 1. Summary Statistics Comparing the National (DMSP-MRLC) and Regional (ETM+) Impervious Cover Maps

	National Map	*Regional Map*	*Absolute Difference*	*Relative Difference, %*
Study domain				
Mean intensity, %	14.6	18.3	-3.7	-25.3
Extent, km^2	34,848	32,178	2,670	7.7
Recent change areas				
Mean intensity, %	23.9	22.2	1.7	7.1
Extent, km^2	4,356	4,784	-428	-9.8
Urban areas				
Mean intensity, %	26.5	24.2	2.3	8.7
Extent, km^2	10,327	10,204	123	1.2
Urban clusters				
Mean intensity, %	17.3	17.9	-0.6	-3.5
Extent, km^2	1,906	1,879	27	1.4

Comparing the Maps

In order to assess the accuracy and utility of the national map for hydrologic and urban change modeling applications, it was compared with the regional map, which was aggregated to one-square-kilometer spatial resolution while preserving the finer-resolution information within each grid cell. Comparisons were conducted of both the extent of the built environment and the intensity of development within each one–square-kilometer grid cell across the Chesapeake Bay watershed.

The per-pixel impervious values in the aggregated regional map ranged from near zero percent to more than 50 percent, but comparisons of spatial extent were only considered for grid cells that contained at least five percent impervious cover, in order to be consistent with the national map. In other words, one-square-kilometer cells with values less than five percent of impervious cover were not considered 'developed.'

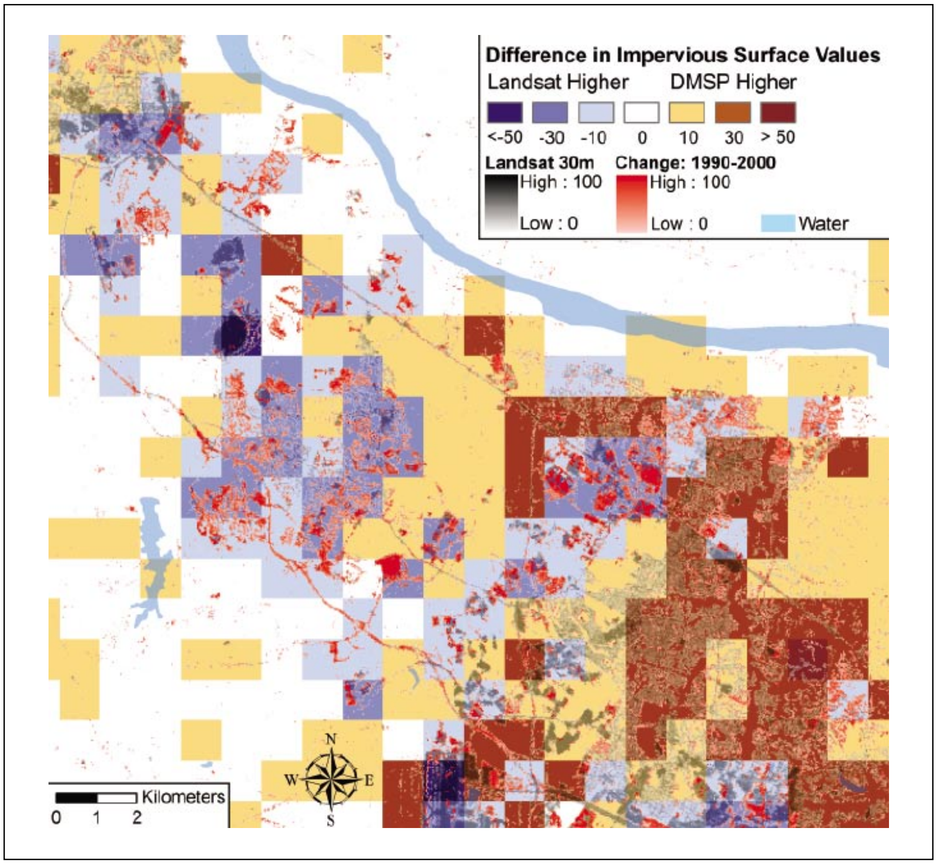

Fig. 2. Inset view of Figure 1 highlighting differences between the aggregated regional map and the national map. The fine resolution of the Landsat 30-meter regional map (gray scale gradient) reveals the underlying basis for observed differences, including areas where intensification of development was mapped between 1990 and 2000 (red gradient). The larger blocks are one-square-kilometer aggregates, as depicted in Figure 1. Note the tendency for the national map to underestimate impervious cover (blue colors) in areas where subpixel intensification occurred over the 10-year period, and to overestimate (orange colors) in existing, more densely developed areas.

The maps were coregistered and differenced (one subtracted from the other), providing spatially explicit estimates of areas where biases were present within the national map (Figure 1). The data were also summarized statistically, differentiating the extent and the intensity of the impervious cover estimates (Table 1).

The national map captured the spatial extent and intensity of impervious cover at the regional scale. Overall, the spatial extent of impervious cover differed by just 7.7 percent from the regional map, although the intensity (subpixel density of impervious development) estimates differed by 25 percent (Table 1). Some systematic biases in the comparisons were clearly associated with changes in the urban landscape between the timing of the circa-1990 NLCD component of the national map and the circa 2000 regional map. This was particularly evident in areas where new development occurred over the approximately 10-year period (Figure 2), as determined using fine-scale impervious cover maps derived using Landsat imagery for both 1990 and 2000 [*Jantz et al.*, 2005]. The national map estimates of impervious cover were consistently lower than the regional estimates in these recently developed areas, which were dominated by commercial and residential development (Table 1). This is a reasonable limitation of the national map that could be remedied using more recent urban land cover products currently being developed as part of the circa 2000 NLCD mapping activity.

Systematic overestimation in the national map was noted in highly developed areas, particularly large urban centers (Figure 2). This characteristic was probably associated with the tendency of the DMSP-OLS products, which are based on diffuse nighttime light emissions, to saturate in highly urbanized areas. Landscape features such as urban parks were thus likely to be underestimated at these coarser spatial scales. To examine this difference more closely, the landscape was stratified using year 2000 population statistics at the census tract level, delineating urban areas with population density ≥ 1000 people per square mile (386 per square kilometer) and urban clusters with population density ≤ 500 people per square mile (193 per square kilometer), as per the U.S. Census Bureau definitions. Those results confirmed the tendency for the national map to somewhat overestimate impervious extent and intensity in the more highly populated areas (i.e., urban centers rather than urban clusters) (Table 1). This is evident in the difference maps as well (Figures 1 and 2).

Utility to Watershed Management

Overall, the national map of impervious cover [*Elvidge et al.,* 2004] provides a unique view of the extent and intensity of the built environment across the nation, which continues to rapidly evolve as exurban development expands. The information captured in these maps can be used to help mitigate increased flood risk, reduced water quality, and impoverished stream biota associated with the impervious nature of built environments [e.g., *Snyder et al.,* 2005].

In the same way that the regional map has informed various Chesapeake Bay watershed restoration efforts [*Goetz et al.,* 2004], the information contained within the national impervious cover map has utility for incorporating landscape configuration information into large-area hydrological models, and for improving a range of watershed management efforts [*Wickham et al.,* 2005]. Current maps of the built environment provide a baseline data set upon which ongoing regional and national mapping efforts can be developed to better inform environmental policy, particularly those related to human modification of the landscape that have multiple impacts on aquatic ecosystems and water quality.

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