SPRAWL DEVELOPMENT:
ITS PATTERNS, CONSEQUENCES, AND MEASUREMENT

by

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About the Cover Photograph

The cover photograph is an oblique aerial view of the Towson, Maryland area looking southeastward from the vicinity of York Road and Fairmount Avenue toward the intersection of Fairmount Avenue and Dulaney Valley Road. In our opinion, the photograph clearly documents the various components of sprawl. We thank Dale Johnson, a former employee of the Baltimore County Department of Environmental Protection and Resource Management, for permission to use this photograph in our research report. We also thank Lauren Tucker, Geography Department Graduate Research Assistant for her efforts in reviewing, editing, and updating the latest version of this report.

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Introduction

Partly in response to the country's expanding networks of roads and increasing reliance on the automobile, population began shifting from cities to suburbs before World War II. Highway expansion allowed workers to commute greater distances between their residences and central cities and encouraged businesses and industries to locate or relocate to suburban locations that not only provided good access to highways but also imposed lower taxes on their operations. Nationwide, the growth rates of populations in these new suburban areas soared beyond that of the central cities, whose own growth rates were either stagnating or declining. After World War II, conversion of rural lands, specifically those located outside nearby central cities, to residential, commercial, and industrial uses accelerated so that by 1970 the population of suburban residents, for the first time in the nation's history, exceeded that of city dwellers or farmers (U.S. GAO 1999, 1).

The past several decades have not only witnessed the expansion of suburbs but also the development of "edge cities," unincorporated urban cores on the fringes of metropolitan areas (Garreau 1991; Stoel 1999). This shift of population and capital continues into the 21st century. Extrapolating the current pattern into the future could mean:

> … at least 80 percent of the new people--and their jobs--are likely to locate in edge cities and suburbs that disperse development on the far fringes of metropolitan areas, further extending roadways and encroaching onto farms and other resource lands (Diamond and Noonan 1996, 87).

Besides radically transforming the landscapes within and surrounding major metropolitan areas, the ongoing decentralization of urban land-uses and associated economic and social functions has dramatically altered how Americans live, work, recreate, use energy, and impact the environment. Cities have experienced a concurrent decline in tax revenues and an increase in demand for public services and for the maintenance and improvement of urban infrastructures such as schools, hospitals, roads, water mains, and sewers. The steady hemorrhaging of resources from cities has led to increasing urban blight and an associated decline in the quality of life, especially for the growing urban underclass. Moreover, suburban development has also affected distant rural lands and their associated natural resources. The nature and resultant patterns of many suburban developments is often called sprawl.

What is Sprawl?

A disconcerting aspect of sprawl is the lack of agreement over its definition (US GAO 1999; Johnson 2001). Johnson (2001) presents several alternative definitions for consideration, concluding that there is no common consensus. Because sprawl is demonized by some and discounted by others, how sprawl is defined depends on the perspective of who presents the definition. Suburban sprawl is often described as irresponsible, poorly-planned development that destroys green space, increases traffic and air pollution, crowds schools, and drives up taxes. Others compare sprawl to the disease process, calling it a cancerous growth or a virus (DiLorenzo 2000). Less strident descriptions include “the scattering of urban settlement over the rural landscape” (Harvey and Clark 1971, 475), “low-density urbanization” (Pendall 1999, 555), and “discontinuous development” (Weitz and Moore 1998). Therefore, sprawl must be considered in a space-time context as not simply the increase of urban lands in a given area, but the rate of increase relative to population growth. “At a metropolitan scale, Sprawl may be said to occur when the rate at which land is converted to non-agricultural or non-natural uses exceeds the rate of population growth” (USEPA 2001, 1).

The seriousness of sprawl and the appropriateness of efforts to curtail it are also debated. K. Lloyd Billingsley, editorial director of the Pacific Research Institute For Public Policy, generally downplays concern about sprawl and attacks anti-sprawl efforts for the lack of a precise definition of the concept, stating “Some evidence suggests that the rate of ‘sprawl’ is actually lower today than it was in the 1950s and 1960s” and “Most of the ideas that make up the conventional wisdom on the subject at the moment…are misguided” (Billingsley 1999, 2). Critics of sprawling urban growth bemoan its sterile civic life, lack of community cohesion, and environmental, economic, and social costs (Diamond and Noonan 1996; Kunstler 1993; Stoel 1999; Thompson 1967), and they call for concerted efforts to limit sprawl. Clearly, opinions held by researchers, policy makers, activists, and the public differ sharply, and the lack of agreement over how to define sprawl undoubtedly complicates efforts to curtail this type of land development.

Regardless of how it is defined and evaluated, sprawl is a response to often bewildering sets of economic, social, political, and physical forces (Kaiser and Weiss 1971; Pendall 1999). These forces include municipal fragmentation, the patterns of infrastructure investments, subsidization of infrastructure, and ‘white flight’ from cities. Harvey and Clark (1971) and Ewing (1994) provide valuable insights into urban sprawl, and readers interested in the characteristics, economics, and causes of sprawl will find these studies excellent resources with which to begin their inquiries.

This report, an outgrowth of previous work mapping impervious land surfaces for the Chesapeake Bay Watershed and adjacent areas of the Mid-Atlantic region of the United States using Landsat satellite data, relies upon the data and maps generated by the Chesapeake Bay and Mid-Atlantic From Space project to apply a working definition of sprawl as *a pattern of land-use/land cover conversion in which the growth rate of urbanized land (land rendered impervious by development) significantly exceeds the rate of population growth over a specified time period, with a dominance of low-density impervious surfaces*.

Impervious surfaces are promoted as useful environmental indicators (Arnold and Gibbons 1996; Barnes, Morgan, and Roberge 2000; Schueler 1994), and one environmental condition that impervious surfaces clearly indicate is urbanization. Maps produced for the Chesapeake Bay and Mid-Atlantic From Space project differentiate between high-density and low-density surfaces.

Spatial Forms of Sprawl

Sprawl development consists of three basic spatial forms: low-density continuous sprawl, ribbon sprawl, and leapfrog development sprawl (Harvey and Clark 1971). *Low-density* sprawl is the highly consumptive use of land for urban purposes along the margins of existing metropolitan areas. This type of sprawl is supported by piecemeal extensions of basic urban infrastructures such as water, sewer, power, and roads. *Ribbon* sprawl is development that follows major transportation arteries outward from urban cores. Lands adjacent to corridors are developed, but those without direct access remain in rural uses/covers. Over time, these nearby “raw” lands may be converted to urban uses as land values increase and infrastructure is extended perpendicularly from the major roads and lines. *Leapfrog development* sprawl is a discontinuous pattern of urbanization, with patches of developed lands that are widely separated from each other and from the boundaries, albeit blurred in some cases, of recognized urbanized areas. This form of development requires the “greatest capital expenditures…to provide total urban services at the time of development” (Harvey and Clark 1971, 476). Leapfrog development sprawl is caused by various factors. Physical geography such as rugged terrain, wetlands, mineral lands, or water bodies may preclude continuous development or make it prohibitively expensive. Other factors encouraging leapfrog sprawl are not necessarily physical: restrictive land-use policies in one political jurisdiction may lead development to “jump” to one that is favorably disposed toward development or is less able to prevent or control it.

A form of development not necessarily equated as sprawl, but which merits consideration, is *exurban development*, consisting of scattered non-farm residential dwellings in predominantly agricultural and forested areas located beyond the suburbs of cities. Exurban development has increased appreciably over the latter half of the 20th century and has been described as “extended low-density development” (Shands 1991, 23) that differs dramatically from the commonly recognized urban-suburban-rural pattern of land-use/land cover. Exurbanites are often former urbanites who desire the solitude and perceived amenities of “country-living” and/or purchase second homes as rural retreats and as investments. Exurban development can place additional burdens on rural economic/land-use activities such as forestry, mining, and farming, since the values of exurbanites may clash with those of traditional users regarding the most suitable uses of rural lands.

What are the Consequences of Sprawl?

The phenomenon of urban sprawl has been subject to considerable scrutiny by academics, social critics, and public policy makers since the shift of people and economic activities beyond city cores intensified after 1945. The consequences and significance of sprawl, good or ill, are evaluated based on its socioeconomic and environmental impact. In the following section, the social consequences of sprawl are considered, as well as the impact of sprawl on environmental resources and natural resources.

Social. Opinion appears to be divided over the social and economic impact of sprawl, and evidence indicates that both benefits and costs accrue from this phenomenon. For example, an editorial in The Boston Herald on September 5, 2001 that considered the social benefits of sprawl cited a recent study by Matthew Kahn of Tufts University's Fletcher School, where Kahn concludes that sprawl is reducing the housing gap between blacks and whites and is increasing the affordability of housing in both suburbs and cities. "As sprawl increases, the housing of black Americans more closely approaches that of white Americans in the size of their homes and likelihood of home ownership" (*The Boston Herald,* 2001). Critics of current anti-sprawl programs are concerned that these efforts will drive up housing prices, increasing the potential for exclusionary effects.

Nevertheless, sprawl imposes considerable economic, emotional, aesthetic, and physical costs on residents in the nation's major metropolitan areas. Unfavorable economic costs include higher taxes, higher costs of providing infrastructure, adverse fiscal impacts on local governments, ill-health from air pollution generated by traffic, and reduced worker productivity. Emotional costs include loss of community spirit and values and loss of a sense of place. Aesthetic costs include less leisure time and more ugly, monotonous suburban landscapes. Physical costs include over-crowded schools, increased traffic congestion, longer commuting times, and more aggressive driving patterns. There is marked spatial disparity in wealth between cities and suburbs, and land development patterns make establishing and using mass transit systems difficult (APA 2001, Benfield et al. 1999; EPA 2001; Kunstler 1993; Mitchell 2001; Stoel 1999; Harrison 1967). For instance, Stoel cites a 1998 study on traffic congestion that estimates the average Washington D.C. commuter loses two workweeks per year stuck on roads and highways, with the cost in delays and fuel totaling $1,055.00 per resident of the metropolitan region (1999, 8).

Despite traffic congestion and long commutes to work, moving to the suburbs remains a goal for many city residents who perceive quality of life in the suburbs as better. Unless this perception changes and the conditions of urban life improve, sprawl development will continue as the flight from cities to suburbs continues. Society faces the challenge of striking a balance between curtailing urban growth beyond developed areas, and providing housing opportunities for inner-city residents who struggle to improve their quality of life. Billingsley suggests that there is considerable cognitive dissonance among the American public with respect to land development: "they're against sprawl, and they're against density" (1999, 2). This divergence of views further complicates efforts to rein in low-density development and promote compact development.

Environmental Resources. Sprawl has a considerable impact on ecosystems and other environmental resources, which provide societal and environmental benefits simply by existing and functioning. These essential biological and physical systems include wetlands that provide flood control and wastewater renovation; atmosphere, forests, and grasslands that provide climate regulation; biodiversity factors that contribute to healthy, well-functioning ecosystems; and goods such as solar energy, wind energy, aesthetics, clean air, clean water, and potential resources. Environmental resources contribute to, but are not direct inputs or outputs of economic systems, for they are goods and services provided by nature in-place, goods and services that continue as long as the ecological systems and spaces needed to generate them remain unaltered. However, excessive pollution, ecosystem destruction, and other forms of misuse degrade or destroy environmental resources (Daily 1997).

The environmental impact of sprawl spans local, regional, and global geographical scales. For example, the cumulative effect on energy consumption and air pollution of individual suburbanites and exurbanites commuting back and forth to work are considerable and global in significance. The carbon dioxide in vehicular emissions is a major greenhouse gas that has been linked to global warming. Traffic-generated air pollution threatens human health, agricultural production, and ecological systems. This is illustrated by ground-level ozone, a major air pollutant linked to the patterns and volumes of traffic stimulated by sprawl development. Ozone impairs respiratory functions in healthy individuals and aggravates the ill health of those suffering from heart and respiratory diseases. Other health problems arising from ozone exposure include chest pains, nausea, and throat irritation. Ozone also damages foliage, interferes with the physiological operations of plants, and is responsible for an annual loss of $500 million in reduced crop production (USEPA 2001). In addition to poor air quality, other environmental impacts of sprawl include poor water quality stemming from urban nonpoint sources of pollution; destabilization of stream channels and flooding due to stormwater runoff from developed areas; alterations of micro-climates and local climates, including the urban heat island effect and increases in extreme summer heat hazard; loss and fragmentation of wildlife habitats; degradation of landscape aesthetics; and noise and light pollution (Barnes et al. 2000, Doyle et al. 2001, NWF 2001).

Other effects of sprawl may not be so obvious. Because they impair the quality of both ground and surface waters, poorly performing septic systems pose a significant environmental threat. Residents who are dependent on nearby or on-site wells for their water supply may find that groundwater contamination by failing septic systems threatens their health and welfare. In addition, influent from polluted groundwater sources and storm-water runoff originating from impervious surfaces degrades aquatic, estuarine, and near-shore marine ecosystems.

Another significant threat to environmental resources is the greatest threat to wildlife in the United States: loss of habitat (Doyle et al. 2001). Urbanization alters landscapes and fragments prior patterns of land use and land cover, dramatically reducing the amount of habitat, the size of remaining patches of habitat, and the degree of connectedness among the remaining patches. Land development increases the distances between remaining fragments of habitat, making interactions between isolated populations of plants and animals difficult and hazardous. Sprawl not only consumes wildlife habitats, but also degrades adjacent habitats with light and noise pollution emanating from developed areas (NWF 2001). Some species deliberately avoid areas that are illuminated at night. According to the National Wildlife Federation, “artificial lighting may also fragment the landscape and habitat for wildlife, even if there are connecting corridors” (NWF 2001). Furthermore, artificial lighting degrades the aesthetics of the nighttime sky by dimming the visibility of stars while interfering with behaviors of wildlife. Noises issuing from sprawl development also diminish the value of wildlife habitat, since such noises have a negative impact on wildlife behavior.

Note: A more complete overview of the environmental impacts of urbanization and impervious surfaces is found in *The Chesapeake Bay and Mid-Atlantic From Space*, a paper prepared for the Synergy project (Barnes, Morgan, and Roberge 2000). Other valuable references include Arnold and Gibbons 1996; Doyle et al. 2001; Scheuler 1993; and Johnson 2001. Individuals seeking information on the environmental impacts of urbanization and impervious surfaces will find these sources useful to their investigations.

Natural Resources. Suburbs “are now the dominant residential, retail, and commercial centers of growth and political muscle,” and the continuation and replication of this trend “place(s) enormous pressure on land, water, and other resources” (Diamond and Noonan 1996, 94). Suburban and exurban development not only degrades environmental resources such as water quality, air quality, and wildlife habitats, but also limits or eliminates accessibility to natural resources such as agricultural lands, timberland, minerals, and water. Natural resources are the building blocks of economic systems, without which economies would cease to function. Natural resources are extracted from the environment and transformed into finished goods or used for power. Agricultural lands, timber, and water are renewable resources in that they respond to human manipulation, and, with careful management, their use can be extended almost indefinitely. Minerals such as fossil fuels and metallic ores are non-renewable, for they are consumed in the production of goods, and humans cannot induce their accumulation.

Croplands and grazing lands are natural resources in that the products or goods derived from these lands--crops, meat, and poultry--are “extracted,” then distributed among members of society via marketplace transactions. Agricultural production in the United States depends on a mix of environmental services such as soil fertility, soil moisture, solar energy, and climate; inputs of human, animal, and fossil fuel energy via labor and machinery; and an array of other inputs, practices, and programs such as fertilizers, pesticides, irrigation, soil conservation, research, and government agricultural support programs.

There is no shortage of agricultural land in the United States—not at present nor for the foreseeable future. Geographer John Fraser Hart notes, “The United States has more good farmland than it needs to feed and clothe its people, so American farmers must export because they can produce more than the American people can consume” (1991, 356). Surplus production, rather than the loss of cropland to urban development, is seen as the greater threat to American agriculture. In fact, Crosson (1991) notes that by the mid-1980s, the conversion of cropland to urban land was no longer viewed by the federal government as a threat to the nation's long-term agricultural productivity. Surplus production, on the other hand, drives down the market price of agricultural products and makes continuing in farming difficult for some operations. This is especially true for farms within and near metropolitan areas that face an array of pressures and problems arising from urbanization (Furuseth and Pierce 1982).

Although sprawl may not threaten overall national agricultural production, it does result in alterations and declines in local agricultural activities and to the loss of prime farmland. Many cities were sited, and subsequently thrived, due to the rich agricultural soils of their hinterlands. Now, as metropolitan areas grow spatially, the prime farmlands of their hinterlands sprout houses rather than crops. Fortunately or unfortunately, depending on one's perspective, the characteristics of prime agricultural soils also make them well suited for commercial and residential development. Therefore, competition for use of these lands is often intense, with uses generally converting to those that provide higher immediate economic returns. To compete with alternative uses, farmers in urbanizing areas must work remaining agricultural lands more intensively, change to more profitable crops, or shift to operations that require less investment in infrastructure.

Since the mid-twentieth century, American farmers have been producing more crops on fewer acres. However, whether this trend can continue is uncertain. Agricultural production in terms of increased crop yields per unit of land stemming from the use of hybrids, fertilizers, and pesticides may have reached a plateau and may even be declining. If this is indeed the case, the loss of prime farmland does not bode well for the future.

> With less "prime" quality agricultural land available, greater reliance on marginally productive land will occur, resulting in increased soil erosion, increased fertilizer requirements, and increased environmental damage. Farming lower quality agricultural lands is also more energy intensive (Furuseth and Pierce 1982, 27).

Most of our food in the United States is produced near metropolitan areas, and for farmers this is both "a blessing and a curse" (Buelt 1996, 242). Metropolitan areas provide markets for a range of agricultural products, but encroaching suburban and exurban development threatens the stability and continuation of farm operations. In advance of suburban encroachment into rural areas, several notable changes occur, including the rise of part-time farming, idle agricultural lands, declines in agricultural capital investments, and changes in modes and types of farming (Furuseth and Pierce 1982). Berry (1978) found dairy operations and related activities in the northeastern United States to be very sensitive to sprawl, whereas corn and alfalfa production are least affected by sprawl. The high levels of investments and long term planning horizons required for the latter discourage dairy production in the face of urbanization, whereas the former operations require less investments and long-term planning (Furuseth and Pierce 1982).

Sprawl threatens farming directly with heavy traffic and congested roads, damage to crops from air pollution, fragmentation of farms, proliferation of weeds, nuisance suits, higher taxes, high land prices, and declines in farm service infrastructure (Buelt 1996; Furuseth and Pierce 1982). Farmers often find themselves legally and socially harassed by suburbanites and exurbanites who object to farm odors and noises, dust, movement of equipment, and long farm operating hours. Sprawl is amplifying the conflict in values and land use between farm and more recent non-farm residents. Moreover, urbanization is radically transforming rural landscapes, shifting the economic base away from agriculture toward other uses, and changing the aesthetic characters of these landscapes.

Forest resources have made significant contributions to the economic development and industrial growth of the United States, and in many regions of the country the forest products industry is still important. However, the future of timber harvesting operations in many areas is now uncertain. In some cases, harvesting of timber is prevented or severely curtailed in order to preserve habitat needed for endangered and threatened species, or to support economically important, non-extractive uses of forests, such as recreation. In other cases, harvesting of timber is threatened by sprawl. Timberlands close to metropolitan areas must increasingly compete economically with residential land use as commuters choose to live farther away from metropolitan areas. In fact, with expanding residential land use, forests become more valuable for development than for timber production. For example, in a non-metropolitan area of New York State, most of the land converted to urban use was formerly forest (LaGro and DeGloria 1992).

Vaux (1982) observes that value conflicts over the use and management of forestlands intensify as urban uses consume more and more open spaces and more urbanites and suburbanites turn to remaining forests for recreation. The economic value of forestlands for any use, such as timber production, recreational, or residential, has risen dramatically over the past several decades. As forests are consumed, the non-timber value of remaining forests for aesthetics, habitat, and recreation increases, and forest management changes to emphasize these values (Barlow et al. 1998).

As suburban and exurban development encroaches on forests, the long-term availability of timber declines. Barlow et al. (1998) note that proximity to development and higher population densities lead to a decline in timber harvest. In some areas, the decline in harvests, in part, is attributable to increased restrictions placed upon the timber industry, such as harvesting permits, buffer zones, and restrictive forestry practices. Exurbanites and suburbanites who live within or nearby to forests and who object to the loss of woodland scenery, to logging traffic on rural roads, to pesticide applications, and to other real or perceived problems, often initiate and support these restrictions (Shands 1991). With reference to southern forests, Barlow and his associates state that the potential impact of urbanization on timber supplies is dramatic (1998, 10). Harris and DeForest (1993) also conclude that urbanization, forest fragmentation, and shrinking timber stand size within the southeastern United States will increase the costs of harvesting timber.

Often occurring in areas remote from major centers of population, the extraction of fossil fuels and uranium, of non-fuel mineral resources such as ferrous and non-ferrous metallic ores, of limestone, sand and gravel, and of phosphate is often viewed as a rural activity. Although this is certainly the case for some operations, such as oil from the remote North Slope of Alaska or large open pit copper mines in the western United States, the reality is that many mining and quarrying operations have always been in close proximity to urban areas, and the subsequent growth (and decline) of many cities and towns is linked to extractive industries. For example, the fates of Pittsburgh and Scranton in Pennsylvania are, or were, respectively tied to bituminous coal and anthracite coal and to the industries dependent upon these resources. In both cases, the cities are extensively undermined, for urbanization occurred around and within active mining areas. This is also true for many other communities in coal mining areas. One residual problem associated with past mining activities in these urban areas is coal mine subsidence hazards stemming from the collapse of surface materials into the voids of abandoned underground mines (Barnes 1990).

Deposits of limestone, granite, clay, sand, gravel, and other building stone located near cities are important resources from which roads, cities, and towns are constructed. These raw materials are known as “industrial minerals” because they can be used in building with little or no processing (Legett 1973). While the proximity of these deposits to urban areas provides economic advantages to cities and to construction industries, the mining process also imposes significant environmental costs; therefore prudent measures to minimize such costs should be followed.

Industrial mineral operations are now being engulfed by waves of residential and commercial development. The irony is that these operations provide the raw materials for the same urban growth that threatens their existence. With suburban and exurban encroachment, extraction of mineral resources shifts from a legitimate primary economic activity to a public nuisance and locally unwanted land use (LULU). Quarries are forced to shut down and/or re-locate, where possible, to alternative sites. This can be problematic for several reasons. First, industrial minerals such as the limes, sands, and gravels used to make cement and required in large amounts for building, are high bulk/low value commodities sensitive to transportation costs. Therefore, the total costs of these mineral supplies are considerable despite their low costs per cubic yard. If these must be “transported any appreciable distance from the originating pit to the building site, then transport costs can readily come to be even higher than the original purchase price” (Legget 1973, 322). The farther from the market these resources are located, the more costly is their procurement. Second, shifting operations to other sites can result in despoiling previously undeveloped lands. Driving mining operations from existing sites compromises and destroys the ecological and aesthetic integrity of remaining open spaces.

It is important to note that landscapes altered by mining operations often become the sites of new residential development. Following mineral extraction, reclaimed mine lands near metropolitan areas, such as sand and gravel operations, are often converted to residential use. This conversion from extractive to residential use is sensible if it is part of a broader vision of efficient land use. Or, such a conversion may simply promote leapfrog sprawl into the nearby countryside, as relatively inexpensive former mine lands enter the real estate market. As sprawl invades previously undermined lands or land slated for undermining, such as Appalachian coal land, a new generation of homeowners and renters is exposed to mine subsidence hazard. Residences located near limestone quarries and strip-mining activities often suffer loss of aquifer due to de-watering operations associated with extraction of mineral resources. Lowering groundwater tables by quarrying operations can result in sinkhole formation as the hydrostatic support provided by groundwater is removed and surfaces collapse into underlying voids within limestone formations. Surface subsidence over larger areas underlain by unconsolidated materials also results from groundwater withdrawal to meet growing urban demands and from the extraction of natural gas. As these fluids are withdrawn, the sediments are compressed and the ground surface drops (Cooke and Doornkamp 1974). Sprawl development can therefore expose suburban and exurban residents to an array of problems and hazards associated with past and present mining activities (Kern et al. 1981).

Lands immediately surrounding water supply reservoirs, especially in the eastern United States, are typically protected from development to maintain or improve water quality in order to control water treatment costs and water-borne diseases, and to manage these lands to increase yields of water into reservoirs while protecting water quality (Dzurik 1990). Recharge areas for aquifers (underground layers that yield water) serving as public water supply sources are also targeted for special use and protection in order to prevent the contamination of groundwater supplies from inappropriate surface activities (The Conservation Foundation 1987; USEPA 1990). However, not all the lands draining into reservoirs or lands overlying important aquifers are protected from development. Sprawl development in these areas can pose significant threats to the quality of surface and groundwater supplies and the long-term viability of watersheds and aquifers as sources of potable water. Increased suburban and exurban development may also heighten competition for water resources between older, established uses and newer, often higher value uses associated with development.

<u>Summary of Sprawl's Impacts Upon Environmental and Natural Resources</u>. As residential, commercial, and industrial uses consume more and more land, conflicts over the use and management of remaining agricultural and resource lands will intensify. Such conflicts are not limited to urbanizing political jurisdictions, but extend at various spatial scales to public and private lands beyond built-up areas. As agricultural land, wetlands, forests, and streams are lost or degraded due to land development within metropolitan areas and beyond, what remains becomes more and more "valuable" to those with interests in these lands. This includes farmers concerned about the lack of land to rent or to purchase at affordable prices in order to expand operations or to continue in farming; wildlife and rural preservation advocates acting to halt or reverse the continued loss of valuable habitats and rural landscapes; and land developers, timber and mining advocates, and those in the construction industry, who hold that their livelihoods are threatened by land-use restrictions and the "locking up" of lands suitable for development. The question that begs an answer is: Should remaining

landscapes be valued and managed solely for the environmental services they provide in place or for the natural resources that can be extracted, or can an acceptable compromise over their management be reached? Concern over sprawl highlights the differences between these two broad classes of resources and the conflicts over their uses.

Other Sprawl-Related Concerns

Suburban and Exurban Water Resource Insecurity. New development beyond the reach of metropolitan water supply infrastructures must rely on wells located on-site, or even cisterns, for water supply. Wells are drilled into underlying strata and rock formations that can store and transmit water. These formations are known as aquifers. Unfortunately, some development occurs over rock formations that are poor aquifers, resulting in scarce and unreliable supplies of water. In other instances, increased competition for limited groundwater supplies due to new development or to reductions in water supply during drought results in diminished yields and wells going dry as water tables drop. Loss of aquifer for some residences is a recurring, often seasonal, problem, and the patterns of interference from other wells can be complicated and difficult to trace, especially in fractured rock. Failure to consider the adequacies of groundwater to meet the demands required for development leads to increased insecurity regarding seasonal and future supplies of on-site water. Water supply insecurities within and beyond the metropolitan fringe has led to proposals to base residential zoning densities on the ability of aquifers to provide dependable year-round yields in areas not serviced by infrastructure (Pizor et al. 1984).

Sprawl and Vulnerability to Natural Hazards. As populations become more widely dispersed by sprawl and exurban development, increasing numbers of people are exposed and vulnerable to natural hazards (Mileti 1999). For some, the hazards are new and unfamiliar, as are the adjustments needed to protect life and property (Mitchell 1976). Natural hazards, such as floods, landslides, earthquakes, expansive soils, subsidence, and wildfires arise due to an incompatibility between land uses and the natural processes operating in those areas. In other cases, the incompatibility exists between technology and environmental conditions, such as high-speed transportation (vehicles, airplanes) and fog. Despite efforts to restrict or prevent development in hazardous areas, sprawl and exurban development have encroached onto river and coastal floodplains, and into areas prone to flash floods, slope failures, tectonic activities, and wildfires (FEMA 1997; Mileti 1999). Two consequences of increased urban expansion and population growth in hazardous areas of the United States are the rising costs of natural disasters and the increasing number of people at risk (FEMA 1997).

Some hazards may not necessarily be life threatening, but they can impose considerable costs on individuals and municipal governments. Examples of such hazards include winter storms and fog. The costs and the time required to remove snow and ice from roads are greater for more dispersed settlement patterns than for more clustered or compact settlement patterns. Poor visibility due to fog is problematic, dangerous, and stressful as both large numbers of commuters in individual vehicles and school bus drivers contend with fog-shrouded roads and highways, especially if road conditions are slick or icy. Limited visibility due to inclement weather, along with speeds too fast for conditions, is a leading cause of vehicular accidents

Fire has always been and remains a serious hazard in congested urban areas. History is replete with examples of tragic urban fires such as the Great Fire of London in 1666 and the Chicago Fire of 1871. While sprawling development reduces the opportunity for house fires to spread to nearby structures, it increases exposure and vulnerability to wildfires, which impair air quality, reduce visibility, and thus create unsafe driving conditions from smoke. Shands notes, “Whether urban or remote, it is not uncommon for new homes to be located in areas of high fire hazard” (1991, 25). Developments along the metropolitan fringes of California are notorious for encroaching into areas of fire-prone vegetation (Davis 1998), and recent droughts in the eastern and southeastern United States, including Maryland during autumn 2001, highlight the threat wildfires pose to suburban and exurban residences in this part of the country

<u>Human-Wildlife Conflicts</u>. As land development consumes more agricultural and wildlife habitats and as residential land uses intrude into areas located farther and farther from metropolitan cores, human-wildlife conflicts are on the rise. For example, automobile accidents involving deer in urbanizing areas occur frequently. During calendar year 2000, nearly 2,100 deer were reported killed by vehicles in Montgomery County Maryland, a suburban county adjacent to Washington, D.C. (Hotton 2001). While large numbers of other wildlife are also killed and injured by traffic, deer/vehicle collisions pose greater threats to drivers and property. Other human/wildlife conflicts include raids on suburban and exurban gardens by wildlife, predation of household pets by local carnivores, harassment of wildlife by free-roaming pet dogs, and predation of native songbirds and other fauna by domestic and feral cats (Shands 1991; Garrett 1994; Hotton 2001).

The increasing fragmentation of forested areas by land development increases the amount of “edge” habitats, transitional, linear ecosystems between two very different ecosystems like a field and a forest. Along the boundaries of forests, tall trees give way to scrub brush and other non-shade types of trees and herbaceous plants. Even re-forested lands near metropolitan areas, those lands once cleared for farming and other uses, now support forest communities that differ substantially from those that existed prior to initial clearance. These newer environmental conditions favor certain “edge species” such as rodents (squirrels, chipmunks, mice, and rats), raccoons, starlings, and white-tailed deer (Harris and DeForest 1993). Hotton observes that white-tailed deer populations thrive in fragmented landscapes consisting of woods, fields, and other open areas, and that “the expansion of housing developments into forests or onto farms provides excellent white-tail habitat” (2001, 13).

Controlling the animal populations is a problem for many residential communities located in wooded environments (Garrett 1994), and larger predators that could control deer populations are generally absent. Deer hunting restrictions for safety and other reasons, the expansion of habitat, and the absence of larger predators have all combined to dramatically increase many local deer populations, increasing the probability of vehicular accidents involving deer. Collisions of automobiles with deer pose significant threats to the safety and welfare of drivers and their passengers, as well as to the deer. This raises questions of how to best address this threat to public safety. Montgomery County Maryland, for example, reduced its deer vehicular mortality by over 50% since 1997 following the introduction of a short controlled hunt (Hotton 2001). How deer populations should be managed in suburban and developing areas, however, is a controversial and divisive issue that falls beyond the scope of this report.

Summary of Other Sprawl-Related Concerns. Inattention to the adequacies of local groundwater supplies and to the physical and ecological processes that operate within areas undergoing sprawl development has given rise to a host of problems, including loss of on-site groundwater supplies, increased exposure to natural hazards, and human-wildlife conflicts such as high deer vehicular mortality and the spread of Lyme's disease.

Measuring Sprawl

In addition to an agreed-upon definition of sprawl, informed public policy to address sprawl development requires measures to assess sprawl. The metrics presented in this section summarize and clarify the land-use/land cover data derived from satellite imagery and data obtained from other sources. Sprawl metrics can foster better communication among interested parties and the general public and assist decision-makers in their efforts to promote less land resource consumption and environmental degradation, and more sustainable types and patterns of land development.

Several characteristics are attributed to sprawl; therefore, their detection and measurement provides a means by which to delimit the spatial extent of sprawl and quantify its magnitude. These traits include:

- Strip and leapfrog development;
- Fragmented habitats and land-use patterns (patchiness);
- Poor accessibility between adjacent land uses/segregated land uses;
- Lack of functional open spaces;
- Brownfields in abandoned urban areas;
- Automobile dependence and weak public transportation systems;
- Rural to urban land conversion rates that exceed population growth rates;

- Higher rates of energy consumption than more compact settlement forms;

- Increased tax burdens and costs in delivering public services over time (APA 2001; Ewing 1994; Johnson 2001; Kline 2000; Nelson 1999; USEPA 2001).

Measurement of these traits and additional attributes are used to develop standardized indices of sprawl development. Some researchers, such as Nelson (1999), employ an array of indicators, including land-use conversion, population change, traffic and vehicle miles traveled, energy consumption, and fiscal measures. Other researchers focus on measuring sprawl through the use of population data and detailed land-use data obtained from the USDA Natural Resource Conservation Service's National Resource Inventory (Kline 2000), or by detecting the physical expressions of sprawl on landscapes via the use of remote sensing and GIS technologies (Civco et al. 2000; Hurd et al. 2001; Nautilus 2001; Yeh and Li 2001).

Hanson and Freihage (2001) employed an array of fiscal, socio-economic, land-use indicators along with descriptive spatial statistics to assess sprawl and the effectiveness of Maryland's Smart Growth Policy. They also provide useful criteria for selecting and judging the worthiness of sprawl indicators. These indicators should:

- Measure conditions that people deem important, such as density;

- Be objective or value-free so that reasonable people can agree on their use, even if they are interpreted differently;

- Measure factors that are claimed to be measured, for example, percent imperviousness as an indicator of development;

- Be reliable and accurate, such as indicators derived from US Census Data and other data generated under strict protocols;

- Be able to be calculated for measurement and comparison at different geographical scales;

- Be easily understood;

- Be widely and effectively used in other locations and context and/or have professional endorsement;

- Have relevant associations with other indicators used to assess sprawl (Hanson and Freihage 2001, 5).

The physical expressions and patterns of sprawl on landscapes can be detected, mapped, and analyzed using remote sensing and geographical information system (GIS) technologies and software. Patterns of urbanization and sprawl can be described by a variety of metrics generated using statistical software such as Fragstats and other comparable programs. For example, earth scientists with the NAUTILUS (Northeast Applications of Useable Technology In Land Use Planning for Urban Sprawl) program are using these technologies to characterize urbanizing landscapes over time and to calculate spatial indices that measure dimensions such as contagion, the patchiness of landscapes, fractal dimension, and patch shape complexity (Hurd et al. 2001; Nautilus 2001). Yeh and Li (2001) use Shannon's entropy, which reflects the concentration or dispersion of a spatial variable in a specified area, to measure and differentiate types of sprawl. This measure is based on the notion that landscape entropy, or disorganization, increases with sprawl. Urban land uses are viewed as interrupting and fragmenting previously homogenous rural landscapes, thereby increasing landscape disorganization.

Hanson and Freihage (2001) employ metrics to describe land development along six geographical dimensions: density, continuity, concentration, centrality, nuclearity; and diversity. *Density* is the amount of low-density development as a ratio or percentage of total developed land. Higher ratios of low-density development to total developed land indicate sprawl, whereas lower ratios indicate more compact, "smarter" growth patterns. *Continuity* reflects the degree to which urban development is spatially contiguous or discontinuous, the latter being reflective of leapfrog sprawl. *Concentration* is the extent to which development is concentrated on a relatively small portion of a jurisdiction's total land area; low levels of urban concentration provide evidence of sprawl. *Centrality* indicates the degree to which development is sited close to a jurisdiction's most intensely developed areas or designated growth areas. *Nuclearity* concerns the organization of urban growth around one or several concentrated employment centers: the greater the numbers of employment centers, the more decentralized and sprawling the development patterns. *Diversity* reflects the mixture of housing and employment opportunities in a given area. One characteristic of sprawl is the segregation of land uses. In this case, diversity indicates the degree to which residential land uses are removed from employment-generating land uses such as offices, retail stores, businesses, and industrial land uses. The more separate these land uses, the longer the commuting distances between homes and employment opportunities. Low diversity denotes sprawl; high diversity denotes more compact patterns of development (Hanson and Freihage 2001, 7-20).

Remote sensing and GIS technologies analyze the spatial extent and the patterns of sprawl. Following is an overview of the sprawl characterization and mapping efforts undertaken by Towson University's Center for Geographic Information Sciences (CGIS). As part of the Synergy II project, CGIS used Landsat imagery (Landsat 5 and 7) to characterize temporal and spatial patterns of land development within the Chesapeake Bay Watershed and Mid-Atlantic region. To analyze and map urban sprawl, CGIS acquired imagery for the 10-state region for 1990 and 1999/2000. Use of 1990 and 1999/2000 satellite imagery enables the detection of changes from agricultural and forested lands to urban uses during the 10-year interval separating the scenes. Changes in impervious cover are related to census data to generate "sprawl metrics" for immediate use to state and local government agencies in support of "smart growth" efforts in the Mid-Atlantic region. Mindful of the need for sprawl indicators to be simple, clear, and convenient, only those that are readily comprehended, commonly used by planners, and easily computed using census data and the impervious surface data available from the project's website (http://chesapeake.towson.edu/), are presented.

The data and indicators used in the Synergy project to characterize sprawl are summarized below. The indicators are limited to those based on the physical attributes of sprawl detectable via remote sensing, combined with population data. These indicators are based primarily on those proposed by Kline (2000), but while Kline uses NRCS data of urbanized land to calculate his metrics, imperviousness serves here as the measure of urbanization. Fiscal and other socio-economic indicators such as tax burdens and vehicle miles traveled are not considered. Nelson (1999) and Hanson and Freihage (2001) explore the use of these indicators, and readers are encouraged to consult those sources for information on their applications.

US Census and Landsat-Derived Data and Indicators for Sprawl Measurement and Assessment

Population 1990
Units of impervious lands 1990
Population per unit of impervious land (density by developed land) 1990
Impervious land per capita 1990
Population 2000
Units of Impervious lands 2000
Population per unit of impervious land (density by developed land) 2000
Impervious land per capita 2000
Change in units of impervious land 1990-2000
Impervious lands percent change 1990-2000
Population change 1990 to 2000
Population percent change (1990-2000)
Population per unit of impervious land, % change 1990-2000
Amount of impervious land units per new resident
Low density impervious land as a percentage of total impervious (1990)
Low density impervious land as a percentage of total impervious (2000)
Units of resource (agricultural/forest) lands 1990
Units of resource (agricultural/forest) lands 2000
Change in units of resource (agriculture/forest) lands
Resource lands percent change 1990-2000
Change in resource land units per new resident

The percentage of an area covered by impervious surfaces such as asphalt and concrete is a straightforward measure of development. That developed areas have greater proportions of impervious surfaces than less-developed areas is not a surprising fact. For any area, the percent change in impervious surfaces can be compared with the percent change in population over a given period of time. If the percent change in impervious surfaces exceeds the percent change in population, then a more sprawling pattern of urban growth is likely; if not, a more compact development pattern is likely.

The amount of impervious land per capita and the population per unit of impervious land--density by developed land--are two other indicators of sprawl. Areas undergoing sprawl will have comparatively higher amounts of impervious land per person, whereas areas undergoing more compact urban growth will have comparatively lower amounts of impervious land per person. Therefore, sprawl results in lower population densities per unit of impervious surface, while compact growth patterns lead to higher population densities per unit of impervious surface. Over time, changes in these two measures provide some indication of whether sprawling patterns of development are continuing or in-filling of available land is occurring within designated growth areas, areas zoned for higher density residential development. Given an expanding population, if per capita rates drop and population densities in developed areas rise, then sprawl is yielding to more compact growth. However, if per capita rates hold steady or rise and population densities in developed areas remain constant or drop, sprawling growth patterns are continuing. The amount of impervious land per new resident is the final sprawl metric combining population and impervious surface data, and it assumes a growing population. In areas undergoing sprawl development, the amount of impervious land per new resident will be greater than that for areas undergoing more compact growth. Finally low-density impervious lands as a percentage of total impervious lands indicate the extent to which an area's population is accommodated by low-density housing or by higher density residential development. Low density factors are more characteristic of sprawl development, with ratios of low-density impervious lands to total impervious lands being greater relative to areas with compact patterns of urban growth.

The conversion of resource lands, agricultural and forest, to urban uses provides another set of indicators by which to assess sprawl. Agricultural lands and forestlands are considered jointly as resource lands, for over time agricultural lands may convert to forest or forest to agriculture, neither case indicating land being consumed by urbanization, although the changes in use may be connected to urban growth elsewhere in the region. Three relatively simple measures include the amount of resource land, the change in the amount of resource land over a given period, and the percent change in resource lands over the same period. The percent change provides a standardized indicator that allows comparison among different factors. The change in resource land per new resident indicates how well jurisdictions control sprawl, which occurs at the expense of land uses, since the development of resource lands will continue in order to accommodate growing metropolitan populations. Sprawl consumes more of resource lands than compact development patterns do. Therefore, if the rate at which resource lands are consumed exceeds the rate at which a metropolitan population is growing, then sprawl is the likely culprit. Jurisdictions that control sprawl can achieve a more favorable balance between population growth and a decline in resource lands.

Conclusion

Sprawl has been and remains a problematic aspect of metropolitan growth and development in the United States. Despite over 50 years of experience with this phenomenon, there is still no widely agreed upon definition of sprawl. This paper defines sprawl as a pattern of land-use/land cover conversion in which the rate at which land rendered impervious by development exceeds the population growth rate over a specified time period, with a dominance of low-density impervious surfaces. The issues and problems associated with this pattern of land development are serious and often divisive, especially when efforts are directed to reining in sprawl at the local jurisdictional scale. The social and economic consequences of sprawl include both positive and negative effects. The impact sprawl has upon environmental and natural resources, however, is predominantly adverse. Government, private organizations, and concerned citizens are directing much effort toward mitigating the negative effects of sprawl.

Other issues and concerns arising from sprawl development include pollution threats to public and private water supplies; insecurity with respect to the adequacy of water supplies along the metropolitan fringe; suburban and exurban populations being exposed to an array of new and unfamiliar natural hazards; and increased conflicts between humans and wildlife. One serious consequence of the wildlife conflict is the spread of Lyme disease within the suburban and exurban fringes of major metropolitan areas.

A variety of technologies and techniques are used to assess, measure, and monitor sprawl development, including remote sensing and GIS applications. Sprawl metrics or indices that describe landscape characteristics, such as fragmentation of rural land-use patterns, are useful communication and decision-making tools effective for summarizing growth trends and patterns. The value of a sprawl index is that it combines two or more variables in a single measure and helps clarify trends within sets of variables.

The ability to assess, measure, and monitor sprawl depends upon the availability of relevant, accurate, reliable data. Synergy II and Nautilus demonstrate the value of applying land-use/ land cover data derived from satellite imagery. With suitable ground level resolution, Landsat provides significant, repetitive spatial coverage of regions, offering a series of “snapshots” of prevailing environmental conditions over time, including the spatial extent and density of land development. This makes its use ideal for monitoring urban growth at regional, state, county, or, in some cases, local jurisdictional scales. Monitoring sprawl and urban growth requires repetitive images of the same scene overtime, a requirement that makes the use of satellite imagery cost effective compared to detailed, but more expensive, high resolution-low altitude aerial photography or time and labor intensive field surveys. Use of satellite imagery provides planners, policy-makers, and other land-use decision-makers with timely, accurate data for evaluating sprawl and basing decisions pertaining to its control.

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