A Geospatial Approach to Measuring New Development Tracts for Characteristics of Sprawl

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Abstract: *Many localities are struggling to deal with the undesirable consequences of sprawl. "Smart Growth" has been championed as a solution to many of these problems. However, disagreements or misunderstandings often surface regarding the exact characteristics of sprawl or whether or not a particular housing tract embodies those characteristics. This paper develops a set of 12 geospatial measures for objectively analyzing development tracts for characteristics of sprawl: (1) land use density, (2) leapfrog development, (3) segregated land use development, (4) development that is inconsistent with regional planning, (5) highway strip development, (6) new road network efficiency, (7) alternate transportation mode accessibility, (8) accessibility to important community nodes, (9) loss of important land resources (such as wetlands, prime farmland and endangered habitat), (10) encroachment upon sensitive, preserved open space, (11) excessive per unit impervious surface coverage, and (12) growth trajectory. These measures are operationalized for three recent subdivisions in Hunterdon County, New Jersey. The measures help to reduce sprawl rhetoric by focusing on quantifiable problematic characteristics of a particular tract of development.*

Introduction

Sprawl has become a hot-button topic throughout the United States and indeed throughout the world. The rapid urbanization of farmland, wildlife habitat, watershed lands, and other open spaces is producing many unforeseen consequences, including loss of land resources, increased pollution, traffic congestion, as well as many other environmental, social, and fiscal effects (Ewing 1997, Downs 1998, Burchell and Shad 1999, Sierra Club 1999, Vermont Forum on Sprawl 1999, Hasse and Lathrop 2003b). Furthermore, the patterns of sprawling developments are often scattered and disconnected, spreading the impacts deep into the rural countryside while urban centers experience disinvestments, decay, and a host of related social consequences (Duncan 1989, Frank 1989, Burchell et al. 1998, Kunstler 1993, Kahn 2000, Freeman 2001). Yet the discourse on sprawl is varied, including arguments on the benefits of sprawl-styled development (Gordon and Richardson 1997, Easterbrook 1999, Carliner 1999).

A growing trend of new urbanism has attempted to address sprawl by promoting more efficient, pedestrian-scale designs for new development (Duany and Plater-Zyberk 1991, Nelessen 1994, Christoforidis 1995). The term *smart growth* has been widely adopted to characterize compact patterns of development that do not embody the negative characteristics of sprawl (Danielsen et al. 1999, Smart Growth Network 2002). Urban growth that follows the principles of smart growth—such as pedestrian-friendly development, multi-nodal transportation coordination, and urban redevelopment—hold the potential to lessen the environmental impacts and social costs of sprawling development growth. However, while the principles of new urbanism and smart growth are being touted as solutions to the undesirable consequences of sprawl, achieving smart growth has proven to be a perennially challenging endeavor.

Part of the difficulty in addressing issues of sprawl and smart growth is politically loaded vocabulary that creates misunderstandings and complicates sprawl rhetoric. How does one decide whether a tract of development is actually sprawl? Is smart growth simply the binary opposite of sprawl, or is there a continuum between the most extreme sprawl and the most ideal manifestation of smart growth? If so, how do we determine the degree to which a particular tract of development is actually sprawling or smartly growing? Furthermore, is sprawl something that can be measured with a single variable, or do we need multiple measures of sprawl to capture the multiple dimensions of problematically dispersed development patterns? Might a particular tract of development simultaneously embody some characteristics of sprawl and other characteristics of smart growth? Needless to say, the vagaries, inconsistencies, and rhetoric surrounding sprawl and smart growth often interfere with prudent land management. What one person may have in mind as objectionable sprawl may be another person's smart growth American dream. These differing perspectives demand a standardized means of objectively quantifying the characteristics of sprawl.

Background in Measuring Sprawl. A number of recent studies analyzing the spatial signatures of sprawl have utilized census and economic data on a county or metropolitan-level (Pendall, et al. 2000, Galster, et al. 2000,

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Torrens and Alberti 2000, El Nasser and Overberg 2001, Ewing, et al. 2002). These approaches employ a relatively coarse spatial resolution in their underlying unit of analysis, such as a census tract (dozens to thousands of acres in size) or .25-mile grids (160 acres in size). This scale of analysis is useful for comparing one metropolitan area to another but is limited in its ability to distinguish spatial details of urban growth necessary to characterize sprawl at the subdivision-level. For example, the land area within a single ½-mile grid may contain a number of development tracts with widely differing characteristics of sprawl. Assumptions about the individual developments within each ½-mile grid cell cannot be inferred by simply looking at the grid cell or census tract average (Openshaw 1984). Characterizing the nuances of sprawl at the development tract level requires an analytical approach with a higher spatial resolution.

Developing a Measurable Definition of Sprawl. Characterizing sprawl requires a concise definition of what exactly constitutes sprawl. The wide variety of researchers, designers, and land planning stakeholders interested in sprawl make it difficult to develop a single, all-encompassing definition upon which to base spatial measures. Many aspects of sprawl include socioeconomic components that are impossible to delineate in a land use map of urban growth. Nonetheless, many characteristics of sprawl are spatially discernable and lend themselves to the development of geospatial measures.

Furthermore, the literature on sprawl itself is sprawling, demonstrating slipshod use of the term by a wide range of stakeholders with varied interests. Current definitions of sprawl run the gamut from a very specific manifestation of problematic urban growth (Benfield, et al. 1999) to any new urban development at all (Fodor 1999). However, an objective geospatial approach to characterizing sprawl requires a concise, spatially measurable definition. A number of publications help to provide such a spatially meaningful definition.

Burchell and Shad (1999) present 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." Ewing (1997) offers the following summary of 17 references to sprawl in the literature: "low density development, strip development and/or scattered or leapfrog development." Ewing also uses a transportation component to help define sprawl. He suggests that the lack of non-automobile access is a major indicator of sprawl. Downs (1998) and the Florida Growth Management Plan (Florida Division of Community Planning 1993) provide succinct descriptions of sprawl (Table 1) from which to develop spatial measures.

The smart growth discourse also helps to inform the development of geospatial measures. The characteristics of smart growth are in some respects the mirror opposites of the definitions of sprawl. Danielsen et al. (1999) define smart growth as a "type of high-density development, one in which land uses are mixed in such a way that people benefit from greater built densities." Danielsen and colleagues (1999) and the Smart Growth Network (2002) have similar definitions of smart growth (Table 2).

Methods

A Geospatial Framework for Characterizing Sprawl. The following geospatial measures attempt to delineate

Table 1. Characteristics of Sprawl

Downs (1998)	Florida Growth Management Plan (1993)
Unlimited outward extension of development	Allows large areas of low-density or single-use development
Low-density residential and commercial settlements	Allows leapfrog development
Leapfrog development	Allows radial, strip, or ribbon development
Fragmentation of powers over land use among many smaller localities	Fails to protect natural resources
Heavy reliance on private automobiles as the primary transportation mode	Fails to protect agricultural land
No centralized planning or control of land uses	Fails to maximize use of public facilities
Widespread commercial strip development	Allows land use patterns that inflate facility costs
Significant fiscal disparities among localities	Fails to clearly separate urban and rural uses
Segregation of land use types into different zones	Discourages infill development or redevelopment
Reliance on a "trickle-down" or filtering process to provide housing to low-income households	Fails to encourage a functional mix of uses
	Results in poor accessibility among related land uses
	Results in loss of significant amounts of functional open space

the most often cited spatial characteristics of sprawling urban growth in a quantifiable manner. 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 measures of sprawl. In the analysis, the geospatial measurements are calculated for individual housing units (Hasse and Lathrop 2003a) and then averaged with the other housing units within a given development tract to produce the overall tract values. A housing tract is defined in this paper as a contiguous group of housing units constructed at approximately the same time period. Often a tract of new development is constructed by a single developer. The suite of twelve sprawl measures are referred to throughout the paper as geospatial indices of urban sprawl (GIUS).

Land Use Patterns of Sprawl. The land use pattern imposed by new development can occur in many different configurations and manifestations. In order to identify the inefficient, dispersed, and scattered land use patterns associated with residential sprawl, a number of land use-based geospatial measures were developed, including (1) low land use density, (2) leapfrog development, (3) segregated land use development, (4) development that is inconsistent with regional planning, and (5) highway strip development.

1. Low land use density. The land use density index provides a measure of how much land is consumed for each new housing unit. Low-density urban growth consumes more land for each housing unit added to a landscape, thereby leaving less of the landscape able to function in other capacities. More simply stated, low-density land use is inefficient and wasteful use of land. The density measure was calculated by determining the amount of land consumed for each new residential unit and then averaging the individual housing units within a given development tract to produce a tract-level average density value. Low density in this measure indicates sprawling growth whereas high density signifies less sprawling or smart growth.

2. Leapfrog development. Dispersed development is another characteristic of sprawl. Historically, the American land use system has not adequately controlled the sequencing of development growth (Diamond and Noonan 1996). This lack of control has resulted in the phenomenon of new development *leapfrogging* over vacant lands that are adjacent to existing development in favor of parcels that are deeper in the rural countryside.

The leapfrog index provides a measure of how far a tract of new development is located from the edge of a previously existing settlement. The leapfrog index was calculated in this analysis by a straight-line distance measurement from each new housing unit to the perimeter of the nearest previously settled area. The individual housing unit leapfrog values within the tract were then averaged to provide an overall tract leapfrog value. Tracts with large leapfrog distances are considered sprawling compared to tracts developed in close proximity or contiguous to previous settlement (namely, infill or concentric growth), which are considered less sprawling or smart growth.

3. Segregated land use. Segregated land use consists of single-use zoning in which large areas of land are strictly confined to only one type of land use, such as residential or commercial. The segregated land use index as developed in this analysis 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 housing unit. Nelessen (1994) suggests that 1,500 feet (the distance that an average pedestrian will walk in 10 minutes) constitutes reasonable walking distance. The index was

Table 2. Characteristics of Smart Growth

Danielsen et al. (1999)	Smart Growth Network (2002)
Promote denser subdivisions in suburbia	Mixed land use
Encourage urban infill housing	Compact building design
Place higher density housing near commercial centers and transit lines	Range of housing affordability
Phase convenience shopping and recreational opportunities to keep pace with housing	Walkable neighborhoods
Transform subdivisions into neighborhoods with well-defined centers and edges	Distinctive communities-sense of place
Maintain housing affordability through mixed-income and mixed tenure development	Preserve the appropriate open space
Offer diverse housing options, including "life-cycle" housing	Build on existing communities
	Provide a variety of transportation choice
	Make development process fair and equitable
	Community involvement in development process

calculated by counting the number of different land use types within 1,500 feet of each housing unit as delineated in a land use map. The housing unit values were then averaged across the development tract. Since one category of land use in the dataset was labeled *mixed urban*, it was considered three land use types in the calculation. Tracts of new urban growth with little or no alternate land uses within the pedestrian distance are considered sprawling whereas tracts with a variety of neighboring land uses are considered less sprawling or smart growth.

4. Regional planning inconsistency. Many of the haphazard, uncoordinated, and conflicting land use patterns associated with sprawl can be attributed to nonexistent or ineffective regional land use planning. Sample causes include the short terms of elected officials who have little political incentive for long-term planning or regional coordination, and the frustrated efforts 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.

The regional planning inconsistency index measures whether or not a tract of new development is consistent with a regional or state plan. This index was calculated in this analysis by comparing a new development tract with the New Jersey State Development and Redevelopment planning map. Each planning area was assigned a weighted value to reflect the appropriateness of development within each of the different planning area categories. Zones designated as *rural environmentally sensitive* receive larger weighting values whereas *growth zones* and *town centers* are assigned lower weighting values. The location of each new housing unit within the regional planning map thereby determines its regional planning inconsistency value. The individual housing unit values are then averaged across the development tract. Development tracts that have high regional planning inconsistency values are considered sprawling whereas tracts of new development that occur in designated growth areas with low weighted values are considered smart growth.

5. Highway strip development. Corridors of fast food and large, big box retailers exemplify the commercial expression of highway strip, which is often the most aesthetically offensive form of highway strip development (Kunstler 1993). However, rural residential ribbon development where single homes line rural roads, often blocking scenic vistas and fragmenting rural lands, typifies the residential manifestation of highway strip development. Highway strip generally does not occur when development occurs in clusters, hamlets, and villages. The highway strip measure was calculated in this analysis by determining whether a new housing unit occurred within a 300-foot buffer of a rural highway. Housing units within the highway buffer were assigned a value of one, whereas housing units outside the buffer were assigned a value of zero. The values were then averaged across each development tract to produce the tract highway strip value. Under this scheme, the tract values would then range from 0.0 (no units of highway strip) to 1.0 (all units of highway strip). Development tracts with higher index values of rural highway strip are considered sprawling by this measure whereas tracts with low index values are considered smart growth.

Transportation Infrastructure Measures of Sprawl. Sprawling patterns of urban development are inherently reliant upon private automobile transportation (Anderson et al. 1996, Ewing 1997, Downs 1998, Benfield et al. 1999, Sierra Club 1999, Vermont Forum on Sprawl 1999, Burchell 1999). The reliance of sprawl development on the automobile as the primary mode of transportation necessarily results in more transportation infrastructure, more vehicle miles traveled, more traffic, and, by implication, more impact to the environment than less sprawling growth. 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 sprawl strive to capture a number of the problematic transportation network implications that result from a given new tract of development. They include (6) new road network inefficiency, (7) alternate transportation mode inaccessibility, and (8) inaccessibility to important community nodes.

6. New road infrastructure inefficiency. Sprawling residential and commercial developments create a less efficient road network of loops and lollipops, laying down greater lengths of new road lane miles, more cul-de-sacs, and fewer intersections per unit than more efficient grid networks often associated with compact patterns of growth (Southworth and 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 via arterial roads.

The new road infrastructure inefficiency index is a measure of the newly constructed road networks that accompany a given tract of new development. The measure was calculated in this analysis by summing up the length of roads, the number of cul-de-sacs, and the number of intersections within each tract of development and then normalizing by the number of housing units within each tract. Greater lengths of lane-miles, more cul-de-sacs, and fewer intersections for each new housing unit within a development tract indicate a sprawling growth pattern whereas development tracts with more efficient patterns of road infrastructure are considered less sprawling or smart growth.

7. Inaccessibility to alternate modes of transportation. Sprawl is primarily suited to the use of private automobiles as the sole means of transportation, neglecting the interest of pedestrians, bicyclists, and would-be users of public transportation. Such patterns of development exhibit reduced efficiency in their ability to facilitate movement, and they inherently discriminate against age and class.

The inaccessibility to alternate transit index attempts to measure the extent to which new development is accessible by alternate (that is, non-automobile) modes of transportation. In this analysis, sub-components of the index measured the road and path network distances from each hous-ing unit to the nearest transit stop or bus route, bike path, and sidewalk/pedestrian path. The housing unit values were then averaged to the development tract. Tracts that require substantial distances to reach alternate modes of transportation for any given new development tract are considered sprawling for this characteristic, whereas tracts within closer proximity to alternate transportation are considered less sprawling or smart growth.

8. Community node inaccessibility. Sprawling land use patterns disperse development growth haphazardly throughout a landscape. Sprawl provides little sense of place because community nodes (important community destinations) are not situated in a coordinated and integrated location to each other or to new residential development. This characteristic is especially significant when a tract 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 of land use that creates a lack of definable town identity, a necessarily inefficient traffic-inducing transportation pattern, longer response times for emergencies, and a diminished sense of community.

The community node inaccessibility index as calculated in this analysis measures the road distance from each new housing unit to important community nodes: schools, emergency service stations, grocery stores, post offices, and parks, among others (node types were selected by a combination of logical important community destinations and feasibility of creating the data). The individual housing unit values were then averaged by development tract. The locations of the community nodes were identified by use of county maps, expert knowledge, in-field observation, and orthophotography. Larger average road distances from development tracts to community nodes signify a more sprawling pattern for this measure whereas smaller distances to community nodes indicate a less sprawling pattern consistent with smart growth.

Environmental Resource Impact Measures of Sprawl. The eight preceding land use and transportation geospatial measures focus on characteristics of development patterns that are problematic or inefficient regarding human landscape functions. The following four environmental resource impact measures attempt to capture the environmental impacts of sprawl development evident in the spatial patterns and configurations of development relative to environmental resources (Hasse and Lathrop 2003b). The environmental impact indices include (9) loss of important land resources (such as wetlands, prime farmland, and endangered habitats); (10) encroachment upon sensitive, preserved open space; (11) excessive per capita impervious surface coverage; and (12) explosive growth trajectory imposed on localities by new development.

9. Loss of important land resources. Despite the existence of protective regulations, a significant amount of important natural land resources such as wetlands, prime farmland, and critical wildlife habitats are lost to unbounded urban growth. The wasteful destruction of these important land resources often is an irreversible consequence of sprawl and perhaps the most significant impact of urbanization on the ecological functioning of a landscape. Sprawling development has a greater ecological footprint than smart growth.

The land resources impact index measures the amount of important land resources consumed by any given tract of new development. The index as calculated for this analysis consists of three sub-components: loss of wetlands, prime farmland, and endangered wildlife habitats. The index was calculated by overlaying maps of each sub-component with maps of new development tracts to determine the land area of wetlands, prime farmland, and endangered wildlife habitats that was displaced by new development growth. The amount of land resources consumed was normalized by the number of housing units within each tract to provide a per unit consumption of important land resources. Development growth that consumes large proportions of important land resources per unit of new development is considered sprawling whereas growth that consumes little or no land resources per unit is considered less sprawling or smart growth.

10. Encroachment on sensitive, preserved open space. Sprawl not only consumes important land resources directly through development but also impacts lands that may be protected yet vulnerable to negative impacts of development in close proximity. For example, the viability of farmland within a region can be significantly diminished by encroaching urbanization (Adelaja and Schilling 1998). Even permanently preserved farms may become subject to irreconcilable conflicts with neighboring residential uses (for example, complaints about the application of pesticides, foul odors, trespassing, agricultural vehicles on roads, etc.), thus undermining and making impractical any sense of the land as preserved for farm use. Similar arguments can be made about the reduced ecological viability of preserved wildlife habitats due to encroachment by incompatible urban land use. The open space encroachment measure attempts to focus on the impact of urbanization to protected sensitive open spaces that are vulnerable to disturbance by conflicting urban land uses.

The open space encroachment index as developed for this analysis focuses on preserved open space, including sensitive wildlife management areas and lands enrolled in the New Jersey state farmland preservation program. The index calculated the inverse weighted distance from new residential units to sensitive preserved open space. Larger inverse distances to sensitive open space (that is, development that is close to sensitive open space) indicates a sprawling pattern of urban growth for this measure whereas new development at a large distance away from sensitive open space represents less sprawling or smart growth.

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. Impervious surfaces created by parking lots, roadways, and building footprints prevent ground water infiltration, increase stream surges, and channel non-point-source pollution directly into water bodies (Kaplan and Ayers 2000). Impervious surface coverage is becoming an increasingly reliable environmental indicator for land planning due to its vital associations to water quality (Arnold and Gibbons 1996, Brabec et al. 2002).

High-density urban land uses generally have higher impervious surface percentages at the site-level, but they consume smaller amounts of land per unit than sprawl, leaving more pervious, undeveloped area within a watershed. This contrasts with sprawling residential land uses that may have a lower site-level percentage of impervious surface but that spread out over a greater total area, thereby creating a greater gross amount of impervious surface for each new residential unit.

The per-unit impervious surface index measures the acreage of impervious surface per new residential unit that is contributed to the landscape by a new tract of development. In this analysis, estimates of percent impervious surface were made by expert airphoto interpretation of the development tract, converted from percentage into acres, and then normalized by the number of housing units. Development tracts that contribute excessive amounts of impervious surface per each housing unit suggest a sprawling development pattern whereas tracts that contribute a small per unit amount of impervious surface is considered less sprawling or smart growth.

12. Explosive urban growth trajectory. In areas experiencing rapid development pressures, unchecked development eventually consumes all available lands. Build-out occurs when all lands are developed to their highest and best use. A built-out landscape generally results in an entrenched, haphazard landscape pattern with no definable town center or rural hinterland to separate one town from another town. Sprawl is often associated with explosive growth in which new development leaves once rural localities unprepared to handle the onslaught of growth pressures such as the need for new schools and expanded community services. The explosive urban growth trajectory index attempts to provide an indication of the magnitude of change contributed by a tract of new development within the context of its local community.

The growth trajectory index as calculated for this analysis consists of three subcomponent measures that quantify the rate of growth and the rate of available land consumed. The first two sub-measures capture different aspects of the rate of growth. The first does so by normalizing the area of the new development tract by the area of previously existing urban lands within a locality (percent urban land growth). The second quantifies a different aspect of the growth-rate by normalizing the area of the new development tract by the area of the entire territory of the municipality (percent growth of the development tract relative to the size of the locality). These two measures are important to differentiate because as a locality develops, the same acres of development will result in a smaller percentage of urban growth but will nonetheless incur a substantial impact. The third sub-measure calculates the rate of remaining available land consumption by normalizing the area of the new tract by the amount of available land within the county as estimated at the time when new construction begins (percent available land consumption). Available land data were generated by a combination of land use and preserved open space data. The three sub-measures were summed to create an index that indicates the significance of a new development tract to the overall growth of a locality. A tract of new development that contributes a significant rapid increase in developed land and/or consumes a significant amount of remaining available land is considered explosive growth and therefore sprawling. Alternatively, new development growth that imposes a relatively small increase in urban land and/or consumes little remaining open lands is considered less sprawling or smart growth.

Each of the twelve individual geospatial indices of sprawl outlined above provides quantifiable information about specific spatial characteristics of new development growth related to sprawl. The following section demonstrates the utility of the GIUS measures by operationalizing them in order to characterize three recent developments in Hunterdon County, New Jersey.

Case Study Approach: Measuring Three New Residential Tracts for Characteristics of Sprawl. Hunterdon County is located in a traditionally agricultural region of western New Jersey, approximately 50 miles west of New York City and 50 miles north of Philadelphia (Figure 1). This location puts the entire county within *acceptable* commuting distance to these major metropolitan areas. Hunterdon County's demographic setting also makes for an interesting analysis of suburbanization because it has experienced significant population growth over the last few decades, rising from 69,718 in 1970 to 121,989 by 2000, a 75.2 percent increase in population (United States Census Bureau 2001). The most recent (1990 to 2000) census figures demonstrate the county's 13.1 percent growth outstripping the state as a whole, which grew 8.6 percent in the same time period. Hunterdon County is 460 square miles in area and hosts 26 separate municipalities.

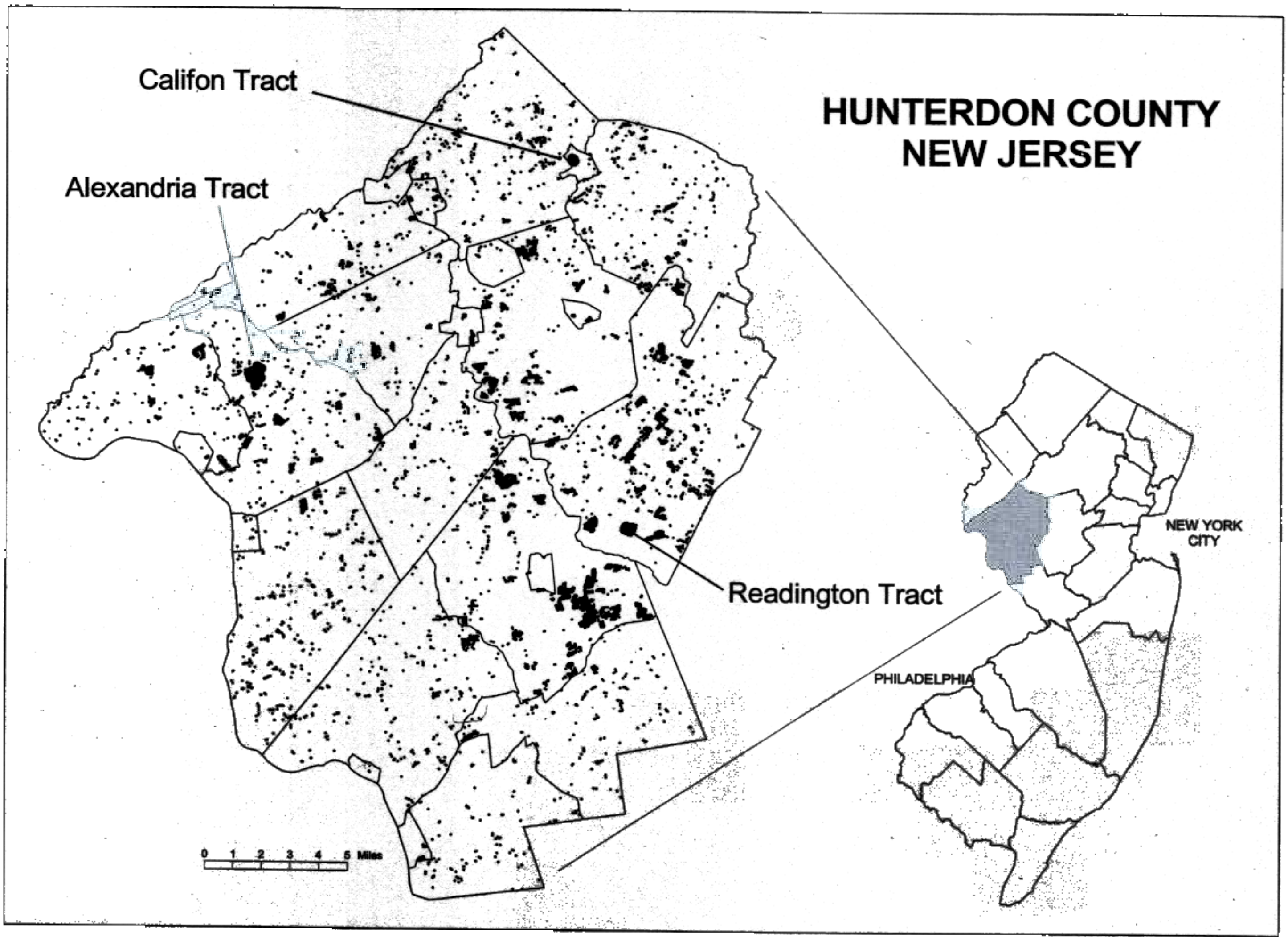


Figure 1. Location of selected case study development tracts and all housing built in Hunterdon County, New Jersey, between 1986 and 1995. Each dot represents the location of one of approximately 9,000 new residential housing units built within the county during the period of analysis.

Hunterdon County developed over 9,000 new housing units between 1986 and 1995. The GIUS measures were calculated for all housing units across the county (technical description of the per housing unit calculation methodology is provided in Hasse and Lathrop 2003a). The individual housing unit values were then averaged by each polygon of new urbanization representing the individual housing tracts and then gauged against the county-wide average of all new residential growth that occurred during the time period of analysis (Hasse 2002).

In order to illustrate the applied functionality of the GIUS measures for this paper, three tracts of housing development were selected that epitomized a range of characteristics and spatial configurations representing smart growth, average growth, and sprawl relative to the entire population of new housing units within the county. The development tracts, consisting of 70 units of new residential development, were selected from three different municipalities. The tracts were identified utilizing a GIS land use database in which polygons of land use changed from non-residential to residential according to the NJDEP digital land use/land cover dataset (Thornton et al. 2001). These data consist of detailed delineations of land use/land cover for both 1986 and 1995 as interpreted from aerial orthophotography (NJDEP 2000).

The Character of the Three Selected Subdivision Tracts. The Califon tract is the first selected tract of new development and consists of an eleven-unit subdivision in Califon Borough (Figures 2 and 3). The Califon tract contains 11 single-family houses on 5.0 acres. The tract is serviced by public sewer, which permits smaller lot sizes. The Califon tract is nestled

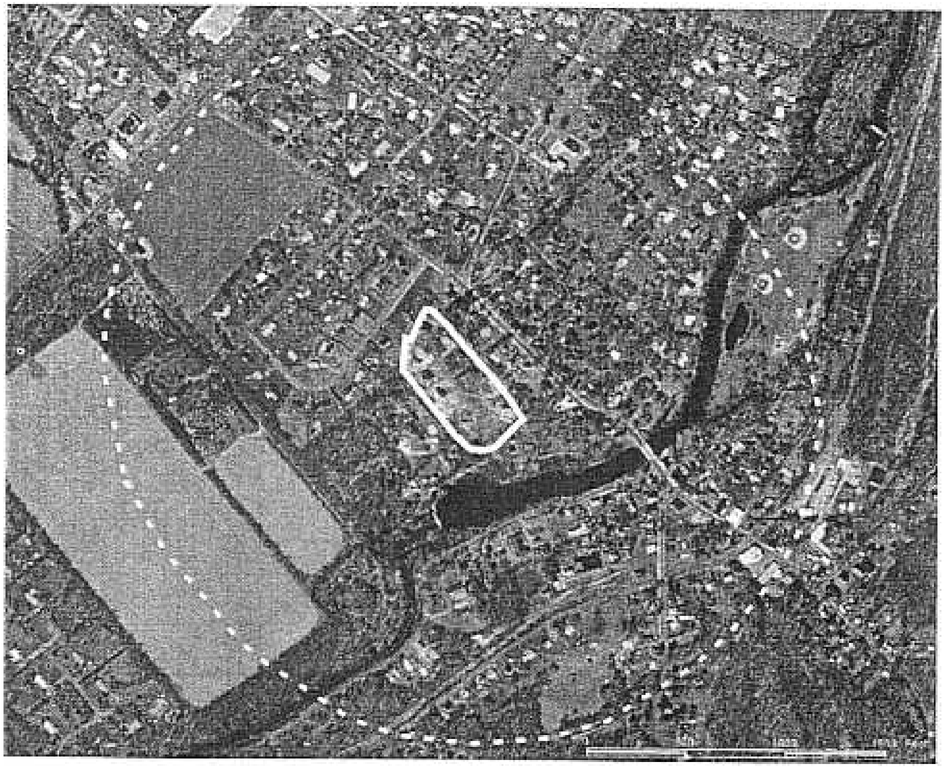


Figure 2. Orthophoto of the Califon tract. The 5-acre, 11-unit subdivision tract depicted in the solid white outline is nestled within the village of Califon. Many features such as schools, ball fields, and shops can be seen within the 1,500-foot pedestrian accessibility zone depicted as a dashed line.

Figure 3. This photo depicts the streetscape of the Califon tract. While the ½-acre lots are larger than what is usually considered smart growth, its location and coordination with the town structure of Califon allow it to benefit from many other characteristics of smart growth.

within the existing town structure and demonstrates a pattern of in-fill development. Parks, schools, and stores are within the 1500-foot pedestrian accessibility zone of this new tract (dashed line in orthophoto Figure 2). Califon Borough is designated as an Existing Village (EV) according to the New Jersey State Development and Redevelopment Plan (SDRP). The tract is within the village limits and does not front a major roadway. The county loop bus travels within yards of the tract, allowing accessibility to non-automobile transport. The compact and integrated nature of the Califon tract is evident within the orthophoto.

The Readington Township tract, which is the second selected residential tract for analysis, typifies the most common patterns of residential development to occur in Hunterdon County during the 1986 to 1995 period. The tract (Figures 4 and 5) is located in Readington Township near the village of Three Bridges (lower right of the orthophoto), approximately a quarter mile from highway Route 202. It is a 25-unit subdivision that occupies 30 acres. The Readington tract is not serviced by sewer; therefore each unit must have an individual, on-site septic system. The tract is located in a Rural Planning Area (PA4) of the New Jersey State Plan and is surrounded on three sides by active agriculture. This site is substantially isolated from other land uses as demonstrated by the 1,500-foot pedestrian accessibility zone depicted with the dashed line (Figure 4).

The Alexandria Township tract consists of luxury mansions on three-acre lots, exemplifying high-end rural sprawl that has occurred in Hunterdon County in recent decades. The tract (Figures 6 and 7) is perched on rolling hills between farms and forested areas, located deep within the agricultural belt of western Hunterdon County. The tract provides 34 housing units dispersed over 91.5 acres. The tract epitomizes land use segregation with only a few other housing units within the 1,500-foot pedestrian zone. The tract is constructed on land that is designated *Rural, Environmentally Sensitive* (PA4B) by the New Jersey State Plan. There are no sidewalks within the subdivision. The Alexandria tract also encroaches upon the preserved sensitive open space of the Schick Conservation Reserve that borders the development tract to the west.

Results of Comparative Analysis

The twelve GIUS measurements were conducted for each of the three subdivisions. Table 3 depicts the measurement results for the three subdivision tracts as well as the county average GIUS measurement for all housing units built between 1986 and 1995.

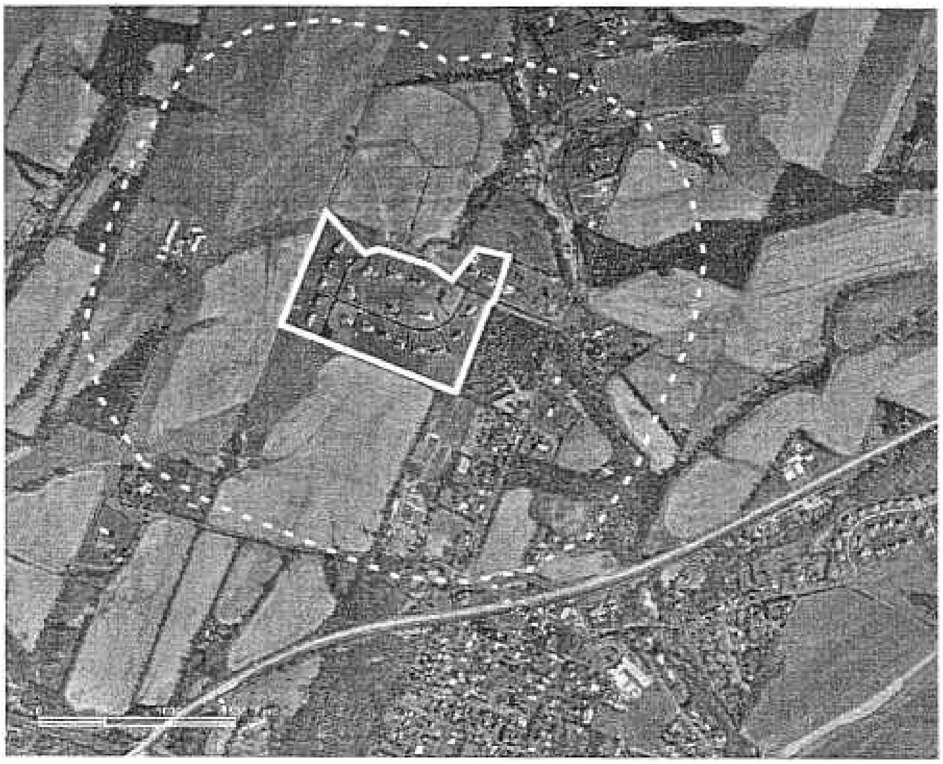


Figure 4. Orthophoto of the Readington tract. The 30-acre, 25-unit subdivision tract depicted in the solid white outline is situated in an agricultural area approximately ⅔ of a mile from the Village of Three Bridges visible in the lower right of the image. Few community amenities are evident within the 1,500-foot pedestrian accessibility zone depicted as a dashed line.

Figure 5. This photo depicts the streetscape of the Readington subdivision tract. These one-plus-acre lots are typical for the majority of new residential development that has recently occurred in Hunterdon County.

Land Use Patterns of Sprawl.

1. Density. The three tracts demonstrate widely differing development densities with Califon, Readington, and Alexandria consuming an average of 0.45, 1.19, and 2.69 acres of land, respectively, for each housing unit. While the ½-acre lots of the Califon tract may not be considered small or smart growth for more urban communities, they are nonetheless smaller than the average lot in this characteristically rural region. The 1.19-acre average lot size of the Readington tract is similar to the 1.25-acre countywide average lot size for all residential growth of that period. The 2.69-acre lots of the Alexandria tract illustrate the consumptive nature of large-lot zoning, a technique that is often implemented in an effort to slow growth or maintain rural character. Whether or not large three-acre parcels retain rural character or whether they simply result in a more rapid and sprawling consumption of land is a debatable point. One challenge to a predominantly rural county such as Hunterdon is that minimum lot size is entrenched by the lack of availability of public services such as water and sewer. The need to locate drinking water wells at a safe distance from septic leaching fields often necessitates a minimum one-acre lot size. The Califon tract is able to accommodate relatively smaller lot sizes because it is within a sewer service area. Most of Hunterdon County falls outside of a public sewer service area.

2. Leapfrog. The leapfrog index for Califon, Readington, and Alexandria is 93, 2,516, and 5,824 feet, respectively. The index demonstrates that the Califon tract is contiguous to previous settlement. The Readington tract is located approximately ½ mile from the village of Three Bridges. The Alexandria tract takes one giant leap from the nearest existing settlement with a separation distance of over one mile. The tract is sited deep within agricultural lands and has imposed a fragmentary effect on the farmland and wildlife habitat of the locality.

3. Segregated land use. The segregated land use measure indicates the manner in which new development is integrated within the fabric of neighboring land use. The Califon tract boasts a mixture of 5.0 different land uses within a 1,500-foot radius of the development whereas the Readington and Alexandria tracts have only 1.8 and 2.0 different land uses, respectively (decimal values are due to the number of land uses within 1,500 feet to each house averaged 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 tracts

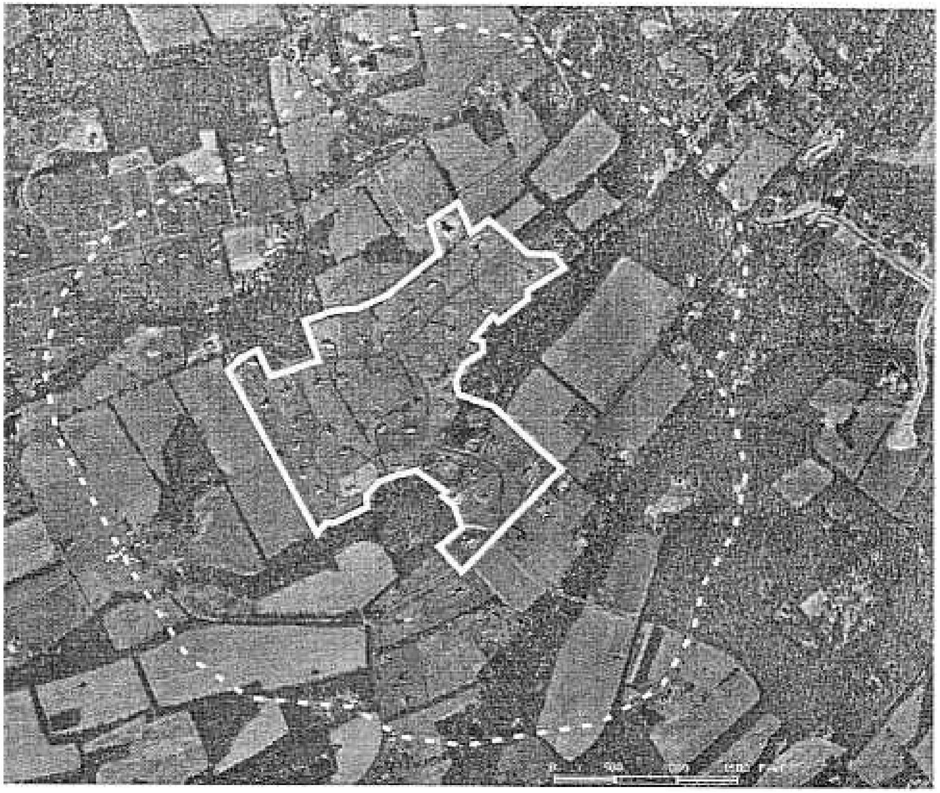


Figure 6. Orthophoto of the Alexandria tract. This 92-acre, 34-unit subdivision tract depicted in the solid white outline is situated in a remote agricultural area of the county miles from any existing established settlements. Virtually no community amenities are located within the 1,500-foot pedestrian accessibility zone depicted as a dashed line.

Figure 7. This photo depicts the landscape of the Alexandria subdivision tract. These three-plus-acre lots are a common result of large-lot zoning utilized by many towns as a growth control measure.

exhibit a segregated land use pattern indicative of an isolated housing tract.

4. Regional planning inconsistency. The regional planning measure provides insight into the compatibility of a development tract with the goals of the New Jersey State Development and Redevelopment Plan (SDRP). The Califon tract is sited within the village of Califon, an SDRP-designated *Existing Village* (EV), which according to the New Jersey State Plan should encourage in-fill development in order to revitalize existing town centers. The Califon tract, therefore, manifests the kind of growth envisioned by the principles of the SDRP. The Readington tract is located in a swath of *Rural Planning Area* (PA4), which is envisioned by the New Jersey SDRP as "cultivated or open land surrounding rural Regional, Town, Village and Hamlet Centers, and . . . other sparse residential, commercial and industrial sites . . ." (NJOSP 2001). The Alexandria tract is located in a special subcategory of the rural planning area designated as *Rural/Environmentally Sensitive Area* (PA4-B) because it also contains "valuable ecosystems or wildlife habitats" (NJOSP 2001). When growth does occur in PA4 and PA4B, the plan envisages that it should occur in existing or planned centers while the rural environs remain intact. The GIUS measures indicate that the Readington and Alexandria development tracts are incongruous with the State Plan in that they do not exist in a configuration that implies clustered, centripetal growth, and both encroach upon protected agricultural and sensitive environmental lands.

5. Highway strip. The highway strip measure determines the degree to which development lines rural roadways. None of the three selected development tracts demonstrates the characteristic of highway strip development, largely because these new development tracts are *major* subdivisions (containing more than three units of development). Major subdivisions are usually oriented around their own internal road network. Minor subdivisions of one or two units accounted for the majority of rural highway strip development that occurred in Hunterdon County during the study period.

Transportation Infrastructure Measures of Sprawl.

6. New road network inefficiency. The Califon tract created 60 feet of road per each housing unit whereas the Readington and Alexandria tracts produced 129 and 220 feet per unit, respectively. This metric is especially

Table 3. Geospatial Indices of Urban Sprawl measures for three selected Hunterdon County, NJ Subdivisions.

	Califon	Readington	Alexandria	*county mean*
1 Density				
Size of tract in acres	5.0	29.8	91.5	3.9
Residential units in tract	11	25	34	4.5
Acres per unit	0.45	1.19	2.69	1.25
2 Leapfrog				
Distance to previous settlement in feet	93	2,516	5,824	3006
3 Segregated Land Use				
Average no of LUs w/in 1500 ft	5.0	1.8	2.0	2.3
Segregated LU index	2.0	5.2	5.0	4.7
4 Regional Planning Inconsistency				
State plan designation	Existing Village	PA 4	PA 4B	—
Weighting	1	5	5.9	3.1
5 Highway Strip				
Pct of units w/in 300 ft highway	0.00	0.00	0.00	0.14
6 New Road Efficiency				
Total rd length w/in tract in feet	660.0	3,228	7,479	—
Rd length feet per unit	60.0	129.1	220.0	186
Total # cul-de-sacs in tract	1.0	1.0	2	—
Cul-de-sacs per unit	0.1	0.04	0.06	0.05
Total no intersections in tract	1.0	2.0	4	—
Intersections per unit	0.1	0.08	0.12	0.07
7 Alternate Transit Inaccessibility				
Rd distance to transit in feet	718	17,079	24,536	13,375
Rd distance to bike path in feet	1,750	74,252	29,583	34,038
Distance to foot path or side walk in feet	40 ft	no sidewalk	no sidewalk	—
8 Community Node Inaccessibility				
Rd distance to rescue in feet	1,942	23,501	24,137	16,797
Rd distance to police in feet	2,106	24,029	29,568	19,069
Rd distance to fire in feet	1,879	4,703	14,930	12,122
Rd distance to hospital in feet	7,123	25,306	26,577	27,869
Rd distance to school in feet	1,608	4,685	24,198	11,655
Rd distance to grocery in feet	2,260	20,430	25,033	17,083
Rd distance to post office in feet	3,649	4,094	30,374	16,867
Rd distance to library in feet	42,505	35,750	59,459	37,449
Rd distance to municipal hall in feet	2,106	24,889	29,352	15,022
Rd distance to recreation/park in feet	1,586	5,336	20,750	8,172
Average to all nodes in feet	6,676	17,272	28,438	18,211
9 Land Resource Consumption				
Acres wetlands loss	0	0	7.16	—
Wetlands loss per unit	0	0	0.21	0.057
Acres prime farm loss	0	19.4	25.5	—
Prime farmland loss per unit	0	0.77	0.75	0.211
Acres heritage site loss	0	0	0	—
Heritage loss per unit	0	0	0	0.139
10 Open Space Encroachment				
Distance to sensitive OS in feet	3626	4480	1580	5104
Inverse * 10,000	2.76	2.23	6.32	1.96
11 Impervious Surface Per Unit				
Acres of impervious surface	1.26	4.45	7.91	—
Acres impervious per unit	0.11	0.18	0.23	0.161
12 Growth Trajectory				
Municipality size in acres	621	30,553	17,714	10,774
Tract % of urban growth	1.70	0.39	4.71	0.230
Tract % municipality size	0.81	0.10	0.52	—
Tract % of remaining avail	2.27	0.18	0.73	—
Combined trajectory index	4.78	0.67	5.96	—

Note: **The county mean value was calculated for all housing units constructed during the study period. Some measures, represented by a line, could not be calculated for the entire county.**

significant to a locality because the roads constructed by the developer eventually become the maintenance responsibility and future expense of the host municipality. The number of cul-de-sacs and intersections created per housing unit provides an indication of accessibility and isolation of the units.

7. Alternate transit inaccessibility. The Califon Tract is the most ideally sited development regarding access to alternate modes of transportation. The county loop bus stops within several hundred feet of the tract. A county rails-to-trails path is located only ½ mile away, and although there are no sidewalks in the development itself, contiguous sidewalks connect the tract to the rest of the village. In contrast, the Readingon tract is nearly three miles from the nearest alternate transit option and offers little accessibility to bike paths or sidewalks. Likewise, the Alexandria tract is over five miles from the nearest public transit route and has no bike or pedestrian trails within a reasonable riding or walking distance.

8. Community node inaccessibility. The community node inaccessibility index provides an interesting indication of the coordination of land use, roadway connectivity, and the accessibility of new development to important destination nodes of the community. The designated community nodes in this analysis include rescue stations, police stations, fire stations, hospitals, schools, grocery stores, post offices, libraries, municipal halls, and active recreational fields. The values for the three development tracts 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 tract has an average community node accessibility measure of slightly more than one mile whereas the Readington and Alexandria tracts have average community node distances of approximately three miles and five miles, respectively. The average community node distance measure for the Califon tract 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 a quarter-mile walking distance. By contrast, the Readington and Alexandria tracts have much larger community accessibility measures, indicating that many daily activities will require an inefficient trip between distant and uncoordinated destinations. The relative inaccessibility of community nodes bears significant implications for public safety and the added expense of community services such as trash collection. Great distances between residential development tracts and emergency services result in increased response times where seconds and minutes may mean the difference between life and death.

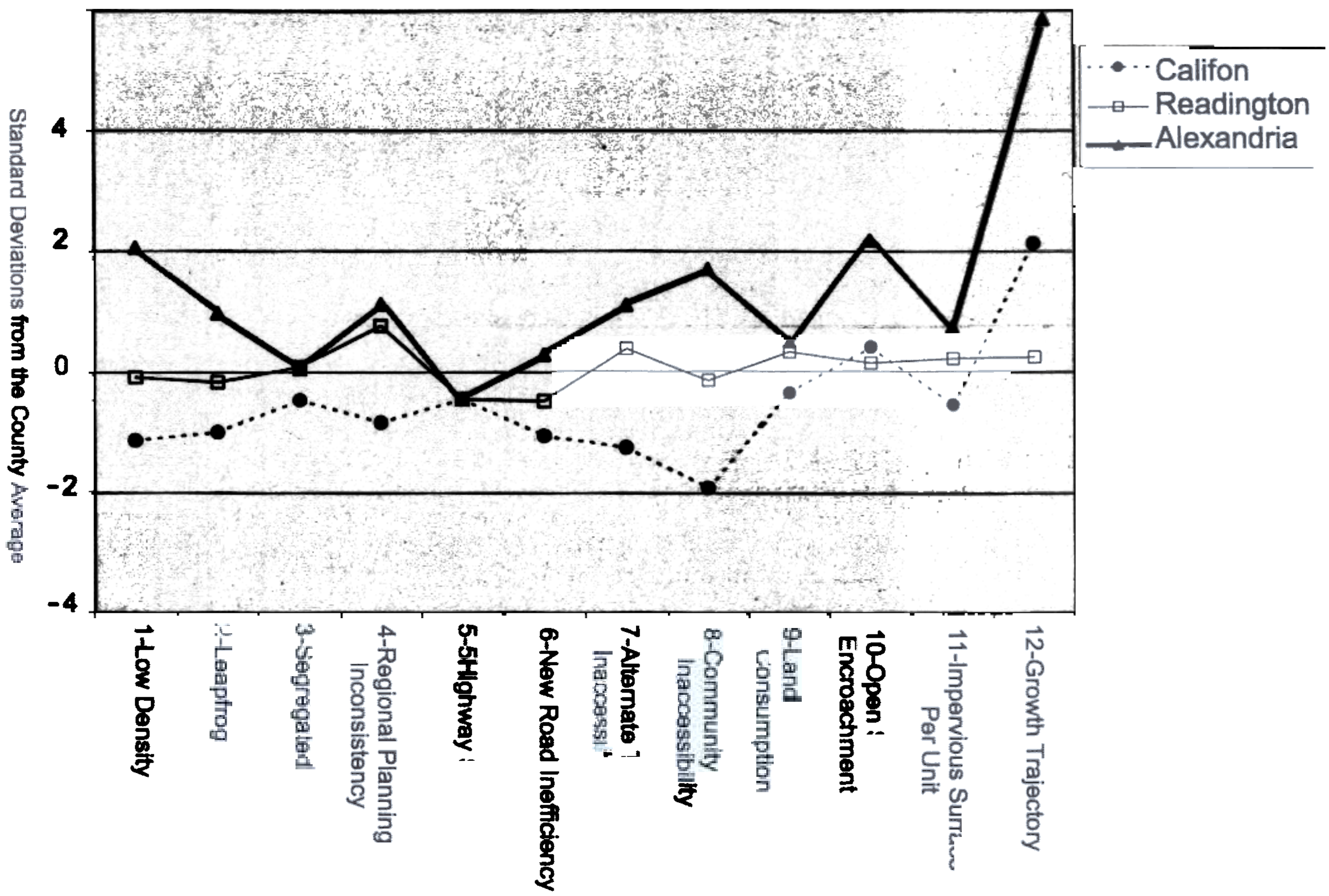
Environmental Resource Impact Measures of Sprawl

9. Land resource consumption. The three selected tracts exhibited a range of resource consumption on a per-housing-unit basis. None of the tracts were developed on heritage lands (containing documented threatened or endangered species), and the Califon tract consumed no other critical lands. Although the Readington tract did not consume wetlands, it was responsible for the loss of 19.4 acres of prime farmland (0.77 acres per unit). The Alexandria tract 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 tracts each demonstrate a significant loss of these important land resources under differing constraints. The Readington tract is located in a region that is nearly all prime farmland. Given the one-acre zoning and private septic requirements of this area, the impact of lost prime farmland would have been difficult to avoid, barring complete relocation of the project. In contrast, the Alexandria tract contains prime farmland soils on only one-third 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.

10. Open space encroachment. Significant sensitive open space encroachment occurred at all three tracts due to their adjacency to vulnerable preserved open space. The most significant impact is the Alexandria tract, which borders preserved land on several sides, resulting in a 1,580-foot average distance of each home in the tract to the neighboring sensitive open space. While the adjacent protected open space no doubt will benefit the property value of the housing within the tract, the open space parcel is conversely vulnerable to impacts of the adjacent residential activity.

11. Impervious surface per unit. 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 housing units provides a measure of the water quality footprint on a per-house basis. The Califon, Readington, and Alexandria tracts created 0.11, 0.18, and 0.23 acres of impervious surface per housing unit, respectively. This difference in per-unit 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. This analysis demonstrates the tendency for inefficient sprawling development to impose greater cumulative environmental impacts.

12. Growth trajectory. The growth trajectory index provides a context for the impact of the new development on the overall growth pressures of the municipality in which it is located. Large growth trajectory values were incurred by two of the analysis tracts for significantly different reasons. The Alexandria tract 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 often imparts significant increase in public service



costs, the need for added school capacity, and conflicts with the traditional land uses of the community. The Califon tract made a solid contribution to urban land (1.7% increase) but, more importantly, used 2.27% of the borough's remaining available land. The five-acre Califon tract 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 of open space for the community, it warrants 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). At nearly three times the county average municipal size, Readington Township is the largest Hunterdon County municipality with an areal extent of 30,553 acres. Although every development impacts the landscape in significant ways, the Readington tract did not contribute a dramatic amount of growth in the context of overall land development of this large community.

Interpreting the GIUS Measures. Figure 8 graphs the performance of the development tracts for each of the 12 GIUS measures in standard deviations from the county average value. The Califon tract scored below the county mean for most of the 12 indices, suggesting that it is the least sprawling (that is, smartest growing) of the three example development tracts. The GIUS measures provide a quantitative measure of performance demonstrating that the pattern of development therein is relatively compact and has an integrative relationship to the community in which it is situated. The GIUS measures confirm what is evident in the orthophotography for the Califon tract (Figure 2). The Califon tract was developed in a manner consistent with the principles of smart growth, demonstrating characteristics of cohesive community connection to the adjacent village landscape. The Califon tract also exhibits highly efficient spatial patterns that result in fewer transportation costs as well as lower impacts to important land resources. Although the Califon tract scored poorly on growth trajectory due to the relatively small size of the municipality (640 acres), the tract nonetheless embodies nearly all the characteristic goals of the New Jersey State Plan.

The GIUS measures indicate that the Readington tract exemplifies the sprawling rural growth that has been the most common pattern of growth to occur in Hunterdon County in recent decades. The county-wide average GIUS measures confirm that the Readington tract unfortunately typifies much of the recent residential subdivisions being constructed throughout rural New Jersey. However, the GIUS measures hold promise to buttress better performance in developing alternative development scenarios. For example, the Readington tract would exhibit far fewer characteristics of sprawl if the lots were decreased by two-thirds in size and the tract pushed south 2,000 feet to be contiguous with the village of Three Bridges. This type of alternate scenario analysis objective as evaluated through GIUS measure may help support better-performing development decisions.

The third tract exemplifies highly consumptive and highly impacting extreme rural sprawl. The Alexandria tract demonstrates the most striking disconnect of residential development with smart growth design principles and rural landscapes preservation. This luxury development houses few residents relative to the land it consumes and the impact it imposes upon the agricultural fabric of this rural community. The GIUS measures confirm that the Alexandria tract is wasteful of land resources, has little connection to the community, and requires excessive automobile travel for most daily activities. The tract has an inefficient land use and transportation pattern, fragments prime farmland and wildlife habitats, contributes an excessive amount of impervious surface per capita, and imposes the consequences of explosive growth on a rural community. The Alexandria tract has no connection to an existing or planned center and therefore is discordant with goals set forth by the State Plan.

Discussion

The analysis demonstrates that spatial characteristics of sprawl can be objectively analyzed and meaningfully quantified. The GIUS measures help to focus attention on the performance of development patterns and the propensity for development to impose specific problematic consequences, thereby helping to depoliticize the discourse on sprawl. Discussing the three case study tracts without a quantifiable means of evaluation would be far less meaningful and far more contentious due to the political nature of land development, the powerful interests of stakeholders in the development process, and the rhetoric that surrounds sprawl. By focusing on the measurable performance of development patterns for identifiable problematic characteristics, the term sprawl need not even be used.

While this case study demonstrates the GIUS measures for three tracts of development that have already been built, the measures hold potential for evaluating developments at the design and proposal stage. In this respect, the measures may help designers, planning boards, and land managers steer new development away from patterns of sprawl and toward patterns of smart growth by focusing on their performance. Ultimately the measures hold promise for developing a standard sprawl/smart growth rating system similar to the United States Green Building Council's LEED building standards for environmental building performance. Similarly, environmental interests could employ GIUS measures to help leverage environmentally responsible development design.

This analysis demonstrates that the GIUS measures provide a sophisticated approach to evaluate sprawl. Rather than a simple binary characterization of development as sprawl or not sprawl, individual tracts of new development will each have their own unique combination of GIUS values. Each of the GIUS measures elucidates a different aspect of the sprawl qualities of new development, and most development scenarios will express a wide range of values. It is up to the user of these metrics to interpret which are the most important under the particular circumstances of a given tract of development as well as in relation to the specific goals of a community.

The analysis also illuminates a number of problematic issues, limitations, and assumptions that must be adequately addressed with this approach to urban development analysis. One of the most sticky issues is the question of nomenclature. The word sprawl means many different things to many different stakeholders. Furthermore, many different manifestations and categories of sprawl complicate discussions of the subject. For example, there is an arguable difference between urban sprawl, suburban sprawl, and rural sprawl. A rural county such as Hunterdon is really dealing with rural sprawl. Characteristics that may be considered smart growth for Hunterdon County may be viewed as sprawl for a more suburban or urban locality as is exemplified by the Califon tract's ½-acre lot size. This situation demands the development of concise definitions for urban, suburban, and rural sprawl and the establishment of particular GIUS performance standards for each category. Statistical techniques such as cluster analysis or principle components analysis should be utilized in future research to help delineate different groupings or types of sprawl. Research also needs to be done to establish thresholds that are performance based, such as reasonable pedestrian usability.

A second issue arises as to whether all 12 measurements are necessary or whether some of the indices are redundant. Although the three selected Hunterdon County development tracts highlighted in this analysis represent a consistent gradient in sprawl characteristics for most of the 12 geospatial indices, the correlation between the indices is not as strong as these three examples may imply. Many other Hunterdon county development tracts had a substantially different GIUS profile from the three case study tracts presented in this paper. A correlation analysis of the GIUS measures for all new residential units within the county demonstrates that each of the 12 sprawl indices is substantially independent (Hasse 2002). The majority of correlation coefficients between each individual GIUS index are below $r = 0.50$. The strongest correlation was between community node inaccessibility and transit inaccessibility with a correlation coefficient of $r = 0.72$.

The development of geospatial indices of sprawl is intended not only to provide tools for theoretical academic analysis but also to provide tools to assist land managers and policy makers addressing the problematic consequences of sprawl. While there is potential for this type of analysis to be very helpful in depoliticizing the issues of sprawl and supporting the actualization of smart growth, a third issue of analysis feasibility and data availability arises. The analysis as carried out in this pilot study required a substantial skill with GIS spatial analysis as well as collecting and interpreting a wide variety of data, including orthophotography, digital tax parcel maps, and land use change data, among others. While New Jersey is rich with geospatial data produced by various agencies such as the New Jersey Department of Environmental Protection, other localities may not have the capabilities or data availability to conduct all the GIUS measures as presented herein. Nonetheless, more simplified variations of GIUS measures that utilize available data may provide substantially useful similar information.

A further concern is that while the 12 GIUS measures help to focus on specific problematic characteristics of sprawling development, care must be exhibited that other aspects of sprawl not captured by the GIUS measure are not neglected. This is especially important for the social costs and consequences of sprawl that the GIUS measures are unable to represent directly. The use of GIUS measures to evaluate sprawl should not preclude other social and economic considerations in policy development and implementation.

Conclusion

The sample tracts highlighted in this paper demonstrate that the geography, spatial configuration, and contextual landscape determine the degree to which development tracts are sprawling or not sprawling. While a verbal description of the sprawling characteristics of these three example development tracts might be intuitively conducted without GIUS measures—for example, by examining the orthophotos or visiting the individual sites—the ability to objectively quantify these important characteristics of sprawl through specific and reproducible geospatial measures renders analysis and policy-making less arbitrary or conceptual. The GIUS measures show that tracts of new development have quantifiable spatial patterns that can provide meaningful insight into the specific impacts that a development tract imparts to the land use integrity of a region.

The GIUS measures also provide a framework for the objective characterization and comparison of spatial patterns of urban growth. When utilized in combination as a suite of measures, these geospatial indices of urban sprawl provide a robust mechanism for profiling the nuanced spatial signatures of development and its impact upon the functional integrity of a landscape. The measures as presented are not intended to be the final version of spatial sprawl measurements but rather a first step in the research and development of this line of approach to characterizing sprawl and smart growth. Nonetheless, these 12 measures have been carefully researched and developed in order to capture 12 highly significant spatial patterns associated with sprawl.

Future research is needed to develop smart growth performance standards, to determine thresholds and benchmarks for the individual indices, and to establish the most effective strategies to incorporate the metrics into the land management process. While sprawl seems to be globally ubiquitous, it occurs with different manifestations in different locations. There is rich potential for utilizing the GIUS measures for comparative urban growth analysis among different localities and regions, as well as among different international settings.

The site-specific tract-level GIUS measures described in this paper present measures of sprawl at the level in which it occurs—the individual housing unit within a development tract. By atomizing the measures to individual housing units, the GIUS measures can easily be summarized by larger spatial units such as census tracts, planning zones, municipalities, cities, counties, and so on (Hasse 2002). Whatever scale is utilized, the GIUS measures provide a powerful mechanism of profiling the spatial patterns of developments for characteristics of sprawl and hold promise for supporting an empirical approach to land management to achieve the goals of smart growth.

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