CHAPTER 3 DEVELOPING GEOSPASTIAL INDICES OF URBAN SPRAWL

I. Introduction:

Measuring Urban Sprawl Versus Smart Growth

The preceding section of this dissertation presented the remarkable magnitude of urban growth occurring in New Jersey at the turn of the millennium. While the magnitude of growth in itself has many social and environmental implications, the question arises whether or not all urban growth carries the same degree of undesirable consequences. This is a debate that has been on-going for decades in the Planning and Policy literature. It is necessary to objectively distinguish the difference between general urban growth as described in the previous chapter and particular forms of urban growth in order to fully understand urban sprawl. The term *urban sprawl* is often used to label many of the problematic patterns associated with post WWII urban growth such as low density, spread-out, and haphazard housing tracts. More recently, the term *smart growth* has often been used to describe a more idyllic pattern of urbanization that counters many of the negative consequences of urban sprawl. A missing component in the discourse on sprawl versus smart growth is an objective and consistent means of quantifying urban sprawl, smart growth, and the range of growth patterns that fall somewhere between these two extremes. The following section of this dissertation addresses the challenge of distinguishing the differences between general urban growth and urban growth that is characteristically sprawling. This is accomplished through the development of GIS-based geospatial measures of urban sprawl.

II. A Theoretical Framework

Measuring Sprawl: Characterizing an Elusive Concept

The term *urban sprawl* has a decades-long history in the academic discourse and yet there is surprisingly no commonly agreed upon definition nor are there standardized measures for characterizing what exactly constitutes urban sprawl. The term is even more elusive and off-handedly used to rhetorical ends. What one person may have in mind as sprawl may be another person's American dream.

But is urban sprawl really something that is different from general urban growth? If so, what are the defining characteristics that distinguish urban sprawl from general urban growth? Finally, can urban sprawl be objectively characterized for analysis and comparison to general urban growth? The intent of this chapter is to develop a theoretical framework for distinguishing urban sprawl from other forms of growth through the measurement of distinct spatial patterns exhibited by tracts of new urban growth. The measurements are developed as a suite of *geospatial indices of urban sprawl* (GIUS), which can be used to empirically quantify the spatial patterns associated with the problematic aspects of urban sprawl.

Background

There has been a range of approaches to the analysis of certain aspects of sprawl, but most have focused on socioeconomic factors that utilize census and economic data on a county- or municipal-level (Pendall, et. al. 2000, Burchell & Shad 1999, Orfield 1997, Burchell 1992). These approaches vary in spatial resolution but generally employ a unit of analysis that is too coarse to distinguish spatial details of urban growth that may be useful or necessary to

characterize urban sprawl. For example, low density is often identified as one of the characteristics of sprawl. However, a unit of analysis such as a census tract may contain a significant mixture of non-residential land use and open space that would result in the actual density at the development tract level being significantly different than the overall average density for the census tract. It is ecological fallacy to assume that site-specific housing density within the tract can be determined by the average housing density of the tract (Openshaw 1984b). A higher spatial resolution is needed in order to adequately characterize the nuances of urban sprawl.

Substantial progress has been made in the modeling of land use change and urban growth (see US EPA 2000a & JAPA 1994). There has even been some use of modeling to characterize the impacts of alternate urban growth scenarios (Landis 1995). Yet there is, thus far, little work done to specifically analyze and model urban sprawl by its spatial-temporal characteristics at the development tract level. The intent of this research is to develop a conceptual framework for such an approach to urban spatial analysis by characterizing urban sprawl through detailed spatial measures of changing land use.

Defining Sprawl

The cognitive definition of the term "urban sprawl" refers to a variety of spreading suburban development with implied negative connotations, usually associated with rapid housing constructions and increased traffic congestion. Further scrutiny reveals indiscriminate use of the term by a wide range of stakeholders with a variety of interests. The term "urban sprawl" is at risk of becoming hackneyed or out right meaningless. Some define sprawl as a very specific manifestation of problematic urban growth (Benfield et. al. 1999), while others characterize sprawl as any new urban development at all (Fodor 1999). The literature of urban sprawl has

itself begun to sprawl into what is characterized by George Galster (et. al. 2000) as an ambiguous "semantic wilderness". Galster categorizes the literature into six groups that define sprawl in the following ways: 1) sprawl defined by example; 2) sprawl defined by aesthetic definition; 3) sprawl as the cause of an unwanted externality; 4) sprawl as a consequence; 5) sprawl as selected patterns of land development, and 6) sprawl as a process of development of land use (Galster, et al. 2000). While definition categories 1, 2 and 4 are difficult if not impossible to translate into spatial measure, categories 3, 5 and 6 have potentially measurable spatial characteristics.

(Burchell & Shad 1999; 1998) is widely cited in the sprawl literature and presents a working definition of sprawl as "low density residential and nonresidential intrusions into rural and undeveloped areas, and with less certainty as leapfrog, segregated, and land consuming in its typical form." He goes on to specify that individual forms of sprawl usually vary from location to location, and must be understood within the cultural context of the region. Burchell also contends that sprawl is an inefficient form of development that is often "too costly to maintain."

Reid Ewing (1997) offers a summary of 17 references to sprawl in the literature as being characterized by "low density development, strip development and/or scattered or leapfrog development." Ewing uses a transportation component to help define sprawl. He suggests that the lack of non-automobile access is also a major indicator or sprawl.

Downs (1998) characterizes sprawl as development that exhibits some of the following qualities: 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 smaller localities; 5) heavy reliance on private automobiles as the primary transportation mode; 6) no centralized planning or control of land uses; 7) widespread commercial strip development; 8) significant fiscal disparities among localities; 9) segregation of land use types into different

zones; and 10) reliance on a "trickle-down" or filtering process to provide housing to low-income households.

The Florida Growth Management Plan (1993) gives a succinct description of sprawl as unplanned suburban development which: 1) allows large areas of low-density or single-use development; 2) allows leapfrog development; 3) allows radial, strip, or ribbon development; 4) fails to protect natural resources; 5) fails to protect agricultural lands; 6) fails to maximize use of public facilities; 7) allows land use patterns that inflate facility costs; 8) fails to clearly separate urban and rural uses; 9) discourages infill development or redevelopment; 10) fails to encourage a functional mix of uses; 11) results in poor accessibility among related land uses; and 12) results in loss of significant amounts of functional open space.

The Sierra Club defines sprawl as "low-density development beyond the edge of service and employment, which separates where people live from where they shop, work, recreate, and educate – thus requiring cars to move between zones" (Sierra Club 1999).

The definition put forth by the Vermont Forum on Sprawl adds another dimension differentiating sprawl as "dispersed development outside of compact urban and village centers, along highways and in rural countryside… characterized by unnecessary land consumption, low average densities in comparison with older centers, auto dependence, fragmented open space, wide gaps between development, scattered appearance, separation of uses into distinct areas, repetitive one story commercial buildings surrounded by acres of parking, and lack of public spaces and community centers" (Vermont Forum on Sprawl 1999). These various definitions attempt to describe sprawl as a specific form of urban development with specific qualities and characteristics that distinguish sprawl from urban growth in general and by implication suggest that there must also be non-sprawling patterns of urban growth.

Negative Impacts of Sprawl

While the previous definitions attempt to define what sprawl *is*, another approach characterizes the associated negative impacts and costs, or what sprawl *does*. The costs and negative externalities associated with sprawl have been documented in terms of greater energy consumption and air pollution; increased traffic congestion; increased infrastructure and public service costs; impacts on abandoned city centers; social costs; and loss of resource lands among other consequences (Freeman 2001, Kahn 2000, Duncan 1989, Burchell & Shad 1999, Frank 1989). Burchell & Shad (1999) characterizes the costs of sprawl as the "resources expended to a relative type, density and/or location of development." Burchell's analysis defined the major cost categories of sprawl as: 1) public/private capital and operating costs; 2) transportation and travel costs; 3) land/natural habitat preservation; 4) quality of life; and 5) social issues. Burchell's seminal work (Burchell et. al. 1998) provides an excellent overview of the significant literature examining the costs and impacts associated with sprawl. A number of these costs and impacts are potentially discernable in the spatial patterns of sprawl and will be drawn upon in the subsequent development of the GIUS metrics.

Positive Benefits of Sprawl

Is sprawl really all that bad? Others have argued against the criticisms of sprawl and the burgeoning smart growth movement by defending the benefits incurred from sprawl-style development. Such proponents of the ubiquitous American pattern of growth contend that sprawl is the result of free market forces, consumer choice, and a reflection of the freedom of the democratic system of governance. The general argument is that the negative consequences of urban sprawl are outweighed by the many positive benefits provided by market choice and the

democratic land ethic of property rights. Sprawl may or may not be associated with some problems such as traffic congestion but continuing new housing sales suggest the popular sprawling suburbs reflect consumer demand. This is, therefore, a more desirable form of urban growth than the socially contrived "smart growth" alternatives that are often championed by anti-sprawl activists but not widely embraced by the market (Easterbrook 1999, Carliner 1999, Wilson 1997, Hayward 1996, Gordon & Richardson 1997). As one attendee at a recent American Collegiate Schools of Planning (ACSP) conference commented, "The only thing that Americans hate more than sprawl is density." It is suggested that the benefits accrued by the sprawling suburbs outweigh the costs incurred. Therefore, sprawl is not a major issue of public concern.

Impacts of Sprawl on the Landscape

The sprawl debate has been largely conducted around policy, broad environmental and socioeconomic-oriented costs of sprawl to date. Far less research has been conducted on the actual landscape impacts specifically attributable to sprawl (Frank 2000). One study conducted by the American Farmland Trust (1997) examined the rates of urban conversion of high quality farmland within major metropolitan regions. Another study focused on the projected impacts of various degrees of sprawl on farmland conversion in California (Bradshaw and Muller 1997) using a GIS-based future growth model (Landis 1995). Many studies have focused on the ecological and hydrological impacts of general urbanization (Zampella and Laidig 1997, Zampella and Bunnell 1998, Laidig and Zampella 1999). But little research was found that looked at how different types of urbanization (i.e. sprawl versus smart growth) might affect ecological and hydrological conditions.

A method by which to characterize and quantify the problematic aspects of urban sprawl is needed if it is, in fact, a form of development that is more problematic then other forms of urban

growth. Such measures need to be applicable on a development tract level since urban growth occurs one development tract at a time.

Developing a Measurable Definition of Urban Sprawl

The wide variety of research interests and land planning stakeholders interested in sprawl make it difficult to develop a single, all-encompassing definition of urban sprawl upon which to base spatial measures. Many aspects of sprawl include socioeconomic components that are impossible to "see" in a land use map of urban growth. Regardless, many other factors related to sprawl are spatial in nature. They may be gauged by landscape change analysis performed by use of appropriate GIS techniques.

Researchers are beginning to redefine sprawl in terms of measurable spatial patterns. Torrens & Alberti (2000) are developing an empirical landscape approach to sprawl measurement that focuses on the characteristics of density, scatter, the built environment, and accessibility. They have outlined a set of metrics for quantifying these characteristics which employ density gradients, surface-based approaches, geometrical techniques, fractal dimension, architectural and photogrammetric techniques, measurements of landscape composition and spatial configuration, and accessibility calculations. Galster et. al. (2000) present an approach to sprawl as a *condition of land use*. Galster's analysis defines sprawl as "a pattern of land use in an urbanized area that exhibits low levels of some combination of eight distinct dimensions: density, continuity, concentration, compactness, centrality, nuclearity, diversity, and proximity (Galster et al 2000)". Galster operationalizes these dimensions for 13 urbanized areas providing a comparison of the nature and extent of sprawl for these metro areas utilizing 1990 census data grided into ½mile cells.

The burgeoning spatial analysis approach to sprawl is providing a more rigorous and objective analytical foundation for academic research. The methods are geographically based in well-developed spatial mathematics but also somewhat conceptually complex. They present insightful academic analysis of urban spatial form. However, this work needs to be further developed in two significant capacities: 1) the temporal nature of the sprawl process, and 2) utility to the planning process. Many of the metrics developed thus far are static in nature missing the dynamic component of sprawl. Sprawl metrics are needed that focus on characteristics of urban growth rather than an analytical static snapshot of overall urban structure. Secondly, metrics are needed that can be realistically utilized within the trenches of the planning process. Sprawl metrics developed thus far present little cogent information on what is specifically problematic about a particular tract of development or what land use measures might effectively address the problematic characteristics of a new development tract. Planning board-level personnel would likely have difficulty translating concepts such as *nuclearity* and *fractal dimension* into planning decisions regarding a pending development proposal. The logical next step in the spatial analysis of sprawl is to develop measures that could potentially be more conceptually accessible. They should be developed for meaningful use by planning board-level users who wish to identify and address problematic aspects of sprawling new development proposals.

I propose an approach to the characterization of sprawl that builds on the spatial approach initiated by Torrens & Alberti and Galster et. al to focus on the inefficiencies and dysfunction inherent in the spatial configuration, location, and landscape context of a development tract. The *geospatial indices of urban sprawl* (GIUS) are designed to illustrate the consequences of urban sprawl by focusing on the problems or inefficiencies of urban growth as can be distinguished from spatial patterns of changing land use. In a phrase, GIUS metrics illustrate that *urban sprawl is inefficient, problematic and/or dysfunctional urban growth within a landscape.* Explication is

required to justify my contentious and unorthodox use of the term *dysfunctional* to describe urban sprawl.

Sprawl as Dysfunctional Urban Growth

The sprawl debate must be recast somewhat by focusing on what is problematic or unsustainable about sprawling patterns of urban growth to an otherwise normally functioning landscape in order to develop meaningful spatial measures that get to the heart of what distinguishes sprawl from non-sprawling development. The term *landscape* is defined by landscape ecologists as a region of land that functions as an interrelated ecosystem in its human and ecological components (Forman and Godron 1986). The extent of a landscape exists at hierarchal domains of scale (Urban et al. 1987). A multitude of natural and anthropogenic functions occur within a given landscape. Biological, geological, social and economic forces all affect the ecosystem (Redman 1999) as well as the environmental and social setting in which people live within the local landscape. Most of these landscape functions are not isolated but are interrelated within the regional (i.e. landscape-scale) context of an ecosystem (Peck 1998). In other words measuring sprawl is most meaningful when it is analyzed within the context of the larger spatial area than just the specific site at which it located. Performance standards, in essence, need to be scaled to a landscape level.

An illustration of a functional landscape is a watershed. A watershed provides the spatial setting for the natural function of the hydrological cycling of water. That same watershed may also provide a place for residential housing and other human activity such as work and recreation. The quality of life within the watershed is dependent upon an ample supply of high quality water that is, in turn, dependent upon the proper functioning of the hydrologic system throughout the

watershed. The quality of life is likewise affected by the condition of many other ecological functions of the watershed such as wildlife habitat and air quality. The health of the ecosystem can also be affected by the pattern and configuration of human land use functions within the watershed. A human activity will impact its immediate environs to some extent, but the regional context of a watershed offers the opportunity for the sustainable coexistence of many different human and ecological functions without significantly diminished overall function (Grant et. al. 1996). For example, impervious surface within a watershed will begin to impact water quality once coverage exceeds 10% of the watershed (Arnold & Gibbons 1995). The hydrological system remains generally functional below 10% impervious surface coverage within a watershed. The hydrologic function of the watershed begins to significantly degrade once the 10% threshold of impervious surface is surpassed. The functionality of the ecosystem and the activity of humans within a given landscape are intimately interconnected.

In our example of a watershed, the housing need not exist in a manner that significantly affects water quality within the watershed and the hydrological function of the watershed need not impact the function of the housing. However, when the pattern of housing is configured such that water quality is significantly affected or if housing is located within the natural flood plain of a stream corridor where it is likely to be flooded, then the expression of urban development exhibits an inordinate degradation of the functionality of the landscape in its hydrological capacity. Human activity must occur within the boundaries and limits of what the natural and human landscape can sustain in order to maintain the maximum functionality of a landscape in both its human and ecological aspects (Frey 1999). Figure 3-1 illustrates a concept that can be called *socioeconomic / geo-biological landscape integrity* where the majority of both human and ecological landscape functions are able to occur in a sustainable manner.

Within a watershed, the domain of landscape integrity for its hydrologic function occurs when human land use is limited to less than 10 percent impervious surface. There would be a similar domain of landscape integrity for the many other functions of the watershed.

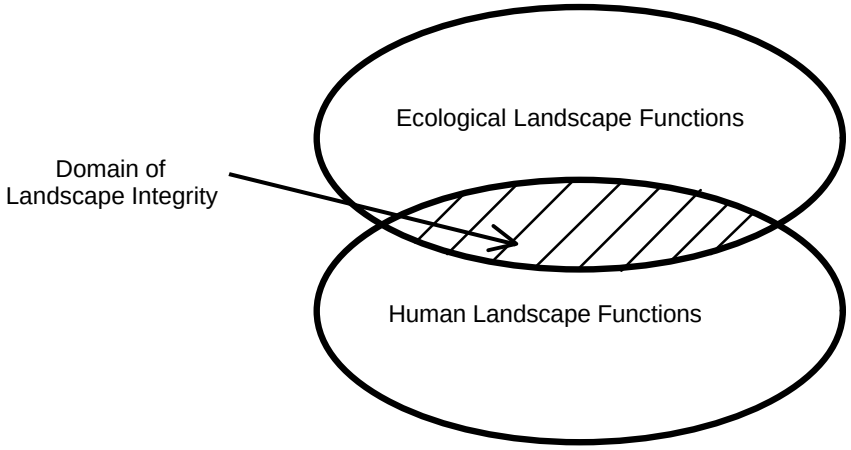


Figure 3-1 *Landscape integrity occurs when a landscape is able to sustainably function in the majority of its ecological and human capacities.*

Every landscape has a unique range of functionality for its domain of landscape integrity that is dependent upon geography, environment and population. A watershed with 100 people will have the potential for more intact ecological function than can be expected for a watershed that accommodates one million people. Likewise, a watershed with 60 % prime farm soils would have the potential for more agricultural functionality than a watershed with 6 % prime lands. Therefore the domain of landscape integrity (i.e. the state of maximum possible human and ecological function) would have a different potential expression dependent upon the inherent environmental, demographic and geographic setting unique to each particular landscape.

To further illustrate the concept of landscape integrity, one could imagine viewing our selected watershed from a scenic overlook high on an adjacent ridge. It is possible to see a wide variety of functions performed by the landscape before us from such a vantage point. These functions are conveniently grouped into human and ecological categories. Some of the human landscape

functions we would likely observe include: place of residence, place of work, place of commerce, place of social affairs, place of transportation, place of recreation, place of food production, place of water resource, place of community cohesion, and place of spiritual/aesthetic inspiration. Some of the natural functions or ecosystem 'services' of the landscape we might observe include: place of wildlife habitat, place of wildlife movement, place of water cycling, purification and storage, place of air cleansing, oxygen creation and carbon sequestration, place of ecological symbiosis, place of soil development, productivity and fertility, and place of ecological evolutionary process. It would also be evident from our bird's-eye view that the human patterns of land use within the watershed would be affecting how well these human and ecological landscape components could function.

We could imagine what the extremes of landscape function and dysfunction might look like from our perch above the watershed. Maximum landscape functionality (for our human settled watershed) would include a pollutant-free landscape in which the hydrologic system was pristine with adequate areas of ground water recharge, intact natural wetlands, extensive networks of protected wildlife habitat, and clean air. High quality human settlements in our maximally functional landscape would be efficiently designed within the mosaic of this thriving ecosystem. Communities would be cohesive and would exist at a scale in which children could walk to school; emergency services were in close proximity; employment was accessible by walking, biking or transit; groceries would be available at the corner store that sells fresh produce grown on local, protected prime farmland. The population of our landscape would enjoy a high quality of living within an ecologically vital, maximally functioning landscape that exists sustainably within the domain of landscape integrity of our watershed.

We could also imagine an extremely dysfunctional landscape by contrast. The entire watershed is largely denuded and extensively covered with asphalt and concrete while containing only a few

scattered residences. The hydrologic system would be degraded to the same quality as a stagnant drainage ditch. There would be virtually no wildlife habitat, and therefore no wildlife save a few pigeons or rodents. The human functionality of our concrete landscape may embody a few benefits. Perhaps the few houses are really nice inside. There would be no problem finding a parking space or landing an airplane. But most human functions in our concrete landscape would be diminished, as every activity undertaken by the dispersed residents would require auto travel. Daily activities would be more time and energy consumptive. Emergency services would dangerously distant from residences. Bottled water and food would need to be imported. The land would be polluted and there would be few recreational options outside of rollerblading or hopscotch. The quality of life in this dysfunctional landscape would be exceedingly diminished. The conditions of our watershed would be degraded well below the potential of its domain of landscape integrity.

Our imagined extremes illustrate the possible range of landscape function. But how realistic are these extremes? The ideal of maximum functionality conjures images of many European villages. The extremely dysfunctional landscape brings to mind images of some inner-city neighborhoods, expansive parking lots surrounding large box retailers, industrial brownfields and expansive houses scattered over former farm fields. Landscape functionality can exist in its extremes and can dramatically change over time as land use patterns change. The actual functionality of any given settled landscape in America is likely to exist somewhere along the continuum between our imagined extremes of maximum landscape function and dysfunction. The connection between landscape integrity and urban sprawl (Figure 3-2) is that patterns of urban development within a region that exhibit a more inefficient, haphazard and dispersed pattern of growth impart a greater impact on landscape functionality than less sprawling development that houses a similar number of residents.

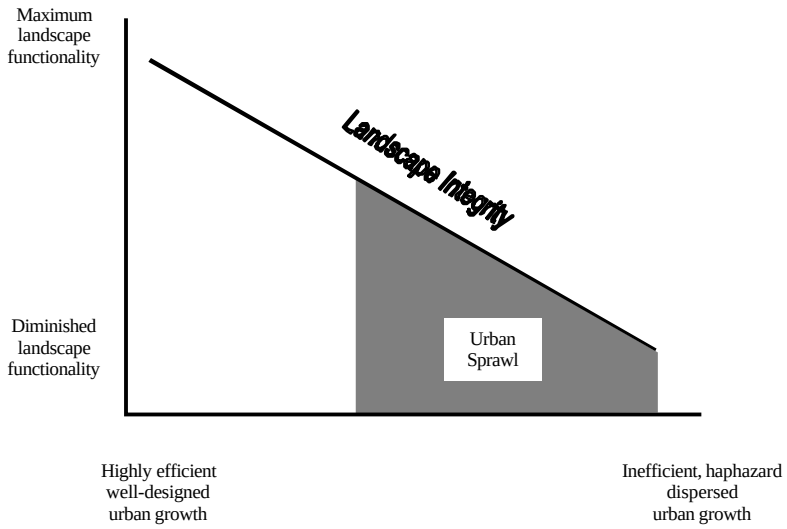


Figure 3-2 *As urban growth becomes more sprawling the human and ecological functionality of the landscape decreases, diminishing the overall integrity of a landscape.*

Many human activities that are unrelated to sprawl (for example, a toxic spill or poor soil conservation practices) may diminish landscape integrity, but I argue that urban sprawl is a problematic form of urbanization precisely because it significantly affects the ability of a region to realize the maximum landscape integrity for its given population. Fewer numbers of people create greater amounts of impervious surface, consume greater amounts of water, encroach on more regions of wildlife habitat and pollute a wider extent of the landscape under sprawl conditions. Sprawling urban growth renders a landscape less able to function in both its ecological and human aspects.

This is of course an overly simplistic framework to describe the functioning of a landscape. The dysfunctional characteristics of urban sprawl are complex. In some ways sprawl patterns of development provide exceptional functionality for some factors but at the major expense of others. A large home on the rural fringe, for example, may very effectively provide individual housing amenities such as personal comfort, a quality school system, a feeling of personal safety, lower taxes, etc. (Gordon and Richardson 1997). Likewise, a large box commercial strip retailer

may very efficiently provide consumer choice for desired products at competitive prices. These individual and short-term benefits are often gained at the expense of many other human and ecological functions of a landscape. Quality opportunities for community interaction, job accessibility, efficient travel, sustainable agriculture, ample supply of high quality water, wildlife habitat, aesthetic/spiritual inspiration, and recreational amenities are often lost under sprawling growth conditions (Benfield 1999).

The difference of scope in what is functional and dysfunctional in a sprawling landscape pattern further complicates the issue. That which is functional about sprawl occurs on an individual/personal location or place-level basis, whereas that which is dysfunctional about sprawl usually occurs on a broader community or cumulative environmental level. Benefits to the individual stakeholder are experienced immediately or in the short-term. The dysfunctional consequences are externalized and born by the community at large and/or may be long-term in their cost to the landscape.

Nevertheless, sprawling urban growth demonstrably impacts the ecological functions of a landscape. Wildlife habitat is often indiscriminately destroyed; water quality is diminished; hydrologic functions are interfered with; and local ecosystems interrupted through the creation of effective barriers and landscape fragmentation (Kahn 2000). Many times the ecological functioning is devalued economically compared with the human land use function provided by a landscape. This, however, is often shortsighted since the continued loss of the ecological functions of a landscape will inevitably result in diminishment of human quality of life and ultimately degradation of a landscape's sustainability (Grant et. al. 1996).

Per capita impact on landscape integrity distinguishes urban sprawl from other impacting forms of urban growth. The greatest consequence of urban sprawl is the inordinate impact upon

ecological and human landscape functionality associated with it. It is this aspect of sprawl in which following spatial measurements hope to capture. Therefore in the context of this research, I define *urban sprawl* as follows:

> ***Urban sprawl*** *is a wasteful form of urban growth that significantly damages the ecological functionality of a landscape and/or demonstrates substantial inefficiencies in the provision of human functionality due to its haphazard, indiscriminant and dispersed land use pattern. Urban sprawl is, on balance, a form of urban growth that significantly degrades the ecological, social and/or aesthetic function of a landscape in a discernible manner despite some demonstrable, short-term benefits to the individual.*

This definition is best captured and simplified by the following slogan:

Urban sprawl is wasteful, inefficient and/or dysfunctional urban growth within the context of a landscape.

Can we see sprawl in a map of land use?

The previous definition may render some characteristics of sprawl difficult to quantify or downright subjective, but much of the problematic, inefficient and dysfunction characteristics of sprawl at a landscape level can conceivably be identified within patterns of land use as they change over time. The following section presents a conceptual framework for measuring spatial patterns of urban growth within a temporal land use map to delineate particular characteristics of urban sprawl that are evident in the geographic configuration, context and juxtaposition of new development. The measures are grouped into three general categories: 1) land use patterns of sprawl; 2) transportation infrastructure measures of sprawl; and 3) environmental resource impact indices of sprawl.

III. Developing Geospatial Indices of Urban Sprawl

A Geospatial Approach to Characterizing Urban Sprawl

A suite of twelve *geospatial indices of urban sprawl* (GIUS) are proposed to delineate various spatial aspects of urban growth associated with the problematic, inefficient and dysfunctional characteristics of urban sprawl as defined in the planning and policy literature. The GIUS measures employ various spatial metrics of landscape parameters identifiable in land use, road network and various environmental mapping sources. Although the measures are developed for academic research, it is hoped that they remain conceptually accessible to planning board personnel who make common development decisions at the development tract level.

The analytical methods employed by the GIUS metrics draw on the discipline of landscape ecology in order to characterize land use/land cover patterns of a landscape (Forman 1995). The landscape ecology approach conceptualizes a landscape as a mosaic of relatively homogenous land regions called *patches*. Many landscape ecology researchers employ geospatial techniques to analyze landscape characteristics and trends of landscape change (O'Neil *et al.* 1988). These include methods of measuring patch shape (La Gro 1991) landscape mosaic patterns (Gustafson 1998) and various models of landscape change (Baker 1989). I utilize the term "new urban patch" to delineate a relatively homogeneous region of new urban growth that has occurred over a particular period of time. The term 'new urban patch' is employed rather than 'new development tract' because the latter, which may be more comfortable language to the planning field, implies a distinction between individual development projects even when they are adjacent. The landscape ecology term "patch" is utilized because the GIUS metrics are based on remote sensing delineations of new urban growth with which it is impossible to distinguish individual tracts

when they are contiguous. The remotely sensed delineation of urban growth results in homogenous zones most suitably described as patches in the landscape mosaic.

The following geospatial measures attempt to delineate the major spatial signatures of sprawling urban growth with regard to impacts on a landscape by extension of the various characteristics of sprawl defined in the planning and policy literature and principles of spatial analysis from landscape ecology.

Twelve Characteristic Geospatial Sprawl Indices

Spatial Patterns of Land Use Related to Urban Sprawl

Perhaps the most significant factor to influence the functionality of a given landscape is the land use patterns imposed upon it by human development. Land is a finite resource that can be used with varying degrees of efficiency to produce varying degrees of functionality of the human and natural landscape. The land use spatial indices of sprawl include *land use density, leap-frog development, segregated land use development, development that is inconsistent with regional planning* and *highway strip development*.

1) Urban Density **-** Low-density urban growth is the one characteristic that is most often associated with sprawl (Galster *et al.* 2000; Torrens & Alberti 2000; Sierra Club 1999; Vermont Forum on Sprawl 1999; Burchell 1999; Downs 1998; Ewing 1997; Gordon & Richardson 1997; Anderson *et al.* 1996; Florida Growth Management Plan 1993; Peiser 1989).

The *urban density index* provides a measure of how much land is consumed per capita for a patch of new development (Figure 3-3). Low-density urban growth consumes more land for each resident added to a landscape thereby leaving less of the landscape able to function in other capacities. The density index is a function of new development patch size and number of residents. Density represents the amount of land occupied by a given number of residents. For the purposes of analysis the amount of land utilized for a new housing unit is utilized as a proxy for per capita development density. Lower density is indicative of more sprawling growth whereas higher density signifies less sprawling growth.

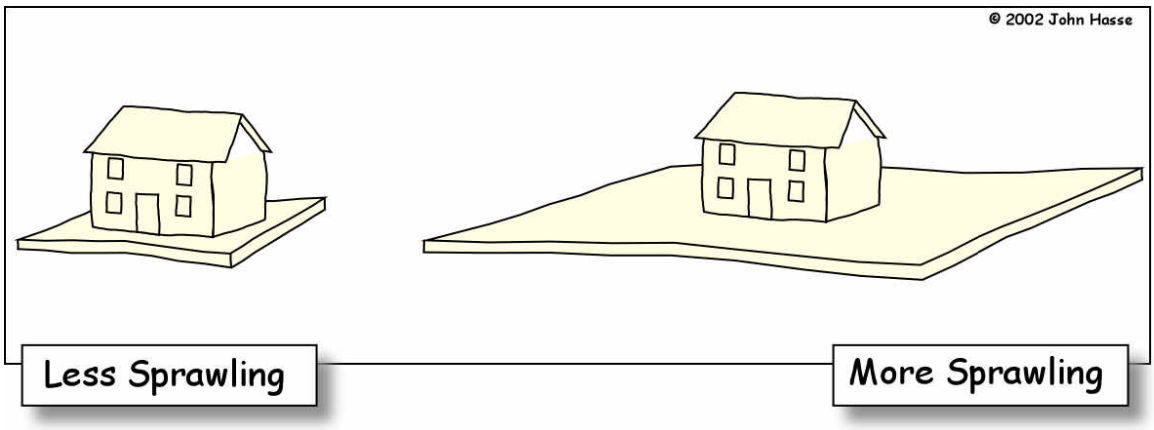


Figure 3-3 *The urban density index provides a measure of the of land utilized for the population of residents accommodated by the new urban growth or per capita land consumption. For the purposes of analysis each new housing unit is used as a proxy for residential population growth. Sprawling development is more consumptive of land than less sprawling development.*

2) Leapfrog Development - Dispersed development is another often-cited characteristic of sprawl (Galster *et al* 2000.; Torrens & Alberti 2000; Benfield *et al*. 1999; Seirra Club 1999; Burchell 1999; Downs 1998; Ewing 1997; Florida Growth Management Plan 1993). The American land use system historically lacks the ability to adequately control sequencing of development growth (Diamond and Noonan 1996). This has resulted in the phenomenon of new development 'leapfrogging' over vacant lands that are adjacent to existing development in favor of the development of parcels that are deeper in the rural countryside (Figure 3-4). This haphazard

pattern of development has a domino affect on landscape functionality. It produces an increasingly fragmented land use pattern that in turn leads to elevated transportation requirements. Valuable agricultural lands are consumed or are otherwise impacted, and habitat fragmentation is accelerated.

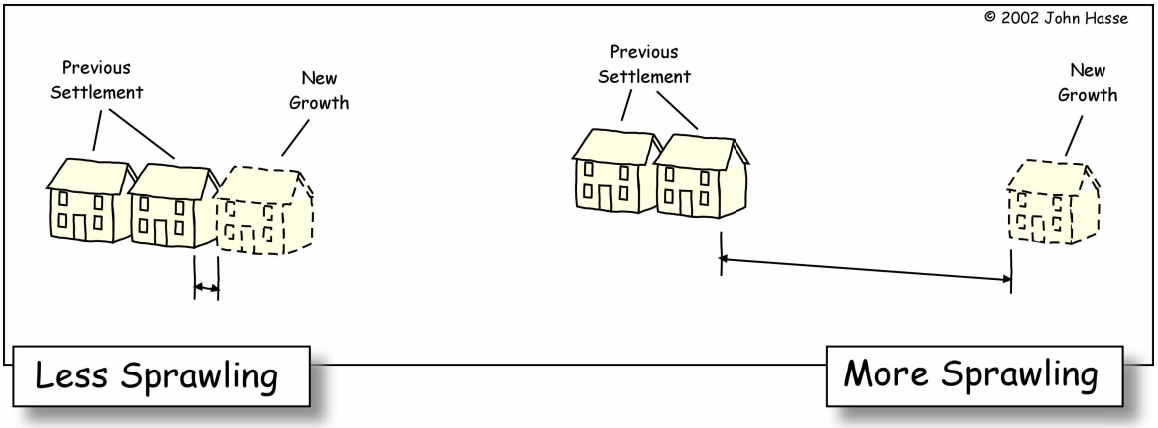


Figure 3-4 *The leapfrog index provides a measure of the distance of a new development to previous settlement. Sprawling development leapfrogs further into the countryside than less sprawling development.*

The *leapfrog index* provides a measure of how far a patch of new development is from the edge of a previously existing settlement. While various approaches to measuring dispersion can be taken (Galster et. al. 2000, Torrens & Alberti 2000), this analysis calculated the leapfrog index by a straight-line distance measurement from the new development patch to the perimeter of the nearest previously settled area. Patches with large leapfrog distances are considered sprawling whereas patches in close proximity or contiguous to previous settlement (i.e. infill or concentric growth) are considered less sprawling.

3) Segregated Land Use - A third characterization of sprawl is segregated land use (Galster *et al.* 2000; Benfield *et al.* 1999; Sierra Club 1999; Vermont Forum on Sprawl 1999; Burchell 1999; Downs 1998; Ewing 1997; Anderson *et al.* 1996; Florida Growth Management Plan 1993). Segregated land use (Figure 3-5) consists of single-use zoning in which large areas of land are strictly confined to one type of land use such as residential only or commercial only.

This homogenization of land use results in a less functionally efficient landscape in which every household activity requires automobile transportation whether it is commuting to work or school, gathering for social activities or shopping. Segregated land uses are defined for purposes of this analysis as single urban land uses beyond reasonable walking distance to multiple other urban land uses.

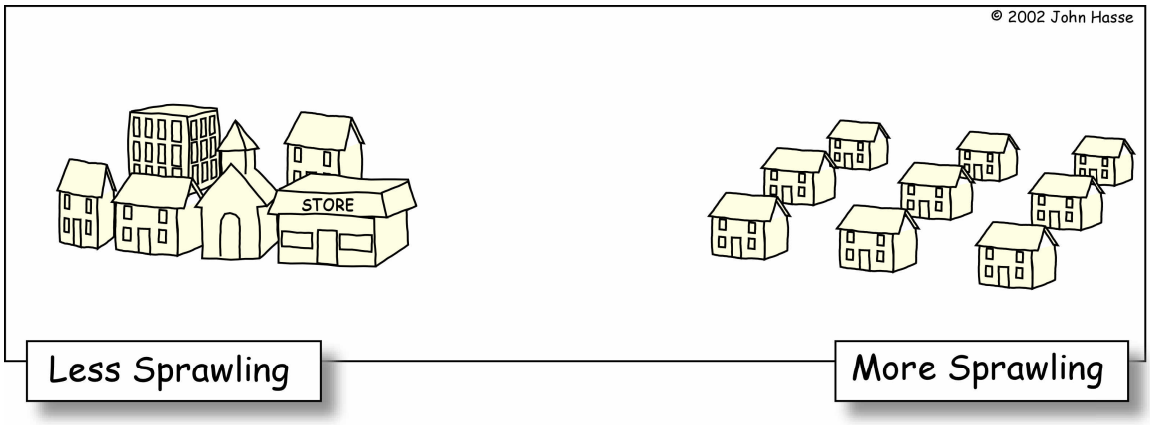


Figure 3-5 *The segregated land use index provides a measure of the number of different types of human land use s within walking distance to a new patch of development. Sprawling development has few to no other land uses within walking distance whereas new development in walking proximity to a mix of land uses is considered than less sprawling.*

The *segregated land use index* measures the degree to which land use is mixed at a pedestrian scale. It is a measure of the number of different types of land uses that are within reasonable walking distance to a new patch of development. Nelessen (1993) suggests that 1,500 ft (the distance that an average pedestrian will walk in 10 minutes) constitutes *reasonable walking distance*. A pedestrian distance zone (i.e. buffer) based on this premise was delineated around new development patches, and the number of different "developed" land uses within that buffer were counted in order to calculate the segregated land use metric. The measure was calculated to provide the average number of different land uses within the pedestrian distance for the entire patch since some parts of a patch may be in proximity to multiple uses while other regions of that patch are not. Mixed zoning areas such as village and multi-use zones were weighted to emphasize the multi-use nature of these urban land uses. Patches of new urban growth with few

or no alternate land uses within the pedestrian distance are considered sprawling whereas a mixture of neighboring land uses is considered less sprawling.

4) Regional Planning Inconsistency **-** Many of the haphazard, disjointed and conflicting land use patterns of sprawl can be attributed to uncoordinated land use planning. This occurs for many reasons, the most compelling of which include the short terms of elected officials who have little political incentive for long-term planning or regional coordination, and the elusive ratable chase to allay growing tax burdens (New Jersey Future 2000, Orfield 1997). In addition, the lack of regional coordination often occurs in spite of existing regional and/or statewide planning initiatives. (This is especially problematic in New Jersey, a state that is peculiarly bound by municipal home rule). Development that is inconsistent with the intent and functional goals of a regional plan has been cited as a defining characteristic of sprawl (Razin & Rosentraub 2000; Burchell 1999; Orfield 1997; Downs 1998).

The *planning inconsistency index* measures whether or not a patch of new development is consistent with a regional or state plan (Figure 3-6). This index is calculated by the overlay of new development patches on a regional planning map. Each planning area is assigned a weight to reflect the appropriateness of development within each of planning area category. Zones designated as rural environmentally sensitive receive larger weighing values whereas growth zones and town centers are assigned lower weighting values. Patches of new development that occur in high-weighted zones are disharmonious with regional planning goals are considered more sprawling than patches of new development that occur in designated growth areas.

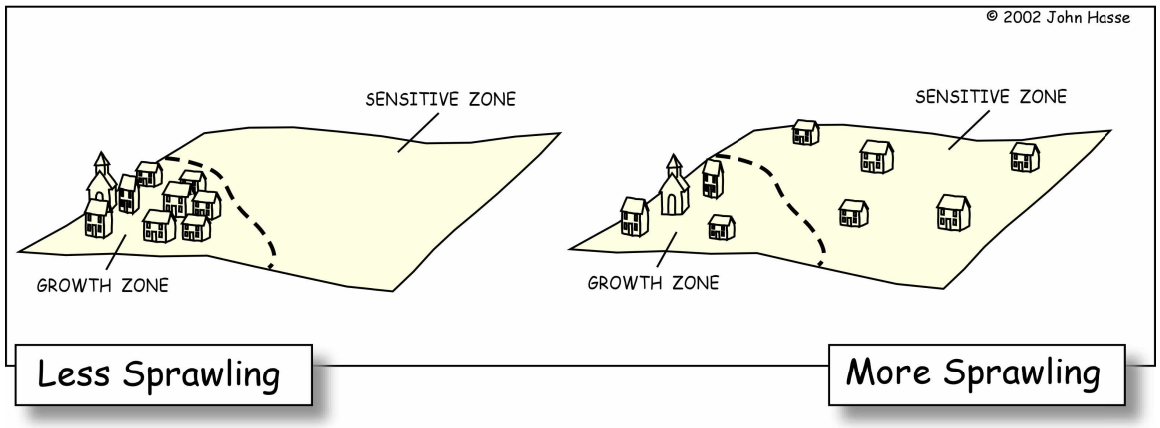


Figure 3-6 *The **regional planning inconsistency** index provides a measure of whether a given patch of new development is consistent with the planning objectives of a regional master plan. New development that is in conflict with the land use intentions of a regional masterplan is considered sprawling whereas development that is consistent with the plan is less sprawling.*

5) Highway Strip Development – Highway strip development is another commonly cited characteristic of sprawl (Benfield et. al 1999; Vermont Forum on Sprawl 1999; Downs 1998; Ewing 1997; Florida Growth Management Plan 1993). Rural "ribbon" development where single residences line rural roads, often blocking scenic vistas and fragmenting rural lands typifies the residential form of highway-strip development. Residences along rural highways present traffic safety-related issues due to multiple driveways fronting on relatively high-speed rural highways. Corridors of fast food and large, "big box" retailers exemplify the commercial expression of highway strip (Figure 3-7). Commercial strips are usually limited to automobile access for customers and are often fronted by large expanses of parking lots. Some find that highway strip development is the most aesthetically offensive component to sprawl, and that is exemplifies the 'ugliness factor' (Kunstler 1993). Highway strip development impacts accessibility as well as social and aesthetic functions of the landscape.

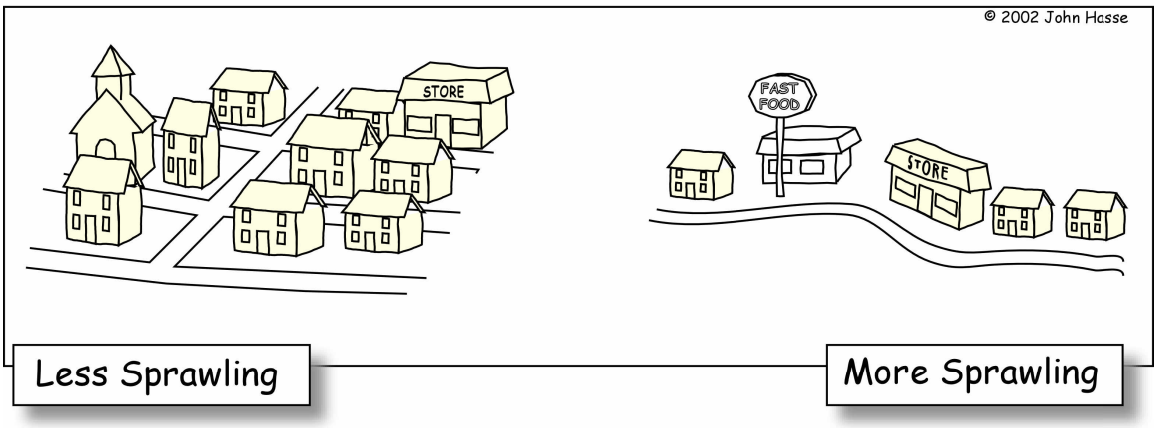


Figure 3-7 *The **highway strip** index provides a measure of whether a given unit of new development is located along arterial rural highways beyond the environs of a town. New development aligned along rural highways is considered sprawling for this measure.*

The highway-strip index measures the degree to which new development occurs along rural highway corridors. For the purposes of measuring residential highway strip the measure is calculated determining whether a new housing unit occurs within 300 feet of a rural highway. Housing units that occur within the rural highway corridor are considered sprawling by this measure.

Transportation Network Spatial Measures

Sprawling patterns of urban development are inherently reliant upon the existence of private automobile transportation (Torrens & Alberti 2000; Benfield *et al.* 1999; Sierra Club 1999; Vermont Forum on Sprawl 1999; Burchell 1999; Downs 1998; Ewing 1997; Anderson *et al.* 1996). The dominance of the automobile as the primary if not only mode of transportation results in more vehicle miles traveled and by implication more impact to the environment. Development that is exclusively dependent upon the automobile also impacts the social functionality of a landscape as new housing, community services, and nodes of commerce and employment are only accessible to automobile drivers. The proposed transportation-related spatial measures of

urban sprawl strive to capture the transportation network implications that result from a given new patch of development. They include *new road network efficiency, alternate transportation mode accessibility* and *accessibility to important community nodes.*

6) New Road Infrastructure Efficiency - Sprawling residential and commercial developments create a less efficient road network of loops and lollipops (Figure 3-8), laying down greater lengths of new road lane miles, more cul-de-sac and fewer intersections per capita than more efficient grid networks often associated with compact patterns of growth (Southworth & Owens 1993). The road infrastructure that accompanies sprawl is less functionally efficient and forces greater amounts of automobile travel to reach adjacent but non-adjoining tracts of new development.

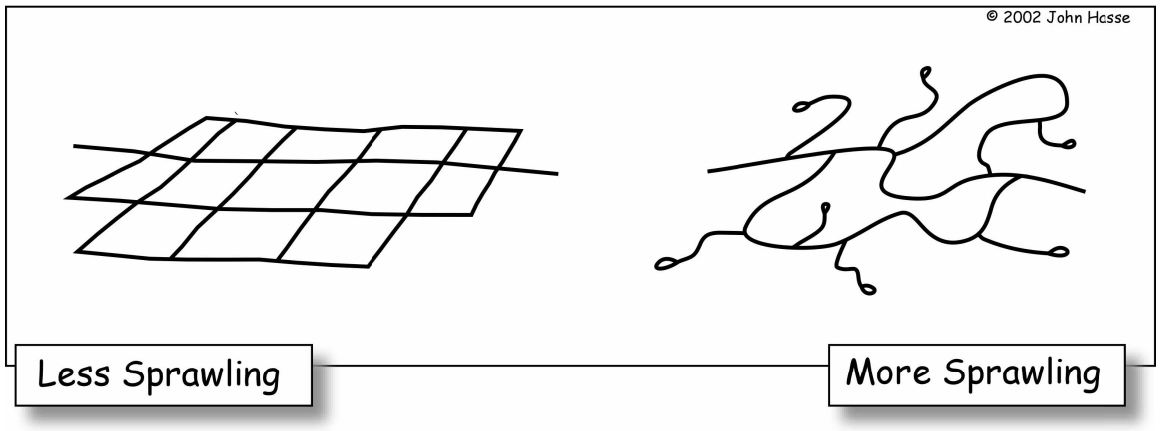


Figure 3-8 *The **new road infrastructure inefficiency** index provides a measure of efficiency of new roads created by new urban growth. More sprawling growth creates road infrastructure that results in more lane-miles of road, more cul-de-sacs and fewer intersections than less sprawling patterns of urban growth.*

The new road infrastructure efficiency index is a measure of the efficiency of new road networks that accompany a given patch of new development. Three sub-measures comprise the index in this analysis: created road lane-miles; number of intersections; and number of cul-de-sacs per capita for new development patches. Greater lengths of lane-miles, more cul-de-sacs, and fewer intersections for each new person accommodated by new urban patches translate to more sprawling growth.

7) Inaccessibility to Alternate Modes of Transportation - The failure of sprawling growth to create opportunities for alternate modes of transportation is another critique of this form of development (Sierra Club 1999; Downs 1998; Ewing 1997; Southworth 1997; Florida Growth Management Plan 1993; Calthorpe 1993). Urban sprawl is primarily suited to the use of private automobiles as the sole means of transportation, neglecting the needs of willing pedestrians, bicyclists, and would-be users of public transportation. Such patterns of development exhibit reduced landscape functionality and efficiency in their ability to facilitate movement, and are inherently age and class-discriminatory.

The *alternate transit inaccessibility* index measures the extent to which a patch of new development is accessible by alternate (i.e. non-automobile) modes of transportation (Figure 3-9). Sub-measures of the distances from each new urban patch to the nearest transit stop or bus route, bike path and sidewalk/pedestrian path comprise the index in this analysis. The sub-components can be weighted to reflect the importance of public transportation and summarized. The need to travel great distances to reach alternate modes of transportation for any given new development patch is considered more sprawling for this characteristic.

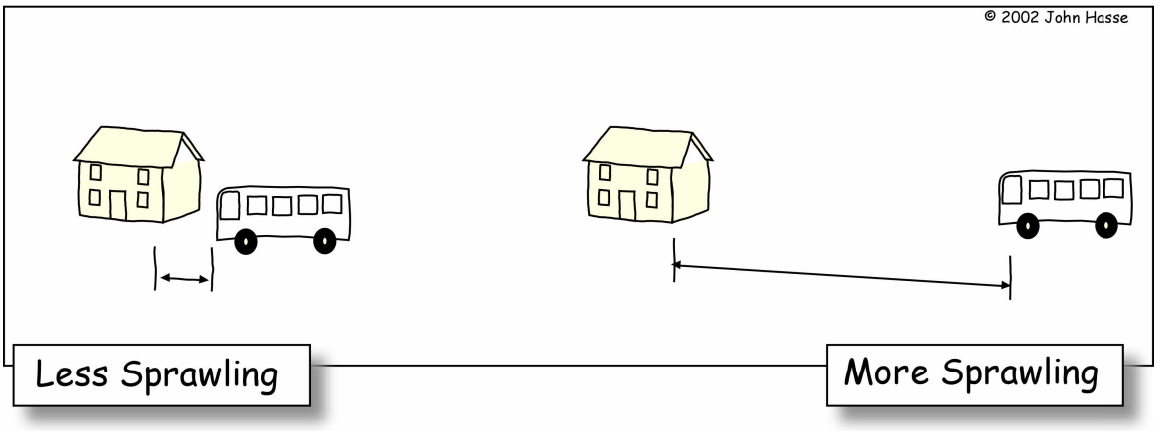


Figure 3-9 *The Alternate Transit Inaccessibility index provides a measure of road distance from new development to alternate modes of transportation. Development that is far away from alternate transit options is considered more sprawling than development closer to non-auto transit options.*

8) Community Node Inaccessibility - Urban sprawl has been characterized as generally lacking a definable urban cohesion due to dispersed or acentric development patterns (Galster *et al* 2000; Sierra Club 1999; Vermont Forum on Sprawl 1999; Ewing 1997, Kunstler 1993, Garreau 1991). Sprawling land use patterns seem to spread all growth haphazardly throughout a landscape. There is little "sense of place" as community nodes are not situated in sensible relation to each other or to new urban development. This is especially significant when a patch of new development is located at a large distance from important community centers such as schools, police, fire and rescue, recreational facilities, etc. The result is a dysfunctional pattern that creates a lack of definable town identity; a necessarily inefficient transportation pattern; longer response times for emergencies; and diminished sense of community.

The *community node inaccessibility* index measures the distance from a new patch of development to important community nodes such as schools, emergency service stations, grocery stores, post offices, and parks (Figure 3-10). This measure summarizes the average road network distance from new development patches to these community nodes, the locations of which were identified by use of county maps, in-field observation, and orthophotography. Larger average distances from new development to community nodes signify a more sprawling pattern for this measure.

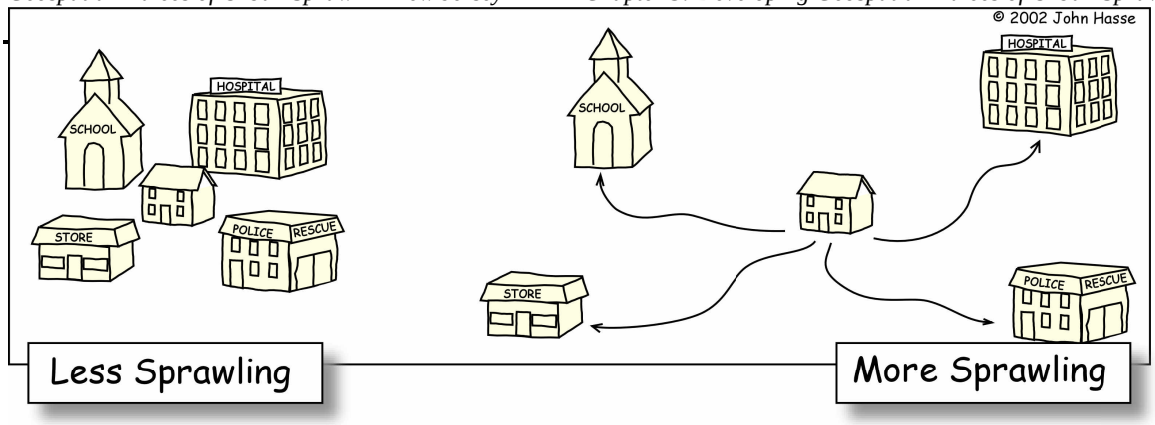


Figure 3-10 *The* ***community node inaccessibility*** *index provides a measure of road distance from a patch of new development to important community nodes. New development that is farther away from community nodes such as schools, emergency services, grocery stores among others is considered more sprawling than development nearer to these important centers. The measure captures the vehicle mile travel by residents of new development as well as the accessibility of new development to emergency services, schools and other community functions.*

Spatial Patterns of Environmental Impacts of Urban Growth

The eight preceding land use and transportation GIUS measures focus on development patterns that are problematic or inefficient regarding human landscape functions. The following four environmental resource impact measures attempt to capture the geo-biological impacts and ecological dysfunctions of sprawl development. The environmental impact indices include *loss of important land resources* (such as wetlands, prime farmland and endangered habitat); *encroachment upon sensitive, preserved open space; excessive per capita impervious surface coverage;* and the *growth trajectory* imparted to municipalities by new development.

9) Loss of Important Land Resources - Urban sprawl has been characterized as consumptive of important agricultural and natural land resources (Sierra Club 1999; Vermont Forum on Sprawl 1999; Burchell 1999; Bradshaw & Muller 1997; Florida Growth Management Plan 1993). A significant amount of natural wetlands and critical habitat are lost to unbounded urban growth despite the existence of protective regulations. The wasteful destruction of these important land

resources is an often irreversible consequence of sprawl, and perhaps the most significant impact of urbanization on the ecological functioning of a landscape (Figure 3-11).

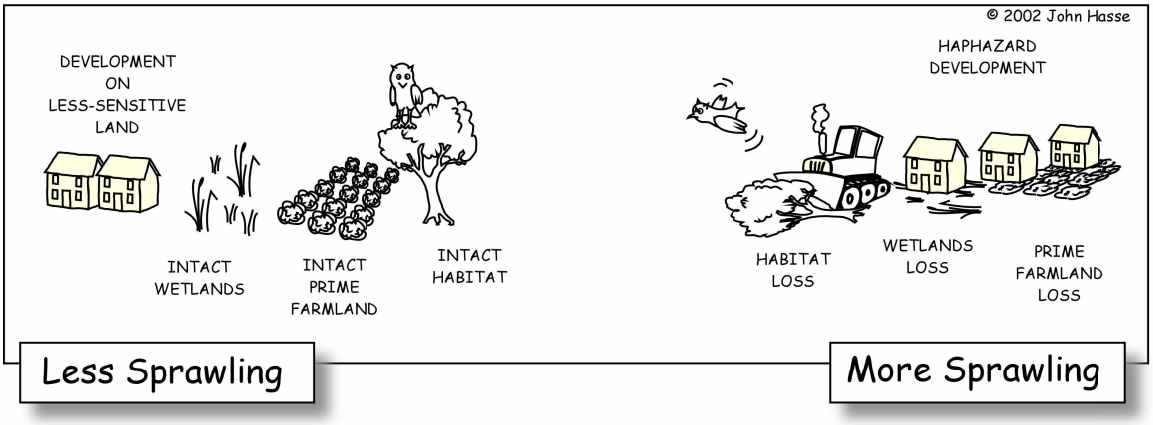


Figure 3-11 *The **land resource impact** index provides a measure of the amount of important land resources consumed for development including prime farmland, wetlands and endangered wildlife habitat. The measures are normalized by the number of new residences (new housing units are used as a proxy) to provide a per capita impact to important land resources. Development which impacts a larger amount of land resource for each resident housed is considered more sprawling than development that impacts relatively few important land resources.*

The land resources impact index measures the amount of important land resources consumed by any given patch of new development. The index consists of three sub-components that include wetlans, prime farmland and endangered wildlife habitat. Maps of each sub-component are overlaid with maps of new development to determine the land area of wetlands, prime farmland and endangered wildlife habitat that is consumed by new urban growth. The amount of land resources consumed is normalized by the growth in population (new housing units used as a proxy) to provide a per capita consumption of important land resources. Urban growth that consumes large proportions of important land resources per unit of new development is considered more sprawling than growth with a lower per unit consumption.

10) Encroachment on Sensitive Preserved Open Space - Inadequate preservation of open space is another characteristic of sprawl (Benfield *et al.* 1999; Fausold & Lilieholm 1999, Sierra Club

1999; Vermont Forum on Sprawl 1999; Burchell 1999; Florida Growth Management Plan 1993). The rapid urbanization of once open lands challenges communities to preserve adequate open space for purposes of active and passive recreation, maintenance of environmental quality, habitat preservation and farmland preservation. A comprehensive index that meaningfully characterizes networks of protected open space and their relationship to ecological and human functions is quite challenging. Such an endeavor is probably more appropriately developed and applied where the quantity and geography of open space can be evaluated at a regional scale. A sophisticated open space analysis such as this will be reserved for future research. For this tract-level analysis a more simplified approach was taken for a measure of the impact of sprawl to open space.

The measure as developed for this analysis focuses on the impact of urban encroachment on protected open spaces that are vulnerable to disturbance by conflicting urban land uses (Figure 3-12). For example, the viability of farmland can be significantly diminished by encroaching urbanization (Adelaja & Schilling1998). Farms that are preserved in perpetuity through statutory preservation mechanisms may become subject to irreconcilable conflicts with neighboring residential uses (i.e. complaints about the application of pesticides, foul odors, agricultural vehicles on roads, etc). In addition, farmland viability is reliant upon a community of neighboring farms to support local agricultural services and suppliers. Regional farmland fragmentation and conflicts that stem from encroaching urban development inhibit the ability of the farm to function efficiently. The fact that the land has been preserved and therefore is not available for development is effectively defeated by the impracticality of its intended use due to conflicting neighboring land uses. Similar arguments can be made about the reduced ecological viability of preserved wildlife habitat due to encroachment by incompatible urban land use.

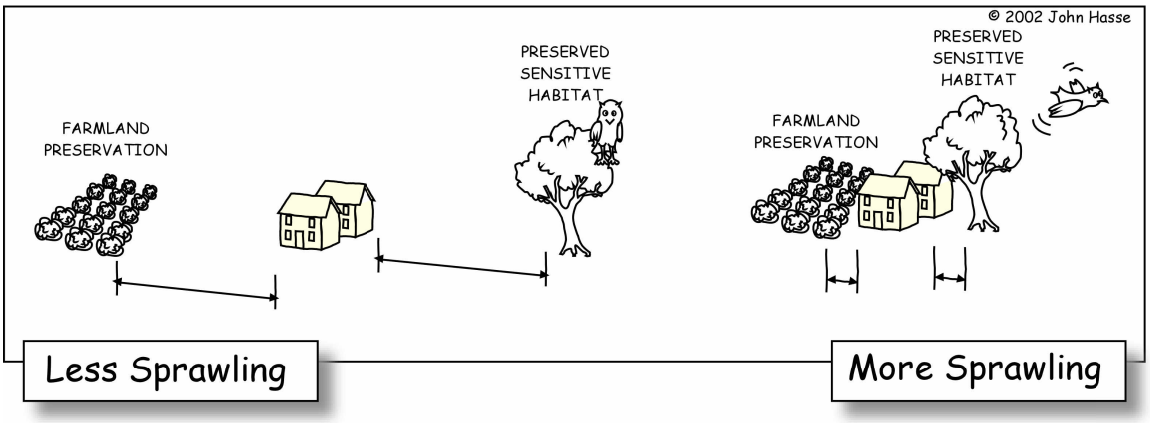


Figure 3-12 *The **sensitive open space encroachment** index provides a measure of the degree to which urban growth encroaches on sensitive protected open space including farmland that is in permanent preservation and important habitat that is in preserved open space. Development that occurs closer to sensitive open space is considered more sprawling for this measure than development that occurs at a distance from sensitive open space.*

The open space encroachment index, as developed for this analysis, focuses on preserved open space that is intended to protect sensitive wildlife management areas or lands enrolled in the state farmland preservation program. The index calculates the weighted inverse distance from new development to sensitive preserved open space. Larger inverse distances to sensitive open space (i.e. development that is close to sensitive open space) indicates a more sprawling pattern of urban growth for this measure.

11) Increased Per Unit Impervious Surface - Impervious surface is human-created land cover that reduces or eliminates the capacity of the underlying soil to percolate water thus impeding the natural infiltration of precipitation into the ground. Studies have long demonstrated that accelerated runoff from impervious surfaces directly channeled into water bodies leads to increased frequency and magnitude of flooding and subsequent potentially disastrous consequences (Carter 1961; Wilson 1967; Seaburn 1969; Hammer 1972). Impervious surface also impacts water quality by concentrating non-point source pollutants such as road salts, sediments, hydrocarbons and refuse, channeling them directly into waterways (Klein, R 1979, Booth 1991). Other research has indicated that the overall environmental quality of water within

a watershed is directly related to the amount of impervious surface within that basin (Alley & Veenhuis 1983;Todd 1989; Horner et. al.1996; Booth & Jackson 1997). Important impacts such as changes in alkalinity, nutrient loading and chemical contamination can be associated with impervious surface coverage.

Impervious surface coverage is increasingly relied upon as an environmental indicator for land planning due to its vital associations with water (Arnold and Gibbons 1996). The implications for landscape functionality carried by impervious surface demand that it be included as a tool for measuring sprawl, although no quantitative expression for the relationship of impervious surface to sprawl has yet been shown. High-density urban land uses generally have higher impervious surface percentages at the site-level, but they consume smaller amounts of land in total leaving more undeveloped area to remain pervious. This contrasts with sprawling residential land uses that may have a lower site-level percentage of impervious surface but consume a greater total area thereby creating a greater gross amount of impervious surface for each new resident (Figure 3-13). The impervious surface measure indicates the impact that new urban growth imparts to the hydrologic function of the landscape.

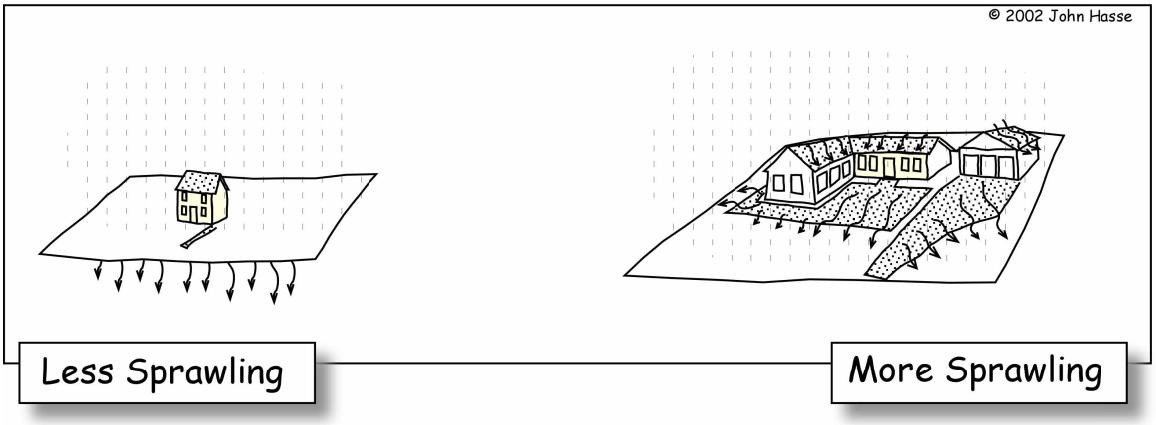


Figure 3-13 *The **increased per unit impervious surface** index provides a measure of per unit impervious surface created by new urban growth (new housing units are used as a proxy for population growth). Sprawling patterns of growth create more acres of impervious surface for each new resident accommodated by the development compared with less sprawling growth. Impervious surface has a direct correlation to water quality.*

The *per unit impervious surface* index measures the acreage of impervious surface per new resident that is contributed to the landscape by a new patch of development. Summaries of estimated impervious surface area attributed to new urban patches, normalized by population, comprise the index. (Estimations of impervious surface are provided in the NJDEP land use dataset). New urban growth that contributes large amounts of impervious surface per capita suggest a more sprawling development pattern than those that contribute small per capita measures of impervious area.

12) Urban Growth Trajectory **-** Urban sprawl has been associated with rapid, unlimited, explosive growth (Vermont Forum on Sprawl 1999; Burchell 1999; Downs 1998;; Anderson *et al*. 1996, Kunstler 1993). Unchecked development eventually leads to a state of "build-out" on the landscape where all lands that are available for construction are developed to their maximum legal density. A built-out landscape generally results in wall-to-wall development with no definable town center or rural hinterland to separate one town from another town. The rapid speed of new development often finds localities unprepared to handle the pressures of growth such as the need for new schools and expanded community services. Such explosive haphazard land use patterns indicate a significant reduction in landscape integrity for both the human community and the ecology of the landscape. The *urban growth trajectory index* provides an indication of the magnitude of change contributed by new development within the context of its location. The index is produced by measuring three components of the pace of development including: 1) the rate of urban growth; 2) the rate of growth relative to the locality; and 3) the degree to which new growth consumes remaining available land (Figure 3-14).

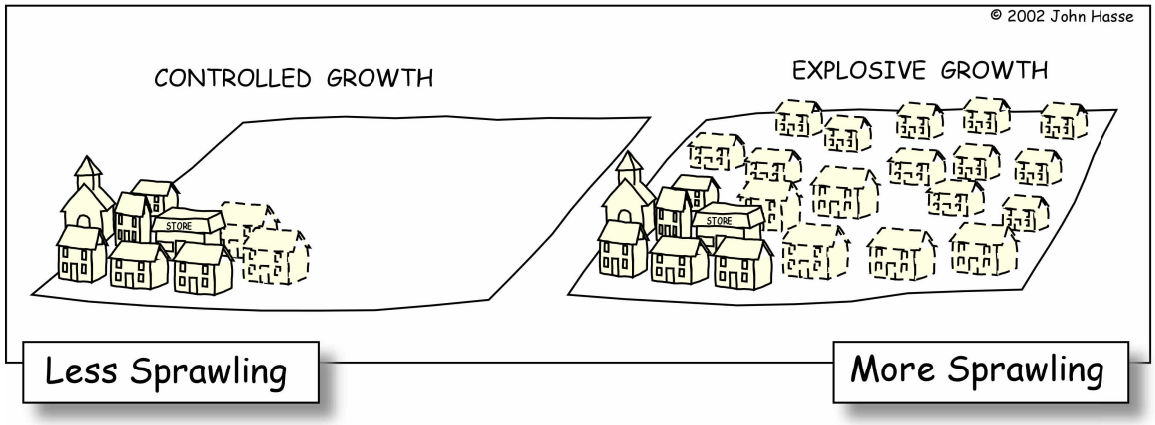


Figure 3-14 *The **growth trajectory** index provides a measure of pace of development over time within the context of the locality in which the development occurs. Rapid development carries implications for inundating localities with the consequences of growth such as the need to provide schools and community services and the loss of open space as a town reaches build-out. Development which contributes explosive growth while consuming available lands is considered more sprawling for this measure than development which exhibit characteristics of controlled growth.*

The urban growth trajectory index gives important temporal and geographical context to new growth, and is therefore a vital measure of urban sprawl. For example a new development that doubles the existing urban infrastructure of a small community will have dramatic consequences for the community in terms of services required (schools, police, etc.), whereas the location of the same amount of new development in a much larger, existing community would have relatively less impact on the receiving town. At the other extreme, a new development that consumes 50% of the remaining available land of a locality that is nearing build-out is far more significant to that locality than if the same new development is located in a community where it consumes less than 1% of the remaining locally available lands. The urban growth trajectory index measures the degrees to which new development tracts contribute to growth and detracts from remaining available land in their target communities.

The *growth trajectory index* consists of three subcomponent measures that quantify the *rate of growth* and the *rate of available land consumed*. Two of the sub-measures capture different aspects of the rate of growth. The first does so by dividing the area of the new urban patch by the area of all urban land use that existed in the locality prior to the initiation of development. The

second quantifies growth-rate by dividing the area of the new urban patch by the area of the entire territory of the municipality. The rate of available land consumption is calculated by dividing the area of the new patch by the amount of available land estimated at the time of new development initiation. (Available lands data are generated by a combination of land use and preserved open space data). The three sub-measures are summed to provide an index that captures community impacts attributable to sprawling growth. Large relative rates of expansion and/or rapid rates of available land consumption are two such impacts. A patch of new urban growth that contributes a significant change to the urban fabric and/or consumes a significant amount of remaining available land is considered more sprawling than new urban growth that exhibits lower rates for this metric.

Each of the twelve individual geospatial indices of urban sprawl *(GIUS)* provide interesting information about the spatial characteristics of new growth, and the impact that growth has on the functional integrity of the landscape. The GIUS provide a robust mechanism for profiling the spatial signatures of sprawling development upon a landscape when used in combination. The following section employs a housing tract-level GIUS analysis to characterize three recent developments in Hunterdon County New Jersey.

IV. Operationalizing Geospatial Indices Of Urban Sprawl

Measuring Individual Development Tracts for Characteristics of Sprawl

Three patches of new residential development were selected to demonstrate utilization of the geospatial indices of urban sprawl at the patch (i.e. housing tract) level. The patches present examples of new residential growth that occurred in three Hunterdon County, New Jersey municipalities between 1986 and 1995. The patches were identified as polygons in which land use changed from non-residential to residential according to the NJDEP digital dataset. These data consist of detailed delineations of land use/land cover for both 1986 and 1995 as interpreted from aerial orthophotography (NJDEP 2000). The selection of growth patches for the analysis was further refined by visual examination of changed land use polygons overlain on digital orthophotographic quarter quadrangles *(DOQQ)* of the county. The three residential patches analyzed here were chosen as those that intuitively appeared to exemplify low, moderate and high signatures of sprawl.

On-screen measures were then made using the available GIS tools, ancillary maps (digital and paper), in-field observations and photo interpretation of the DOQQs (see Figure plates 3-15 thru 3-17). This semi-automated approach to GIUS calculation for a given tract of development demonstrates the accessibility of GIUS analysis for potential use at the planning board level. A fully automated approach to GIUS measurement is detailed in chapter 4 and averaged county-wide to provide Z-scores as a normalization value in the GIUS signature graphs (Figure plates 3-15 thru 3-17).

Low-Sprawling Geospatial Signature – the Califon Tract

This first subject of analysis is a patch of new development that consists of an eleven-unit subdivision in Califon Borough (yellow outline Figure plate 3-15). The Califon patch scored low for most of the 12 indices suggesting that it is the least sprawling of the three exemplary patches. The Califon patch contains 11 single-family houses on 5.0 acres which results in a density of 2.2 units per acre (or 0.45 acres per unit). While these ½acre lots may not be considered small for some communities, they are smaller than the 0.8-acre countywide average lot size for all residential growth of that period in this characteristically rural region. The patch is serviced by public sewer which permits the smaller lot sizes.

The Califon patch is nestled within the existing town structure and demonstrates non-leapfrog or contiguous in-fill development. Five different urban land uses including parks, schools and stores are within the 1500-foot pedestrian zone of this new patch (white line in orthophoto figure plate 3-15). Califon Borough is an *Existing Village* according to the New Jersey State Plan and should encourage in-fill development such as this patch to reinforce the idea of town centers. The patch is within the village limits and does not front a major roadway so it is not considered highway strip.

The transportation-related geospatial indices show that the Califon patch exhibits characteristics of efficient and accessible growth. The road infrastructure is lower than the county average for new patches. The per unit length of new road was 60 feet. The transit accessibility measure is excellent because the Hunterdon County Loop bus line passes within several hundred feet of the subdivision. The clustering of community nodes within the village makes the community node inaccessibility very low (i.e. the tract is very close to community nodes on average) suggesting

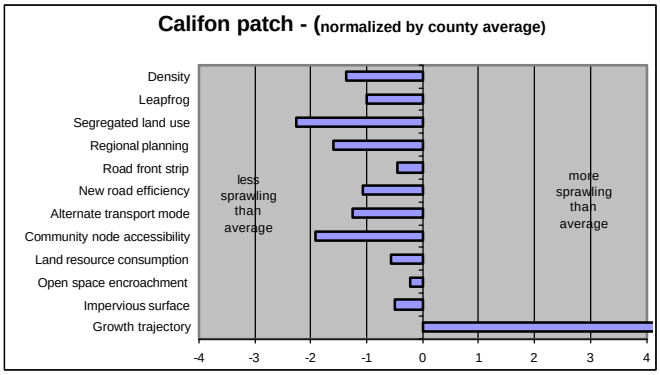
that the residents of this subdivision will be contributing fewer vehicle miles of travel for daily activities and closer to emergency services.

The land resource geospatial indices for the Califon patch also demonstrate desirable qualities. There were virtually no acres of wetlands, prime farmlands or heritage lands (regions of documented threatened or endangered species) consumed for this development. The patch was within 500 ft of only 1.1 acres of wildlife management area or preserved farmland. This results in an open space encroachment index of 0.1 units when normalized by the 11 units in the development. The patch contributed 1.26 acres of impervious surface resulting in a per unit contribution of 0.11 acre. This is significantly less than the 0.16 acre per unit countywide average of impervious surface that was created by concurrent residential growth.

The *growth impact trajectory* index is very high for the Califon patch. The patch contributed to a 1.7 % increase in urban growth for the town, 0.81% increase growth relative to municipal size, and consumed 2.27 % of the remaining available land. These values are comparatively high because the village of Califon only occupies a total of 621 acres and does not have large tracts of available land remaining. While new development in a town such as Califon epitomizes smart growth and is compliant with the kind of development prescribed by the State Plan, the small size and fragile town character suggests that future growth in Califon will need to be carefully managed.

The Califon Tract		
1	**Density**	
	size of patch	5.0
	units in res patch	11
	acre per unit	0.45
2	**Leapfrog**	
	Distance to previous settlement	93
3	**Segregated Land Use**	
	Average no of lu's w/in 1500 ft	5.0
4	**Regional Planning Inconsistency**	
	state plan designation	Existing Village
5	**Highway Strip**	
	pct of patch w/in 300 ft highway	0.00
6	**New Road Efficiency**	
	total rd length in patch	660.0
	rd length per unit	60.0
	total # cul-de-sacs in patch	1.0
	cul-de-sacs per unit	0.1
	total no intersections in patch	1.0
	intersections per unit	0.1
7	**Alternate Transit Inaccessibility**	
	rd distance to transit	718
	rd distance to bike path	1,750
	distance to foot path or side walk	40
8	**Community Node Inaccessibility**	
	rd distance to rescue	1,942
	rd distance to police	2,106
	rd distance to fire	1,879
	rd distance to hospital	7,123
	rd distance to school	1,608
	rd distance to grocery	2,260
	Rd distance to post office	3,649
	rd distance to library	42,505
	rd distance to municipal hall	2,106
	rd distance to recreation /park	1,586
	average to all nodes	6,676
9	**Land Resource Consumption**	
	acres wetlands loss	0
	wetlands loss per unit	0
	acres prime farm loss	0
	Prime farmland loss per unit	0
	Acres heritage site loss	0
	heritage loss per unit	0
10	**Open Space Encroachment**	
	distance to sensitive OS	1,762
	inverse * 10,000	5.68
11	**Impervious Surface Per Capita**	
	Acres of impervious surface	1.26
	acres imperv per unit	0.11
12	**Growth Trajectory**	
	mun size in acres	621
	tract % of urban growth	1.70
	tract % mun size	0.81
	tract % of remaining avail	2.27
	combined trajectory index	4.78

(a) orthophoto



(b) GIUS graph depicted in standard deviations from county average

(c) photograph of the Califon tract.

Figure plate 3-15 GIUS measures for a new tract of development in Califon Borough*, Hunterdon county, NJ. This tract exemplifies recent growth that exhibited some of the least sprawling characteristics within the county. The tract (outlined in yellow) was within a 10 minute walk (1,500 feet outlined in white) to many of the community nodes including a public transit stop and fire department. The graph depicts each of the GIUS measurements in standard deviations from the county average. All variables except growth trajectory indicate that this development was less sprawling than the average development during the same period in Hunterdon County.*

Typical Sprawling Geospatial Signature – the Readington Township Tract

The second residential patch selected for analysis typifies the average sprawling subdivision that occurred in Hunterdon County during the period. The patch (outlined in yellow in figure plate 3-16) is located in Readington Township near the village of Three Bridges, approximately a quarter mile from Route 202. It is a 25-unit subdivision that occupies 29.8 acres and yields a 1.19 acres per unit housing density. This is a typical configuration for 1 acre zoning where approximately 20% of a subdivision is consumed by roads and odd lot configurations. The Readington patch is not serviced by sewer, therefore each unit must have an individual, on-site septic system. The patch has leapfrogged a significant distance from the village of Three Bridges (lower right of the orthophoto), and is surrounded on 3 sides by active agriculture. The land use is virtually segregated with an average mixed use value of 1.8 different urban land uses within the pedestrian zone (white outline in orthophoto). The patch is located in a *Rural Planning Area*, and is therefore in conflict with the New Jersey State Plan.

The Readington patch fares poorly in the transportation indices as well. Each housing unit required 129 feet of new roadway. It is nearly three miles to the nearest transit option. There are no dedicated bike or foot trails in the region, and the subdivision contains no sidewalks. Transportation is limited to personal automobiles in this development. The average distance to community nodes such as schools, emergency services and grocery store is over 3 miles. The vehicle miles traveled by residents of this patch will be significantly higher than those of the Califon patch. Alternate modes of transportation will not, in all likelihood, be used by the resident of this development due to significant distance needed to reach it.

The Readington patch exerts significant impact on land resources as demonstrated by the land resource indices. The municipality sustained a significant loss of prime farmland due to the new

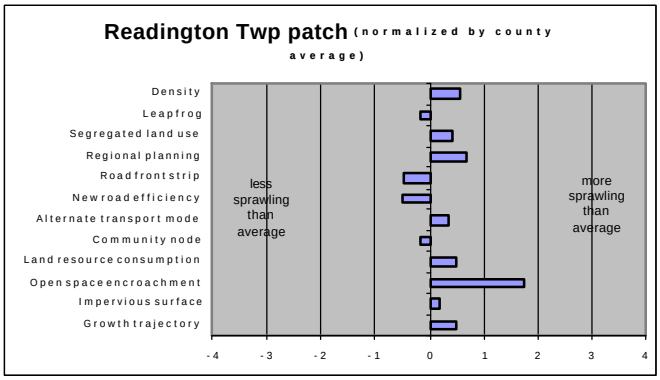
subdivision, although there was no loss of wetlands or heritage land (threatened or endangered habitat). Sixty five percent of the subdivision consumed prime farmland (19.4 of 29.8 acres). The result is a 0.78 acre per housing unit consumption of prime farmland.

Open space analysis demonstrates a significant encroachment upon neighboring sensitive preserved lands. The subdivision is within 500 feet of 11.6 acres of adjacent preserved farmland to the south and west. This has resulted in a 0.46-acre per unit impact to this protected open space. The preserved parcels are actively farmed as is evident in the orthophoto, and are therefore vulnerable to nuisances associated with proximity to conflicting land use (i.e. trespassing, complaints, etc.).

The patch contributed 0.18 acres of impervious surface per unit. This is equal to the countywide average for all new development during the 1986 to 1995 time period. The growth-impact trajectory index indicates that this patch, having scored less than one percent for each sub-measure, has contributed a modest amount of growth. The project increased urban area by 0.39 percent, grew 0.10 percent relative to the township size and consumed 0.18 percent of the available lands. The trajectory index of this patch of development indicates less urgency in the overall context of the municipality. This can be attributed to the substantial size of the municipality. Readington Township is the largest municipality in Hunterdon County and is nearly three times the county average municipal size at 30,550 acres.

The Readington Tract		
1	**Density**	
	size of patch	29.8
	units in res patch	25
	acre per unit	1.19
2	**Leapfrog**	
	Distance to previous settlement	2,516
3	**Segregated Land Use**	
	Average no of lu's w/in 1500 ft	1.8
4	**Regional Planning Inconsistency**	
	state plan designation	PA 4
5	**Highway Strip**	
	pct of patch w/in 300 ft highway	0.00
6	**New Road Efficiency**	
	total rd length in patch	3,228
	rd length per unit	129.1
	total # cul-de-sacs in patch	1.0
	cul-de-sacs per unit	0.04
	total no intersections in patch	2.0
	intersections per unit	0.08
7	**Alternate Transit Inaccessibility**	
	rd distance to transit	17,079
	rd distance to bike path	74,252
	distance to foot path or side walk	no sidewalk
8	**Community Node Inaccessibility**	
	rd distance to rescue	23,501
	rd distance to police	24,029
	rd distance to fire	4,703
	rd distance to hospital	25,306
	rd distance to school	4,685
	rd distance to grocery	20,430
	Rd distance to post office	4,094
	rd distance to library	35,750
	rd distance to municipal hall	24,889
	rd distance to recreation /park	5,336
	average to all nodes	17,272
9	**Land Resource Consumption**	
	acres wetlands loss	0
	wetlands loss per unit	0
	acres prime farm loss	19.4
	Prime farmland loss per unit	0.77
	acres heritage site loss	0
	heritage loss per unit	0
10	**Open Space Encroachment**	
	distance to sensitive OS	4,319
	inverse * 10,000	2.32
11	**Impervious Surface Per Capita**	
	Acres of impervious surface	4.45
	acres imperv per unit	0.18
12	**Growth Trajectory**	
	mun size in acres	30,553
	tract % of urban growth	0.39
	tract % mun size	0.10
	tract % of remaining avail	0.18
	combined trajectory index	0.67

(a) orthophoto



(b) GIUS graph depicted in standard deviations from county average

(c) photograph of the Readington tract.

Figure plate 3-16 GIUS measures for a new tract of development in Readington Township*, Hunterdon county, NJ. This tract exemplifies recent growth that exhibited typical sprawling characteristics within the county. The tract (outlined in yellow) is not within a 10 minute walk (1,500 feet outlined in white) to any of the community nodes averaging over 3 miles to these destinations. The graph depicts each of the GIUS measurements in standard deviations from the county average. All variables were approximately average for all the development that occurred in the county during the same period as depicted by the graph, and suggesting that average growth within this county is substantially sprawling in nature.*

Extreme Rural Sprawl – the Alexandria Township Tract

The Alexandria patch exemplifies high-end rural sprawl consisting of luxury mansions on 3-acre lots. The patch (yellow outline in orthophoto figure plate 3-17) is perched on rolling hills between farms and forested areas, located deep within the agricultural belt of western Hunterdon County. The patch provides 34 housing units dispersed over 91.5 acres, providing a nominal density of 2.69-acres per unit. The leapfrog distance is the greatest of the 3 residential patches selected for this analysis exceeding a mile into the rural lands of the township. The patch is epitomizes land use segregation with only a few other housing units within the 1,500-foot pedestrian zone (white outline in orthophoto). The patch is constructed on land that is designated *Rural, Environmentally Sensitive* by the New Jersey State Plan, and is therefore in conflict with regional planning goals. No highway strip characteristics can be observed.

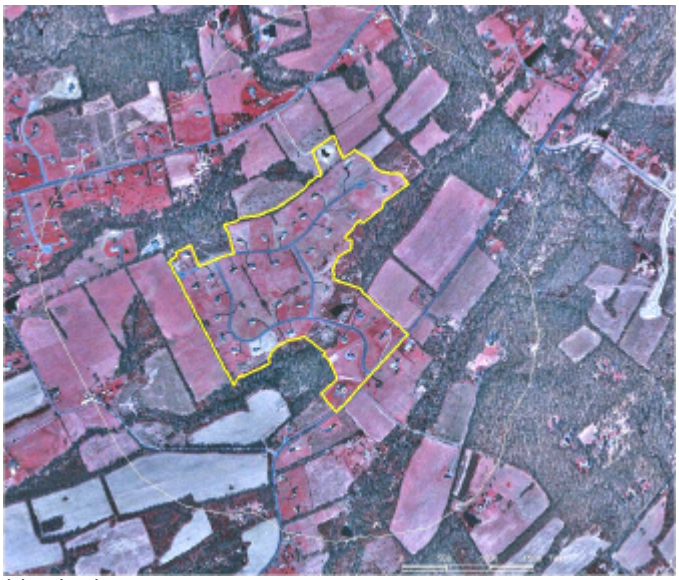
The patch also exhibits poor efficiency of transportation patterns. The length of new road per housing unit is 220 feet. The patch is over 5 miles from the nearest public transit route, and has no bike or pedestrian trails within a reasonable riding or walking distance. There are no sidewalks within the subdivision. The average distance to community nodes from the patch is 5.4 miles, ensuring excessive vehicle miles traveled for daily activities and prolonging response times for emergency services.

The land resource impact indices also show that the sprawling patch has a significant impact on the physical landscape. The patch encroached on both wetlands and prime farmland consuming 0.21acres and 0.75 acres respectively per residential unit. The patch also exhibited a higher amount of impervious surface per housing unit than the previous study patches. The 0.23 acres of

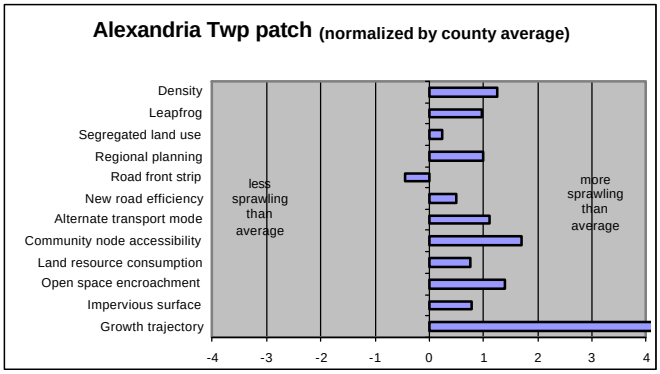
impervious surface per housing unit is more than double the per unit impervious surface exhibited by the Califon patch.

The Alexandria patch also encroached upon preserved the sensitive open space of the Schick Conservation Reserve which borders the development to the west. Finally the growth *trajectory index* indicates that this development contributed a sizeable 4.71 percent urban growth for the rural municipality.

The Alexandria Tract		
1	**Density**	
	size of patch	91.5
	units in res patch	34
	acre per unit	2.69
2	**Leapfrog**	
	Distance to previous settlement	5,824
3	**Segregated Land Use**	
	Average no of lu's w/in 1500 ft	2.0
4	**Regional Planning Inconsistency**	
	state plan designation	PA 4B
5	**Highway Strip**	
	pct of patch w/in 300 ft highway	0.00
6	**New Road Efficiency**	
	total rd length in patch	7,479
	rd length per unit	220.0
	total # cul-de-sacs in patch	2
	cul-de-sacs per unit	0.06
	total no intersections in patch	4
	intersections per unit	0.12
7	**Alternate Transit Inaccessibility**	
	rd distance to transit	24,536
	rd distance to bike path	29,583
	distance to foot path or side walk	no sidewalk
8	**Community Node Inaccessibility**	
	rd distance to rescue	24,137
	rd distance to police	29,568
	rd distance to fire	14,930
	rd distance to hospital	26,577
	rd distance to school	24,198
	rd distance to grocery	25,033
	Rd distance to post office	30,374
	rd distance to library	59,459
	rd distance to municipal hall	29,352
	rd distance to recreation /park	20,750
	average to all nodes	28,438
9	**Land Resource Consumption**	
	acres wetlands loss	7.16
	wetlands loss per unit	0.21
	acres prime farm loss	25.5
	Prime farmland loss per unit	0.75
	acres heritage site loss	0
	heritage loss per unit	0
10	**Open Space Encroachment**	
	distance to sensitive OS	3,703
	inverse * 10,000	2.70
11	**Impervious Surface Per Capita**	
	Acres of impervious surface	7.91
	acres imperv per unit	0.23
12	**Growth Trajectory**	
	mun size in acres	17,714
	tract % of urban growth	4.71
	tract % mun size	0.52
	tract % of remaining avail	0.73
	combined trajectory index	5.96



(a) orthophoto



(b) GIUS graph depicted in standard deviations from county average

(c) photograph of the Alexandria tract.

Figure plate 3-17 GIUS measures for a new tract of development in Alexandria Township*, Hunterdon county, NJ. This patch exemplifies recent growth exhibiting extreme sprawling characteristics within the county. The tract (outlined in yellow) is excessively distant from other community nodes averaging 5.4 miles. The isolation of the tract is evident by the empty pedestrian zone (1,500 feet outlined in white). Significant amounts of land resources were consumed, and a larger per capita amounts of impervious surface was created. The graph depicts each of the GIUS measurement in standard deviations from the county average. All variables were well above average for development that occurred in the country during the same period demonstrating the excessively sprawling character of this subdivision.*

Comparative Discussion

The three patches of urban growth demonstrate the application of the GIUS measures, and provide examples of below county average, typical and excessive expressions of sprawl during the study period. The patches selected for analysis present a cross-section of the spatial patterns associated with sprawl for recent growth patterns in Hunterdon County (figure plate 3-18). The patches were chosen to represent the range of sprawling growth patterns that have occurred in Hunterdon County over the 9-year period of study. Although the patches demonstrate a consistent gradient in sprawl characteristics for all 12 geospatial indices, the correlation between the indices may not be as strong as these few examples may imply. A correlation analysis of the GIUS measures for all new urban patches within the county (table 4-2) demonstrates that each sprawl index is substantially independent. The majority of correlation coefficients between each GIUS index are below $r = 0.50$. The strongest correlation was between community node inaccessibility and transit inaccessibility with a correlation coefficient of $r = 0.72$. Each individual patch of new development that occurred in the county expressed a unique signature with varying values for each of the 12 indices. Nonetheless, tract-level GIUS measures for the analysis sites shed light on the patterns of urban growth occurring within the county and the consequences of these patterns for the functional integrity of the landscape.

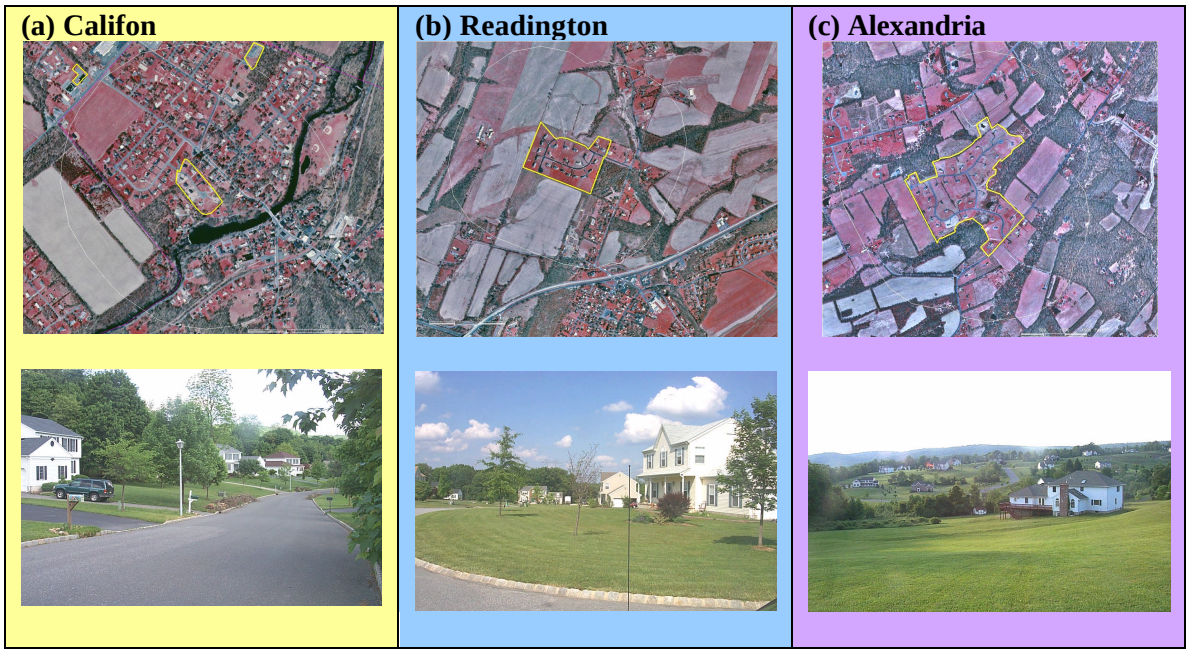


Figure plate 3-18 *GIUS analysis of 3 selected residential housing development tracts exhibiting a range of sprawling characteristics experienced in Hunterdon County during the 1980's and 1990's.*

Land Use Patterns Of Sprawl

The land use pattern GIUS measures for the selected subdivisions (Figure plate 3-19) demonstrate the varying spatial expressions of growth. The density index shows the excessive consumption of land exhibited by recent development. The ½acre lots of the Califon tract are higher density (i.e. less-sprawling) than average for a rural county such as Hunterdon, although they are hardly "high density" according to planning discourse. The 3-acre lots of the Alexander patch illustrate the consumptive nature of large-lot zoning, a technique that is often implemented in an effort to slow growth or maintain "rural character". It is arguable whether large 3-acre parcels with excessive lawns (as depicted in the photo) retain rural character or whether they simply result in a more wide spread suburban tract. It should be mentioned, however, that minimum lot size in a rural region is affected by the availability of public services such as water and sewer. The need to locate drinking water wells at a safe distance from septic leaching fields results in a minimum

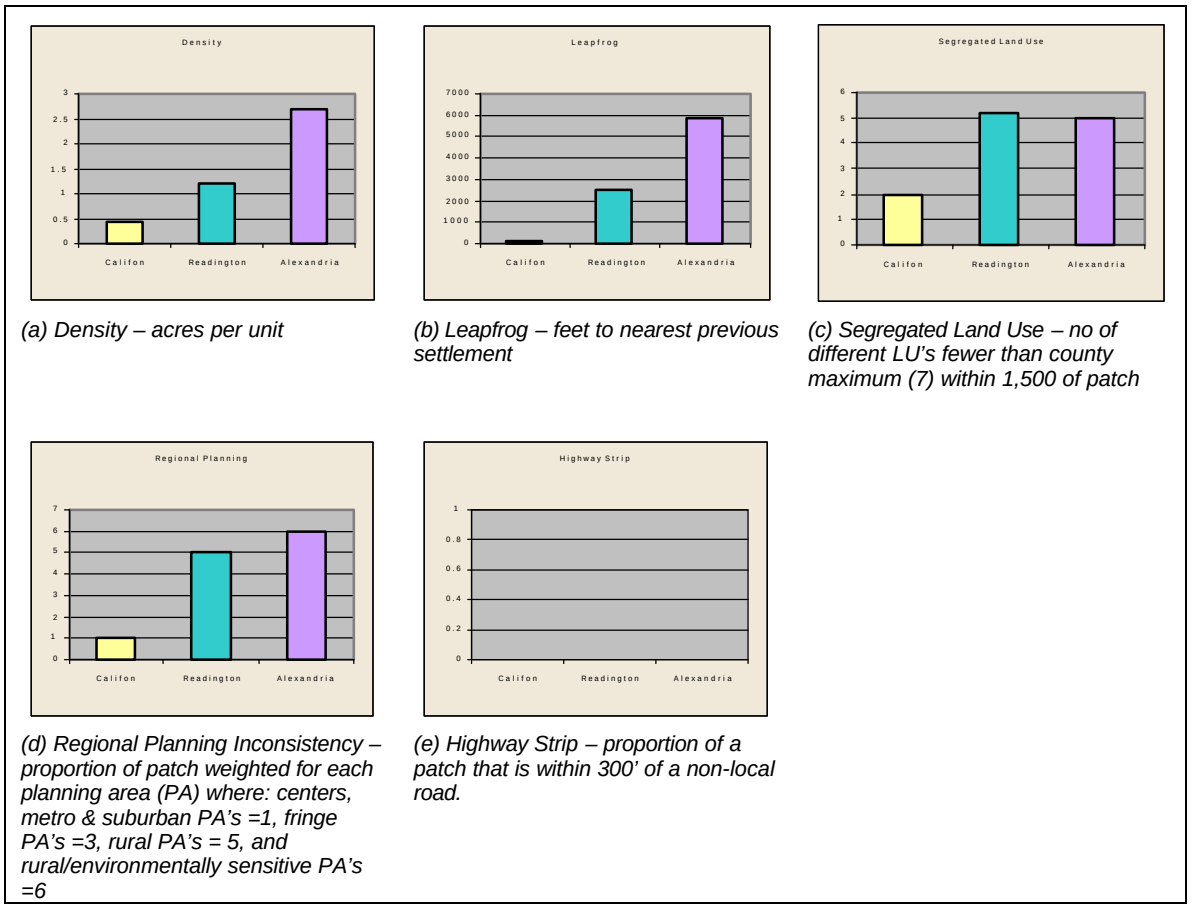
one-acre lot size. The Califon tract is able to accommodate smaller lot sizes because it is within a sewer service area. Most of Hunterdon County is not within a public sewer service area.

The leapfrog index quantifies the degree to which development is dispersed into the countryside. The Califon patch is the only tract that is contiguous to previous settlement. The Alexandria patch exhibits a leapfrog separation of over one mile from previous settlement. The tract is nestled deep within agricultural lands, and produces a fragmentary effect on the farmland and wildlife habitat of the locality. The leapfrog measure, however, is dependent upon the definition of *previous settlement*. Much of the residential development in Hunterdon County has occurred in the form of individual houses scattered across the landscape. Distance to any previous settlement that includes such instances of development is meaningless. Previous settlement patches (i.e. settlement extent as of 1986) are, therefore, defined as *patches of 1986 urban land use that are greater than 50 acres or those less than 50 acres that are coincident with settled place names on USGS quadrangle maps* for purposes of this analysis.

The segregated land use measure indicates the way in which new development occurs within the fabric of local land use. The metric is based on the number of different urban land uses within a 1,500 -foot pedestrian zone (buffer) around the new patch. The Califon tract boasts a mixture of 5.0 different land uses within the pedestrian domain whereas the Readington and Alexandria patch have 1.7 and 2.0 different land uses, respectively (decimal values are due to the number of land uses within 1500 feet to each house average over the entire tract). The Califon pattern of mixed land use suggests that it is part of a functional, multi-use town landscape, whereas the Readington and Alexandria patches exhibit the segregated land use pattern that is indicative of an isolated housing tract.

The regional planning measure provides insight into the compatibility of development with the goals of the New Jersey State Development and Redevelopment Plan (SDRP). Although the SDRP does not prescribe where development should and should not go, it does delineate regions of urban growth and town centers as well as regions of sensitive and rural lands. The SDRP also sets forth principals for growth that endorse the ideas of community and town centers. The Califon patch is contiguous to the village of Califon, an SDRP-designated existing town center. The Califon patch, therefore, manifests the kind of growth envisioned by the principles of the SDRP. The Readington patch is located in a swath of *Rural Planning Area* (PA4), the SDRP vision of which is "cultivated or open land surrounding rural Regional, Town, Village and Hamlet Centers, and… other sparse residential, commercial and industrial sites…" (NJOSP 2001). The Alexandria patch is located in a special subcategory of the rural planning area designated as *Rural/EnvironmentallySensitive Area* (PA4-B). This is inclusive of the previous parameters, but also contains "valuable ecosystems or wildlife habitats" (NJOSP 2001). Both of these rural planning areas envisage that growth should occur in existing or planned centers while the rural environs remain intact. The Readington and Alexandria development patches are incongruous with the State Plan by virtue of the facts that they do not exist in a configuration that implies centripetal growth, and both encroach upon protected agricultural and sensitive environmental lands.

The highway strip measure determines the degree to which development lines rural roadways. None of the three development patches demonstrate the characteristic of strip development. This can be attributed to the fact that these new development patches were major subdivisions (i.e. containing more than 3 units of development). Major subdivisions are usually oriented around their own internal road network. The strip development characteristic of sprawl is generally attributed to single housing units along rural highways or highway commercial strips.



(a) Density – acres per unit

(b) Leapfrog – feet to nearest previous settlement

(c) Segregated Land Use – no of different LU's fewer than county maximum (7) within 1,500 of patch

(d) Regional Planning Inconsistency – proportion of patch weighted for each planning area (PA) where: centers, metro & suburban PA's =1, fringe PA's =3, rural PA's = 5, and rural/environmentally sensitive PA's =6

(e) Highway Strip – proportion of a patch that is within 300' of a non-local road.

Figure plate 3-19 Land use pattern GIUS measures for 3 selected residential development tracts.

Transportation Infrastructure Measures of Sprawl

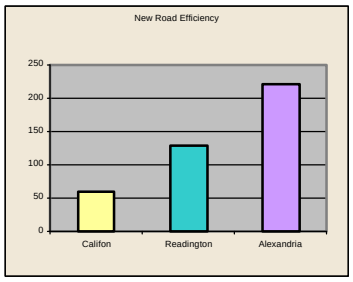
The transportation GIUS provide a measure of the transportation impacts of new development tracts and their level of reliance on the automobile (Figure 3-20). The difference in transportation infrastructure between the Califon, Readington and Alexandria patch is strikingly evident in all three transportation sub-measures. Each subdivision in our analysis contributes new paved roadways and characteristic cul-de-sacs. However, the per capita lane-miles of new paved road are substantially different: 60 ft of road per unit in the Califon patch; 129 ft per unit in the Readington patch; and 220 ft per unit in the Alexandria patch. This metric is significant because

the roads constructed by the developer become the maintenance responsibility of the municipality in which they were built. The road infrastructure measurement provides an indication of one of the future costs imparted to a community by new development.

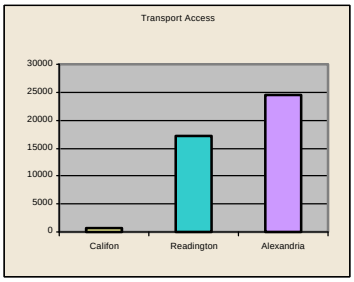
The alternate transportation accessibility index provides a measure of distance from the new development to alternate modes of transportation. The Califon patch exemplifies the characteristics of smart growth with respect to opportunity for residents to utilize alternate modes of travel. This patch is within walking distance to multiple transit options including sidewalks, the county loop bus, and a rails-to-trails hiking/biking/cross country skiing corridor. The Readington and Alexandria patches are, by contrast, approximately 3 and 5 miles from a transit node, respectively. The distance that a user must travel to alternate modes of transportation is proportionate to the likelihood of its utilization.

The community node accessibility index provides an interesting indication of the coordination of land use and the accessibility of new development to important destination nodes of the community. The community nodes used in this analysis include rescue stations, police stations, fire stations, hospitals, schools, grocery stores, post offices, libraries, municipal halls, and active recreational fields. The community accessibility values for the three development patches demonstrate the distinction between new development that is contextually coordinated with preexisting land uses and those that are haphazardly sited with little or no connection to community activities. The Califon patch has an average community node accessibility measure of slightly more than one mile, whereas the Readington and Alexandria patches have average community node distances of approximately 3 miles and 5 miles, respectively. The average measure for the Califon patch would be substantially smaller if the sub-measures for the regional hospital and county library were excluded. Most of the community node sub-measures for Califon are actually within walking distance (1500 feet). By contrast, the Readington and

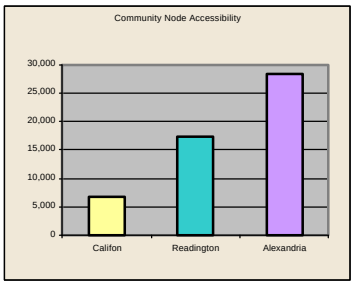
Alexandria patches have much larger community accessibility measures indicating that many daily activities will require an inefficient trip between distance uncoordinated destinations. The relative inaccessibility of community nodes bears significant implications for public safety and the expense of community services. Great distances between residential development tracts and emergency services result in increased response times. Seconds and minutes can mean the difference between life and death.



(a) New Road Efficiency – length of roads per unit created or fronted by patch (cul-de-sacs and intersections were removed from the pilot analysis for simplicity).



(b) Transport Accessibility – road network distance to nearest bus or transit route.



(c) Community Node Accessibility - average road network distance to nearest, rescue, fire, police, municipal bldg, hospital, school, grocery, park, and post office.

Figure plate 3-20 Transportation GIUS measures for 3 selected residential development tracts

Environmental Resource Impact Measures of Sprawl

The land resource impact (LRI) GIUS measures (Figure plate 3-21) illuminate the environmental impacts of urban growth upon the landscape. The first LRI index measures the loss to development of lands that are particularly important or sensitive. It consists of 3 sub-measures including wetlands, prime farmland and Heritage lands (contain documented occurrences of threatened or endangered species). None of the 3 patches developed on Heritage lands, and the Califon patch consumed no other critical lands. The Readington patch is not responsible for the conversion of wetlands, but its construction did consume 19.4 acres of prime farmland (0.77 acres per unit). The Alexandria patch consumed 7.16 acres of wetlands (0.21 acres per unit) and 25.5

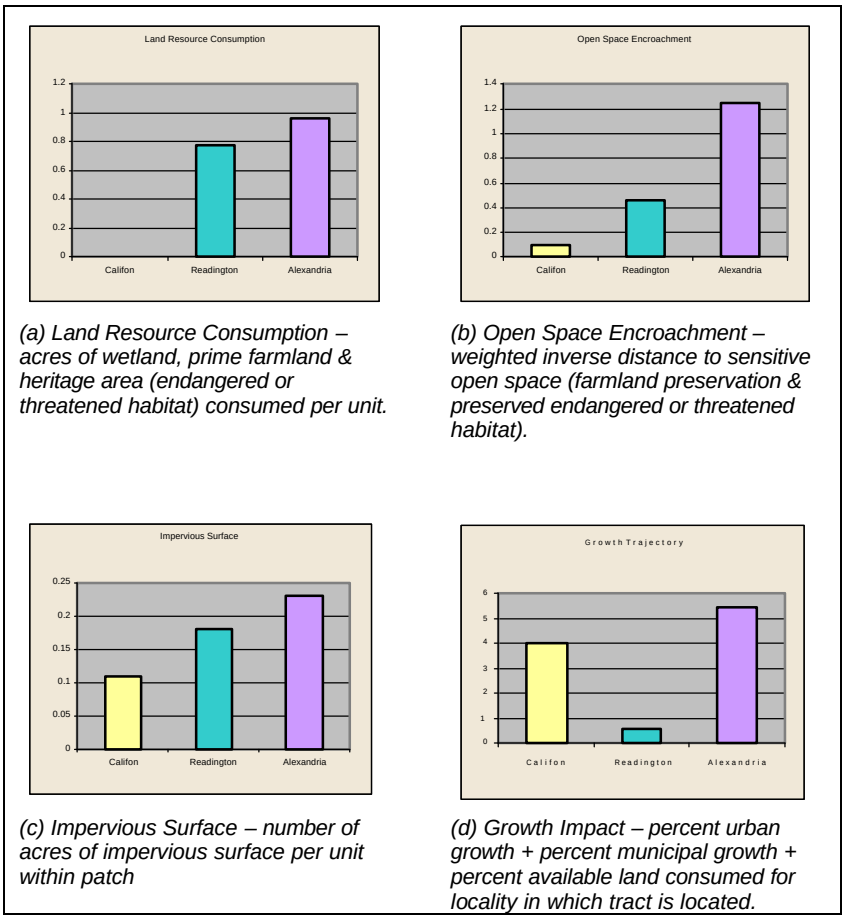
acres of prime farmland (0.75 acres per unit). The Readington and Alexandria patches each demonstrate a significant loss of these important land resources under differing constraints. The Readington patch is located in a region that is nearly all prime farmland. This impact would have been difficult to avoid, barring relocation of the project, given 1-acre zoning and private septic requirements. The Alexandria patch contains prime farmland soils on only 1/3 of the parcel. The site plan could have been reconfigured such that the housing units were clustered on non-prime soils, leaving farmland and wetlands intact. Open space encroachment occurred at all 3 patches due to their adjacency to sensitive preserved open space. The per capita normalization of the index provides a measure of loss incurred for the number of residents that are accommodated by the housing development. Again, the measure becomes more impacting as density drops, and the subdivisions become more diffuse and consumptive of land.

The impervious surface index provides an indication of the impact to water quality imparted by the development. Normalization of the raw impervious surface acreage by population provides a measure of the cost to water quality. The Califon, Readington and Alexandria patches created 0.11, 0.18 and 0.23 acres of impervious surface per housing unit, respectively. This difference in per capita impervious surface can be attributed to the unit size, driveway length and lane miles of roadway created proportionate to the sprawling nature of the development. Each patch contributed to water quality decline to some degree, but the per capita costs reveal the landscape dysfunction attributable to the decline. To elucidate this within our representative developments, if the landscape is to function as both a hydrological system and as a place for human habitation, the Alexandria patch exhibits a more significant loss of hydrological function to the function of housing each resident as compared to the Califon patch.

The growth trajectory measure reveals the degree to which a new patch contributes to explosive growth and/or build-out of the locality. The 3 sub-components measure a) percent urban growth,

b) percent growth of municipal size, and c) the percent consumption of available remaining land. This index puts the growth contributed by a tract of new development in the overall context of the municipality in which it is located. Large growth trajectory values were incurred by two of the analysis patches for significantly different reasons. The Alexandria patch experienced a high urban growth sub-measure indicating that this one development contributed a 4.71 % areal increase in urban lands to this rural municipality. Explosive growth of this nature imparts significant impacts to the social and environmental fabric of the community increasing public service costs, the need for schools and conflicts with the traditional land uses of the community. The elevated measure signifies the positioning of the community to rapidly change from a rural to suburbanizing community.

The Califon patch made a solid contribution to urban land (1.7% increase), but more importantly used of 2.27% of the borough's remaining available land. The five-acre Califon patch was not excessive in size, but presented a significant growth impact to the municipality due to the consumption of a significant proportion of available remaining land. Since the development of the tract represents a significant loss open space for the community, it warrants attention to careful land management to ensure the development fits within the vision of the master plan. The Readington tract, by contrast, did not contribute appreciably to the overall growth trajectory of the municipality (0.67 combined measure). Readington Township is the largest Hunterdon County municipality in areal extent at 30,553 acres. It is nearly 3 times the county average municipal size. The Readington patch did not contribute a dramatic amount to the growth of the community as a whole, although every development impacts the landscape in significant ways.



(a) Land Resource Consumption – acres of wetland, prime farmland & heritage area (endangered or threatened habitat) consumed per unit.

(b) Open Space Encroachment – weighted inverse distance to sensitive open space (farmland preservation & preserved endangered or threatened habitat).

(c) Impervious Surface – number of acres of impervious surface per unit within patch

(d) Growth Impact – percent urban growth + percent municipal growth + percent available land consumed for locality in which tract is located.

Figure plate 3-21 Environmental impact GIUS measures for 3 selected residential development tracts.

Discussion

The sample patches from the 3 Hunterdon County municipalities highlighted in this chapter demonstrate that the geography, spatial configuration and contextual landscape determine the degree to which the development patches are sprawling. The three patches present excellent examples on which to base the discussion about sprawling characteristics of urban growth and the ideal characteristics of smart growth. The Califon patch exhibits the least sprawling characteristics across all GIUS measures, and can be held up as an example of smart growth. The pattern of development therein is relatively compact and has an integrative relationship to the

community in which it is situated. The orthophotography for the Califon patch (Figure plate 3-18a) gives evidence of the cohesive community connection of this patch to the adjacent village landscape. The Califon patch also exhibits highly efficient spatial patterns that result in fewer transportation impacts as well as lower impacts to important land resources. The Califon patch embodies nearly all the characteristic goals of the New Jersey State Plan.

The Readington Patch demonstrates the rural growth that typically occurs in Hunterdon County. It is significantly sprawling by many standards, but not of excessive impact. The orthophotography of the Readington patch (Figure plate 3-18b) suggests a development that would exhibit far fewer characteristics of sprawl if the lots were decreased by 2/3 in size, and the tract pushed south 2,000 feet south to connect with the village of Three Bridges. The Readington patch typifies modern residential subdivisions throughout Hunterdon County and similar places in the state.

The third patch exemplifies highly consumptive and highly impacting rural sprawl. The Alexandria patch (Figure plate 3-18c) demonstrates the most striking disconnection of development to the landscape. This tract of luxury homes houses few residents relative to the land it consumes, and is insensitively imposed upon the agricultural fabric of this rural community. The Alexandria patch is wasteful of land resources, has little connection to the community and requires excessive automobile travel for most daily activities. The patch has an inefficient land use and transportation pattern; fragments prime farmland and wildlife habitat; contributes an excessive amount of impervious surface per capita; and imposes the consequences of explosive growth on a rural community. The Alexandria patch has no connection to an existing or planned center, and is therefore, discordant with goals set forth by the State Plan.

While a description of the sprawling characteristics of these 3 example development tracts might be intuitively concluded by examining the orthophotos or from visiting the individual sites, the ability to objectively quantify these important characteristics of sprawl renders analysis and policy-making less arbitrary or conceptual. The geospatial indices show that patches of new development have quantifiable spatial patterns that can provide meaningful insight into the specific impacts a tract imparts to the socioeconomic / biogeological integrity of the landscape in which it is located.

V. Conclusion

The *geospatial indices of urban sprawl* developed in this chapter provide a comprehensive means by which to measure the sprawling spatial characteristics of urban development. The GIUS measures provide a framework for the objective characterization and comparison of spatial patterns of urban growth. The indices produce unique spatial signatures for a patch of new development, and provide insight into the impact that an urban pattern has on the functionality of a landscape. The measures as presented are intended to be dynamic in their application and adjustable for any particular application. Different objectives, data and resources availability may make some of the 12 indices more important to some users than others. Nonetheless, these 12 measures have been carefully researched and developed to capture 12 highly significant spatial patterns associated with urban sprawl. Most development patches within the county exhibit a heterogeneous mix of sprawling characteristics contrary to the exemplary development patches presented in this chapter that exhibit consistently non-sprawling, average sprawling and excessively sprawling characteristics across most GIUS measures. Each of the GIUS measures elucidates a different aspect of the sprawling qualities of new development, and most development scenarios will express a wide range of values. These characteristics can be used to

stratify trends of similar sprawling signatures into general categories of sprawl at the municipal level, although the exact sprawling signature of each development tract is generally unique, as explored in the next chapter.

The site-specific patch-level GIUS measures described in this chapter present measures of sprawl at the level in which it occurs, one development at time. The GIUS measures applicability for the characterization of sprawling trends at different geographic extents. The following chapters scale the GIUS measure to the municipal and state scale.