# Changing Urban Growth Patterns in a Pro-Smart Growth State: The Case of Maryland, 1973-2002

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**Abstract**

This paper presents a study of recent urban growth patterns in the state of Maryland, which is known as a leader in the current smart growth movement. Five research questions are addressed in this study. First, what have been the trends in urban growth and land use in Maryland for the past 30 years? Second, to what extent have recent urban development patterns in Maryland matched the typical characterization of sprawl? Third, how have the intensity of urban land uses and the physical forms of urban growth in this state varied among its counties? Fourth, have the smart growth initiatives, especially the "Smart Growth Area Act," significantly affected urban development patterns? Fifth, does the effectiveness of smart growth initiatives vary significantly across local jurisdictions? To answer these research questions, we measure, analyze, and model urban development patterns in Maryland using land use and land cover (LULC) and demographic data for 1973, 1992, 1997, 2000, and 2002. By calculating several important indicators of urban development patterns, we find that for the past three decades population densities have continued to decrease for the state as a whole. However, this trend has slowed since 1997, when the state implemented the smart growth programs. The land conversion rate has somewhat decreased, which indicates that smart growth initiatives have helped, in a limited way, curtail the growing demand for urban land and residential space. Further, we find that the patterns of urban growth and land use have generally become slightly less fragmented and more continuous since 1997. Additionally, we find significant variations in urban development patterns among local jurisdictions. In general, higher densities, higher levels of compactness, and lower levels of fragmentation are observed in the more urbanized counties. Moreover, by estimating a series of logit models of land conversion, we find that Maryland's "Smart Growth Area Act" has generally increased the probability of land use change from non-urban to urban for areas designated as "Priority Funding Areas." The effectiveness of this program, however, varies significantly across the counties. We discuss the implications of these findings and identify the directions for future research.

Keywords: Urban Development Patterns, Urban Sprawl, Smart Growth, Land Use, Models of Land Conversion, Maryland

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## Introduction

How cities grow spatially – where development takes place, at what level of density, and for what mix of people and activities – has profound implications for economic efficiency, social equity, and environmental sustainability. In the US, low-density and auto-oriented suburban expansion of cities has been the dominant form of urban growth for more than half a century (Downs, 1998). This urban development pattern has raised many issues, including higher costs of infrastructure provision (Burchell, et al 2002), auto dependence (Newman and Kenworthy, 1999), central city decline (Downs, 1999), poor transportation accessibility and longer trips (Ewing, 1997; Handy, 1996), spatial barriers for people relying on public transit to seek economic opportunities (Shen, 1998; 2000), lack of functional open space (Ewing, 1997), loss of resource lands (Nelson, 1992), and deterioration of environmental conditions (Daniels and Daniels, 2003).[1]

The growing concern that the prevailing development pattern is not in the long-term interest of cities has become a powerful driving force behind the smart growth movement, which emerged in the late 1990s and has since gained great momentum. While there is no concise definition of "smart growth" that is universally accepted, this term is generally used by its proponents to portray an alternative vision of urban development that promises to help cities achieve certain goals deemed desirable for the community, the economy, and the environment.[2] The most frequently stated goals are to facilitate economic growth while protecting the environment, to reduce development costs, to revitalize central cities, and to improve community livability. Smart growth is described as development that helps to achieve these goals by following certain principles, such as mixing land uses, creating housing and transportation choices, preserving open space and farmland, fostering distinctive communities with a strong sense of place, directing development toward existing communities, and encouraging community and stakeholder collaboration in development decisions.

From a historical perspective, the smart growth movement evolved from the growth management movement that started in the 1960s (Weits, 1999). Along with the new name, the movement has come with a significant shift in policy debate away from the traditional growth/no growth question to the question of how and where new development should be accommodated (US Environmental Protection Agency).

The State of Maryland, consisting of 23 counties and Baltimore City (see Figure 1), has been a national leader in the smart growth movement.[3] In 1996, faced with the projection

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[1] It is important to make it clear that, although these concerns are widely shared among urban planners and researchers, there are different views on the nature of problems related to urban growth (see, for example, Ladd (1992) and Gordon and Richardson (1997)). The debate is far from being settled.
[2] See, for example, online documents by the following organizations:
US Environmental Protection Agency, (http://www.epa.gov/smartgrowth/about_sg.htm),
Smart Growth America (http://www.smartgrowthamerica.com/whatissg.html), and
Smart Growth Network (http://www.smartgrowth.org/about/default.asp).
[3] The State of Maryland is situated on the Atlantic Coast and bordered by the District of Columbia and Virginia in the south and Pennsylvania in the north. It has a total area of approximately 7.9 million acres,

of a million new Maryland residents within twenty years—a 20 percent increase in the total population, Governor Parris Glendening declared his commitment to create and secure passage of a comprehensive package of legislation that would enhance the State's capacity to direct new growth toward areas where the infrastructure is already in place and to revitalize old urban areas (Cohen 2002). In 1997, the State General Assembly passed five pieces of legislation and budget initiatives known collectively as the Maryland Smart Growth legislation. These initiatives recast the policy framework for development decisions in Maryland.

Figure 1 approximately here

The most important element of the Maryland Smart Growth legislation is the "Smart Growth Area Act," which directs State funds for infrastructure and other growth-related services into existing developed areas and areas planned for urban development. According to Cohen (2002), with certain exceptions, only areas designated as "Priority Funding Areas" (PFA) may qualify for these funds. The objective is to use incentives to promote development in central cities and inner suburbs, while discouraging low-density, unplanned urban expansion by denying State subsidies for it.

The second component of the Maryland Smart Growth legislation is the "Rural Legacy Act," which is essentially a grant program enabling local governments and private land trusts to purchase development rights in designated areas for the purpose of protecting agricultural, forestry, and cultural resources.[4] The third piece of the legislation consists of the "Brownfields Voluntary Cleanup and Revitalization Incentive Programs," which aim to stimulate the reuse of contaminated properties. These programs relieve current owners from retroactive liability, provide loans and grants for site cleanup, and offer a tax break on the increased assessment resulting from property improvements. The fourth initiative is the "Job Creation Tax Credits Program," which encourages businesses to expand by providing tax credits for each new full-time job created by a qualified firm. The fifth and final element is the "Live Near Your Work Program," which creates incentives for employees to buy homes near their workplaces. Its purposes are to stabilize targeted neighborhoods by promoting homeownership and to reduce commuting.

While Maryland's smart growth programs encourage and support sensible growth in designated areas, they do not carry the regulatory power to prevent development either inside or outside the designated areas. For Maryland planners and policy makers who are determined to make continuing efforts to pursue smart growth, it is crucial to find out whether or not the smart growth initiatives have facilitated positive changes in urban development patterns, and to identify possible ways to improve their effectiveness. Additionally, planners and policy makers will benefit from a study that examines internal variations in urban development patterns in this pro-smart growth state. It will allow them

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including almost 1.7 million acres of water area (Maryland Office of Planning, 1991). Its population in 2000, according to the decennial census conducted by the US Census Bureau, was nearly 5.3 million.

[4] This description of the components of the Maryland Smart Growth legislation is based on Cohen (2002). Readers should refer to Cohen (2002) for additional information about smart growth initiatives in Maryland.

to gain a fundamental understanding of factors other than state policies that influence the pace and form of urban growth.

For planners and policy makers elsewhere who are interested in learning from the experience of Maryland, a basic understanding of the relationship between smart growth programs and urban development patterns in this state is essential.

The objectives of this study are three-fold. The first is to examine closely the changing pattern of urban growth in Maryland along both the spatial and temporal dimensions. Specifically, we aim to understand how urban development patterns in this state have changed over the past three decades and varied across the twenty-four local jurisdictions. The second objective is to present Maryland as a case for comparison with other states examined by prior or parallel studies funded by the Lincoln Institute of Land Policy. The final objective is to understand the influences of geographic, demographic, and policy factors on urban growth and land use. We are especially interested in investigating the effectiveness, or the lack thereof, of Maryland's smart growth initiatives in influencing the pace and spatial distribution of non-urban to urban land conversion.

Five research questions are addressed in this study. First, what have been the trends in urban growth and land use in Maryland for the past 30 years? Second, to what extent have recent urban development patterns in Maryland matched the typical characterization of sprawl? Third, how have the intensity of urban land uses and the physical forms of urban growth in this state varied among its counties? Fourth, have the smart growth initiatives, especially the "Smart Growth Area Act," significantly affected urban development patterns in this state? Fifth, does the effectiveness of smart growth initiatives vary significantly across local jurisdictions?

To answer these research questions, we measure, analyze, and model urban development patterns in Maryland using land use and land cover (LULC) data for 1973, 1992, 1997, 2000, and 2002. By calculating several important indicators of urban development patterns, we find that for the past three decades population densities have continued to decrease for the state as a whole. However, this trend has slowed since 1997. The land conversion rate has somewhat decreased, which indicates that smart growth initiatives have to some limited degree helped curtail the growing demand for urban land and residential space. Further, we find that the patterns of urban growth and land use have generally become slightly less fragmented and more continuous since 1997.

Additionally, we find significant variations in urban development patterns among local jurisdictions. In general, higher densities, higher levels of compactness, and lower levels of fragmentation are observed in the more urbanized counties. Moreover, by estimating a series of logit models of land conversion, we find that Maryland's "Smart Growth Area Act" has generally increased the probability of land use change from non-urban to urban for areas designated as "PFA." The effectiveness of this program, however, varies significantly across the counties. The result of our empirical analysis suggests that the "Smart Growth Area Act" may have less success in achieving its objective in the less urbanized counties located at the periphery of the state.

The remainder of this working paper is organized as follows. Section 2 provides a review of the literature on three topics: measurement of urban development patterns, modeling of land conversion, and examination of the effects of land use regulations and growth management policies. Section 3 presents the research design of our study. It describes the quantitative measures we employ to characterize urban development patterns and the models we estimate to explain land conversion from non-urban to urban, as well as the data and computation procedures for these analyses. The empirical results are reported and discussed in Section 4. Finally, in Section 5 we draw conclusions from our study and define directions for future research.

## Literature Review

Three strands of literature on urban growth and land use are most relevant for this study. The first deals with the measurement of urban development patterns, the second explores approaches to modeling land conversion, and the third examines the effects of land use regulations and growth management policies on urban development.

### Measurement of Urban Development Patterns

Over the last decade, there has been a rapid increase in the amount of literature on the measurement of urban development patterns. This is because urban sprawl, which encompasses multiple aspects of urban development patterns, has been one of the most popular topics of discussion in city and regional planning.[5] Many scholars have studied urban sprawl and contributed to the current debate over its causes, consequences, and policy implications (see, for example, Brueckner, 2000; Carruthers and Ulfarsson, 2002; Downs, 1999; Ewing, 1997; Galster et al, 2001; Gordon and Richardson, 1997; Landis, 2001; Peiser, 2001; Pendall, 1999). Some researchers have identified measurable characteristics of sprawl, other have proposed specific indicators of sprawl to characterize patterns of urban growth and land use, and still others have employed measures of sprawl to perform empirical analyses.

Downs (1999), for example, derived ten traits of urban sprawl: (1) unlimited outward extension of development, (2) low-density residential and commercial settlements, (3) leapfrog development, (4) fragmentation of powers over land use among many small

[5] According to Hess et al (2001), the word sprawl has been used to describe the urban environment since the mid 20th Century, when two fundamental life changes took place in the US – a dramatic increase in private automobile use and the expansion of the highway system. The early uses of the term sprawl suggest that it consumes excessive space in an uncontrolled, disorderly manner leading to the loss and poor distribution of open spaces, excessive demand for transportation, and social separation. Hess et al also observe that the essential elements of these early definitions have remained relatively unchanged through time. The characteristics associated most frequently with sprawl are low-density development, excessive land consumption and spatial growth of cities, leapfrog and scattered development away from the central city and existing infrastructure, and separation of land uses (see discussions by Brueckner, 2000; Downs, 1999; Ewing, 1997; Galster et al, 2001; Harvey and Clark, 1965, Landis, 2001, and Mills, 1981). It is important to note that, while the discussion on urban sprawl has been going on for more than half a century, serious efforts were rarely made to quantify sprawl until several years ago.

localities, (5) dominance of transportation by private automotive vehicles, (6) lack of centralized planning or control of land uses, (7) widespread strip commercial development, (8) great fiscal disparities among localities, (9) segregation of types of land use in different zones, and (10) reliance mainly on the trickle-down or filtering process to provide housing to low-income households. While this list is quite comprehensive, not all these characteristics can be easily quantified. Furthermore, only some of these traits describe land use patterns; the others are either causal factors or consequences of urban sprawl.

Ewing, Pendall, and Chen (2002) took one step further in sprawl research by developing quantifiable indicators of sprawl. They created a sprawl index based on four factors that can be measured and analyzed: (1) residential density, (2) neighborhood mix of homes, jobs, and services, (3) strength of activity centers and downtowns, and (4) accessibility of the street network. Ewing, Pendall, and Chen applied these measures to 83 metropolitan areas in the US using data from the US Census demographic and TIGER files, Census Transportation Planning Package, the American Housing Survey, the Natural Resources Inventory, and the Zip Code Business Patterns database.

Other researchers have focused on the environmental and resource aspects of urban growth and land use change. Hasse and Lathrop (2003), for example, used a series of five indicators that examine several critical land resource impacts associated with sprawl: (1) density of new urbanization, (2) loss of prime farmland, (3) loss of natural wetlands, (4) loss of core forest habitat, and (5) increase of impervious surface. These indicators were measured for each of New Jersey's 566 municipalities using a 1986 to 1995 LULC digital database along with US Census population data.

Perhaps the most comprehensive set of operational measures of urban sprawl was proposed by Galster et al (2001). Built on their observations that the literature on urban sprawl confuses causes, consequences, and conditions, Galster et al developed a conceptual definition of sprawl based on eight distinct dimensions of land use patterns. They defined sprawl as a pattern of land use that exhibits low levels of some combination of eight distinct dimensions: density, continuity, concentration, compactness, centrality, nuclearity, diversity, and proximity. These eight dimensions of land use pattern were elaborated as follows:

(1) Density: the average number of residential units per square mile of developable land in an urbanized area;
(2) Continuity: the degree to which developable land has been developed at urban densities in an unbroken fashion;
(3) Concentration: the degree to which development is located in relatively few square miles of the total urbanized area;
(4) Compactness: the degree to which development has been clustered to minimize the amount of land in each square mile of developable land occupied by residential or nonresidential uses;
(5) Centrality: the degree to which residential and/or nonresidential development is located close to the central business district of an urbanized area;

(6) Nuclearity: the extent to which an urbanized area is characterized by a mononuclear (as contrasted with a polynuclear) pattern of development;
(7) Diversity: the degree to which two different land uses exist within the same micro-area, and the extent to which this pattern is typical of the entire urbanized area;
(8) Proximity: the degree to which different land uses are close to each other across an urbanized area.

Galster et al tested their definition for 13 large urbanized areas using six of the eight dimensions of sprawl.[6] The quantification of these indicators used data on population and residential land use, as well as various measures of distance relationships.

Landis (2001) proposed a series of measures of urban development patterns that have some similarity with the aforementioned indicators by Galster et al (2001). He grouped these measures into two general categories. The first category, called "land conversion and density trends," includes amount of land urbanized, net urban density, marginal density, and a sprawl index. The second category of measures, under the name of "metropolitan form", characterizes patterns of urban growth and land use in terms of compactness, fragmentation, and continuity. Landis provided further descriptions of these measures:
(1) Amount of land urbanized: the increase in urbanized area during a time period;
(2) Net urban density: the ratio of population to urban land area;
(3) Marginal density: the density of new urban development (computed as the change in population divided by the change in urban land area);
(4) Sprawl index: the relative pace of urban land conversion in comparison with population growth (computed as the rate of growth in urbanized land divided by the rate of population growth);
(5) Compactness: the degree to which development is clustered or dispersed around one or more centers;
(6) Fragmentation: the degree to which urban development is organized into a single contiguous area rather than multiple, disconnected fragments;
(7) Continuity: the degree to which urban sites are surrounded by other urban sites.

Landis employed LULC data for 1972 and 1996, together with the corresponding demographic data, to obtain values of these measures for all counties in California. GIS tools were applied in the data processing and analysis.

A rich set of empirical results has been reported in numerous studies of urban sprawl. Some of the research findings confirmed what we expected or observed. For example, Fulton et al (2001) found that metropolitan areas in the US are adding urbanized land at a much faster rate than they are adding population. Their data analysis revealed that, between 1982 and 1997, the amount of urbanized land in this country increased by 47 percent (from approximately 51 million acres in 1982 to approximately 76 million acres in 1997), but during this same period, the nation's population grew by only 17 percent.

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[6] Galster et al (2001) noted that, because of resources and time constraints, their test was confined only to residential uses. Because of this, they were not able to test the operationalizations for the measures of continuity and diversity, which involve multiple types of land use.

Another example is that most studies identified several old cities in the Northeast region, including New York and Boston, as some of the least sprawling cities and many new cities in the South, such as Atlanta, as the most sprawled (e.g. Ewing, Pendall, and Chen 2002; Galster et al, 2001).

Other research findings are provocative. Fulton et al (2001) found that the West is home to some of the densest metropolitan areas in the nation, as demonstrated by the fact that, in 1997 ten of the 15 densest metropolitan areas in the nation were located in California, Nevada, and Arizona. Similar results were presented in Ewing, Pendall, and Chen (2002) and Landis (2001). Moreover, many studies reported that Los Angeles, which had been widely perceived as one of the worst cases of urban sprawl, actually is among the least sprawled cities based on several important measures, including net and marginal population densities, compactness, fragmentation, and mixed land uses (Ewing, Pendall, and Chen 2002; Galster et al, 2001; Landis, 2001).

Probably the most important result obtained from several recent studies is that metropolitan areas in different parts of the country are growing in different ways. While sprawl has increased over the past decade in most metropolitan areas, there are important geographic variations (Fulton et al, 2001; Lopez and Hynes. 2003; Landis). Fulton et al (2001) noted that metropolitan areas tend to urbanize less land per new resident when they are growing rapidly in population, rely heavily on public water and sewer systems, and have high levels of immigrant residents. These variations, together with the fact that some metropolitan areas witnessed decreases in population density in recent years, suggest that sprawl is not inevitable. In addition, they suggest that policy responses to sprawl should be different for different cities and regions.

**Modeling of Urban Land Conversion**

The 1980s and 1990s witnessed some significant progresses in developing models of urban growth and change. In a review of current urban models, Wegener (1994) discussed several important developments. One fundamental advance in this field was the incorporation of random-utility theory into models of land use and travel demand. Another major development was the maturing of GIS as a powerful tool for processing, managing, and analyzing micro-scale data on land use and activity patterns. These developments resulted in a variety of new or improved models for urban planning and management. The logit model of land conversion developed in the late 1990s by Landis and Zhang (1998a and 1998b) was an example of such urban models.

The starting point for Landis and Zhang to conceptualize the model was the observation that the process of land use change is fundamentally discrete. They noticed that land use change in a metropolitan area occurs as the sum of individual, parcel-level, land use changes, and that the traditional techniques of regression analysis are poorly suited to modeling discrete processes. The alternative they adopted was the discrete choice framework (Domencich and McFadden, 1975; Ben-Akiva and Lerman, 1985). Specifically, Landis and Zhang employed the multinomial logit framework based on several assumptions:

(1) The decision to change land use on a site will be based on a rational evaluation of the prospective profit or rent associated with different development forms;
(2) The profit or rent potential associated with each choice is determined by a set of attributes;
(3) Because some attributes are unobservable, the land use change function is assumed probabilistic.

Landis and Zhang presented the general specification of the multinomial logit model. The probability of land use change was a function of initial site use, site characteristics, site accessibility, community characteristics, policy factors, and relationship to neighboring sites. A total of nine different types of land use change were considered, and more than two dozen independent variables were employed to determine the probability of land use change. Because of the lack of digital parcel data, Landis and Zhang used one-hectare (100m × 100m) grid cell as the geographic unit of analysis. The model was calibrated using data from the San Francisco Bay Area.

In a more recent study, Landis (2001) simplified his framework to make it a binary logit model of land conversion from non-urban to urban. The dependent variable has, therefore, become the binary choices (i.e. 0 for land to stay non-urban, and 1 for land to be urbanized), but the independent variables remain largely the same. Landis measured land use change using LULC data for 1972 and 1996, and estimated the model for counties and regions in California.

Some other studies of urban growth and land use also serve useful references for modeling land use change. For example, Fulton et al (2001) performed a regression analysis to identify a wide range of demographic, socioeconomic, political, fiscal, and infrastructure factors that influence density, density change, and urbanized land change in US metropolitan areas.

**Effects of Land Use Regulations and Growth Management**

There is a large volume of literature on the impacts of governmental regulations on land use and urban development. Many early studies in this field focused on the effect of land use controls on housing supply and price. An important example was the research by Dowall (1984), who found that growth controls enacted by local jurisdictions in California placed a major constraint on residential land supply and development and caused substantial housing price increases. Another example was the work by Levine (1999), who showed that growth control measures restricted rental housing production in the enacting jurisdictions, and that minorities were particularly affected as rental housing production was pushed to the urban periphery.

Some researchers examined the impact of local governments' land use regulations on the spatial pattern of growth. Shen (1996), for example, examined the cumulative spatial impact of locally-enacted growth regulations in the case of the San Francisco Bay Area. He found that there were substantial reallocations of urban growth from jurisdictions that enacted such restrictions to the rest of the region.

A large number of studies examined the connection between land use regulations and urban sprawl. Feitelson (1993) performed a case analysis of the Chesapeake Bay Critical Area and concluded that growth controls do not always lead to more sprawl. In addition, he found that the way in which control measures are implemented have an effect on who is affected. Similarly, Pendall (1999) investigated the relationship between land use regulations and low-density urbanization. He found that land use controls that shift the cost of development onto builders reduce sprawl, whereas regulations that mandate low densities increase sprawl. Carruthers and Ulfarsson (2002) analyzed the effects of governmental policies on urban development by focusing on the relationship between political fragmentation and sprawl. Their empirical result indicated that political fragmentation leads to lower densities.

Nelson (1999) examined the impacts of growth management on population density, farmland preservation, transportation accessibility, energy conservation, and tax burden. He compared two states with growth management efforts, Florida and Oregon, with one state that had no such efforts, Georgia. He found that, between 1980 and 1990, densities in urbanized areas in Florida and Oregon fell only by 5% and 0.5%, respectively, whereas Georgia witnessed a nearly 15% drop in density even though its urbanized population grew by practically the same rate as Florida's. With regard to farmland preservation, Nelson found that during the 1980s Florida lost 0.66 acres of farmland for each new resident, Oregon lost only 0.33 acres per new resident, but Georgia lost 2.10 acres for each additional resident (higher than the national average of 1.79 acres). In terms of transportation accessibility, Nelson showed that between 1990 and 1995 vehicle miles traveled rose merely 1.5% in Oregon, 16% in Georgia, but an unexpected 25% in Florida. The energy conservation effect of growth management was illustrated by the much higher percentages of reduction in per capita energy consumption in Florida and Oregon than in Georgia. Finally, in terms of tax burden, Nelson showed that the relative pace of local government revenue increase between 1982 and 1992 was slower in Florida and Oregon than in Georgia. In virtually all dimensions of the comparison, the growth management states of Florida and Oregon fared better than the laissez-faire state of Georgia.

Kline (1999) commented on Nelson's findings regarding population density and farmland preservation by pointing out that the magnitudes of differences across the three comparison states are smaller when the indicators are computed using the National Resources Inventory data. Furthermore, Kline suggested that these indicators alone are not convincing in demonstrating the effectiveness of growth management. He showed that 10 states performed better than Oregon in preventing urban sprawl, while 12 states performed worse than Georgia, and that 11 states performed better than Florida in preserving farmland, while 20 states, including Georgia, performed better than Oregon.

A recent study by Anthony (2004) also suggests that the existing knowledge of the relationship between state growth management efforts and urban sprawl has major gaps. Anthony examined the efficacy of state growth management laws in controlling urban sprawl by measuring the change in urban densities in 49 states over a 15-year period from 1982 to1997. Using the National Resources Inventory data, he finds that growth management states generally experienced less population density decrease than states without growth management. However, his regression analysis indicates that state growth management did not have a statistically significant effect in curtailing sprawl.

Another recent study, by Howland and Sohn (2004), offer important insights about the impact of smart growth programs by examining the effect of Maryland's "Smart Growth Area Act" on the spatial distribution of water and sewer investments. Howland and Sohn find that there are variations across counties in their compliance with the Smart Growth initiative. While projects built between 1997 and 2002 were located primarily inside PFA, a significant percentage of both state and locally-funded projects went outside PFA. Their empirical analysis suggests that a high population growth rate and a stronger local tax base increase the likelihood for infrastructure investments to take place outside PFA, whereas greater state subsidy in a project and higher county per capita income generate the opposite effect.

## Research Methodology

The research methodology for this study has two main components. The first is to characterize urban land use in the state of Maryland, as well as in its local jurisdictions (i.e. the 23 counties and the city of Baltimore), using a series of measures. The second component is to model land conversion from non-urban to urban for the state and for its local jurisdictions. In order to understand the effects of Maryland's smart growth programs, both the measurement of urban development patterns and the modeling of land conversion are done for two time periods: the pre-smart growth period and the post-smart growth period.

### Characterizing Urban Land Use Patterns

The measures used by Landis (2001) in his quantification of urban development patterns in California counties are especially suitable for our study. These measures are among the most basic as well as most frequently used indicators of land use changes resulting from urban growth. Using these indicators, our study can effectively present Maryland as a case for comparison with similar studies of other states, which is one of our research objectives. Following Landis, we employ two categories of measures: (1) measures of urban land conversion and density trends, and (2) measures of metropolitan form. These measures, along with their data sources, are listed in Table 1. The operational forms of these measures are described in detail below.

Table 1 approximately here

#### *Measures of Urban Land Conversion and Density Trends*

Urban land conversion represents the amount and pace of converting agricultural and forest land to urbanized (i.e. developed) land. An increase in the quantity of urbanized land is a loss of land previously used for agriculture, forestry, and open space. Urban land conversion is the most visible impact of urban growth, and fast-paced land conversion is often a physical manifestation of sprawl.

Two simple measures of urban land conversion are used in this study. One is the increase in urbanized land, which indicates the amount of non-urban land converted to urban use during a time period:

$$L1 = \text{Current area of urbanized land} - \text{Previous area of urbanized land} \quad (1)$$

All else being the same, a higher level of sprawl is associated with a larger increase in urbanized land (L1) in a given time period.

The other measure of urban land conversion is the rate of increase in urbanized land. This measure describes the speed at which agricultural and forest land is converted to urban use during a time period:

$$L2 = 10^{(\log(\text{Current area of urbanized land}) - \log(\text{Previous area of urbanized land})) / \text{Time}} - 1 \quad (2)$$

In our study, the rate of increase in urbanized land (L2) is measured in terms of percentage change per year. Therefore, “Time” in the above expression is the number of years between current and previous measurements of urbanized land. All else being the same, a higher level of sprawl is associated with a higher value of L2.

Population density quantifies the intensity of urban land use. All else being equal, higher population density means that less land resource is consumed by urban activities. This may subsequently lower the cost of infrastructure provision, shorten the average length of trips, improve the efficiency of public transportation, and reduce traffic congestion and pollution. There are many possible ways to quantify population density. One frequently used measure is the net population density:

$$D1 = \text{Number of residents} / \text{Amount of urbanized land} \quad (3)$$

All else being equal, the higher the net population density (D1), the greater intensity is the use of urban land, and the less sprawling is the urban development.

A second common measure of density is the marginal population density, which describes the density of new urban development:

$$D2 = \text{Change in resident population} / \text{Change in urbanized land} \quad (4)$$

A higher value of marginal population density (D2) indicates the more intensive use of land in new urban development. If marginal density is higher than current net density, the overall population density will increase. Conversely, if marginal density is lower than current net density, the overall population density will decline.

A more complicated measure, which describes change in the intensity of urban land use, is known as the sprawl index. It indicates the relative pace of increase in urbanized land in comparison with the pace of population growth:

$$S = \text{Rate of increase in urbanized land} / \text{Rate of population growth} \tag{5}$$

In contrast to marginal density, a higher value of the sprawl index (S) indicates that land has been used less intensively in new urban development. A useful benchmark for S is 1, which is obtained when the rate of increase in urbanized land equals the rate of population growth. When the value of S is above 1, land consumption by urban activities outpaces population growth.[7]

*Measures of Metropolitan Form*

The physical form of urban growth is an important dimension of land use characteristics because it can have a profound effect on infrastructure cost and travel behavior. To capture metropolitan form, we adopt three types of measures. The first is compactness, which describes the degree to which urban development is clustered (versus dispersed). All else being equal, more compact development means a smaller urban footprint, which tends to reduce infrastructure cost, facilitate pedestrian activity, and make public transit service more cost-effective.

Compactness is measured through the use of percentage-point ellipses. In our study, a 50%-point ellipse, which is a geometric shape that includes the central fifty percent of a spatially distributed set of points, is created to depict the compactness of urban development in each local jurisdiction. The points are the polygon centroids of urbanized land in the jurisdiction.

Two ellipse-based measures of urban compactness are computed. The first is the proportion of urbanized land within a 50%-point ellipse, C1, calculated as follows:

$$C1 = \text{Urbanized land within 50\%-point ellipse} / \text{Total land within ellipse} \tag{6}$$

The second ellipse-based measure is net population density within a 50%-point ellipse, C2, which is computed using the following simple equation:

$$C2 = \text{Population within 50\%-point ellipse} / \text{Urbanized land within ellipse} \tag{7}$$

A larger value of C1 generally indicates a higher level of compactness. Similarly, a larger value of C2 indicates greater compactness.

[7] Note that when a city witnesses a simultaneous urban area increase and population decrease, its sprawl index has a negative value. Sprawl index, as calculated here, cannot be meaningfully interpreted when it is negative. Therefore, in this study, subsequent interpretation and analysis of sprawl index will focus on positive values.

In addition, percentage-point ellipses are also useful for representing the shape and orientation of urban development. The flatter a particular ellipse, the more linear is the development pattern.

The second type of measure of urban form is fragmentation. This type of measures indicates the degree to which urban development is organized into a single contiguous area (versus disconnected fragments). A high level of fragmentation is usually associated with leapfrog development, which tends to increase the cost of building infrastructure, makes public transit operation less cost-effective, discourages non-motorized travel modes, and exacerbates auto dependence. Furthermore, as Landis (2001) points out, fragmented development casts a larger urban shadow on the landscape than necessary, because urban land use adversely affects adjacent non-urbanized areas by creating externalities such as water and air pollution.

The most basic fragmentation measure is the patches-population ratio, i.e. the number of free-standing polygons (also known as "patches") of urbanized land divided by the size of resident population:

$$F1 = \text{Number of urban patches} / \text{Resident population} \quad (8)$$

A second fragmentation measure is the average patch size:

$$F2 = \text{Area of urban patches} / \text{Number of urban patches} \quad (9)$$

A third fragmentation measure is the edge-perimeter ratio, i.e. the total edge length of urban patches divided by the perimeter of a full circle that has the same area as the sum of the urban patches:

$$F3 = (\text{Total edge length of patches} / \text{Perimeter of an equal-area circle}) / \text{Square root of total area of patches} \quad (10)$$

Here, the ratio is adjusted by the square root of total area of patches to make the indicator free of scale effect, and hence, comparable overtime. A higher patches-population ratio (F1), a smaller average patch size (F2), or a higher edge-perimeter ratio (F3) generally indicates greater fragmentation and hence more sprawling urban development. It is useful to note that the theoretical minimum value of edge-perimeter ratio is 1 for a patch of unit size, because a single full circle represents the smallest possible total edge length of a given area.

The third and final type of measure of urban form is continuity. This type of measure describes the degree to which urban sites are surrounded by other urban sites. A low level of continuity is associated with leapfrog development and a large urban footprint, which, as mentioned previously, may generate undesirable effects in the forms of increased infrastructure cost, reduced transportation choice, and a polluted environment.

Because urban continuity must be measured from each and every urban site, it is most convenient to work with grid cells. Urbanized areas can be converted to grid cells using certain GIS data processing functions, which will be described later in this section. Continuity measures summarize the degree of site similarity among grid cells. They are based on counts of urban grid cells located within certain distance rings from each and every urban cell.

Two specific measures of continuity are used in the Maryland study. One is the continuity gradient calculated for 1st distance ring, and the other is the continuity gradient calculated for 5th distance rings, as follows:

K1 = Number of urban cells within 1st ring / Total cells within 1st ring (11)

K2 = Number of urban cells within 5th ring / Total cells within 5th ring (12)

The first distance ring is defined to be the area between 0 kilometers and 1 kilometer from the centroid of an urban grid cell. The fifth distance ring is defined to be the area between 4 kilometers and 5 kilometers from the centroid of an urban grid cell.

The greater the continuity gradient values (K1 and K2), the greater the probability will be for someone traveling outward in any direction from an urban site to encounter another urban site, and hence the higher the level of urban continuity.

*Variations in Land Use Patterns among Local Jurisdictions*

We use GIS to help identify spatial variations in land use characteristics among local jurisdictions in Maryland.

Maps provide the most effective tool for identifying spatial patterns. A series of thematic maps are created to display various land use characteristics in Maryland. These maps will help us identify spatial variations among local jurisdictions in terms of urban land conversion, population density, and urban form. Specifically, the following maps are created:

(1) Urbanized land, which shows the geographic extent of urbanization. A map that displays urbanized areas in different years can reveal spatial variations in the quantity and rate of urban expansion.
(2) Net population density, which shows how population density in developed land varies from one jurisdiction to another.
(3) Marginal population density, which displays how population density of new urban development during a time period varies among jurisdictions.
(4) Sprawl index, which indicates how the relative pace of urban land consumption and population growth during a time period varies among jurisdictions.
(5) Compactness, which shows the sizes, shapes, and orientations of 50%-point ellipses for local jurisdictions.
(6) Continuity, which displays the spatial variation of the continuity gradients for the 0-1 kilometer and 4-5 kilometer distance ring.

(7) Fragmentation, which displays how patches-population ratios or edge-circle ratios differ among jurisdictions.

To help identify spatial patterns in urban development, some of these thematic maps are overlaid onto a gross population density map. The overlaid maps can uncover relationships between current population density and land use changes that are taking place in different parts of the state. To reveal possible trends in land use changes, these maps are made for multiple years or time periods.

**Modeling Urban Land Conversion**

This component of the research methodology consists of two major elements. The first is a longitudinal analysis of land conversion for the State of Maryland. Binary logit models are estimated to characterize land-use change from non-urban to urban for both the pre-smart growth period and the post-smart growth period. These models will show us whether the implementation of smart growth initiatives, especially the establishment of "PFA," has had a significant overall effect on urban development patterns in the state.

The second element is a cross-sectional comparison of land conversion among individual counties. Again, binary logit models are estimated for the two time periods, but here the models are estimated for each county separately. By comparing the model estimates across counties, we can identify variations in the effectiveness of the smart growth program across local jurisdictions.

*Model Specification*

Following Landis and Zhang (1998a) and Landis (2001), the specification of the binary logit models of land conversion assumes that the probability for a given land area to change from a non-urban to an urban use is a function of site and location attributes, as well as regulatory constraints. During a time period, a piece of non-urban land can either retain its original status or it can be urbanized. The probability for a land area to be urbanized can be represented by the binary logit model, which has the following mathematical expression:

$$P_i = \frac{1}{1 + e^{-(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_k X_k)}} \tag{14}$$

where $X_1$, $X_2$, … $X_k$ are independent variables influencing the probability of land conversion from non-urban to urban.

Six types of independent variables were used in the logit model: (1) smart growth policy, which is a dummy variable indicating whether a land area is located inside PFA;[8] (2) site

[8] The smart growth policy variable is conceptually only applicable to the models for the post-smart growth period. However, in some of our model specifications for the pre-smart growth period we also included this variable under the name "area later became PFA." We wanted to test the hypothesis that the designation of

characteristics, which measures the physical characteristics of a land area; (3) location characteristics, which measures the proximity of a land area to other features of interest, such as highways and municipalities; (4) characteristics of neighboring sites, which are used to address the potential problem of neighborhood effects or spatial autocorrelation; (5) demographic characteristics; and (6) infrastructure characteristics. All these variables are listed in Table 2. The expected direction of influence of each variable on the probability of land conversion from non-urban to urban is indicated by the plus or minus sign shown in the table.

Table 2 approximately here

For some of the independent variables, the expected effects on the dependent variable are well established theoretically and/or empirically. The smart growth policy variable, PFA, is expected to be positive because the State funding should provide added incentive for development to take place in these target areas.

The two site characteristics variables are both expected to reduce the probability of development. If land is inside a 100-year or 500-year floodplain, it will less likely be developed because of the risk of flood. And if land is within an agricultural land preservation district, which indicates it is good quality farm land, the possibility for urban development is also reduced.

The three variables that measure the location characteristics are all expected to be negatively related to the probability of urban development. The farther a site is located from any existing urbanized land, the less likely it will be developed. Similarly, the farther a site is located from highways, or from a municipality, the lower the possibility for it to change from non-urban to urban use.

One of the three variables characterizing the neighboring sites of a given piece of land is expected to increase the development probability of the land. Specifically, a given land area is more likely to be urbanized if more of its neighboring sites are urbanized. On the other hand, the other two variables measuring the characteristics of neighboring sites are likely to generate the opposite effect. Both higher average slope of adjacent sites and larger difference between the slope of a given land area and the average slope of adjacent sites increase the infrastructure and construction costs, and hence lower the development probability.

For two of the demographic characteristic variables, the expected influence on non-urban to urban land conversion is ambiguous. Pre-existing population density, measured as the gross density for the block group in which a given piece of land is located, can either be an indication of high demand for urban land in the area or an indication of having little open space left in the area. In the former case higher population density will increase development possibility, whereas in the latter case higher density will be negatively related to the probability of development. Similarly unclear is the influence of the

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priority funding areas was to some degree a reflection of market and regulatory forces already in place to spatially allocate urban development.

percentage of residents in the block group who are white. The conventional notion of "white flight" being the primary source of suburban growth would suggest that a higher percentage of white population will have a positive effect on the development probability. However, if suburban growth is fueled by the city-to-suburb migration and international immigration of people with diverse ethnic backgrounds, this variable may show a negative relationship with the dependent variable. The third demographic variable, the percentage of residents in the block group who are foreign-born, is expected to have a positive effect on land development probability because international immigration is a major source of population growth, especially in large metropolitan areas, and because immigrants show the tendency to form ethnic residential and commercial clusters.

Finally, the infrastructure characteristic variable is expected to facilitate urban development. The higher the percentage of housing units in the block group that are on public water, the more likely it is for a given piece of land to be served by public water infrastructure, which increases the land value and subsequently the development probability.

## Data and Analytical Procedure for Characterizing Land Use Patterns

### *Defining Data Needs*

The empirical component of this study must start with a clear understanding of the data requirements. We must define what data are needed, for what times, and at what geographic level.

The measures of urban land conversion, population density, and urban form described earlier require land use and population data. The specific land use data needed are the size and spatial distribution of urbanized land, and the specific population data needed are the size and spatial distribution of the residential population.

Some of the measures of land use characteristics, including the net population density, compactness, fragmentation and continuity, involve data for a single time point. Others, including the rate of increase in urbanized land, marginal population density, and sprawl index, involve data for two time points. To identify the overall trends in urban growth patterns, we must collect data for at least two time points. However, because of our intent to examine the effects of smart growth policy in Maryland, we have to collect data for at least three time points. This will enable us to compare the trends observed before and after the implementation of smart growth programs. Based on the research questions and data availability we collected data for the years 1973, 1997, 2000, and 2002.[9] Note that 1997 was the year when the State of Maryland passed its smart growth legislation. The two time periods for this part of the study are, therefore, 1973-1997 and 1997-2002.

[9] The earliest LULC data available for our study are the Maryland Department of Planning (MDP) data for 1973, and the most recent LULC data available at the time when this study was undertaken were the MDP data for 2002.

The basic geographic unit of analysis is determined primarily by the research questions to be addressed. Some studies (e.g. Fulton et al, 2001) use the metropolitan area as the basic geographic unit, whereas others (e.g. Landis, 2001) measure sprawl at the county level. We use the county as the basic geographic unit for empirical measurements and analyses, because in Maryland land use decisions reside primarily with the county government. Therefore, urban growth trends and patterns identified at the county level are most relevant to policy debates. An additional advantage of using county as the unit of analysis is that counties have constant boundaries, which makes it relatively easy to compare urban development patterns over time and identify trends. It should be noted that, Baltimore City, although a municipality, is treated as a county equivalent in our study because in practice this municipality is considered on a par with county jurisdictions.

The measures of urban form require land use data to be in GIS (i.e. with both location and attribute information) at an appropriate level of spatial resolution. One of the compactness measures, net population density within a 50%-point ellipse (C2), requires population data for small geographic areas at a sub-county level. We will use population data for census block groups for this measure.

*Data Sources*

Size and spatial distribution of urbanized land can be derived from land use and land cover (LULC) data. LULC data for1973, 1997, 2000, and 2002 were obtained from the Maryland Department of Planning (MDP). MDP has developed a large GIS database called *Maryland PropertyView*, which includes location and attribute information for all residential, commercial, industrial, and other types of parcels in the state. In addition to the parcel data, *Maryland PropertyView* includes a wide range of other GIS data. LULC data for 1973, 1997, 2000, and 2002 in the shapefile format are part of this database. These land use data are classified using the Anderson classification scheme (Anderson et al, 1976). Initially developed from high altitude aerial photography and satellite imagery, the urban land use categories have been further refined using parcel data from *Maryland PropertyView*.

We also obtained land use figures for Maryland counties and the state from a report published in 1991 by Maryland Office of Planning (MOP). The MOP data are useful for comparison and sensitivity analysis.

Population data can be obtained from the Census Bureau and from the *County and City Data Book* (CCDB). The decennial census provides the most reliable population data for counties and census block groups for the year 2000. Estimates of county populations for 1997 are available from the CCDB. The results reported in this working paper are based on population estimates obtained from the CCDB. However, intercensal estimates of county populations are not readily available for 1973. A simple linear extrapolation method is therefore used to estimate county populations for 1973:

$$POP73 = POP70 + (POP80 - POP70) * (3/10) \tag{15}$$

The same approach is taken to estimate census block group populations for 1997 and 2002, based on data from Census 1990 and Census 2000.

GIS maps of county boundaries and census block group boundaries can be downloaded from the Census Bureau's website:
http://www.census.gov/geo/www/cob/bdy_files.html

*Processing Land Use Data in GIS*

The land use data were processed using ESRI's ArcGIS. The data processing involves many tasks. The following are the main tasks of data processing in GIS:

(1) Creating GIS layers of urbanized land for 1973, 1997, 2000, and 2002. For each of these years, polygons of urbanized land are selected from the corresponding LULC data. In each case, polygons that have a land use code between 10 and 20 (except for 17, which is surface mining) or equal to 80 are identified as urbanized.

(2) Calculating urbanized land area by county. This task is essential for generating data on urbanized land that will be used to measure land conversion and population density for each year or time period. It can be accomplished using queries to select urbanized land by county and then applying a standard command to calculate summary statistics, including the sum of urbanized land area. The procedure is repeated for 1973, 1997, 2000, and 2002.

(3) Creating 50%-point ellipses and calculating land use and population data for these ellipses. This task is central to the measurements of compactness. It involves the following key steps, and the procedure is repeated for 1973, 1997, 2000, and 2002:

- Using a standard command, urbanized land area is converted into 100 meter by 100 meter grids.
- The central points of these grids are extracted to create a GIS layer of points.
- To create the 50%-point ellipse, we use an ArcView extension called "Animal Movement", which is a spatial analytical tool developed by Philip Hooge. This program can be downloaded (http://www.absc.usgs.gov/glba/gistools/). We choose the Jennrich-Turner method to create a 50%-point ellipse for each county. The output consists of an ellipse polygon and an attached table that contains information about the major axis, minor axis, and area of this ellipse.
- Overlaying this ellipse and the urbanized land area of the county, we can obtain data on the urbanized land area as well as the total land area within the ellipse. Note that the 50%-point ellipse may cover parts of neighboring counties. If that occurs, land areas located in neighboring counties will be excluded.
- Overlaying this ellipse and the census block groups of the county, we can obtain data on the population residing within the ellipse. If the 50%-point ellipse covers parts of neighboring counties, the population located in neighboring counties will be excluded. An additional complexity is that some census block groups are only partly inside the ellipse. For split block groups, we use the area allocation method to estimate the population residing inside the ellipse. For example, if 80 percent of

the land area of a block group is inside the ellipse, we will assign 80 percent of the block group population to the area inside the ellipse. Note that, because our GIS data do not include census block group boundary and population data for 1970, this procedure is only repeated for 1997, 2000, and 2002.

(4) Counting polygons of urbanized land and calculating their edge lengths. This effort is essential for the measurements of fragmentation. The work includes the following major steps, and the procedure is repeated for 1973, 1997, 2000, and 2002:

- To count the number of urban patches, i.e. free-standing polygons of urbanized land, we first use a standard command to dissolve polygons that share common boundaries. The resulting shape file contains only free-standing polygons of urbanized land. However, these polygons all have the same ID.
- To give each resulting free-standing polygons a unique ID, we must find a way to "break" this one polygon ID. We can write a script in Avenue that includes the "Break" command to create IDs for individual polygons.
- Count the number of free-standing polygons of urbanized land using a standard command.
- To calculate the edge length of each free-standing polygon of urbanized land, we can write another script in Avenue. Containing the "Polygon Length" command, this script calculates the edge lengths of polygons.

(5) Counting grid cells of urbanized land located within certain distance rings. This task is essential for the measurements of continuity. It requires the following key steps, and the procedure is repeated for 1973, 1997, 2000, and 2002:

- Use a standard command to convert urbanized land area into 100 meter by 100 meter grid cells.
- The central points of these grid cells are extracted to create "Layer Urban" - a GIS layer of the centroids of urbanized grid cells.
- Use a standard command to convert the whole state area into 100 meter by 100 meter grid cells.
- The central points of these grid cells are extracted to create "Layer All" - a GIS layer of the centroids of all grid cells.
- Write a script in Avenue to draw the first circle (i.e. a distance ring) from each point in "Layer Urban." This circle has a radius of 1 kilometer. Count the number of centroids in "Layer Urban" that are located within the circle. Then count number of centroids in "Layer All" that are located within the circle. Repeat the procedure for all points in "Layer Urban."
- Use the script to draw the second circle from each point in "Layer Urban". This circle has a radius of 4 kilometers. Count the number of centroids in "Layer Urban" that are located within this circle. Then count number of centroids in "Layer All" that are located within this circle. Repeat the procedure for all points in "Layer Urban."
- Use the script to draw the third circle from each point in "Layer Urban." This circle has a radius of 5 kilometers. Count the number of centroids in "Layer Urban" that are located within this circle. Then count the number of centroids in

"Layer All" that are located within this circle. Repeat the procedure for all points in "Layer Urban."

*Calculating Measures of Land Use Patterns*

The processed land use and population data are imported into Excel, which is the spreadsheet software most convenient for calculating the measures of land use patterns described earlier.

*Creating Thematic Maps of Land Use Patterns*

Using the GIS software ArcGIS, thematic maps are created to help identify spatial patterns of urban development in Maryland.

**Data and Analytical Procedure for Modeling Land Conversion**

*Selection of Counties for Modeling Land Conversion*

Due to the extraordinarily large amount of data processing and analysis required for modeling land conversion, we decided to select only 4 of the 23 local jurisdictions in Maryland for this part of the empirical study. These four counties are Anne Arundel County, Baltimore County, Garrett County, and Montgomery County, which are shown in Figure 2.

Figure 2 approximately here

These four counties were chosen for the empirical analysis because, to some extent, they are representative of counties with different histories of growth management, different geographic locations, and different patterns of urban growth. Montgomery County, with a population of over 905,000 in 2002, is the most populous and affluent county in Maryland. It has a long tradition (starting in the 1960s) of implementing policies and programs to shape urban growth patterns, preserve open space, and protect agricultural lands.[10]

Baltimore County is known to have set an urban service boundary to guide urban development. Surrounding Baltimore City, which lost over 84,000 residents between 1990 and 2000, Baltimore County has probably absorbed a large portion of out-migration from the central city. Its population in 2002 reached 768,000.

Anne Arundel County, the home county of the State capital Annapolis, has a long coastline along the Chesapeake Bay, which is a primary focus of environmental conservation in Maryland. This county experienced substantial growth during the 1990s. Its population in 2002 was about 502,000.

[10] Useful information on growth management in Montgomery County can be found in Levinson (1997).

Finally, Garrett County, which is located in the far west of the state, is a typical rural county where more than 95% of land is undeveloped. The county has a rather small population, with less than 30,000 residents in 2002. During the 1990s it experienced only modest population growth but rapid land conversion.

*Geographic Units and Time Periods for the Analysis*

Ideally, the geographic unit of analysis for studying land-use change should be the parcel because parcels are the actual unit of land transactions. However, digital parcel maps are not available for Maryland. We therefore used the one-hectare (100m × 100m) grid cell as the unit of analysis. As Landis (2001) has pointed out, using grid cells as units of analysis has both advantages and disadvantages. While grid cells are not the natural units for land-use decisions or regulations, they have stable boundaries overtime, which simplifies the task of identifying land conversion.

For this part of the empirical study, we once again defined two time periods – one before and the other after – Maryland's 1997 smart growth legislation. However, here we define 1992-1997 (instead of 1973-1997) as the pre-smart growth period partly because we want to have reasonably comparable models for the two time periods, and partly because some of the data required for modeling land conversion are not available for 1973. The post-smart growth period is the three year period of 1997-2000.

*Data Sources, Data Processing, and Statistical Modeling*

The dependent variable for logit models, which indicates whether a land area is urbanized, is measured on the basis of LULC data. The LULC data for 1992 were obtained from the USGS, and the LULC data for both 1997 and 2000 were provided by the Maryland Department of Planning as part of the *Maryland PropertyView* database. To identify land-use conversion taking place among the original undeveloped land areas during each time period, we overlay the three LULC layers.

For each time period, the sample for estimating the logit model consists of all grid cells that were non-urban at the beginning of the period. During the time period, each grid cell can either retain its original non-urban status or it can change from non-urban to urban. If the land remains non-urban by the end of the time period, the dependent variable takes on a value of "0." Alternatively, if the land is urbanized by the end of the time period, the dependent variable takes on a value of "1."

The data sources for the explanatory variables are indicated in Table 2. The smart growth policy variable is obtained by overlaying the GIS layer of PFA with the layers of land-use changes. Note that although PFA designation did not exist until 1997, in some of our models we used a dummy variable to represent the same geographic areas for 1992-1997 to find out whether these areas were already preferred locations for urban growth before the implementation of the smart growth policy. To conceptually distinguish the same geographic areas for the pre-PFA designation and post-PFA designation time periods, we named the variable for the former as "area later became PFA" and the latter as "PFA."

Data on site characteristics, i.e. floodplains and agricultural land preservation districts, were from the Federal Emergency Management Agency (FEMA) and the Maryland Department of Agriculture, respectively.

Location characteristics are measured on the basis of GIS layers of highways, urbanized areas, and municipalities, which are also elements of the *Maryland PropertyView* database.

*Maryland PropertyView* is additionally the data source for determining the percentage of adjacent grid cells that is urban. The other two variables that characterize neighboring sites are slope measures derived from the digital elevation model (DEM) data provided by the USGS. The DEM map is displayed in Figure 3.

Figure 3 approximately here

Finally, the demographic and infrastructure characteristics are block group data obtained from either the 1990 or 2000 US census of Population and Housing.

To examine the overall effect of the smart growth program on patterns of land conversion in the state, we use the pooled data for the four counties to estimate logit models for the two periods. To compare among the four counties the effectiveness of the smart growth program, we use data for individual counties to estimate the logit models.

In selecting sample cells for estimating the logit models, we excluded those grid cells that are extremely unlikely to be developed. Grid cells known to be wetlands, located more than 10 miles from the nearest highway, or with a slope exceeding 15 degree are excluded.

We use SPSS to estimate binary logit models.

## Empirical Results

To help interpret the empirical results of our analyses, it is useful to first look at some basic geographic, demographic, employment, and income indicators for Maryland as a whole and its counties (see Table 3). Notice that gross population density varies greatly among the counties, from 2.8 persons per acre in Montgomery to 0.1 persons per acre in five rural counties (Caroline, Dorchester, Garrett, Kent, and Somerset). The most densely populated counties, Anne Arundel, Baltimore, Howard, Montgomery and Prince George's are all located along the Baltimore-Washington DC corridor. Baltimore City accommodates 12.6 persons per acre of its land. Average household incomes also vary substantially among the local jurisdictions. In general, the peripherally located counties, such as Allegany and Somerset, tend to have low average household incomes. Two of the counties in the Baltimore-Washington DC corridor, Howard and Montgomery counties, have the highest household incomes. But the figures for two other counties located in this corridor, Baltimore and Prince George's, are similar to the average household income for the state.

Table 3 approximately here

## Characteristics of Urban Land Use Patterns

### *Urban Land Conversion*

Measures of urban land conversion are displayed in Table 4. It is apparent that between 1973 and 2002, a large amount of land, over 643,000 acres in total, was urbanized in Maryland. The quantity of urban land conversion varies quite substantially among the local jurisdictions, ranging from merely 1,391 acres in Baltimore City to 59,853 acres in Montgomery County. The annual rate of urban land conversion during this time period was 2.45% for the whole state. The highest annual rate was 5.15% for Garrett County, whereas the lowest was 0.1% for Baltimore City.

Table 4 approximately here

The pace of urban land conversion has slowed down since the passage of the 1997 smart growth legislation. The annual rate of urban land conversion was 2.16% for 1997-2002, which is lower than the 2.52% for 1973-1997.

Figure 4 displays the urbanized land in 1973, as well as the patterns of urban growth during the time periods of 1973-1997 and 1997-2002. From the map, one can see that the quantity of increase in urbanized land was usually larger in counties located along the Baltimore-Washington DC corridor. However, in terms of percentage increase during the period of 1997-2002, the counties of Frederick, Washington, Garrett, and Saint Mary's actually have the highest values.

Figure 4 approximately here

### *Population Densities*

Table 5 shows net population densities and marginal population densities in Maryland counties. From 1973 to 2002, net population density in the state decreased from an average of 6.4 persons per acre to 4.3 persons per acre. This trend of decreasing population density is observed in 23 of the 24 local jurisdictions. In fact, during the post-smart growth period of 1997-2002, the net population density continued to decrease for the state as a whole, as well as for 13 local jurisdictions. However, the marginal population density for 1997-2002 was almost the same as the marginal population density for 1973-1997.

Table 5 approximately here

The geographic extent of urbanization and the net population density in each county are visualized in Figures 5, 6, and 7 for the years 1973, 1997, and 2002, respectively. Generally speaking, counties located along the Baltimore-Washington DC corridor have the largest urbanized areas as well as the highest population densities.

Figures 5, 6, and 7 approximately here

Figures 8, 9, and 10 display marginal population densities in Maryland counties for 1973-1997, 1997-2002, and 1973-2002, respectively. Again, high marginal densities are usually observed in the more urbanized counties, especially those located in the Baltimore-Washington DC corridor. Counties located on the Eastern Shore or in Western Maryland, which have more agriculture-oriented economies, tend to show low marginal population densities.

Figures 8, 9, and 10 approximately here

Table 6 shows sprawl indices for Maryland and its counties. The results indicate that land consumption in Maryland increased more than twice as fast as population growth during the time period 1973-2002. The sprawl index is above 1 for the great majority of counties, suggesting that land consumption outpaced population growth in most counties. However, the sprawl index has decreased since 1997, although it is still much higher than 1. It is also important to notice that the value of the sprawl index has decreased in 11 counties during the post-smart growth period.

Table 6 approximately here

Figures 11, 12, and 13 are thematic maps displaying, respectively, sprawl indices for 1973-1997, 1997-2002, and 1973-2002. What we see in these maps is almost the opposite of what we saw in the marginal population density maps. Generally speaking, the most sprawling counties tend to be low-density counties located in the peripheral areas of the state. Counties situated along the Baltimore-Washington DC corridor, in contrast, tend to show lower values of sprawl indices.

Figures 11, 12, and 13 approximately here

*Compactness*

The measures of compactness of urban development are shown in Table 7. The results indicate that, for the state as a whole, approximately 27% of the land area contained by the 50%-point ellipses for 1997 was urbanized. For 2002, approximately 29% of the area included in 50%-point ellipses was urbanized. Therefore, urban growth became more compact during this five-year period. This trend is observed across the counties in Maryland. The greatest increase in the proportion of urbanized land within the 50%-point ellipse occurred in Frederick County, with a 9% gain.

Table 7 approximately here

Net population density within the 50%-point ellipses, however, dropped between 1997 and 2002. For the state as a whole, the net density was 5.02 persons per acre in 1997, and only 4.78 persons per acre in 2002. This is consistent with the overall decline in net population density discussed earlier. Decrease in net population density within the 50%-point ellipse is observed in 16 local jurisdictions. The largest drops are 0.86 persons per acre and 0.66 persons per acre, which occurred in the counties of Frederick and Cecil, respectively.

Figure 14 displays the 50%-point ellipses for 1973, 1997, and 2002 in three distinctive colors. The ellipses for 2002 are somewhat larger than those for 1973 for most counties, reflecting the geographic expansion of urbanized areas. However, it is important to note that the differences between the ellipses for 2002 and those for 1997 are generally quite small. This suggests that infill might replace expansion as the prevailing form of urban development in the post-smart growth years.

Figure 14 approximately here

*Fragmentation*

Measurements of fragmentation are shown in Table 8. The number of free-standing patches of urbanized land in Maryland increased dramatically between 1973 and 1997, and continued to increase between 1997 and 2002. For the whole state the patches-population ratio, measured as patches per 1,000 people, increased from 1.0 in 1973, to 2.1 in 1997 and dropped to 2.0 in 2002. This general trend existed in the great majority of the counties. There are significant variations among counties, with the more urbanized counties generally showing lower levels of fragmentation. The patches-population ratios for Baltimore City, Montgomery County, and Prince George's Counties in 2002 were, respectively, 0.01, 0.3, and 0.6. In comparison, the patches-population ratios were 19.3 and 14.5 for Garrett County and Dorchester County.

Table 8 approximately here

Average patch size for the state changed from 156.5 acres in 1973, to 103.8 acres in 1997, and 115 acres in 2002. There are enormous differences in average patch size among the counties. For 2002, for example, average patch size was 6778 acres in Baltimore City but was only 36 acres in Somerset County. The more urbanized counties, such as Montgomery and Prince George's, usually had larger average patch sizes.

The edge-perimeter ratio for the state increased from 2.7 in 1973, to 3.4 in 1997, and then dropped slightly to 3.3 in 2002.

Figure 15 shows clearly that counties situated along the Baltimore-Washington DC corridor have substantially lower patches-population ratios than counties located in peripheral areas of Maryland. Similarly, Figure 16, which displays edge-perimeter ratios, also shows that urban development in counties situated along the Baltimore-Washington DC corridor is less fragmented.

Figures 15 and 16 approximately here

*Continuity*

Table 9 indicates that, for the state as a whole, the continuity gradient for the 0-1 kilometer distance ring increased from 40.42% in 1973, to 43.22% in 1997, and 45.18% in 2002. This trend toward greater continuity in urbanized land is observed in 19 counties: an overwhelming majority. The continuity gradient for the 4-5 kilometer distance ring also increased substantially during these time periods, from 18.27% to 28.48%. This increase occurred in all of the 24 local jurisdictions.

Table 9 approximately here

The continuity gradient generally has high values for the more urbanized counties, such as Baltimore, Montgomery, and Prince George's. This reflects the fact that in these counties one is more likely to find urbanized land when moving outward from any location of urbanized land. The differences in continuity gradient values are especially substantial for the 4-5 kilometer distance ring. This is because the less urbanized counties tend to have relatively small patches of urbanized land.

Figure 17 and Figure 18 both show clearly that counties located along the Baltimore-Washington DC corridor tend to have relatively high continuity gradients. In contrast, the less urbanized counties tend to have much lower continuity gradients. The differences are especially striking for the 4-5 kilometer distance ring.

Figures 17 and 18 approximately here

## Models of Urban Land Use Conversion

Land use changes in the four counties selected for this part of the empirical study, i.e. Anne Arundel County, Baltimore County, Garrett County, and Montgomery County, are displayed in Figure 19. These four counties show several distinctive patterns of land conversion. In Baltimore and Montgomery, counties which have a strong tradition of growth management, development tended to take place near the existing urban areas during 1992-1997 as well as 1997-2000. In Anne Arundel, urban land conversion was scattered all over the county during the first period, but became much more concentrated near the existing urban areas during the second period. In Garrett, development displayed a highly fragmented pattern for both periods.

Figure 19 approximately here

The priority funding areas (PFA) for these four counties are shown in Figure 20. The designated areas are mostly surrounding the existing urban areas. The priority funding areas in Garrett are relatively more scattered than those in the other three counties.

Figure 20 approximately here

Table 10 displays the descriptive statistics of the independent variables included in the model of land conversion in the four counties during the period 1992-1997. Table 11 shows the descriptive statistics of the independent variables included in the model for the period 1997-2000.

Tables 10 and 11 approximately here

We will first look at the estimated models for the pooled data for the four counties to examine the effectiveness of the "Smart Growth Area Act" in the state of Maryland as a whole (as represented by the four counties jointly as a group). We will then discuss the results for individual counties to understand variations in the policy effectiveness among the counties.

*Land Conversion in the State (Represented by the Four Counties)*

The results of model estimations using the four-county data for the time periods 1992-1997 and 1997-2000 are shown in Table 12. Notice, first, that the models for the two time periods are broadly consistent in terms of the signs and statistical significance of the regression coefficients. In both models, being located farther from an existing urbanized area, in a block group that has higher population density, in a floodplain or an agricultural land preservation district, or having greater slope difference from adjacent cells reduces the probability for the site to be urbanized. On the other hand, having a higher percentage of adjacent grid cells urbanized, being located in a block group where a higher percentage of residents are foreign-born, and being located in a block group where a higher percentage of housing units are on public water increases the likelihood for the land to be developed. These results are consistent with the expectations indicated earlier in Table 2.

Table 12 approximately here

Secondly, a few variables show inconsistent effects on the dependent variable. The two variables measuring the distances to the nearest highway and municipality have different signs in the two models. This inconsistency is probably attributable to strong multicollinearity among the three proximity variables. Also showing inconsistent results are the variables measuring the average slope of adjacent cells and the percentage of block group residents who are white. The reasons for these inconsistencies are unclear.

Finally, and most importantly, in the model for 1997-2000, the smart growth policy variable, PFA, shows a positive and statistically significant effect on the dependent variable. This means that during the post-smart growth period, land areas designated as PFA were in general more likely to be developed than otherwise comparable land outside

PFA. If the coefficient value of 0.96 is converted to an odds ratio, it will indicate that the odds of land use change from non-urban to urban are 2.6 times higher for areas located within PFA than for otherwise comparable areas located outside. The smart growth program appears to be effective in achieving its intended objective.

Overall, the two estimated logit models present a clear picture of the fundamental forces driving the spatial patterns of urban development in Maryland during the 1990s.

To capture potential inter-jurisdictional variations in land conversion patterns that may be caused by factors unique to each county, we created dummy variables for the counties and added them to the models. The dummy variables substantially increase the overall explanatory power of the binary logit models, as indicated by improved goodness of fit and increased percentage of correct predictions. The new estimates are displayed in Table 13. The signs of the county dummy variables in the model for 1992-1997 indicate that, in comparison with Montgomery, if everything else being the same, the probability for a land area to be developed during the time period was higher in Garrett County but lower in Baltimore County. The model for 1997-2000 shows the continuation of this inter-jurisdictional difference during this period, although the results additionally indicate the relatively lower probability for land conversion in Anne Arundel County in comparison with Montgomery. These differences reflect the relative paces of land conversion in these four counties during the time periods.

Table 13 approximately here

The estimates for the other independent variables remain largely unchanged from the previous results reported in Table 12. The coefficient for the policy variable PFA is slightly larger than before, which provides even stronger evidence of the effectiveness of the smart growth program in influencing the spatial pattern of urban development in the state of Maryland.

*Variations in Policy Effectiveness among Counties*

Four pairs of logit models were estimated, one pair for each of the four counties. These models, shown in Tables 14-17, are summarized and compared as follows.

Tables 14-17 approximately here

First, the smart growth policy variable, PFA, is positive and statistically significant for the 1997-2000 models for the counties of Anne Arundel, Baltimore, and Montgomery. This suggests that the smart growth program increased the likelihood of development for land located in priority funding areas. The magnitude of the policy effect varies among these counties, as indicated by the different values of the coefficients. The greatest policy effect was observed in Anne Arundel, which is consistent with what we saw previously in the patterns of land use changes shown in Figures 19 and 20.

Second, the smart growth policy variable, PFA, is negative for Garrett County. This result is quite unexpected, and no simple explanation can be given. It indicates that there were significant variations among counties in their compliance with the smart growth initiative. Although the empirical evidence is somewhat limited, this finding suggests that the state smart growth policy may be less effective in periphery counties that have less urban agglomeration and lower land values.

Third, Baltimore and Montgomery Counties have the largest negative coefficients for the variable measuring distance to the closest existing urban area, whereas the coefficients for this variable are much smaller for Garrett. This significant difference indicates that urban development takes much more compact forms in the more urbanized counties, which is consistent with what we identified earlier through thematic mapping. It may also suggest that the patterns of land conversion are more compact in local jurisdictions that have implemented effective local growth management programs. It is important to note that the models for Baltimore County, which has an urban growth boundary, show the largest negative coefficients for the distance variable.

Finally, the models show considerable inconsistencies in terms of the signs and levels of statistical significance of various regression coefficients. Other than the measures of distances to nearest highway and municipality, several location, demographic, and infrastructure variables also change signs across models for the different time periods and/or counties. This suggests that not only the effectiveness of the state smart growth program, but also the effects of some other independent variables, vary across local jurisdictions.

*Continuity and Discontinuity in the Patterns of Urban Land Conversion*

An interesting issue is whether the implementation of the "Smart Growth Area Act" causes fundamental and drastic changes in the patterns of urban land conversion. On the one hand, it is conceivable that the designation of the PFA largely reflected the pre-existing development patterns shaped by market forces and/or local growth management policies. If that was the case, the smart growth initiative would have largely reinforced the pre-existing patterns. On the other hand, it is also possible that the designation of PFA represented a fundamental departure from the pre-existing development patterns and caused discontinuities in the pre-existing patterns of land use conversion.

To address this issue, we renamed the PFA dummy variable as "area later became PFA" and added it to the 1992-1997 models. Again, we first estimated the model for the four counties as a group, and then estimated the models for individual counties. The results, shown in Tables 18-22, provide several important insights:

Tables 18-22 approximately here

First, for the state as a whole, as represented by the four counties as a group, the variable "area later became PFA" shows a positive and statistically significant relationship with the probability of land conversion from non-urban to urban use. The regression coefficient is 0.65, which translates into an odds ratio of 1.9. In other words, areas that were later designated as PFA had already tended to be desirable locations for urban growth before the Smart Growth legislation was in place. However, this coefficient is smaller than the 0.96 for the post-smart growth period. Given that the first period was 5 years, whereas the second period was only 3 years, it is without any doubt that the variable PFA had a relatively greater effect on increasing the development probability than "area later became PFA" did. In other words, the PFA designation makes urban development more concentrated in the target areas than before.

Second, when we examine the counties individually, we can see major differences in terms of the nature of the policy impact. The variable "area later became PFA" in the models for 1992-1997 shows positive and significant coefficients in the cases of Baltimore, Garrett, and Montgomery Counties. Anne Arundel County is a clear exception, because its "area later became PFA" has a negative relationship with the dependent variable. The variable PFA in the models for 1997-2000, on the other hand, has positive and significant coefficients for Anne Arundel, Baltimore, and Montgomery, but a negative coefficient for Garrett. These results seem to indicate that establishing the PFA has reinforced, or at least sustained, the pattern of relatively concentrated urban growth in Baltimore and Montgomery, which both had local growth management policies in place before the State smart growth initiatives. The results also suggest that the "Smart Growth Area Act" has generated the most effective outcome in Anne Arundel, where the previously dispersed pattern of development has become concentrated in the PFA since the implementation of the smart growth policy. But the results show that the program has been ineffective in influencing urban growth patterns in the peripheral county of Garrett.

## Conclusion

This empirical study of urban development patterns in Maryland provides a solid basis for answering the research questions raised at the beginning of the paper. Our findings indicate that, first, urban growth in Maryland for the past 30 years has shown some complex trends. The intensity of urban land use, which is measured by net population density, has been declining. Marginal population density, however, has basically remained the same, even though it is significantly lower than the net density. Both the annual rate of non-urban to urban land conversion and the sprawl index have actually decreased since 1997, suggesting that the smart growth initiatives have helped curtail the growing demand for urban land. The physical form of urbanized area, indicated by compactness, fragmentation, and continuity measures, has in general become spatially less extensive since 1997. Specifically, urban development has shown a somewhat higher level of continuity and slightly less fragmentation.

These complex trends present both bad news and good news to urban planners and policy makers in Maryland. The bad news is that, if net population density continues to decrease, land consumption, infrastructure cost, and travel demand per new resident will all likely increase. On the other hand, the good news is that, as the trend of decreasing population density slows and urban development takes less fragmented and more continuous forms, some of the negative effects of urban growth can be moderated.

Second, some aspects of the recent urban development patterns in Maryland have been well matched to the typical characterization of sprawl. In particular, the decreases in net population density in this state are quite similar to what have been observed in other US metropolitan areas (see, for example, data reported in Fulton et al, 2001), and the sprawl index is slightly higher than the average for the 48 continental states reported by the US Department of Agriculture (cited in Landis, 2001). Some other aspects of the urban development patterns are harder to compare because few studies have empirically measured the compactness, fragmentation, and continuity of urbanized areas. The study by Landis (2001) is a noticeable exception in this regard. In comparison with California, Maryland not only has a lower average net density, but also is somewhat less compact, more fragmented, and less continuous in its urban form.

Third, the intensity of urban land uses and the physical forms of urban growth in Maryland vary considerably among its counties. One of the important findings of this study is that there are distinct patterns associated with the variations of land use characteristics among counties. In general, the more urbanized counties tend to have higher population densities, lower sprawl indices, higher levels of compactness and continuity, and a lower level of fragmentation. In the case of Maryland, the most urbanized counties are located in the Baltimore-Washington DC corridor. These counties are, judged on the basis of the most frequently used measures, the least sprawled.

Fourth, the fact that net population density has continued to decrease in Maryland since 1997 indicates that smart growth initiatives have generated only limited effects on density of development. The smart growth programs probably have slowed the trend of decreasing population density, but they have not reversed it. To the best of our knowledge, increasing population densities has not been an explicitly stated objective of Maryland's smart growth programs. It is also worth noting that, for the post-smart growth period, urban growth has continued to become less fragmented. However, it is not clear how much of this changing urban form is attributed to the smart growth programs. What our empirical results have shown unambiguously is the effectiveness of the "Smart Growth Area Act" on the spatial pattern of non-urban to urban land conversion. In general, if everything else is the same, land located within designated PFA is much more likely to be urbanized.

Fifth, the results of our study also show that the effectiveness of smart growth initiatives vary significantly across local jurisdictions. Although the empirical evidence we have gathered is somewhat limited, our models of land conversion show that the "Smart Growth Area Act" has reinforced the relatively compact patterns of urban growth in counties that have a strong tradition of managing growth (e.g. Baltimore County and Montgomery County), and drastically changed spatial distribution of land conversion in some of the counties where the pre-existing patterns of urban development were spatially highly scattered (e.g. Anne Arundel). But the program may not have any measurable effect on other counties (e.g. Garrett). These results provide important insights about the significance of local physical, socioeconomic, and political environments in influencing the pace and patterns of urban development.

These findings have important policy implications. One implication is that, if increasing density and reducing land conversion are to be set as a primary objective of smart growth, additional regulatory mechanisms should probably be introduced to supplement the existing ones. Another related implication is that, if a major objective of smart growth is to reduce sprawl, governmental policies should encourage development to take place in the more urbanized counties where land use is characterized by higher densities, higher levels of compactness and continuity, and a lower level of fragmentation. A third policy implication is that designating priority funding areas is in general an effective way to influence the spatial pattern of land conversion. However, its effectiveness is not universal, as seen in the case of a peripherally located rural county (i.e. Garrett).

It is also important to understand the caveats of this study and share with the readers some of the lessons we learned from this extremely data and computation intensive project. Several caveats and lessons are related to the data. First, studies that involve comparison of land use patterns over time are subject to potentially serious problems caused by inconsistent LULC data qualities. Different rules for dealing with inconsistencies between data from various sources may lead to significantly different results. In our study we partially addressed this issue by using the Maryland Office of Planning's 1991 report on land resources to check our data for earlier years. But some issues about data quality and reliability still remain.

Another problem related to data was that, due to time and resource constraints, we selected only four counties for the modeling of urban land conversion. Therefore, this part of the study can only be seen as exploratory, and its empirical results are preliminary. A further data issue concerns the short period of time, from 1997 to 2002, for which land use changes that have taken place since the implementation of smart growth programs are observed and analyzed.

Yet another caveat is related to the research methods used in our study. Specifically, some of the measures of compactness, fragmentation, and continuity are only effective tools for cross-sectional comparison of urban development patterns but are less than effective as tools for comparing land uses across time periods. Several measures cannot distinguish changes in metropolitan form that are caused by the expansion of urbanized area from changes that are the consequences of smart growth programs.

These caveats point to several future efforts that would be needed to advance our knowledge in this topic area. These efforts include using alternative LULC data for comparison and sensitivity analysis, selecting more counties for modeling land conversion, and using more recent data and increasing the length of the post-sprawl period for data analysis and modeling. It will also be important to improve some of the measures of urban development patterns to make them better suited for cross-time comparisons of land use characteristics.

Ultimately, the most fundamental, as well as the most challenging, future research is to gain a deeper understanding of the interconnections between smart growth initiatives, urban development patterns, and their socioeconomic and environmental consequences. The study presented in this paper is a first step in that direction.

## References


Anderson, James R., Ernest T. Hardy, John T. Roach, and Richard E. Witmer. 1976. *A Land Use and Land Cover Classification System for Use with Remote Sensor Data.* Professional Paper 964. Washington, DC: US Geological Survey.

Anthony, Jerry. 2004. Do State Growth Management Regulations Reduce Sprawl? *Urban Affairs Review* 39: 376-397.

Ben-Akiva, Moshe and Steve R. Lerman. 1985. *Discrete Choice Analysis: Theory and Application to Travel Demand.* Cambridge, MA: MIT Press.

Brueckner, Jan K. 2000. Urban Sprawl: Diagnosis and Remedies. *International Regional Science Review* 23(2): 160-171.

Burchell, Robert W., George Lowenstein, William R. Dolphin, Catherine C. Galley, Anthony Downs, Samuel Seskin, Katherine Gray Still, and Terry Moore. 2002. *Costs of Sprawl – 2000.* TRCP Report 74. Washington, DC: National Academy Press.

Carruthers, John I. and Gudmundur F, Ulfarsson. 2002. Fragmentation and Sprawl: Evidence from Interregional Analysis. *Growth and Change* 33: 312-340.

Cohen, James R. 2002. Maryland's "Smart Growth": Using Incentive to Combat Sprawl. In *Urban Sprawl: Causes, Consequences and Policy Response*, edited by G. Squires. Washington, DC: Urban Institute Press.

Daniels, Thomas and Katherine Daniels. 2003. *Environmental Planning Handbook*. APA Planners Press.

Domencich, Thomas and Daniel McFadden. 1975. *Urban Travel Demand: A Behavioral Analysis.* Amsterdam: North-Holland.

Dowall, David E. 1984. The Suburban Squeeze: Land Conversion and Regulation in the San Francisco Bay Area. Berkeley, California: University of California Press.

Downs, Anthony. 1999. Some Realities about Sprawl and Urban Decline. *Housing Policy Debate* 10: 955-974.

Downs, Anthony. 1998. How America's Cities Are Growing: The Big Picture. *Brookings Review* 16(4): 8-11.

Ewing, Reid. 1997. Is Los Angeles Style Sprawl Desirable? *Journal of the American Planning Association* 63(1): 107-126.

Ewing, Reid, Rolf Pendall, and Don Chen. 2002. *Measuring Sprawl and Its Impact.* Washington DC: Smart Growth America.

Feitelson, Eran. 1993. The Spatial Effects of Land Use Regulations: A Missing Link in Growth Control Evaluations. *Journal of American Planning Association* 59, 4: 461-472.

Fulton, William, Rolf Pendall, Mai Nguyen, and Alicia Harrison. 2001. *Who Sprawls Most? How Growth Patterns Differ across the US.* Washington, DC: Brookings Institution, Center on Urban and Metropolitan Policy.

Galster, George, Royce Hanson, Hal Wolman, Stephen Coleman, and Jason Freihage. 2001. Wrestling Sprawl to the Ground: Defining and Measuring an Elusive Concept. *Housing Policy Debate* 12: 681-717.

Gordon, Peter and Harry W. Richardson. 1997. Are Compact Cities a Desirable Planning Goal? *Journal of the American Planning Association* 63(1): 95-106.

Handy, Susan. 1996. Understanding the Link between Urban Form and Non-work Travel Behavior. *Journal of Planning Education and Research* 15: 183-198.

Harvey, Robert O. and William A. V. Clark. 1965. The Nature and Economics of Urban Sprawl. *Land Economics* 41: 1-9.

Hasse, John E. and Richard G. Lathrop. 2003. Land Resource Impact Indicators of Urban Sprawl. *Applied Geography* 23: 159–175.

Hess, George, Salinda Daley, Becky Dennison, Robert McGuinn, Vanessa Morin, Wade Shelton, Sharon Lubkin, Kevin Potter, Rick Savage, Chris Snow, and Beth Wrege. 2001. Just What Is Sprawl, Anyway? *Carolina Planning Journal* 26(2): 11-26.

Howland, Marie and Jungyul Sohn. 2004. Has Maryland's Priority Funding Areas Initiative Constrained the Expansion of Water and Sewer Investments? Unpublished manuscript.

Kline, Jeffrey D. 2000. Comparing States with and without Growth Management Analysis Based on Indicators with Policy Implications Comment. *Land Use Policy* 17: 349-355.

Ladd, Helen. 1992. Population Growth, Density, and the Costs of Providing Public Services. *Urban Studies* 29(2): 273-295.

Landis, John D. 2001. Unpublished project report on urban sprawl in California. Department of City and Regional Planning, University of California, Berkeley.

Landis, John D. and Ming Zhang. 1998a. The Second Generation of the California Urban Futures Model, Part I, Model Logic and Theory. *Environment and Planning B: Planning and Design* 25: 657-666.

Landis, John D. and Ming Zhang. 1998b. The Second Generation of the California Urban Futures Model, Part II: Specification and Calibration Results of the Land-Use Change Submodel. *Environment and Planning B: Planning and Design* 25: 795-824.

Levine, Ned. 1999. The Effects of Local Growth Controls on Regional Housing Production and Population Redistribution in California. *Urban Studies* 36(12): 2047-2068.

Levinson, David. 1997. The Limits to Growth Management: Development Regulation in Montgomery County, Maryland. *Environment and Planning B: Planning and Design* 24: 689-707.

Lopez, Russ and H. Patricia Hynes. 2003. Sprawl in the 1990s: Measurement, Distribution and Trends. *Urban Affairs Review* 38:325-355.

Maryland Office of Planning. 1991. *Maryland's Land 1973 – 1990: A Changing Resource.* Publication 91-8. Baltimore: Maryland Office of Planning.

Mills, David E. 1981. Growth, Speculation and Sprawl in a Monocentric City. *The Journal of Urban Economics* 10: 201-226.

Nelson, Arthur C. 1999. Comparing States with and without Growth Management: Analysis Based on Indicators with Policy Implications. *Land Use Policy* 16: 121-127.

Nelson, Arthur C. 1992. Preserving Prime Farmland in the Face of Urbanization – Lessons from Oregon. *Journal of the American Planning Association* 58(4): 467-488.

Newman Peter and Jeffrey Kenworthy. 1999. *Sustainability and Cities: Overcoming Automobile Dependence*. Washington, DC: Island Press.

Peiser, Richard. 2001. Decomposing Urban Sprawl. *Town Planning Review* 72(3): 275-298.

Pendall, Rolf. 1999. Do Land Use Controls Cause Sprawl? *Environment and Planning B: Planning and Design* 26: 555-571.

Shen, Qing. 2000. New Telecommunications and Residential Location Flexibility. *Environment and Planning A* 32(8): 1445-1463.

Shen, Qing. 1998, Location Characteristics of Inner-City Neighborhoods and Employment Accessibility of Low-Wage Workers. *Environment and Planning B: Planning and Design* 25: 345–365.

Shen, Qing. 1996. Spatial Impacts of Locally Enacted Growth Controls: The San Francisco Bay Area in the 1980s. *Environment and Planning B: Planning and Design* 23: 61-91.

Sierra Club. Undated. The costs of sprawl.
http://www.sierraclub.org/sprawl/community/costs.asp

Smart Growth America. Undated. *What is Smart Growth?*
http://www.smartgrowthamerica.com/

Smart Growth Network. Undated. *About Smart Growth.*
http://www.smartgrowth.org/about/default.asp

US Environmental Protection Agency. Undated. *About Smart Growth.*
http://www.epa.gov/smartgrowth/about_sg.htm

Wegener, Michael. 1994. Operational Urban Models: State of Art. *Journal of the American Planning Association* 60(1): 17-30.

Weitz, Jerry. 1999. From Quiet Revolution to Smart Growth: State Growth Management Programs, 1960 to 1999. *Journal of Planning Literature* 14: 267–338.

## List of Tables

**Table 1. Measures of Urban Development Patterns**

| Measures | Notations | Data Sources |
| --- | --- | --- |
| *Measures of Land Conversion and Density Trends* | | |
| Increase in Urbanized Land | L1 | LULC data from Maryland PropertyView |
| Rate of Increase in Urbanized Land | L2 | |
| Net Population Density | D1 | US Census of Population and Housing<br>LULC data from Maryland PropertyView |
| Marginal Population Density | D2 | |
| Sprawl Index | S | |
| *Measures of Metropolitan Form – Compactness* | | |
| Proportion of Urbanized Land within a 50%-Point Ellipse | C1 | US Census of Population and Housing<br>LULC data from Maryland PropertyView |
| Net Population Density within a 50%-Point Ellipse | C2 | |
| *Measures of Metropolitan Form – Fragmentation* | | |
| Patches-Population Ratio | F1 | US Census of Population and Housing<br>LULC data from Maryland PropertyView |
| Average Patch Size | F2 | |
| Edge-Perimeter Ratio | F3 | |
| *Measures of Metropolitan Form – Continuity* | | |
| Continuity Gradient for 1st Distance Ring | K1 | LULC data from Maryland PropertyView |
| Continuity Gradient for 5th Distance Ring | K2 | |

**Table 2. Independent Variables for the Binary Logit Model of Land Conversion**

| **Independent Variables** | **Expected Effect** | **Data Source** |
|---|---|---|
| *Smart growth policy* | | |
| Inside Priority Funding Areas (PFA) | + | Maryland PropertyView |
| *Site characteristics* | | |
| Floodplain | – | Federal Emergency Management Agency |
| Agricultural land preservation district | – | Maryland Department of Agriculture |
| *Location characteristics* | | |
| Distance to urban area | – | Maryland PropertyView |
| Squared distance to highway | – | Maryland PropertyView |
| Distance to municipality | – | Maryland PropertyView |
| *Characteristics of neighboring sites* | | |
| % adjacent grid cells urbanized | + | Maryland PropertyView |
| Average slope of adjacent cells | – | USGS |
| Difference between average adjacent slope and site slope | – | USGS |
| *Demographic characteristics* | | |
| Population density in 1990 | +/– | US Census of Population and Housing |
| % population white in 1990/2000 | +/– | US Census of Population and Housing |
| % population foreign-born in 1990/2000 | + | US Census of Population and Housing |
| *Infrastructure characteristics* | | |
| % housing units on public water in 1990 | + | US Census of Population and Housing |

**Table 3. Land Area, Population, Employment, and Household Income in Maryland (Counties, Baltimore City, and State)**

| COUNTY NAME | Land Area (Acres) | Population in 2000 (Persons) | Gross Population Density in 2000 (Persons/Acre) | Private Non-farm Employment in 2000 (Jobs) | Median Household Income in 1999 (US Dollars) |
|---|---|---|---|---|---|
| Allegany | 272,000 | 74,930 | 0.3 | 25,136 | 30,821 |
| Anne Arundel | 266,240 | 489,656 | 1.8 | 184,817 | 61,768 |
| Baltimore City | 51,840 | 651,154 | 12.6 | 298,378 | 30,078 |
| Baltimore | 383,360 | 754,292 | 2.0 | 314,399 | 50,667 |
| Calvert | 137,600 | 74,563 | 0.5 | 14,922 | 65,945 |
| Caroline | 204,800 | 29,772 | 0.1 | 6,538 | 38,832 |
| Carroll | 287,360 | 150,897 | 0.5 | 43,525 | 60,021 |
| Cecil | 222,720 | 85,951 | 0.4 | 20,829 | 50,510 |
| Charles | 295,040 | 120,546 | 0.4 | 29,433 | 62,199 |
| Dorchester | 357,120 | 30,674 | 0.1 | 9,651 | 34,077 |
| Frederick | 424,320 | 195,277 | 0.5 | 72,344 | 60,276 |
| Garrett | 414,720 | 29,846 | 0.1 | 9,219 | 32,238 |
| Harford | 281,600 | 218,590 | 0.8 | 58,837 | 57,234 |
| Howard | 161,280 | 247,842 | 1.5 | 134,990 | 74,167 |
| Kent | 178,560 | 19,197 | 0.1 | 7,021 | 39,869 |
| Montgomery | 316,800 | 873,341 | 2.8 | 404,150 | 71,551 |
| Prince George's | 311,040 | 801,515 | 2.6 | 250,694 | 55,256 |
| Queen Anne's | 238,080 | 40,563 | 0.2 | 9,575 | 57,037 |
| Saint Mary’s | 231,040 | 86,211 | 0.4 | 22,148 | 54,706 |
| Somerset | 209,280 | 24,747 | 0.1 | 3,170 | 29,903 |
| Talbot | 172,160 | 33,812 | 0.2 | 16,897 | 43,532 |
| Washington | 293,120 | 131,923 | 0.5 | 58,604 | 40,617 |
| Wicomico | 241,280 | 84,644 | 0.4 | 37,306 | 39,035 |
| Worcester | 302,720 | 46,543 | 0.2 | 18,406 | 40,650 |
| Maryland | 6,254,080 | 5,296,486 | 0.8 | 2,050,989 | 52,868 |

Sources: Data on land area are based on figures in the County and City Data Book 2000 Edition.
Data on population and household income are from census 2000.
Data on private non-farm employment are from the County Business Patterns.

**Table 4. Land Conversion in Maryland, 1973, 1997, 2000 and 2002**

| | Urbanized land (Acres) | | | | Net Change (Acres) | | | Annual Rate of Change (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **COUNTY NAME** | **1973** | **1997** | **2000** | **2002** | **1973-1997** | **1997-2002** | **1973-2002** | **1973-1997** | **1997-2002** | **1973-2002** |
| Allegany | 16,521 | 25,518 | 26,430 | 25,906 | 8,997 | 388 | 9,385 | 1.83% | 0.30% | 1.56% |
| Anne Arundel | 66,539 | 101,917 | 106,124 | 110,029 | 35,378 | 8,111 | 43,490 | 1.79% | 1.54% | 1.75% |
| Baltimore City | 46,058 | 46,973 | 47,292 | 47,449 | 915 | 476 | 1,391 | 0.08% | 0.20% | 0.10% |
| Baltimore | 98,988 | 137,448 | 141,314 | 150,413 | 38,460 | 12,965 | 51,425 | 1.38% | 1.82% | 1.45% |
| Calvert | 8,818 | 34,074 | 35,536 | 36,613 | 25,257 | 2,538 | 27,795 | 5.79% | 1.45% | 5.03% |
| Caroline | 5,592 | 15,334 | 15,977 | 16,094 | 9,742 | 761 | 10,502 | 4.29% | 0.97% | 3.71% |
| Carroll | 20,265 | 51,526 | 57,743 | 60,469 | 31,261 | 8,944 | 40,204 | 3.96% | 3.25% | 3.84% |
| Cecil | 14,465 | 29,446 | 32,733 | 34,341 | 14,981 | 4,895 | 19,876 | 3.01% | 3.12% | 3.03% |
| Charles | 19,027 | 46,878 | 48,013 | 49,448 | 27,851 | 2,570 | 30,421 | 3.83% | 1.09% | 3.35% |
| Dorchester | 5,972 | 16,270 | 16,735 | 16,944 | 10,297 | 674 | 10,972 | 4.27% | 0.78% | 3.66% |
| Frederick | 18,345 | 50,462 | 66,353 | 68,260 | 32,117 | 17,798 | 49,915 | 4.31% | 6.23% | 4.64% |
| Garrett | 6,557 | 21,375 | 29,733 | 28,145 | 14,818 | 6,770 | 21,588 | 5.05% | 5.66% | 5.15% |
| Harford | 38,156 | 65,480 | 69,511 | 73,564 | 27,324 | 8,083 | 35,408 | 2.28% | 2.35% | 2.29% |
| Howard | 22,615 | 57,250 | 58,666 | 64,804 | 34,635 | 7,554 | 42,189 | 3.95% | 2.51% | 3.70% |
| Kent | 4,597 | 10,421 | 10,806 | 10,763 | 5,824 | 342 | 6,166 | 3.47% | 0.65% | 2.98% |
| Montgomery | 85,540 | 134,867 | 143,136 | 145,392 | 49,328 | 10,525 | 59,853 | 1.92% | 1.51% | 1.85% |
| Prince George's | 77,948 | 120,282 | 138,517 | 126,807 | 42,334 | 6,525 | 48,859 | 1.82% | 1.06% | 1.69% |
| Queen Anne's | 6,931 | 18,580 | 19,767 | 20,302 | 11,649 | 1,722 | 13,371 | 4.19% | 1.79% | 3.78% |
| Saint Mary’s | 16,295 | 36,991 | 39,453 | 48,009 | 20,696 | 11,018 | 31,714 | 3.48% | 5.35% | 3.80% |
| Somerset | 3,700 | 11,980 | 12,099 | 12,163 | 8,281 | 183 | 8,463 | 5.02% | 0.30% | 4.19% |
| Talbot | 7,734 | 20,507 | 21,554 | 21,963 | 12,772 | 1,457 | 14,229 | 4.15% | 1.38% | 3.66% |
| Washington | 17,962 | 41,285 | 51,671 | 51,661 | 23,323 | 10,376 | 33,699 | 3.53% | 4.59% | 3.71% |
| Wicomico | 12,568 | 30,259 | 31,754 | 34,119 | 17,691 | 3,860 | 21,551 | 3.73% | 2.43% | 3.50% |
| Worcester | 10,109 | 20,762 | 21,583 | 21,489 | 10,653 | 728 | 11,380 | 3.04% | 0.69% | 2.63% |
| Maryland | 631,301 | 1,145,884 | 1,242,499 | 1,275,145 | 514,583 | 129,261 | 643,844 | 2.52% | 2.16% | 2.45% |

**Table 5. Population Densities in Maryland, 1973, 1997, 2000 and 2002**

| | Population (Persons) | | | | Net Density (Persons/Acre) | | | | Marginal Density (Persons/Acre) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| COUNTY NAME | 1973 | 1997 | 2000 | 2002 | 1973 | 1997 | 2000 | 2002 | 1973-1997 | 1997-2002 | 1973-2002 |
| Allegany | 82,995 | 75,310 | 74,930 | 73,999 | 5.0 | 3.0 | 2.8 | 2.9 | -0.9 | -3.4 | -1.0 |
| Anne Arundel | 319,862 | 472,356 | 489,656 | 502,081 | 4.8 | 4.6 | 4.6 | 4.6 | 4.3 | 3.7 | 4.2 |
| Baltimore City | 870,073 | 677,342 | 651,154 | 636,141 | 18.9 | 14.4 | 13.8 | 13.4 | -210.6 | -86.8 | -168.3 |
| Baltimore | 630,971 | 741,043 | 754,292 | 768,623 | 6.4 | 5.4 | 5.3 | 5.1 | 2.9 | 2.1 | 2.7 |
| Calvert | 24,869 | 68,641 | 74,563 | 80,905 | 2.8 | 2.0 | 2.1 | 2.2 | 1.7 | 4.8 | 2.0 |
| Caroline | 20,790 | 29,552 | 29,772 | 30,347 | 3.7 | 1.9 | 1.9 | 1.9 | 0.9 | 1.0 | 0.9 |
| Carroll | 77,211 | 144,538 | 150,897 | 159,323 | 3.8 | 2.8 | 2.6 | 2.6 | 2.2 | 1.7 | 2.0 |
| Cecil | 55,433 | 80,952 | 85,951 | 90,366 | 3.8 | 2.7 | 2.6 | 2.6 | 1.7 | 1.9 | 1.8 |
| Charles | 55,200 | 113,563 | 120,546 | 128,215 | 2.9 | 2.4 | 2.5 | 2.6 | 2.1 | 5.6 | 2.4 |
| Dorchester | 29,770 | 30,816 | 30,674 | 30,494 | 5.0 | 1.9 | 1.8 | 1.8 | 0.1 | -0.5 | 0.1 |
| Frederick | 93,887 | 183,285 | 195,277 | 209,103 | 5.1 | 3.6 | 2.9 | 3.1 | 2.8 | 1.5 | 2.3 |
| Garrett | 22,980 | 29,773 | 29,846 | 29,915 | 3.5 | 1.4 | 1.0 | 1.1 | 0.5 | 0.0 | 0.3 |
| Harford | 124,544 | 211,366 | 218,590 | 227,361 | 3.3 | 3.2 | 3.1 | 3.1 | 3.2 | 2.0 | 2.9 |
| Howard | 79,247 | 228,386 | 247,842 | 259,901 | 3.5 | 4.0 | 4.2 | 4.0 | 4.3 | 4.2 | 4.3 |
| Kent | 16,311 | 19,002 | 19,197 | 19,426 | 3.5 | 1.8 | 1.8 | 1.8 | 0.5 | 1.2 | 0.5 |
| Montgomery | 539,682 | 835,432 | 873,341 | 905,995 | 6.3 | 6.2 | 6.1 | 6.2 | 6.0 | 6.7 | 6.1 |
| Prince George's | 662,725 | 780,666 | 801,515 | 827,704 | 8.5 | 6.5 | 5.8 | 6.5 | 2.8 | 7.2 | 3.4 |
| Queen Anne's | 20,548 | 38,461 | 40,563 | 42,876 | 3.0 | 2.1 | 2.1 | 2.1 | 1.5 | 2.6 | 1.7 |
| Saint Mary's | 51,140 | 83,165 | 86,211 | 89,951 | 3.1 | 2.2 | 2.2 | 1.9 | 1.5 | 0.6 | 1.2 |
| Somerset | 19,003 | 24,745 | 24,747 | 25,465 | 5.1 | 2.1 | 2.0 | 2.1 | 0.7 | 3.9 | 0.8 |
| Talbot | 24,259 | 32,919 | 33,812 | 34,367 | 3.1 | 1.6 | 1.6 | 1.6 | 0.7 | 1.0 | 0.7 |
| Washington | 106,606 | 129,890 | 131,923 | 134,787 | 5.9 | 3.1 | 2.6 | 2.6 | 1.0 | 0.5 | 0.8 |
| Wicomico | 57,327 | 82,334 | 84,644 | 86,162 | 4.6 | 2.7 | 2.7 | 2.5 | 1.4 | 1.0 | 1.3 |
| Worcester | 26,376 | 43,791 | 46,543 | 48,024 | 2.6 | 2.1 | 2.2 | 2.2 | 1.6 | 5.8 | 1.9 |
| Maryland | 4,011,808 | 5,157,328 | 5,296,486 | 5,441,531 | 6.4 | 4.5 | 4.3 | 4.3 | 2.2 | 2.2 | 2.2 |

**Table 6. Sprawl Indices for Maryland, 1973-1997, 1997-2002, and 1973-2002**

| | SPRAWL INDEX | | |
|---|---|---|---|
| **COUNTY NAME** | **1973-1997** | **1997-2002** | **1973-2002** |
| Allegany | -4.52 | -0.86 | -3.96 |
| Anne Arundel | 1.09 | 1.26 | 1.12 |
| Baltimore City | -0.08 | -0.16 | -0.10 |
| Baltimore | 2.05 | 2.48 | 2.13 |
| Calvert | 1.34 | 0.43 | 1.21 |
| Caroline | 2.91 | 1.83 | 2.83 |
| Carroll | 1.50 | 1.65 | 1.52 |
| Cecil | 1.89 | 1.40 | 1.78 |
| Charles | 1.25 | 0.44 | 1.14 |
| Dorchester | 29.68 | -3.73 | 44.19 |
| Frederick | 1.52 | 2.33 | 1.66 |
| Garrett | 4.65 | 59.41 | 5.64 |
| Harford | 1.02 | 1.60 | 1.09 |
| Howard | 0.88 | 0.96 | 0.88 |
| Kent | 5.43 | 1.46 | 4.92 |
| Montgomery | 1.04 | 0.93 | 1.02 |
| Prince George's | 2.66 | 0.90 | 2.20 |
| Queen Anne's | 1.58 | 0.81 | 1.47 |
| Saint Mary’s | 1.70 | 3.39 | 1.93 |
| Somerset | 4.54 | 0.53 | 4.13 |
| Talbot | 3.24 | 1.60 | 3.03 |
| Washington | 4.27 | 6.17 | 4.57 |
| Wicomico | 2.45 | 2.66 | 2.48 |
| Worcester | 1.43 | 0.37 | 1.26 |
| Maryland | 2.39 | 2.00 | 2.32 |

## Table 7. Compactness of Urban Development in Maryland, 1973, 1997, 2000, and 2002

| | Land Use Within 50%-Point Ellipse | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total (Acres) | | | | Urbanized (Acres) | | | | Proportion Urbanized (%) | | | |
| **County Name** | **1973** | **1997** | **2000** | **2002** | **1973** | **1997** | **2000** | **2002** | **1973** | **1997** | **2000** | **2002** |
| Allegany | 48,593 | 69,588 | 70,203 | 70,542 | 8,544 | 13,687 | 14,199 | 13,919 | 18% | 20% | 20% | 20% |
| Anne Arundel | 78,329 | 84,399 | 84,293 | 85,706 | 28,984 | 44,800 | 46,077 | 47,725 | 37% | 53% | 55% | 56% |
| Baltimore City | 19,129 | 19,421 | 19,455 | 19,479 | 18,154 | 18,437 | 18,508 | 18,562 | 95% | 95% | 95% | 95% |
| Baltimore County | 70,163 | 92,996 | 93,812 | 98,146 | 39,368 | 54,733 | 56,378 | 59,926 | 56% | 59% | 60% | 61% |
| Calvert | 61,899 | 57,299 | 57,080 | 56,890 | 2,877 | 14,269 | 14,942 | 15,373 | 5% | 25% | 26% | 27% |
| Caroline | 69,440 | 70,034 | 69,745 | 69,983 | 2,562 | 7,463 | 7,744 | 7,802 | 4% | 11% | 11% | 11% |
| Carroll | 105,393 | 96,123 | 97,078 | 96,257 | 8,532 | 21,198 | 24,394 | 25,974 | 8% | 22% | 25% | 27% |
| Cecil | 69,864 | 72,054 | 72,905 | 73,544 | 6,257 | 12,484 | 13,950 | 14,642 | 9% | 17% | 19% | 20% |
| Charles | 113,502 | 105,563 | 105,675 | 105,782 | 8,917 | 22,428 | 23,180 | 23,720 | 8% | 21% | 22% | 22% |
| Dorchester | 89,562 | 108,143 | 108,223 | 107,551 | 3,611 | 8,351 | 8,498 | 8,631 | 4% | 8% | 8% | 8% |
| Frederick | 100,877 | 120,576 | 117,647 | 114,812 | 10,130 | 23,307 | 32,050 | 32,710 | 10% | 19% | 27% | 28% |
| Garrett | 101,937 | 118,128 | 119,115 | 117,191 | 4,222 | 11,861 | 15,888 | 14,840 | 4% | 10% | 13% | 13% |
| Harford | 78,777 | 86,936 | 85,387 | 85,795 | 16,583 | 26,620 | 28,416 | 29,749 | 21% | 31% | 33% | 35% |
| Howard | 41,355 | 47,439 | 47,503 | 49,216 | 10,482 | 24,380 | 25,028 | 26,977 | 25% | 51% | 53% | 55% |
| Kent | 67,452 | 69,807 | 70,213 | 70,573 | 1,910 | 4,369 | 4,486 | 4,448 | 3% | 6% | 6% | 6% |
| Montgomery | 61,935 | 77,314 | 78,282 | 78,351 | 41,118 | 57,616 | 59,827 | 60,589 | 66% | 75% | 76% | 77% |
| Prince George's | 70,761 | 91,983 | 90,833 | 94,704 | 38,960 | 56,350 | 62,739 | 57,822 | 55% | 61% | 69% | 61% |
| Queen Anne's | 60,187 | 65,517 | 62,948 | 64,558 | 3,211 | 7,838 | 8,431 | 8,541 | 5% | 12% | 13% | 13% |
| Saint Mary's | 93,757 | 96,064 | 94,986 | 96,390 | 8,198 | 16,506 | 17,518 | 21,314 | 9% | 17% | 18% | 22% |
| Somerset | 71,879 | 75,304 | 75,906 | 76,007 | 1,612 | 5,414 | 5,492 | 5,515 | 2% | 7% | 7% | 7% |
| Talbot | 34,934 | 44,416 | 45,538 | 45,791 | 4,810 | 10,503 | 11,102 | 11,285 | 14% | 24% | 24% | 25% |
| Washington | 75,700 | 115,993 | 117,916 | 119,820 | 12,742 | 25,162 | 30,177 | 30,210 | 17% | 22% | 26% | 25% |
| Wicomico | 43,947 | 55,105 | 54,591 | 56,704 | 8,496 | 18,527 | 19,261 | 20,434 | 19% | 34% | 35% | 36% |
| Worcester | 69,323 | 82,539 | 84,534 | 84,943 | 4,693 | 9,907 | 10,228 | 10,170 | 7% | 12% | 12% | 12% |
| Maryland | 1,698,693 | 1,922,741 | 1,923,869 | 1,938,735 | 294,971 | 516,209 | 558,511 | 570,876 | 17% | 27% | 29% | 29% |

## Table 7. Compactness of Urban Development in Maryland, 1973, 1997, 2000, and 2002 (continued)

| | Population Density within 50%-point Ellipse | | | | | | |
|---|---|---|---|---|---|---|---|
| | Ellipse Population (Persons) | | | Net Population Density (Persons/Acre) | | | |
| **County Name** | **1997** | **2000** | **2002** | **1997** | **2000** | **2002** | **Change 1997-2002** |
| Allegany | 46,771 | 47,004 | 47,175 | 3.42 | 3.31 | 3.39 | -0.03 |
| Anne Arundel | 209,395 | 213,659 | 218,004 | 4.67 | 4.64 | 4.57 | -0.11 |
| Baltimore City | 375,054 | 358,600 | 374,156 | 20.34 | 19.38 | 20.16 | -0.19 |
| Baltimore County | 299,322 | 304,583 | 311,380 | 5.47 | 5.40 | 5.20 | -0.27 |
| Calvert | 22,311 | 24,299 | 25,638 | 1.56 | 1.63 | 1.67 | 0.10 |
| Caroline | 11,851 | 12,237 | 12,555 | 1.59 | 1.58 | 1.61 | 0.02 |
| Carroll | 60,993 | 65,209 | 67,835 | 2.88 | 2.67 | 2.61 | -0.27 |
| Cecil | 35,901 | 34,098 | 32,481 | 2.88 | 2.44 | 2.22 | -0.66 |
| Charles | 63,652 | 66,627 | 68,713 | 2.84 | 2.87 | 2.90 | 0.06 |
| Dorchester | 20,530 | 20,568 | 20,478 | 2.46 | 2.42 | 2.37 | -0.09 |
| Frederick | 107,389 | 116,231 | 122,525 | 4.61 | 3.63 | 3.75 | -0.86 |
| Garrett | 13,046 | 13,479 | 13,792 | 1.10 | 0.85 | 0.93 | -0.17 |
| Harford | 115,049 | 123,208 | 129,346 | 4.32 | 4.34 | 4.35 | 0.03 |
| Howard | 119,912 | 126,797 | 130,234 | 4.92 | 5.07 | 4.83 | -0.09 |
| Kent | 9,140 | 9,508 | 9,755 | 2.09 | 2.12 | 2.19 | 0.10 |
| Montgomery | 419,602 | 435,977 | 446,262 | 7.28 | 7.29 | 7.37 | 0.08 |
| Prince George's | 399,148 | 397,760 | 416,102 | 7.08 | 6.34 | 7.20 | 0.11 |
| Queen Anne's | 15,475 | 16,014 | 16,719 | 1.97 | 1.90 | 1.96 | -0.02 |
| Saint Mary's | 46,294 | 47,748 | 48,478 | 2.80 | 2.73 | 2.27 | -0.53 |
| Somerset | 11,242 | 11,653 | 11,894 | 2.08 | 2.12 | 2.16 | 0.08 |
| Talbot | 17,004 | 17,654 | 18,066 | 1.62 | 1.59 | 1.60 | -0.02 |
| Washington | 96,695 | 99,568 | 102,209 | 3.84 | 3.30 | 3.38 | -0.46 |
| Wicomico | 56,223 | 57,815 | 59,374 | 3.03 | 3.00 | 2.91 | -0.13 |
| Worcester | 19,262 | 21,805 | 23,514 | 1.94 | 2.13 | 2.31 | 0.37 |
| Maryland | 2,591,261 | 2,642,101 | 2,726,685 | 5.02 | 4.73 | 4.78 | -0.24 |

**Table 8. Fragmentation of Urban Development in Maryland, 1973, 1997, 2000 and 2002**

| | Number of Patches | | | | Patches Per 1000 People | | | | Average Patch Size (Acres) | | | | Edge-Perimeter Ratio | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **County Name** | **1973** | **1997** | **2000** | **2002** | **1973** | **1997** | **2000** | **2002** | **1973** | **1997** | **2000** | **2002** | **1973** | **1997** | **2000** | **2002** |
| Allegany | 100 | 300 | 299 | 297 | 1.2 | 4.0 | 4.0 | 4.0 | 165.2 | 85.1 | 88.4 | 87.2 | 3.4 | 4.0 | 3.9 | 4.0 |
| Anne Arundel | 352 | 606 | 599 | 593 | 1.1 | 1.3 | 1.2 | 1.2 | 189.0 | 168.2 | 177.2 | 185.5 | 2.8 | 3.1 | 3.1 | 3.3 |
| Baltimore City | 11 | 4 | 4 | 7 | 0.0 | 0.0 | 0.0 | 0.0 | 4187.1 | 11743.4 | 11823.0 | 6778.3 | 0.7 | 0.9 | 0.8 | 0.9 |
| Baltimore County | 292 | 761 | 749 | 759 | 0.5 | 1.0 | 1.0 | 1.0 | 339.0 | 180.6 | 188.7 | 198.2 | 2.0 | 2.5 | 2.5 | 2.5 |
| Calvert | 158 | 359 | 364 | 355 | 6.4 | 5.2 | 4.9 | 4.4 | 55.8 | 94.9 | 97.6 | 103.1 | 5.0 | 4.3 | 4.3 | 4.3 |
| Caroline | 105 | 375 | 401 | 397 | 5.1 | 12.7 | 13.5 | 13.1 | 53.3 | 40.9 | 39.8 | 40.5 | 5.0 | 5.6 | 5.6 | 5.6 |
| Carroll | 287 | 714 | 699 | 702 | 3.7 | 4.9 | 4.6 | 4.4 | 70.6 | 72.2 | 82.6 | 86.1 | 4.5 | 4.2 | 4.1 | 4.0 |
| Cecil | 182 | 544 | 545 | 573 | 3.3 | 6.7 | 6.3 | 6.3 | 79.5 | 54.1 | 60.1 | 59.9 | 4.9 | 5.2 | 5.0 | 4.9 |
| Charles | 231 | 462 | 465 | 456 | 4.2 | 4.1 | 3.9 | 3.6 | 82.4 | 101.5 | 103.3 | 108.5 | 4.1 | 3.9 | 4.0 | 3.9 |
| Dorchester | 92 | 432 | 438 | 441 | 3.1 | 14.0 | 14.3 | 14.5 | 64.9 | 37.7 | 38.2 | 38.4 | 4.6 | 5.4 | 5.4 | 5.4 |
| Frederick | 221 | 772 | 636 | 703 | 2.4 | 4.2 | 3.3 | 3.4 | 83.0 | 65.4 | 104.3 | 97.1 | 3.9 | 4.4 | 3.3 | 3.5 |
| Garrett | 112 | 511 | 495 | 576 | 4.9 | 17.2 | 16.6 | 19.3 | 58.5 | 41.8 | 60.1 | 48.9 | 4.6 | 5.5 | 4.4 | 5.0 |
| Harford | 297 | 661 | 683 | 696 | 2.4 | 3.1 | 3.1 | 3.1 | 128.5 | 99.1 | 101.8 | 105.7 | 3.1 | 3.8 | 3.8 | 3.8 |
| Howard | 176 | 355 | 364 | 319 | 2.2 | 1.6 | 1.5 | 1.2 | 128.5 | 161.3 | 161.2 | 203.1 | 2.9 | 3.0 | 3.0 | 2.9 |
| Kent | 64 | 237 | 240 | 242 | 3.9 | 12.5 | 12.5 | 12.5 | 71.8 | 44.0 | 45.0 | 44.5 | 4.4 | 5.2 | 5.2 | 5.3 |
| Montgomery | 239 | 340 | 292 | 301 | 0.4 | 0.4 | 0.3 | 0.3 | 357.9 | 396.7 | 490.2 | 483.0 | 1.7 | 1.8 | 1.7 | 1.7 |
| Prince George's | 277 | 428 | 340 | 537 | 0.4 | 0.5 | 0.4 | 0.6 | 281.4 | 281.0 | 407.4 | 236.1 | 2.1 | 2.3 | 2.3 | 2.6 |
| Queen Anne's | 96 | 332 | 332 | 354 | 4.7 | 8.6 | 8.2 | 8.3 | 72.2 | 56.0 | 59.5 | 57.3 | 4.5 | 4.8 | 4.8 | 4.8 |
| Saint Mary's | 258 | 743 | 758 | 725 | 5.0 | 8.9 | 8.8 | 8.1 | 63.2 | 49.8 | 52.0 | 66.2 | 4.5 | 5.0 | 4.9 | 4.6 |
| Somerset | 52 | 327 | 329 | 331 | 2.7 | 13.2 | 13.3 | 13.0 | 71.1 | 36.6 | 36.8 | 36.7 | 5.3 | 5.8 | 5.8 | 5.8 |
| Talbot | 104 | 395 | 400 | 431 | 4.3 | 12.0 | 11.8 | 12.5 | 74.4 | 51.9 | 53.9 | 51.0 | 4.5 | 4.8 | 4.7 | 4.8 |
| Washington | 140 | 590 | 443 | 457 | 1.3 | 4.5 | 3.4 | 3.4 | 128.3 | 70.0 | 116.6 | 113.0 | 3.2 | 4.2 | 3.5 | 3.6 |
| Wicomico | 98 | 452 | 461 | 477 | 1.7 | 5.5 | 5.4 | 5.5 | 128.2 | 66.9 | 68.9 | 71.5 | 3.4 | 3.9 | 3.9 | 3.9 |
| Worcester | 91 | 344 | 358 | 361 | 3.5 | 7.9 | 7.7 | 7.5 | 111.1 | 60.4 | 60.3 | 59.5 | 4.2 | 4.7 | 4.8 | 4.8 |
| Maryland | 4,035 | 11,044 | 10,694 | 11,090 | 1.0 | 2.1 | 2.0 | 2.0 | 156.5 | 103.8 | 116.2 | 115.0 | 2.7 | 3.4 | 3.2 | 3.3 |

**Table 9. Continuity of Urban Development in Maryland, 1973, 1997, 2000 and 2002**

| County | Percent Cells Urban (0-1 Km) K1 | | | | Percent Cells Urban (4-5 Km) K2 | | | |
|---|---|---|---|---|---|---|---|---|
| | 1973 | 1997 | 2000 | 2002 | 1973 | 1997 | 2000 | 2002 |
| Allegany | 39.11 | 37.99 | 38.74 | 38.38 | 13.83 | 16.50 | 17.07 | 16.35 |
| Anne Arundel | 55.03 | 61.79 | 63.07 | 62.20 | 36.35 | 49.13 | 51.84 | 51.13 |
| Baltimore City | 95.09 | 95.34 | 95.82 | 96.01 | 90.34 | 91.56 | 92.09 | 92.45 |
| Baltimore County | 65.91 | 65.20 | 65.95 | 66.35 | 43.63 | 49.41 | 50.46 | 51.82 |
| Calvert | 21.83 | 39.52 | 40.79 | 41.90 | 6.53 | 25.05 | 26.30 | 27.19 |
| Caroline | 24.15 | 23.91 | 23.79 | 24.23 | 2.63 | 8.32 | 8.66 | 8.62 |
| Carroll | 23.96 | 35.94 | 39.52 | 41.17 | 7.87 | 21.63 | 24.35 | 25.79 |
| Cecil | 30.03 | 30.94 | 32.11 | 32.87 | 7.45 | 15.69 | 17.40 | 18.18 |
| Charles | 28.40 | 39.76 | 39.71 | 40.49 | 8.85 | 20.75 | 20.96 | 21.54 |
| Dorchester | 39.22 | 29.13 | 29.26 | 29.48 | 4.34 | 8.49 | 8.71 | 8.91 |
| Frederick | 29.83 | 34.16 | 45.58 | 44.03 | 8.37 | 17.84 | 24.50 | 24.97 |
| Garrett | 24.02 | 24.00 | 30.18 | 27.13 | 2.73 | 8.46 | 11.13 | 10.17 |
| Harford | 43.02 | 45.05 | 46.38 | 46.84 | 21.58 | 28.88 | 31.00 | 32.09 |
| Howard | 40.69 | 54.82 | 54.62 | 56.58 | 21.88 | 43.19 | 44.54 | 47.08 |
| Kent | 27.18 | 29.39 | 29.68 | 29.32 | 2.42 | 6.00 | 5.95 | 5.92 |
| Montgomery | 67.89 | 73.49 | 75.02 | 75.54 | 53.99 | 63.07 | 64.95 | 65.52 |
| Prince George's | 61.29 | 64.19 | 64.19 | 65.55 | 42.44 | 50.01 | 58.31 | 51.11 |
| Queen Anne's | 19.10 | 34.09 | 37.23 | 36.72 | 5.56 | 13.29 | 14.32 | 14.19 |
| Saint Mary's | 30.43 | 25.28 | 25.15 | 25.21 | 1.61 | 5.49 | 5.59 | 5.59 |
| Somerset | 37.88 | 37.13 | 37.59 | 40.80 | 10.62 | 17.16 | 18.53 | 21.44 |
| Talbot | 38.22 | 36.15 | 36.68 | 36.48 | 8.35 | 16.58 | 17.09 | 17.32 |
| Washington | 40.87 | 37.75 | 43.35 | 42.22 | 16.23 | 22.01 | 25.57 | 25.24 |
| Wicomico | 47.24 | 43.26 | 44.00 | 44.43 | 14.87 | 26.01 | 26.99 | 27.88 |
| Worcester | 39.80 | 39.08 | 39.50 | 40.62 | 5.91 | 12.48 | 12.59 | 12.94 |
| Maryland | 40.42 | 43.22 | 44.91 | 45.19 | 18.27 | 26.54 | 28.29 | 28.48 |

**Table 10. Descriptive Statistics of Variables Included in the Model of Land Conversion in the Four Counties for 1992-1997**

| | N | Minimum | Maximum | Mean | Std. Dev. |
|---|---|---|---|---|---|
| Urbanized | 377856 | 0 | 1 | .05 | .213 |
| Distance to urban area (miles) | 377856 | .00 | 2.94 | .39 | .375 |
| Distance to highway (miles squared) | 377856 | .00 | 99.98 | 16.32 | 22.247 |
| Distance to municipality (miles) | 377856 | .00 | 24.37 | 6.85 | 5.271 |
| Floodplain | 377856 | 0 | 1 | .08 | .273 |
| Agricultural land preservation district | 377856 | 0 | 1 | .05 | .224 |
| Proportion adjacent grid cells urbanized | 377856 | .00 | 1.00 | .08 | .184 |
| Average slope of adjacent cells | 377856 | .00 | 21.84 | 4.15 | 2.803 |
| Difference between average adjacent slope and site slope | 377856 | .00 | 17.00 | .82 | .930 |
| Population density, 1990 | 377856 | .00 | 68.52 | 1.36 | 3.371 |
| Proportion population white, 1990 | 376070 | .00 | 1.00 | .93 | .115 |
| Proportion population foreign-born, 1990 | 376070 | .00 | .59 | .03 | .042 |
| Proportion units on public water, 1990 | 376169 | .00 | 1.00 | .26 | .338 |
| Valid N (listwise) | 375674 | | | | |

**Table 11. Descriptive Statistics of Variables Included in the Model of Land Conversion in the Four Counties for 1997-2000**

| | N | Minimum | Maximum | Mean | Std. Dev. |
|---|---|---|---|---|---|
| PFA | 343309 | 0 | 1 | .12 | .320 |
| Urbanized | 343309 | 0 | 1 | .03 | .177 |
| Distance to urban area (miles) | 343309 | .00 | 2.64 | .34 | .307 |
| Distance to highway (miles squared) | 343309 | .00 | 100.00 | 16.43 | 22.207 |
| Distance to municipality (miles) | 343309 | .00 | 24.37 | 6.95 | 5.309 |
| Floodplain | 343309 | 0 | 1 | .08 | .274 |
| Agricultural land preservation district | 343309 | 0 | 1 | .06 | .233 |
| Proportion adjacent grid cells urbanized | 343309 | 0 | 1 | .06 | .167 |
| Average slope of adjacent cells | 343309 | .00 | 27.07 | 5.14 | 3.172 |
| Difference between average adjacent slope and site slope | 343309 | .00 | 21.64 | 1.50 | 1.537 |
| Population density, 2000 | 343309 | .00 | 68.52 | 1.24 | 3.164 |
| Proportion population white, 2000 | 342922 | .03 | 1.00 | .91 | .134 |
| Proportion population foreign-born, 2000 | 342922 | .00 | .88 | .04 | .057 |
| Proportion units on public water, 2000 | 341886 | .00 | 1.00 | .24 | .330 |
| Valid N (listwise) | 341755 | | | | |

**Table 12. Models of Land Conversion Estimated Using the Pooled Data for the Four Counties for 1992-1997 and 1997-2000 (Without County Dummy Variables)**

| *1992-1997 Model* | | | *1997-2000 Model* | | |
|---|---|---|---|---|---|
| **Independent variables** | **Coefficient** | **Sig.** | **Independent variables** | **Coefficient** | **Sig.** |
| | | | PFA | .960 | ** |
| Distance to urbanized area | -1.971 | ** | Distance to urbanized area | -1.767 | ** |
| Squared distance to highway | .012 | ** | Squared distance to highway | -.006 | ** |
| Distance to municipality | -.077 | ** | Distance to municipality | .001 | - |
| Floodplain | -.547 | ** | Floodplain | -.887 | ** |
| Agricultural land preservation district | -1.942 | ** | Agricultural land preservation district | -1.657 | ** |
| Proportion adjacent grid cells urban | 2.844 | ** | Proportion adjacent grid cells urban | .410 | ** |
| Average adjacent slope | .033 | ** | Average adjacent slope | -.014 | ** |
| Difference of slopes | -.116 | ** | Difference of slopes | -.081 | ** |
| Population density | -.029 | ** | Population density | -.056 | ** |
| Proportion white | 1.375 | ** | Proportion white | -.199 | ** |
| Proportion foreign-born | 6.892 | ** | Proportion foreign-born | 3.108 | ** |
| Proportion units on public water | .339 | ** | Proportion units on public water | .605 | ** |

Note: In the table "**" indicates that the coefficient is statistically significant at the 0.05 level, whereas "-" indicates that the coefficient is statistically not significant.

**Table 13. Models of Land Conversion Estimated Using the Pooled Data for the Four Counties for 1992-1997 and 1997-2000 (With County Dummy Variables)**

| *1992-1997 Model* | | | *1997-2000 Model* | | |
|---|---|---|---|---|---|
| **Independent variables** | **Coefficient** | **Sig.** | **Independent variables** | **Coefficient** | **Sig.** |
| | | | PFA | 1.032 | ** |
| Distance to urban | -1.515 | ** | Distance to urban | -2.131 | ** |
| Squared distance to highway | .002 | ** | Squared distance to highway | -.011 | ** |
| Distance to municipality | -.009 | ** | Distance to municipality | .048 | ** |
| Floodplain | -.622 | ** | Floodplain | -.737 | ** |
| Agricultural land preservation district | -2.171 | ** | Agricultural land preservation district | -1.448 | ** |
| Proportion adjacent grid cells urban | 4.170 | ** | Proportion adjacent grid cells urban | .480 | ** |
| Average adjacent slope | -.069 | ** | Average adjacent slope | -.040 | ** |
| Difference of slopes | -.111 | ** | Difference of slopes | -.049 | ** |
| Population density | -.051 | ** | Population density | -.054 | ** |
| Proportion white | -.747 | ** | Proportion white | -.419 | ** |
| Proportion foreign-born | 2.419 | ** | Proportion foreign-born | 2.341 | ** |
| Proportion units on public water | .522 | ** | Proportion units on public water | .770 | ** |
| Garrett | .077 | ** | Garrett | .289 | ** |
| Anne Arundel | -19.776 | - | Anne Arundel | -.649 | ** |
| Baltimore | -.287 | ** | Baltimore | -.993 | ** |

Note: In the table "**" indicates that the coefficient is statistically significant at the 0.05 level, whereas "-" indicates that the coefficient is statistically not significant.

**Table 14. Models of Land Conversion for Anne Arundel County, 1992-1997 and 1997-2000**

| *1992-1997 Model* | | | *1997-2000 Model* | | |
|---|---|---|---|---|---|
| **Independent variables** | **Coefficient** | **Sig.** | **Independent variables** | **Coefficient** | **Sig.** |
| | | | PFA | 1.756 | ** |
| Distance to urbanized area | 1.424 | ** | Distance to urbanized area | -3.548 | ** |
| Squared distance to highway | -.023 | ** | Squared distance to highway | -.363 | ** |
| Distance to municipality | -.015 | ** | Distance to municipality | .089 | ** |
| Floodplain | .411 | ** | Floodplain | -.722 | ** |
| Agricultural land preservation district | -1.465 | ** | Agricultural land preservation district | -.953 | ** |
| Proportion adjacent grid cells urban | 7.846 | ** | Proportion adjacent grid cells urban | -.235 | ** |
| Average adjacent slope | -.039 | - | Average adjacent slope | -.076 | ** |
| Difference of slopes | .034 | - | Difference of slopes | .023 | - |
| Population density | -.077 | ** | Population density | .014 | ** |
| Proportion white | -.015 | - | Proportion white | .160 | - |
| Proportion foreign-born | 2.435 | ** | Proportion foreign-born | -3.460 | ** |
| Proportion units on public water | -.135 | ** | Proportion units on public water | 1.453 | ** |

Note: In the table "**" indicates that the coefficient is statistically significant at the 0.05 level, whereas "-" indicates that the coefficient is statistically not significant.

**Table 15. Models of Land Conversion for Baltimore County, 1992-1997 and 1997-2000**

| *1992-1997 Model* | | | *1997-2000 Model* | | |
|---|---|---|---|---|---|
| **Independent variables** | **Coefficient** | **Sig.** | **Independent variables** | **Coefficient** | **Sig.** |
| | | | PFA | 1.011 | ** |
| Distance to urbanized area | -9.200 | ** | Distance to urbanized area | -5.835 | ** |
| Squared distance to highway | -.005 | ** | Squared distance to highway | -.005 | ** |
| Distance to municipality | -.018 | ** | Distance to municipality | -.001 | - |
| Floodplain | -.448 | ** | Floodplain | -.257 | ** |
| Agricultural land preservation district | -1.840 | ** | Agricultural land preservation district | -1.999 | ** |
| Proportion adjacent grid cells urban | 3.467 | ** | Proportion adjacent grid cells urban | .685 | ** |
| Average adjacent slope | .008 | - | Average adjacent slope | -.166 | ** |
| Difference of slopes | -.082 | ** | Difference of slopes | .015 | - |
| Population density | -.052 | ** | Population density | -.022 | ** |
| Proportion white | -.370 | ** | Proportion white | .694 | ** |
| Proportion foreign-born | .141 | - | Proportion foreign-born | 3.921 | ** |
| Proportion units on public water | .310 | ** | Proportion units on public water | -.268 | ** |

Note: In the table "**" indicates that the coefficient is statistically significant at the 0.05 level, whereas "-" indicates that the coefficient is statistically not significant.

**Table 16. Models of Land Conversion for Garrett County, 1992-1997 and 1997-2000**

| *1992-1997 Model* | | | *1997-2000 Model* | | |
|---|---|---|---|---|---|
| **Independent variables** | **Coefficient** | **Sig.** | **Independent variables** | **Coefficient** | **Sig.** |
| | | | PFA | -.641 | ** |
| Distance to urbanized area | -.248 | ** | Distance to urbanized area | -.622 | ** |
| Squared distance to highway | .011 | ** | Squared distance to highway | -.032 | ** |
| Distance to municipality | .032 | ** | Distance to municipality | -.005 | - |
| Floodplain | -.357 | ** | Floodplain | -.245 | ** |
| Agricultural land preservation district | -1.499 | ** | Agricultural land preservation district | -2.788 | ** |
| Proportion adjacent grid cells urban | 6.922 | ** | Proportion adjacent grid cells urban | 2.630 | ** |
| Average adjacent slope | -.106 | ** | Average adjacent slope | .059 | ** |
| Difference of slopes | -.077 | ** | Difference of slopes | -.046 | ** |
| Population density | -.081 | - | Population density | .914 | ** |
| Proportion white | -5.173 | ** | Proportion white | 15.874 | ** |
| Proportion foreign-born | 2.076 | - | Proportion foreign-born | 15.565 | ** |
| Proportion units on public water | .864 | ** | Proportion units on public water | -.706 | ** |

Note: In the table "**" indicates that the coefficient is statistically significant at the 0.05 level, whereas "-" indicates that the coefficient is statistically not significant.

**Table 17. Models of Land Conversion for Montgomery County, 1992-1997 and 1997-2000**

| *1992-1997 Model* | | | *1997-2000 Model* | | |
|---|---|---|---|---|---|
| **Independent variables** | **Coefficient** | **Sig.** | **Independent variables** | **Coefficient** | **Sig.** |
| | | | PFA | .505 | ** |
| Distance to urbanized area | -3.992 | ** | Distance to urbanized area | -4.013 | ** |
| Squared distance to highway | -.011 | ** | Squared distance to highway | -.005 | ** |
| Distance to municipality | -.074 | ** | Distance to municipality | -.165 | ** |
| Floodplain | -.724 | ** | Floodplain | -1.251 | ** |
| Agricultural land preservation district | -17.619 | - | Agricultural land preservation district | -17.439 | - |
| Proportion adjacent grid cells urban | 2.419 | ** | Proportion adjacent grid cells urban | -.288 | ** |
| Average adjacent slope | -.320 | ** | Average adjacent slope | -.212 | ** |
| Difference of slopes | -.121 | ** | Difference of slopes | -.177 | ** |
| Population density | -.041 | ** | Population density | -.138 | ** |
| Proportion white | -1.818 | ** | Proportion white | -2.189 | ** |
| Proportion foreign-born | -.384 | - | Proportion foreign-born | 3.825 | ** |
| Proportion units on public water | .488 | ** | Proportion units on public water | .004 | - |

Note: In the table "**" indicates that the coefficient is statistically significant at the 0.05 level, whereas "-" indicates that the coefficient is statistically not significant.

**Table 18. Models of Land Conversion for the Four Counties (with "area later became PFA" dummy variable)**

| *1992-1997 Model* | | | *1997-2000 Model* | | |
|---|---|---|---|---|---|
| **Independent variables** | **Coefficient** | **Sig.** | **Independent variables** | **Coefficient** | **Sig.** |
| Area later became PFA | .650 | ** | PFA | .960 | ** |
| Distance to urbanized area | -1.927 | ** | Distance to urbanized area | -1.767 | ** |
| Squared distance to highway | .014 | ** | Squared distance to highway | -.006 | ** |
| Distance to municipality | -.076 | ** | Distance to municipality | .001 | - |
| Floodplain | -.560 | ** | Floodplain | -.887 | ** |
| Agricultural land preservation district | -1.921 | ** | Agricultural land preservation district | -1.657 | ** |
| Proportion adjacent grid cells urban | 2.762 | ** | Proportion adjacent grid cells urban | .410 | ** |
| Average adjacent slope | .040 | ** | Average adjacent slope | -.014 | ** |
| Difference of slopes | -.108 | ** | Difference of slopes | -.081 | ** |
| Population density | -.041 | ** | Population density | -.056 | ** |
| Proportion white | 1.425 | ** | Proportion white | -.199 | ** |
| Proportion foreign-born | 7.045 | ** | Proportion foreign-born | 3.108 | ** |
| Proportion units on public water | .005 | - | Proportion units on public water | .605 | ** |

Note: In the table "**" indicates that the coefficient is statistically significant at the 0.05 level, whereas "-" indicates that the coefficient is statistically not significant.

**Table 19. Models of Land Conversion for Anne Arundel County (with "area later became PFA" dummy variable)**

| *1992-1997 Model* | | | *1997-2000 Model* | | |
|---|---|---|---|---|---|
| **Independent variables** | **Coefficient** | **Sig.** | **Independent variables** | **Coefficient** | **Sig.** |
| Area later became PFA | -.133 | ** | PFA | 1.756 | ** |
| Distance to urbanized area | 1.403 | ** | Distance to urbanized area | -3.548 | ** |
| Squared distance to highway | -.022 | ** | Squared distance to highway | -.363 | ** |
| Distance to municipality | -.014 | ** | Distance to municipality | .089 | ** |
| Floodplain | .409 | ** | Floodplain | -.722 | ** |
| Agricultural land preservation district | -1.478 | ** | Agricultural land preservation district | -.953 | ** |
| Proportion adjacent grid cells urban | 7.876 | ** | Proportion adjacent grid cells urban | -.235 | ** |
| Average adjacent slope | -.043 | - | Average adjacent slope | -.076 | ** |
| Difference of slopes | .034 | - | Difference of slopes | .023 | - |
| Population density | -.075 | ** | Population density | .014 | ** |
| Proportion white | -.032 | - | Proportion white | .160 | - |
| Proportion foreign-born | 2.628 | ** | Proportion foreign-born | -3.460 | ** |
| Proportion units on public water | -.075 | - | Proportion units on public water | 1.453 | ** |

Note: In the table "**" indicates that the coefficient is statistically significant at the 0.05 level, whereas "-" indicates that the coefficient is statistically not significant.

**Table 20. Models of Land Conversion for Baltimore County (with "area later became PFA" dummy variable)**

| *1992-1997 Model* | | | *1997-2000 Model* | | |
|---|---|---|---|---|---|
| **Independent variables** | **Coefficient** | **Sig.** | **Independent variables** | **Coefficient** | **Sig.** |
| Area later became PFA | .317 | ** | PFA | 1.011 | ** |
| Distance to urbanized area | -9.166 | ** | Distance to urbanized area | -5.835 | ** |
| Squared distance to highway | -.004 | ** | Squared distance to highway | -.005 | ** |
| Distance to municipality | -.014 | ** | Distance to municipality | -.001 | - |
| Floodplain | -.432 | ** | Floodplain | -.257 | ** |
| Agricultural land preservation district | -1.833 | ** | Agricultural land preservation district | -1.999 | ** |
| Proportion adjacent grid cells urban | 3.447 | ** | Proportion adjacent grid cells urban | .685 | ** |
| Average adjacent slope | .011 | - | Average adjacent slope | -.166 | ** |
| Difference of slopes | -.082 | ** | Difference of slopes | .015 | - |
| Population density | -.054 | ** | Population density | -.022 | ** |
| Proportion white | -.413 | ** | Proportion white | .694 | ** |
| Proportion foreign-born | .326 | - | Proportion foreign-born | 3.921 | ** |
| Proportion units on public water | .081 | - | Proportion units on public water | -.268 | ** |

Note: In the table "**" indicates that the coefficient is statistically significant at the 0.05 level, whereas "-" indicates that the coefficient is statistically not significant.

**Table 21. Models of Land Conversion for Garrett County (with “area later became PFA” dummy variable)**

| *1992-1997 Model* | | | *1997-2000 Model* | | |
|---|---|---|---|---|---|
| **Independent variables** | **Coefficient** | **Sig.** | **Independent variables** | **Coefficient** | **Sig.** |
| Area later became PFA | .906 | ** | PFA | -.641 | ** |
| Distance to urbanized area | -.245 | ** | Distance to urbanized area | -.622 | ** |
| Squared distance to highway | .011 | ** | Squared distance to highway | -.032 | ** |
| Distance to municipality | .034 | ** | Distance to municipality | -.005 | - |
| Floodplain | -.395 | ** | Floodplain | -.245 | ** |
| Agricultural land preservation district | -1.463 | ** | Agricultural land preservation district | -2.788 | ** |
| Proportion adjacent grid cells urban | 6.714 | ** | Proportion adjacent grid cells urban | 2.630 | ** |
| Average adjacent slope | -.105 | ** | Average adjacent slope | .059 | ** |
| Difference of slopes | -.076 | ** | Difference of slopes | -.046 | ** |
| Population density | -.309 | ** | Population density | .914 | ** |
| Proportion white | -4.956 | ** | Proportion white | 15.874 | ** |
| Proportion foreign-born | 2.109 | - | Proportion foreign-born | 15.565 | ** |
| Proportion units on public water | .807 | ** | Proportion units on public water | -.706 | ** |

Note: In the table “**” indicates that the coefficient is statistically significant at the 0.05 level, whereas “-” indicates that the coefficient is statistically not significant.

**Table 22. Models of Land Conversion for Montgomery County (with "area later became PFA" dummy variable)**

| *1992-1997 Model* | | | *1997-2000 Model* | | |
|---|---|---|---|---|---|
| **Independent variables** | **Coefficient** | **Sig.** | **Independent variables** | **Coefficient** | **Sig.** |
| Area later became PFA | .514 | ** | PFA | .505 | ** |
| Distance to urbanized area | -3.878 | ** | Distance to urbanized area | -4.013 | ** |
| Squared distance to highway | -.008 | ** | Squared distance to highway | -.005 | ** |
| Distance to municipality | -.050 | ** | Distance to municipality | -.165 | ** |
| Floodplain | -.743 | ** | Floodplain | -1.251 | ** |
| Agricultural land preservation district | -17.706 | - | Agricultural land preservation district | -17.439 | - |
| Proportion adjacent grid cells urban | 2.410 | ** | Proportion adjacent grid cells urban | -.288 | ** |
| Average adjacent slope | -.301 | ** | Average adjacent slope | -.212 | ** |
| Difference of slopes | -.126 | ** | Difference of slopes | -.177 | ** |
| Population density | -.052 | ** | Population density | -.138 | ** |
| Proportion white | -1.605 | ** | Proportion white | -2.189 | ** |
| Proportion foreign-born | -.037 | - | Proportion foreign-born | 3.825 | ** |
| Proportion units on public water | .337 | ** | Proportion units on public water | .004 | - |

Note: In the table "**" indicates that the coefficient is statistically significant at the 0.05 level, whereas "-" indicates that the coefficient is statistically not significant.

## List of Figures

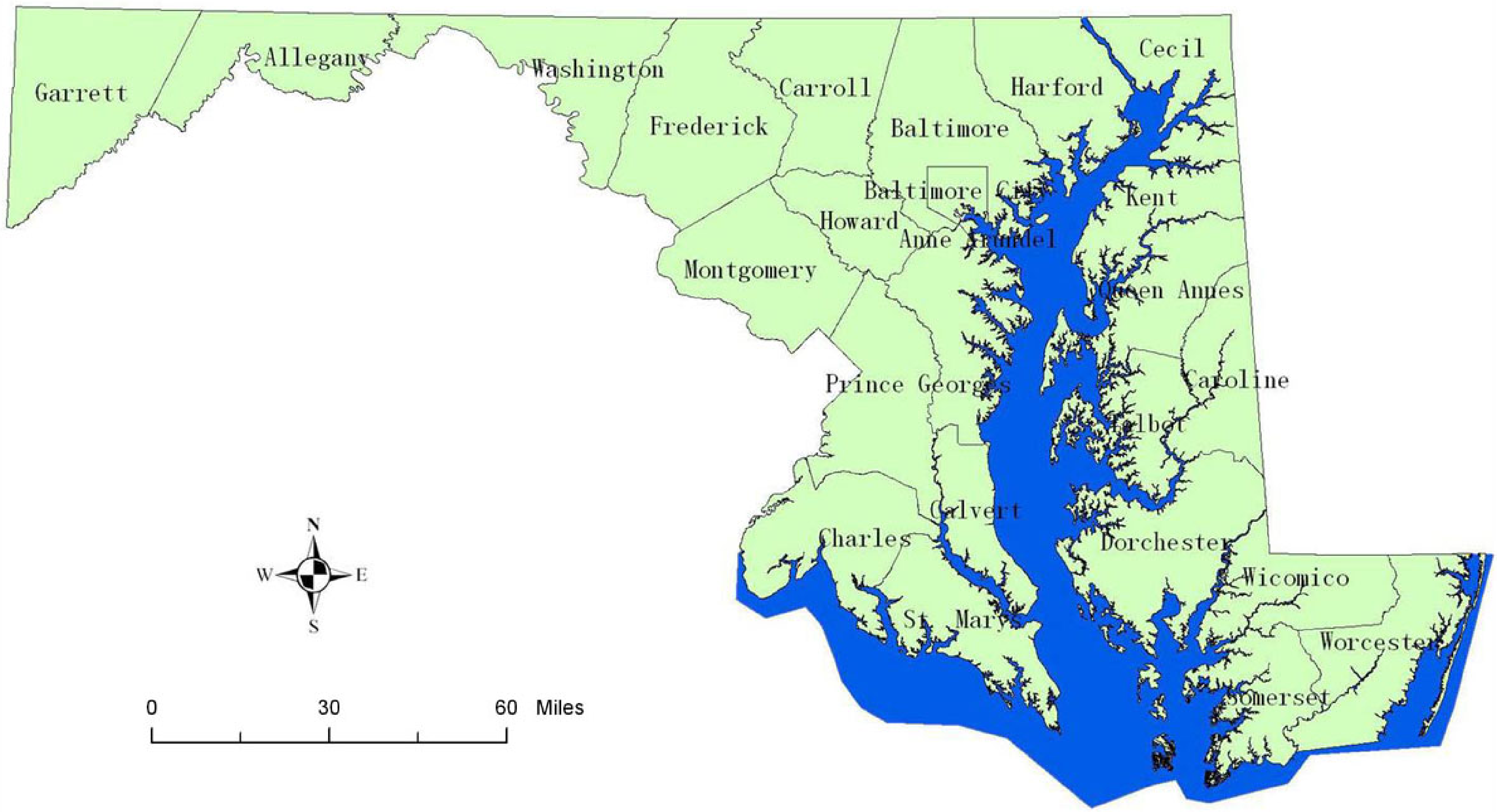


**Figure 1. Maryland and Its Local Jurisdictions (Counties and Baltimore City)**

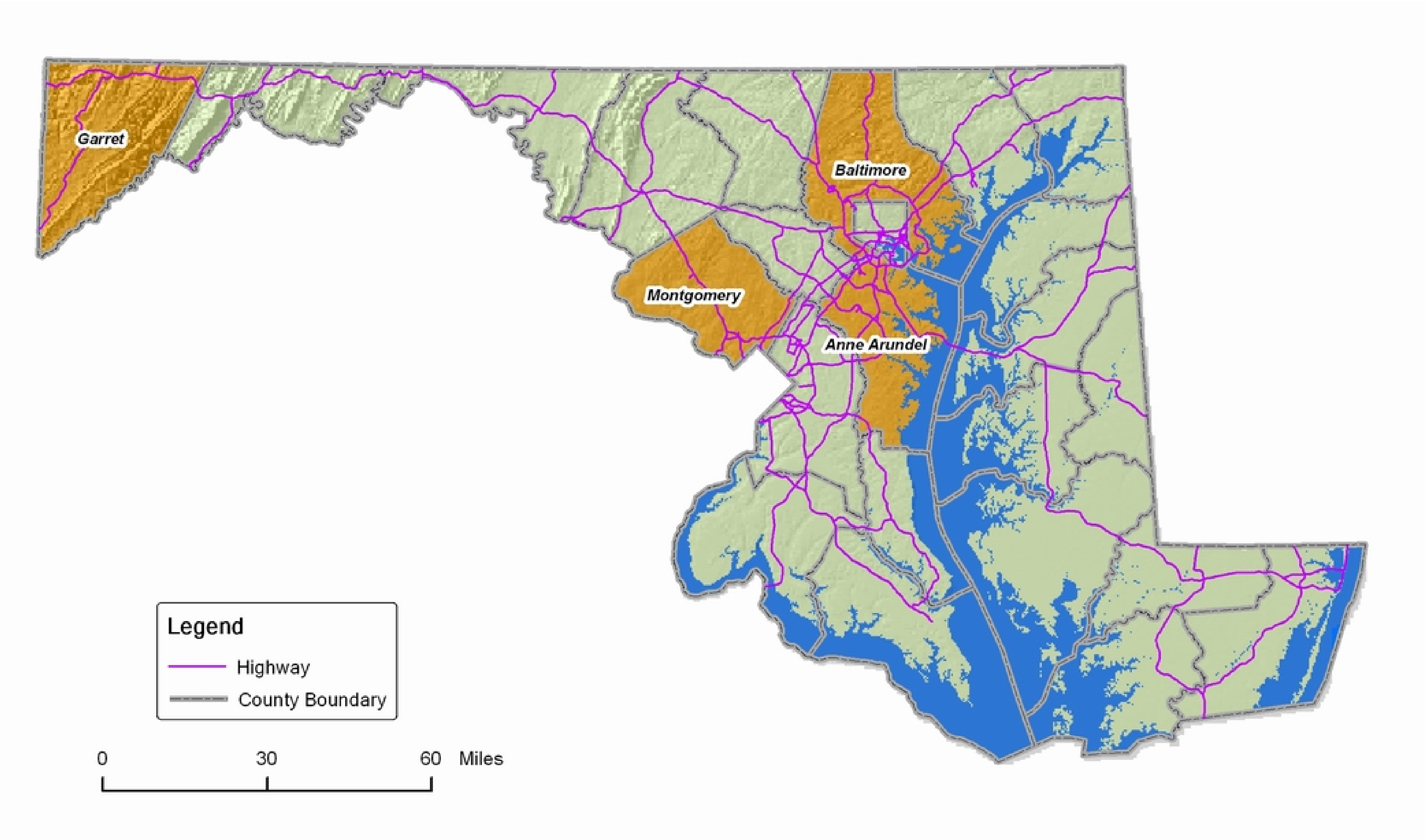


**Figure 2. Selected Counties for Modeling Land Conversion**

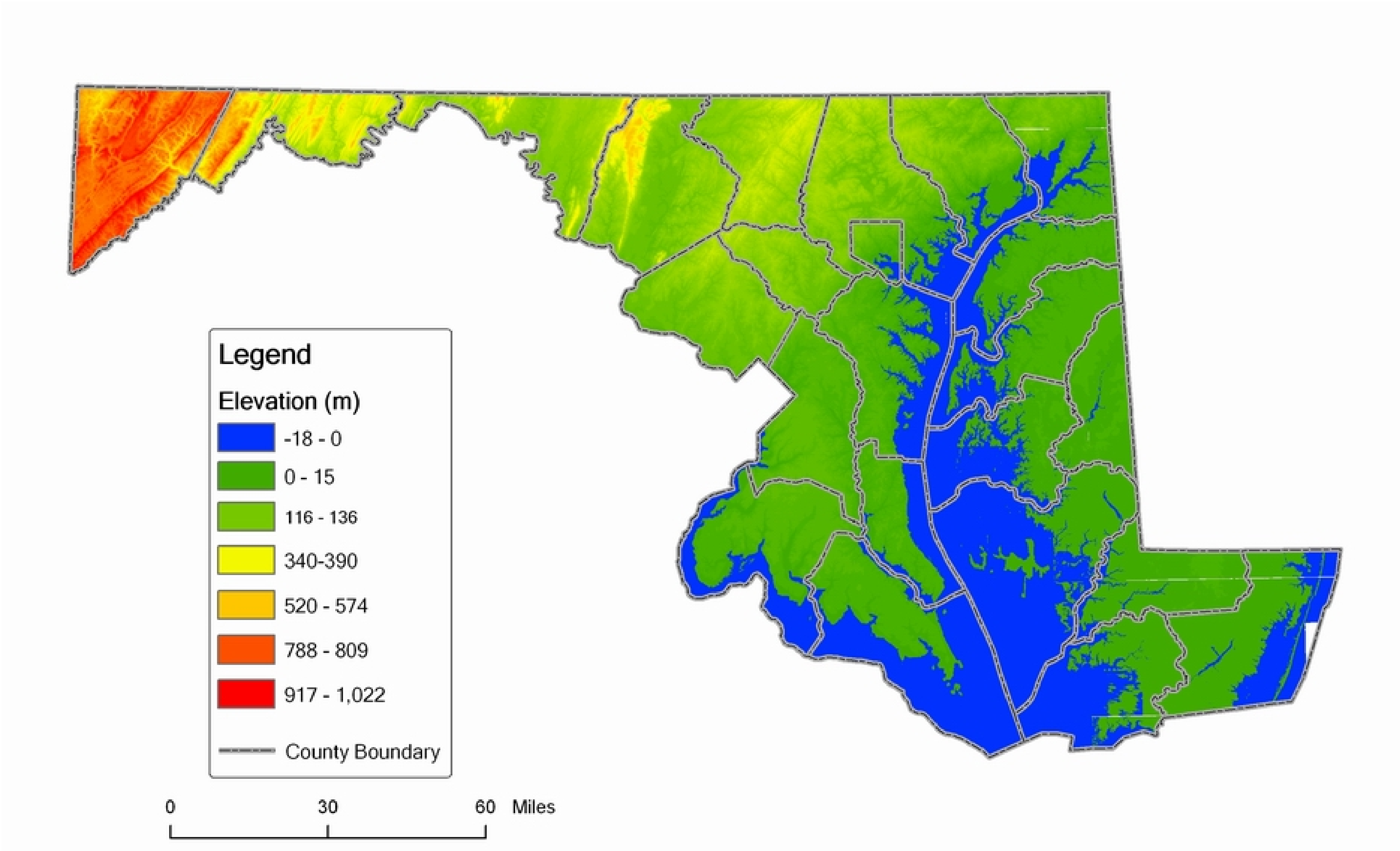


**Figure 3. Elevations of Maryland Counties**

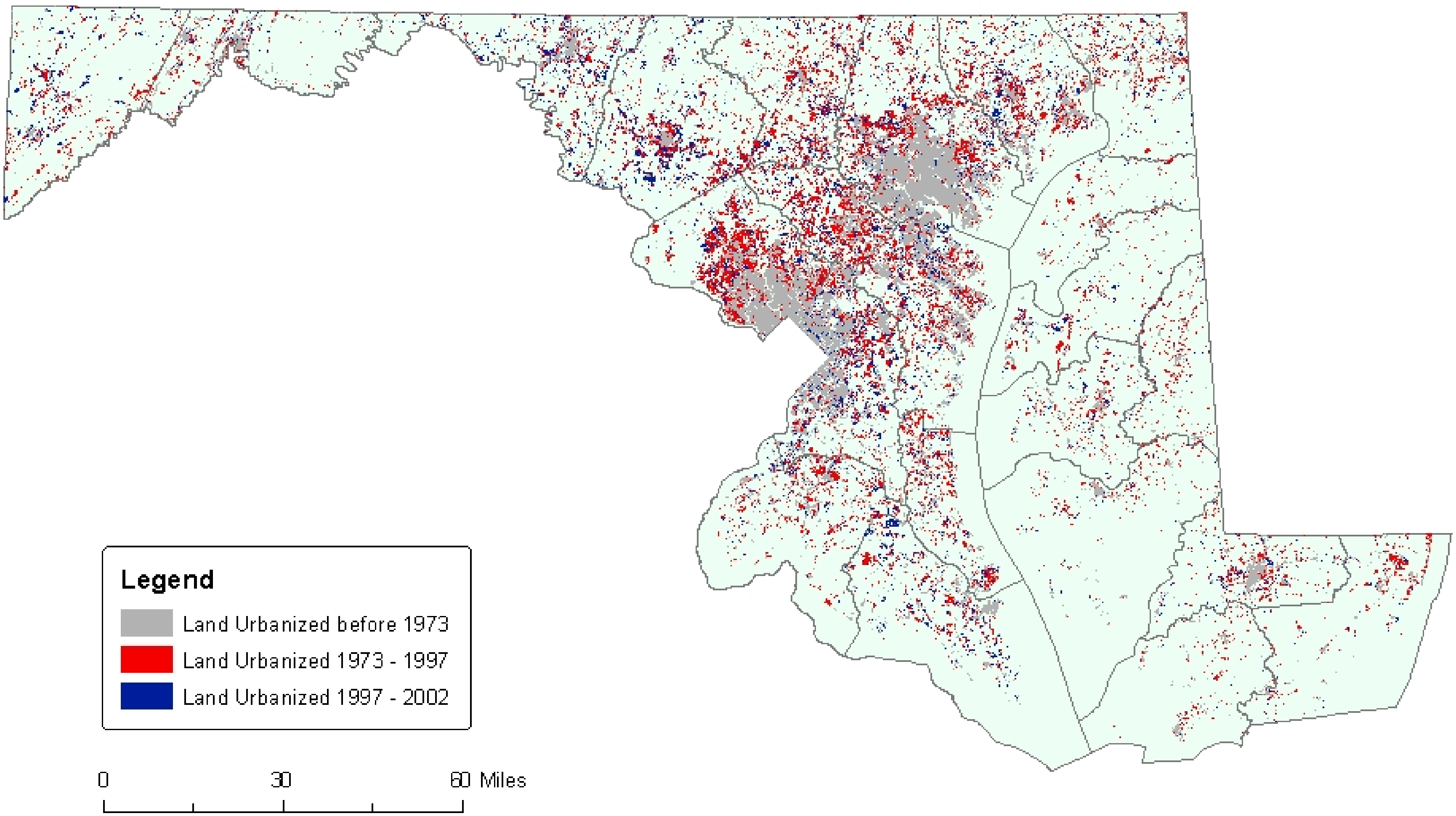


**Figure 4. Urbanized Land Areas in Maryland, 1973, 1997, and 2002**

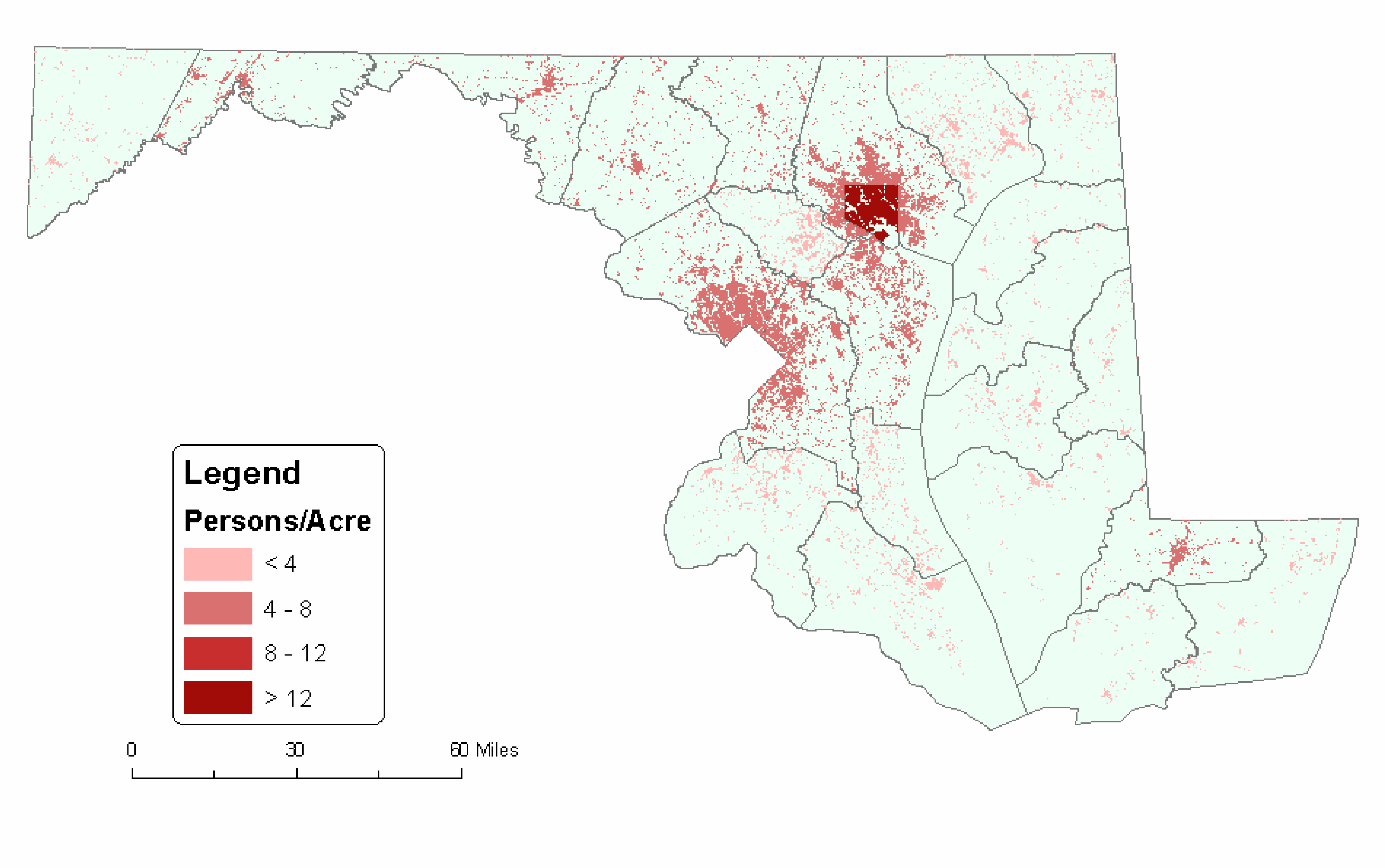


**Figure 5. Urbanized Area and Net Population Density in 1973**

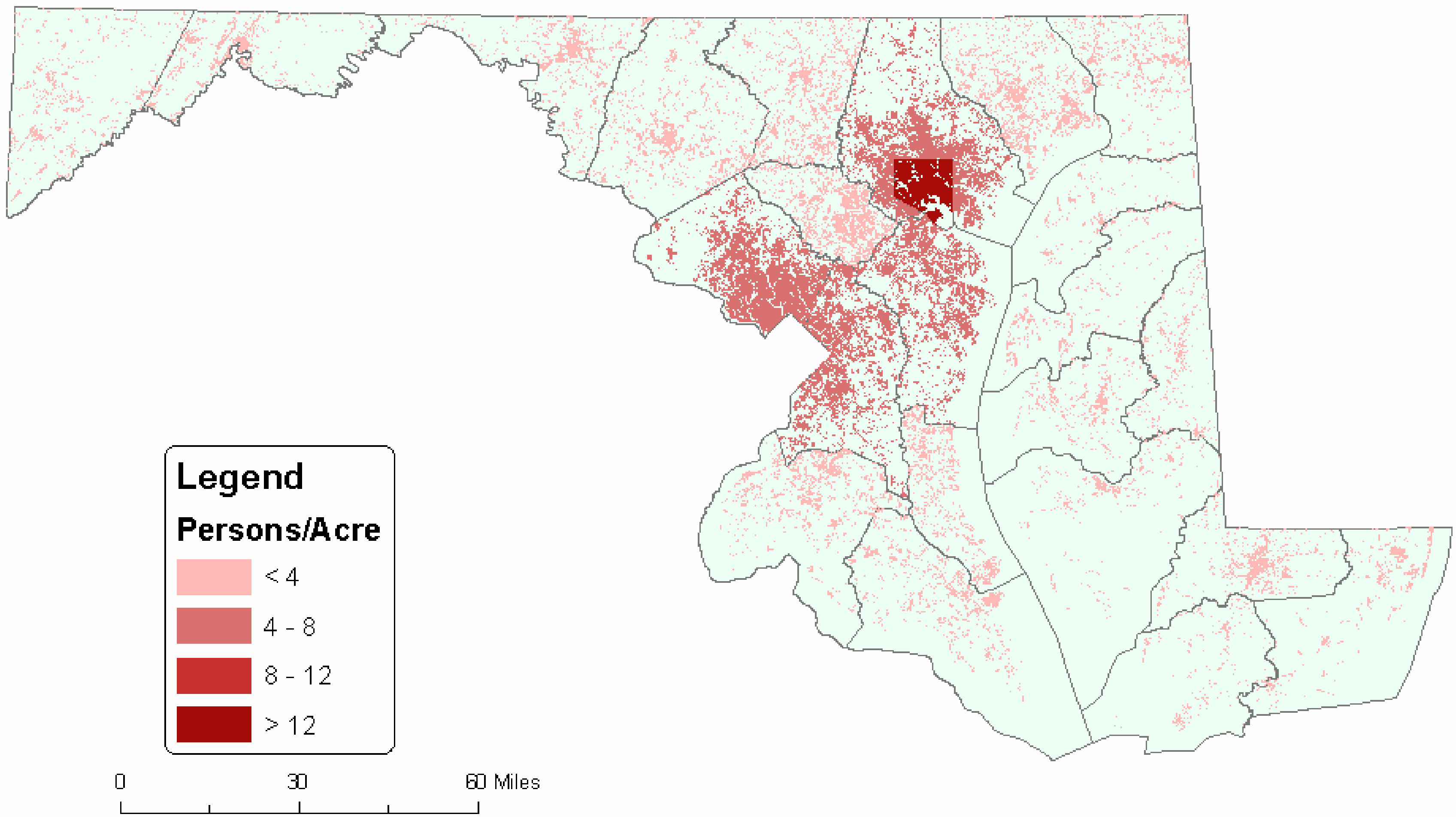


**Figure 6. Urbanized Area and Net Population Density in 1997**

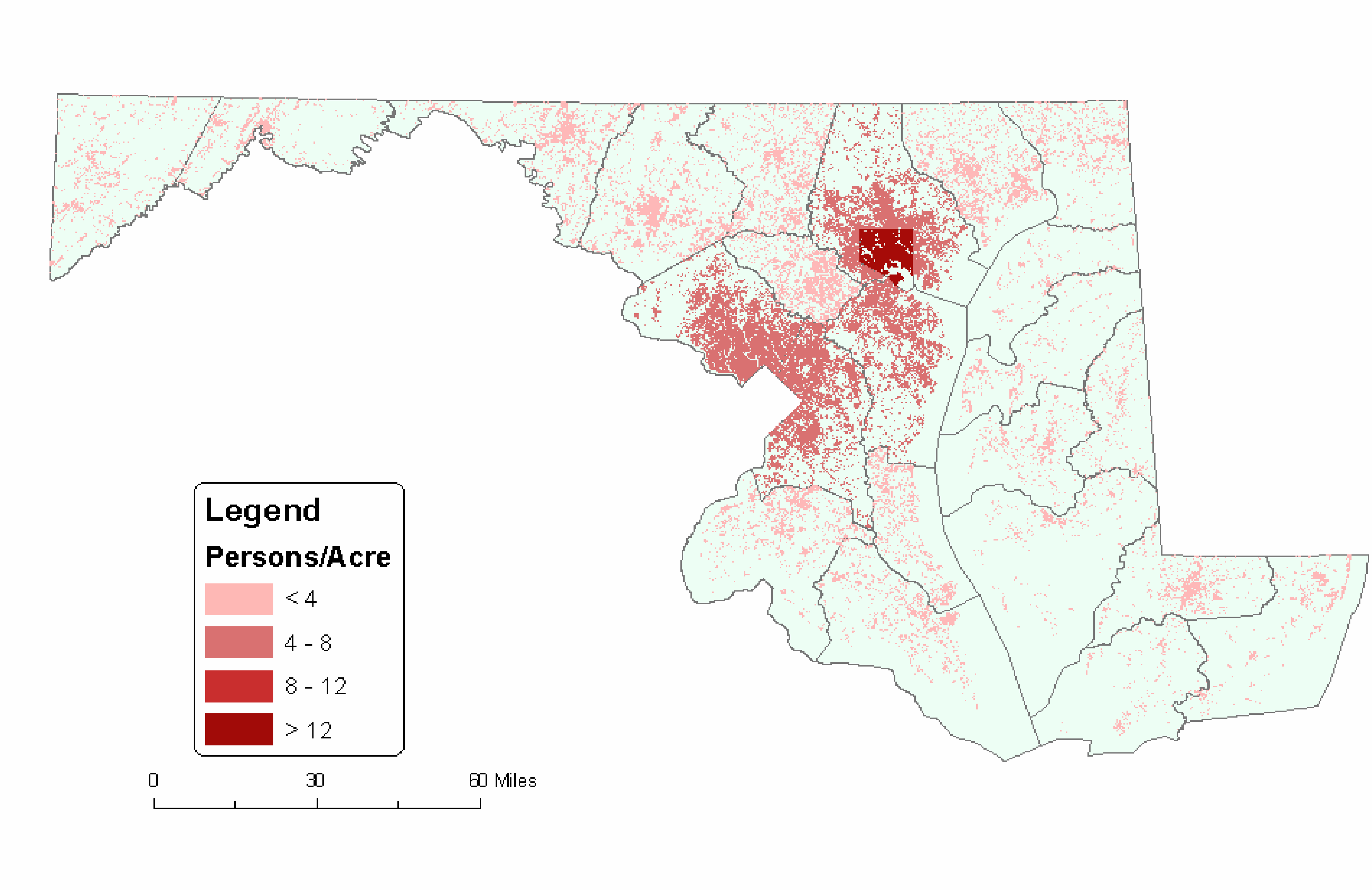


**Figure 7. Urbanized Area and Net Population Density in 2002**

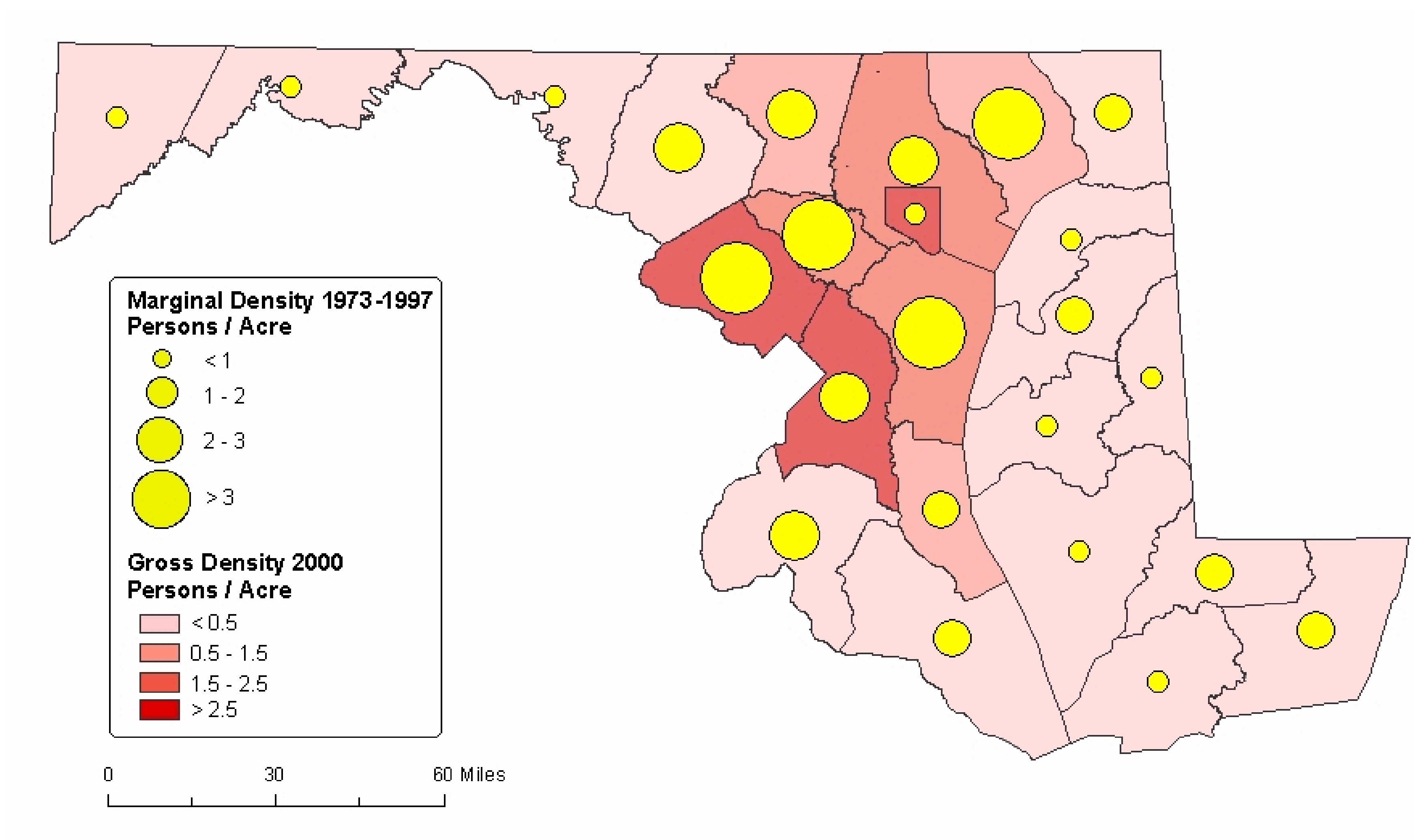


**Figure 8. Marginal Population Density, 1973-1997**

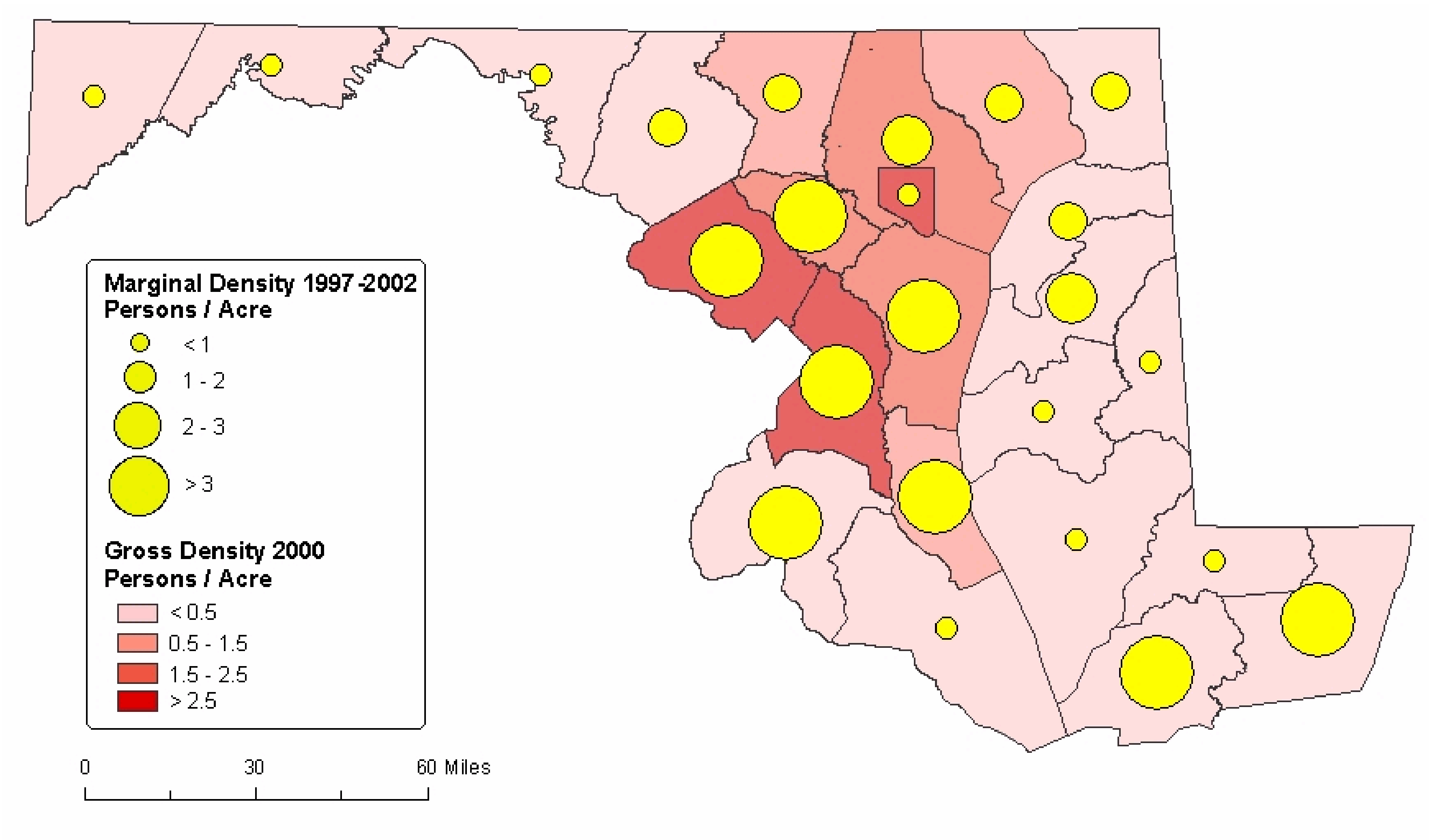


**Figure 9. Marginal Population Density, 1997-2002**

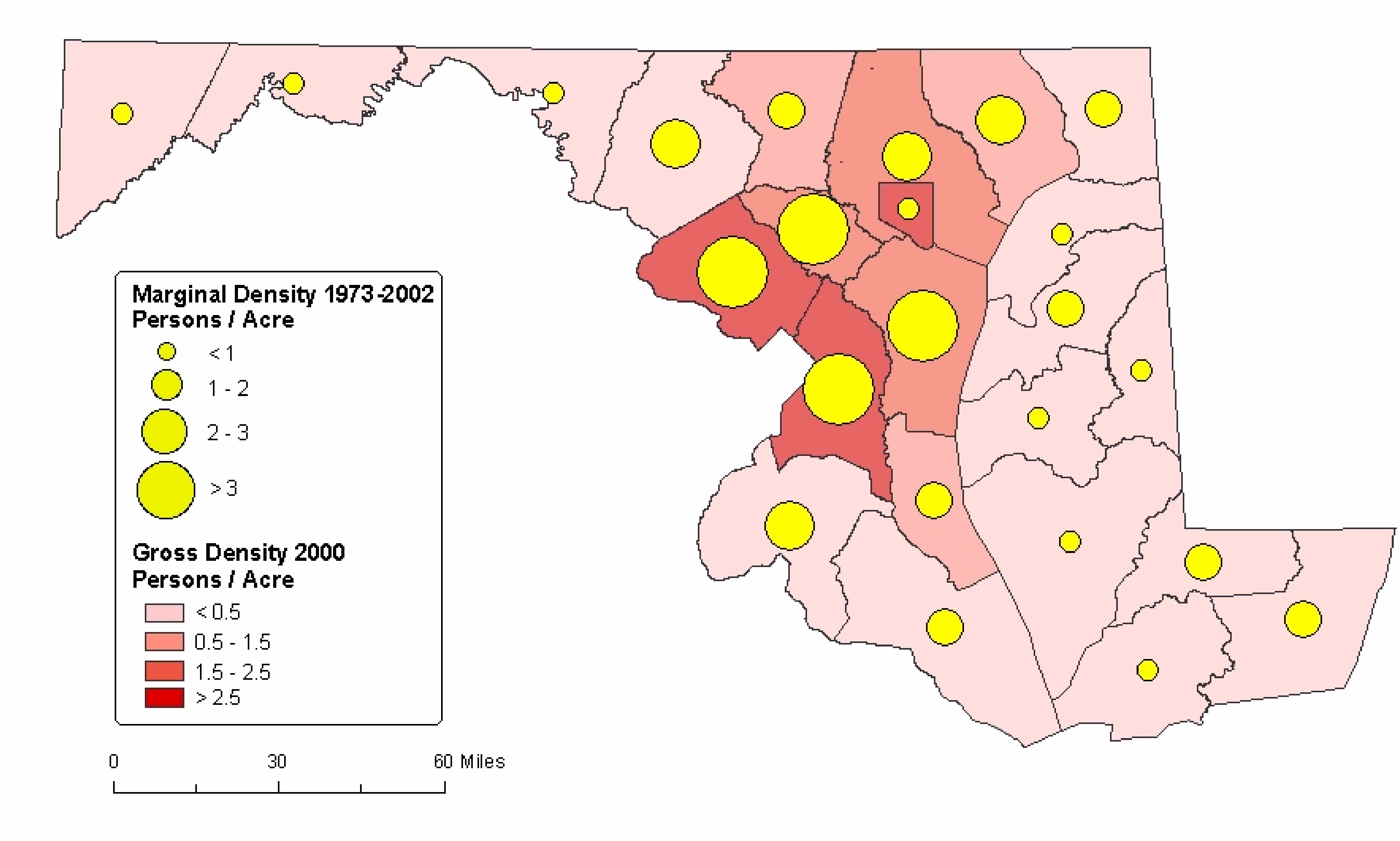


**Figure 10. Marginal Population Density, 1973-2002**

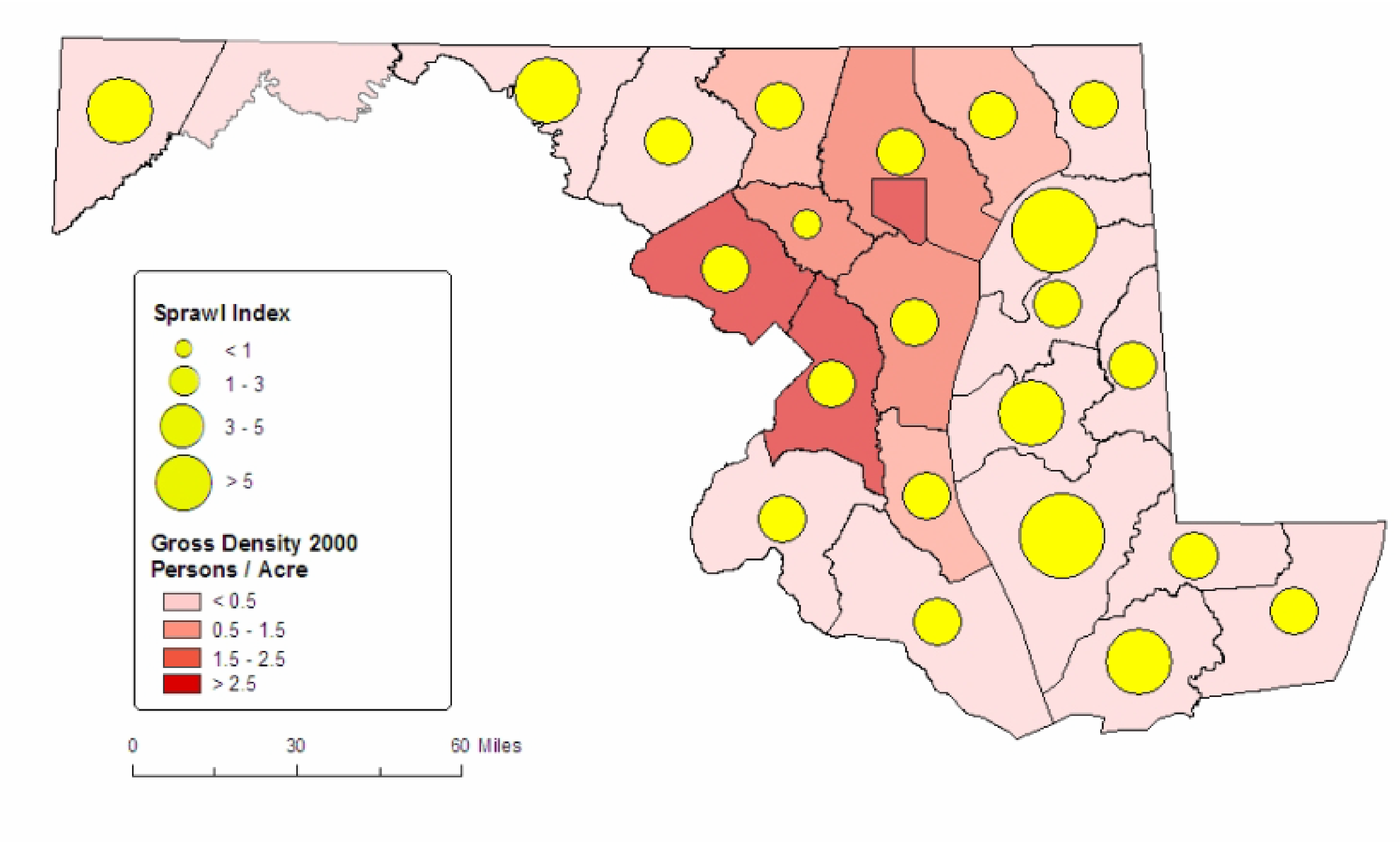


**Figure 11. Sprawl Index, 1973-1997**

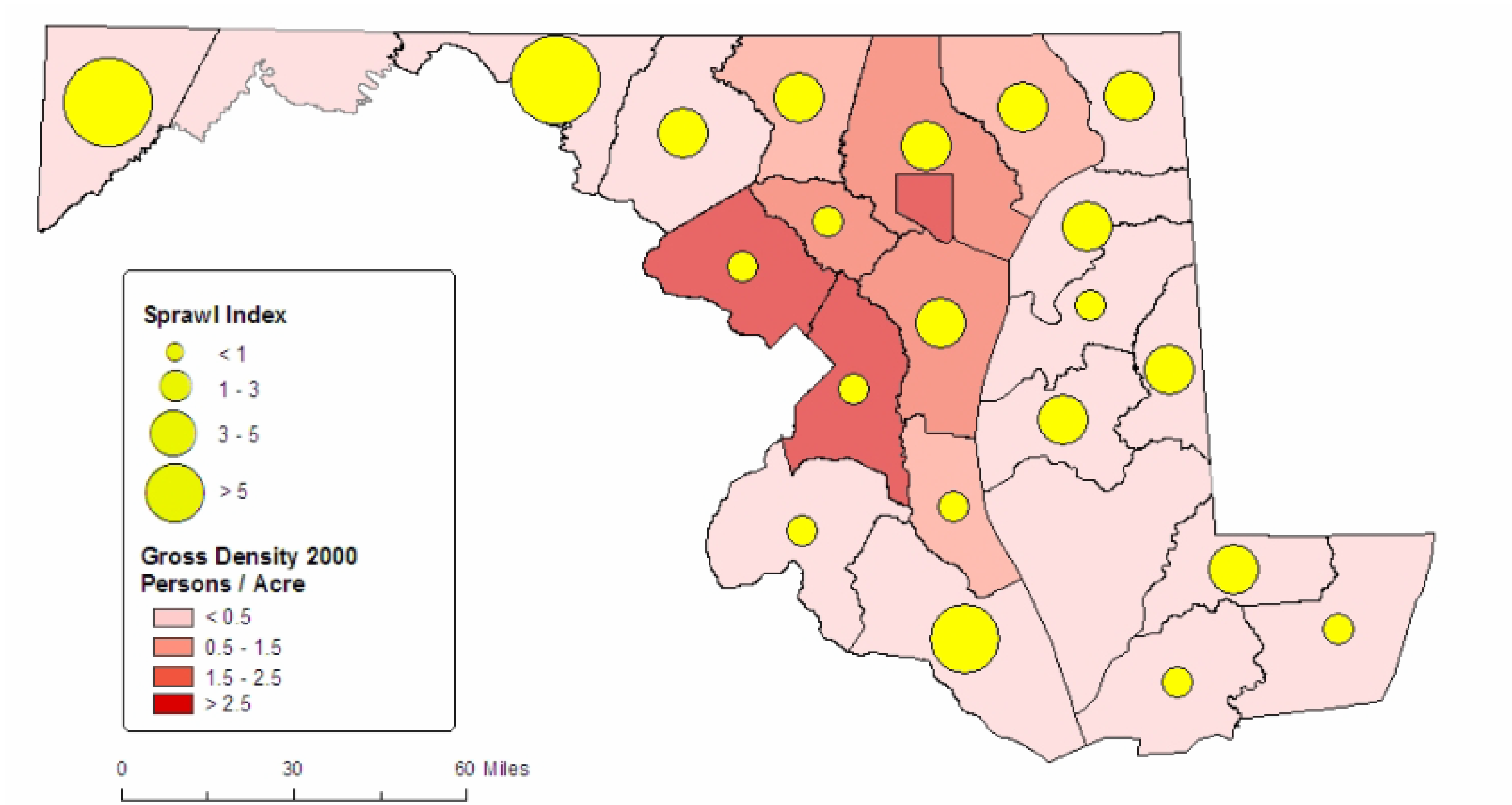


**Figure 12. Sprawl Index, 1997-2002**

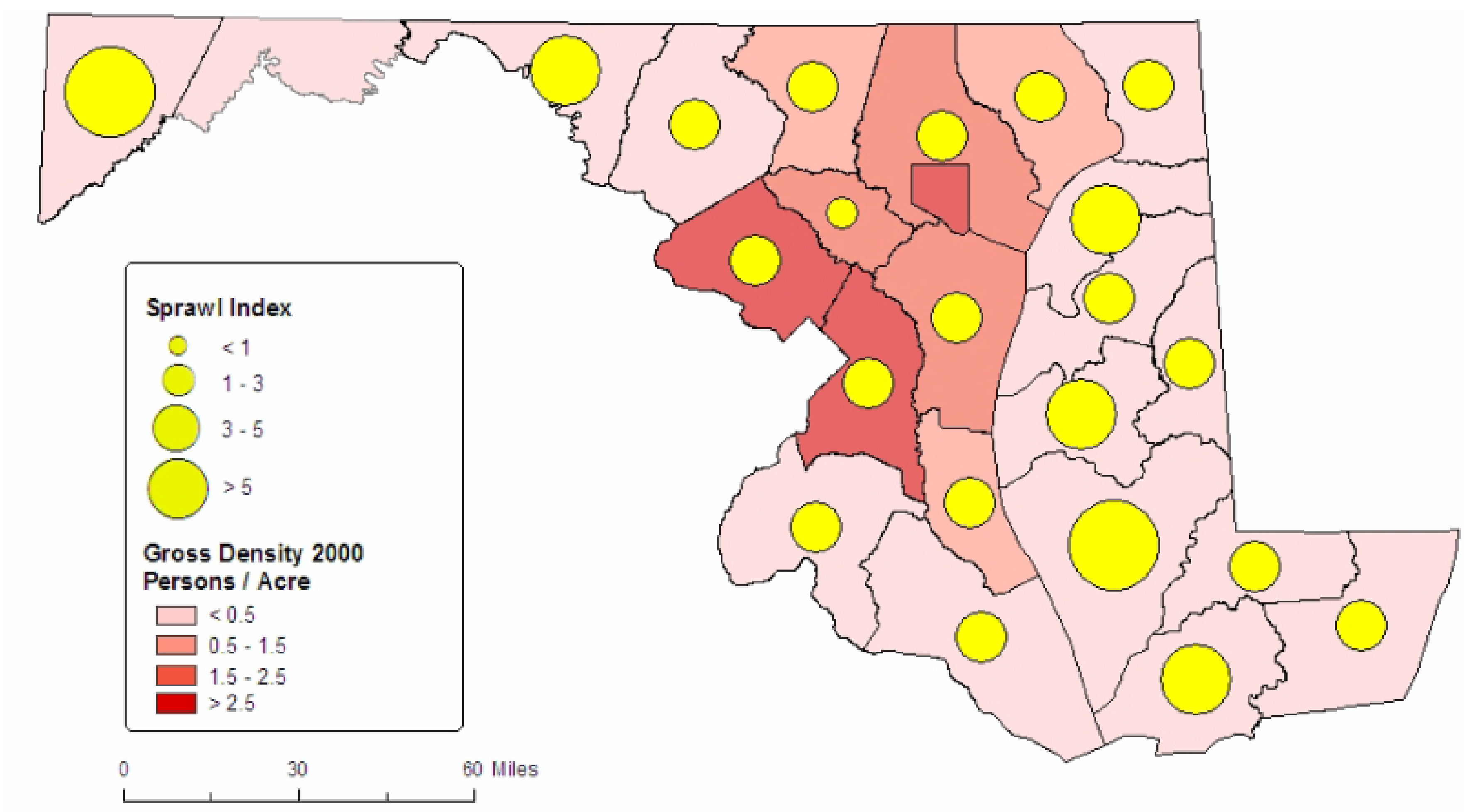


**Figure 13. Sprawl Index, 1973-2002**

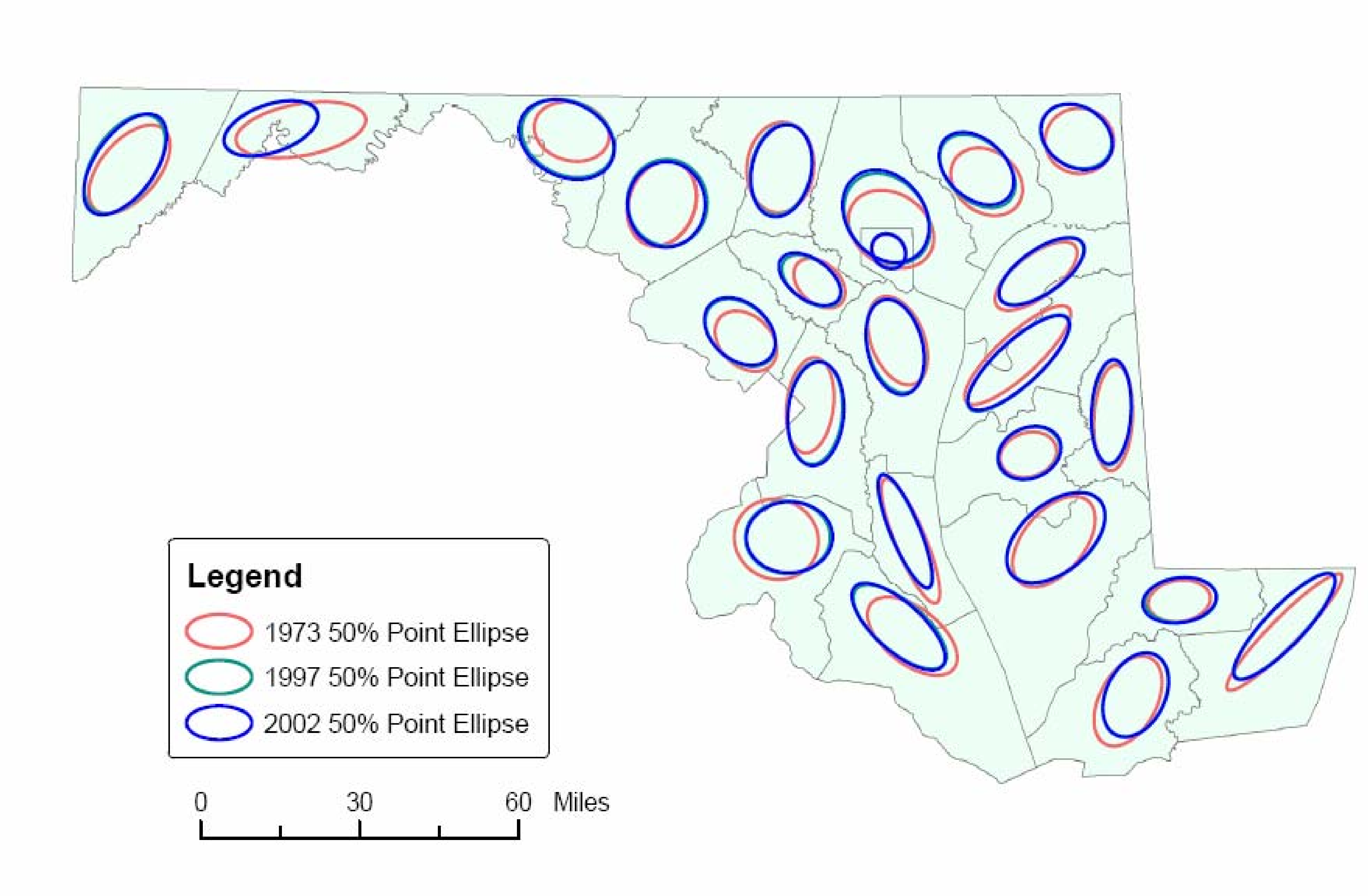


**Figure 14. Compactness of Urban Development, 1973, 1997, and 2002**

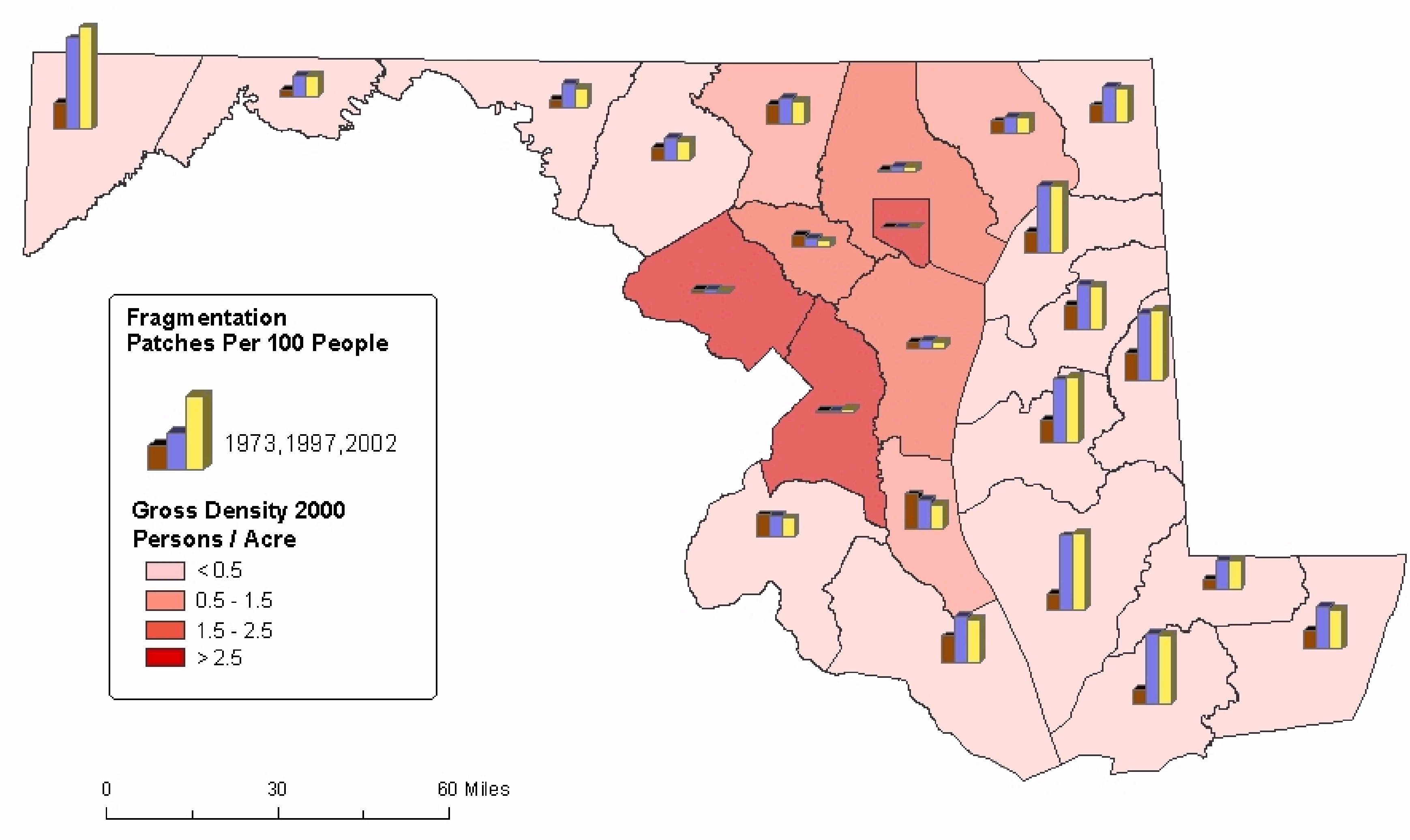


**Figure 15. Fragmentation of Urban Development (Patches-Population Ratio), 1973, 1997, and 2002**

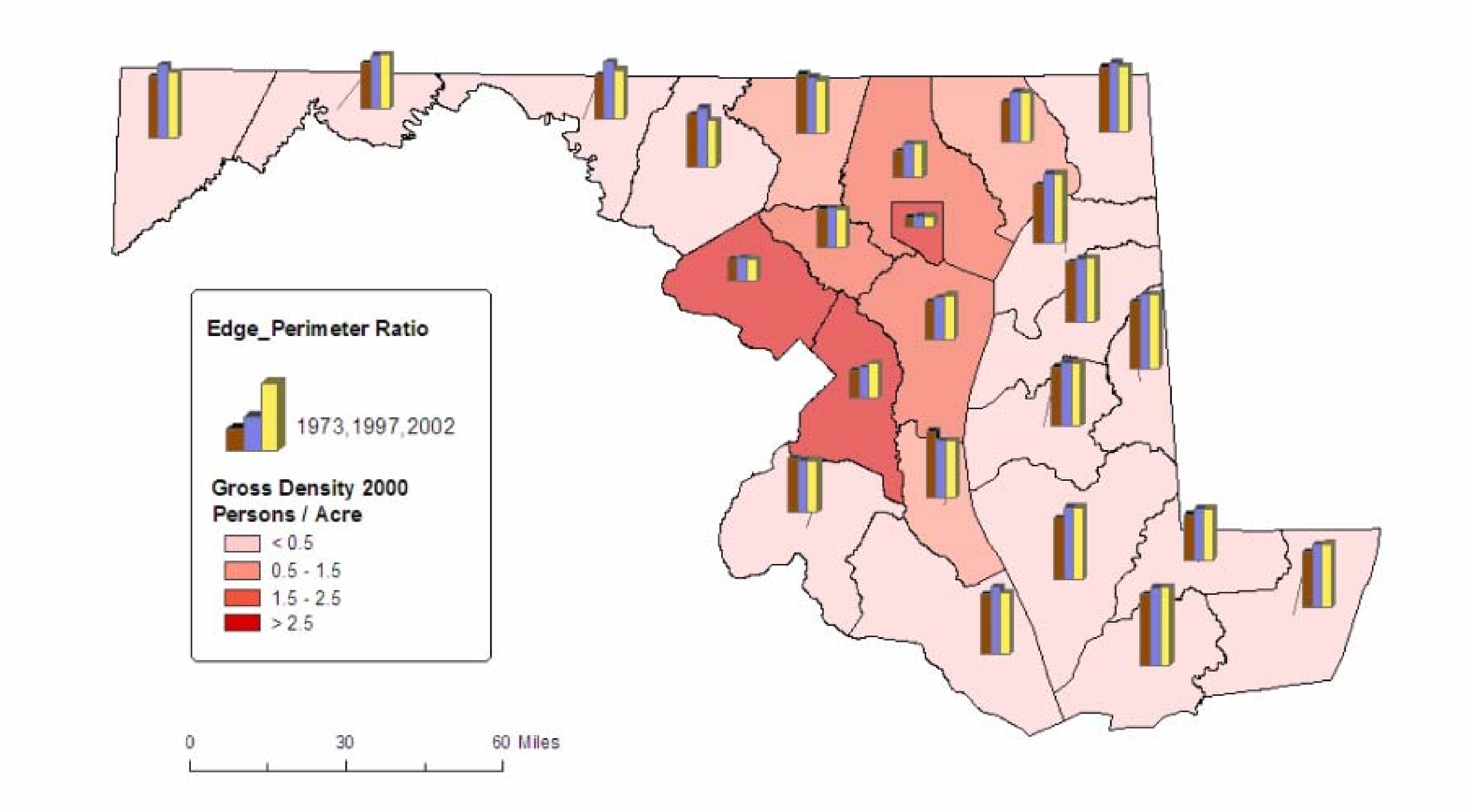


**Figure 16. Fragmentation of Urban Development (Edge-Perimeter Ratio), 1973, 1997, and 2002**

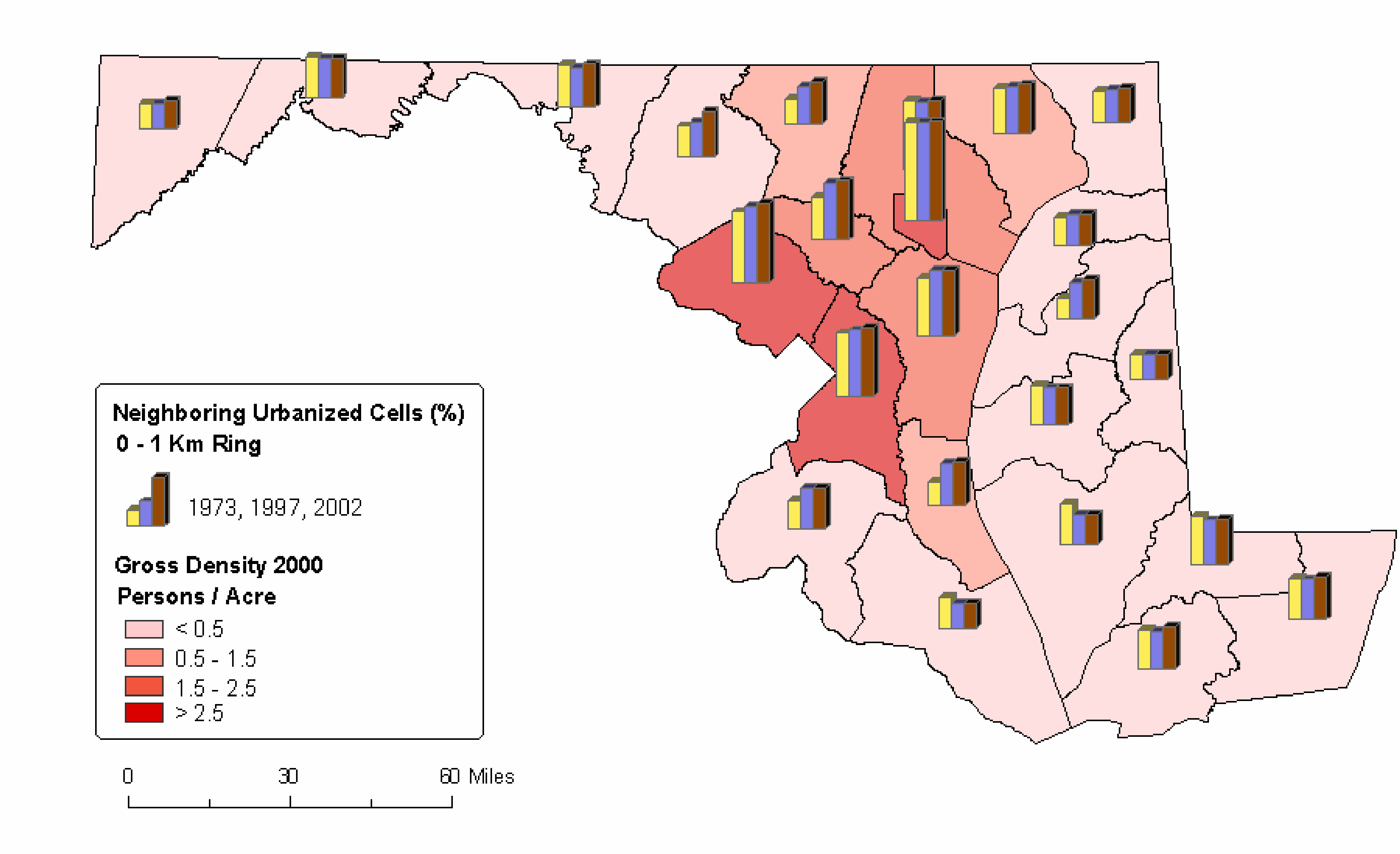


**Figure 17. Continuity Gradients for 0-1 Kilometer Ring, 1973, 1997, and 2002**

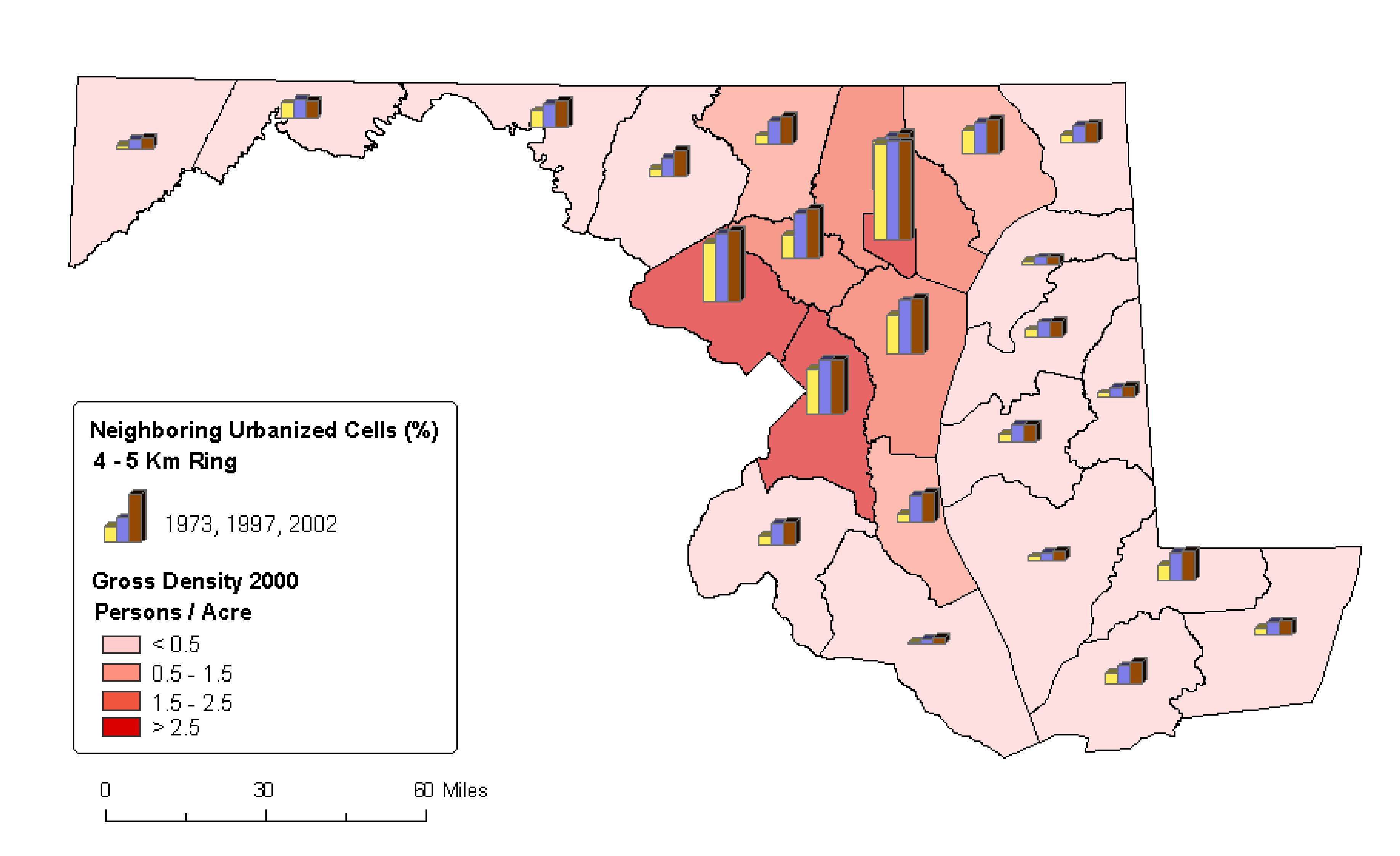


**Figure 18. Continuity Gradients for 4-5 Kilometer Ring, 1973, 1997, and 2002**

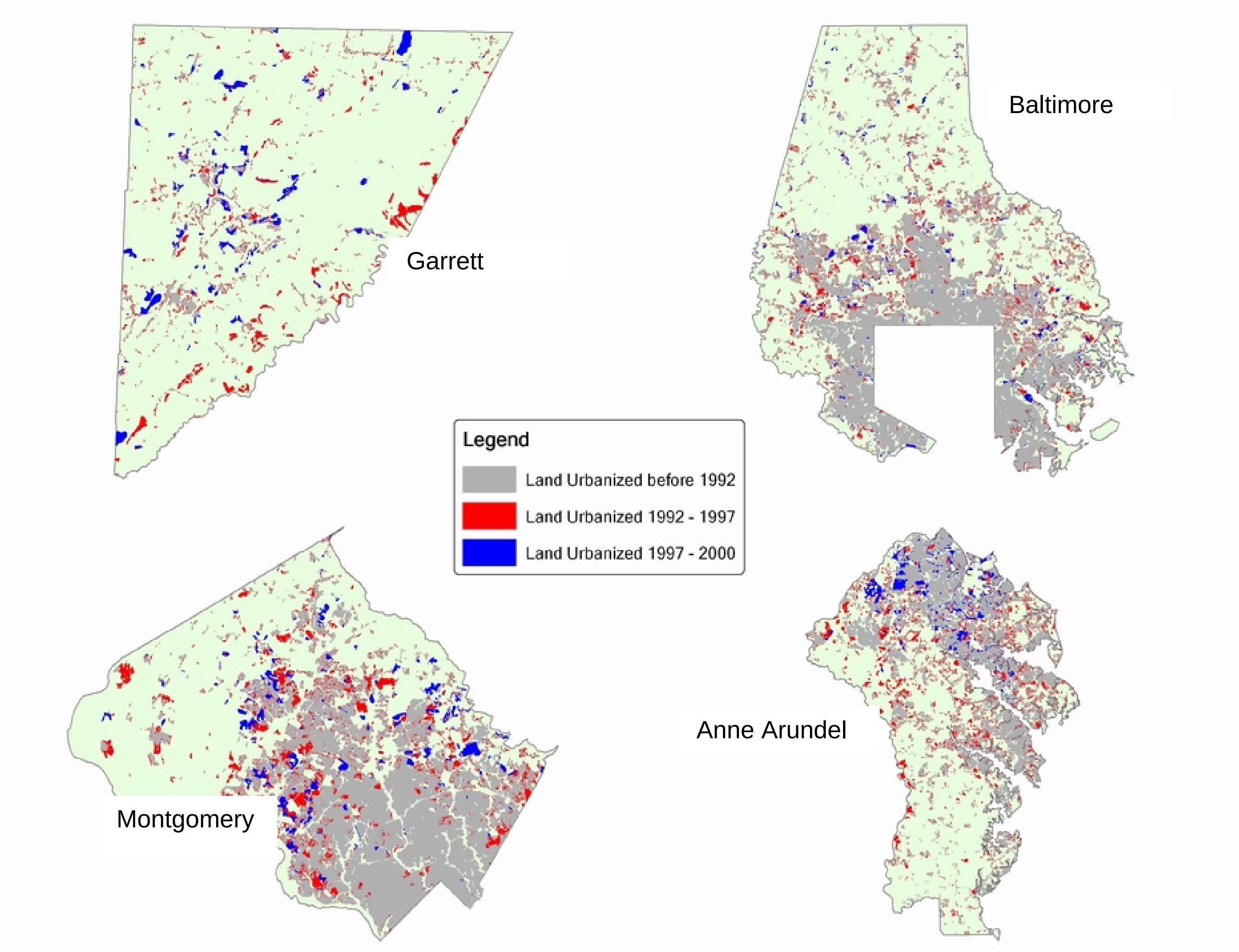


**Figure 19. Land-Use Changes in Four Maryland Counties, 1992-2000**

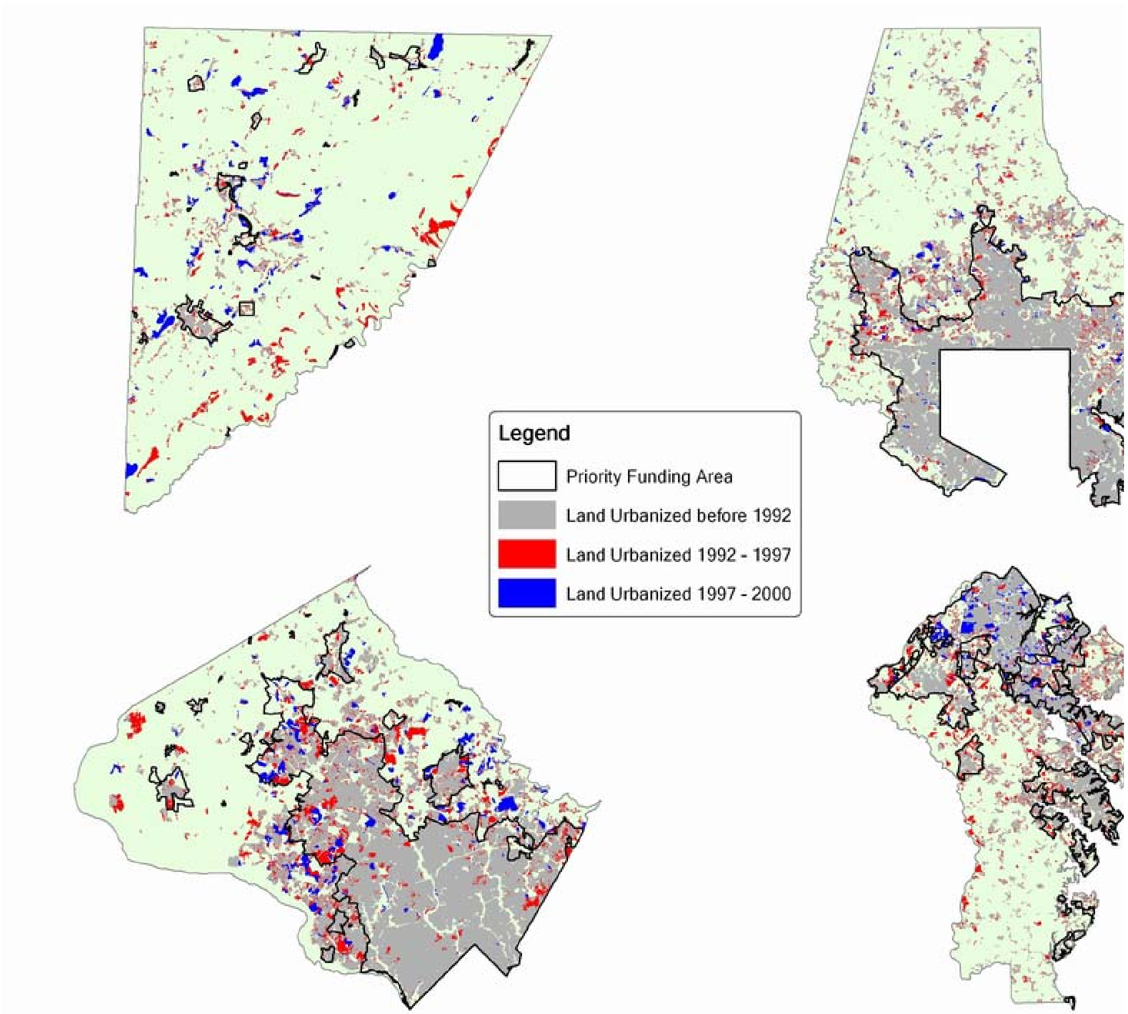


**Figure 20. Priority Funding Areas (PFA) in Four Maryland Counties**