CHAPTER 4 AUTOMATING GEOSPATIAL INDICES OF URBAN SPRAWL

I. Introduction:

From Manual to Automated GIUS Measures

The preceding chapter presented the theoretical framework for geospatial indices of urban sprawl (GIUS) and a tract-level operationalization of the GIUS measures to analyze urban spatial characteristics of sprawl for three residential development tracts. The tract-level measurements demonstrate that the GIUS measures can provide valuable insight to the sprawling nature of new urban development. At the tract-level, GIUS measurements can be conceivably calculated manually utilizing a map wheel and various environmental, land use and general roadmaps of the locality in which the development is located. Although a manual calculation would be somewhat time consuming and require a certain amount of map expertise, one could imagine its utility for local planning purposes. Such manual calculation, however, would be impractical for assessing multiple tracts of development across a region. This chapter develops a methodology for the automation of GIUS measures within a Geographic Information System (GIS) for a countywide analysis of urban growth. The analysis statistically summarizes housing unit-level GIUS measures within the county by municipal boundaries to determine if there are characteristically different types of growth occurring among different localities.

Tract-level GIUS analysis captures the various spatial signatures of sprawl at the housing development level in order to characterize the inefficient, wasteful and dysfunctional spatial form and context of urban sprawl inherent in any given new development. The policies related to urban growth, however, are usually implemented over a larger spatial domain than an individual tract of development. Typically the processes that control development are enacted through regulatory zones delineated by an official zoning map. In New Jersey, the majority of land use decision-making occurs on the municipal level in a system informally referred to as “home rule”. The state employs four categories of municipal incorporation including *cities*, *towns*, *boroughs* and *townships*. Analysis of urban growth at the municipal level will provide important information on how a municipality is growing on whole over a set period of time. The material presented in this chapter scales up the concept of the geospatial indices of urban sprawl to the municipal level by summarizing the housing unit GIUS measures within each municipality. In this manner, urban sprawl analysis can be comparable across localities as well as across regions or potentially across continents.

II. Scaling from Housing Unit-level to Larger Areal Units of Analysis

Many scale related issues are important to consider for proper geographic modeling and analysis including the proper selection of scale of measurement, temporal resolution and spatial variation of the process that is being analyzed (Atkinson and Tate 2000). The smallest meaningful scale of analysis of sprawl is an individual housing unit. Each new individual housing unit built can be analyzed for its specific GIUS measures. The second meaningful scale of sprawl analysis is the development tract. A development tract is a group of new housing construction generally developed by a single developer. The third level of scale of is the landscape “patch”, a term often utilized in within the field of landscape ecology (Forman 19. A patch of new urban growth is a contiguous area of land that changed from an undeveloped to an urbanized state of land use. The significance of the patch-level scale is that a patch is the scale at which remotely sensed imagery can delineate new urbanization. A patch of new urban growth can vary widely in scale consisting a single isolated new building, a single development tract or multiple contiguous development tracts of hundreds of units. Without ancillary data such as a subdivision plats or digital parcel maps, the patch is often the finest scale available to the landscape analyst. Any given patch possesses inherent spatial and temporal characteristics such as the extent of the area it occupies and the time period over which it was developed. Meaningful geographic modeling and analysis of sprawl must employ an appropriate resolution of data as well as appropriate temporal period necessary to capture the underlying process.

Multi-temporal land use data at the appropriate scale was key for the automation of the GIUS measures. The NJDEP land use/land cover data set utilized for the analysis of urban growth described in chapter 2 provides high quality data at such an appropriate scale. The data set contains land use/land cover information for the years 1986 and 1995 hence the temporal scale of urban growth was 9 years. The minimum mapping unit (mmu) of the data was one acre, which captured most single unit development that had occurred. This 9-year temporal scale and 1 acre mmu spatial scale was sufficient to utilize for analyzing the process of sprawl at the housing unit as well as the development tract level as described in the previous chapter.

Urbanization occurs one development at a time. While each new patch of urban growth will have very unique spatial characteristics, the overall growth within any given municipality will have many similarities due to the overarching zoning codes, shared geographic setting and individual policies of the municipality. These factors justify a municipal-scale analysis of urban growth because many of the policies that lead to or control sprawl are implemented at a municipal level. The individual developments within a municipality will each have unique sprawl characteristics, however, it is also likely that the combined pattern of development within a municipality would exhibit an overall average value for each sprawl measurement.

Scaling urban analysis from a housing unit-level to municipal level presents a number of issues. The patterns of urban growth at the municipal scale will reflect somewhat different processes than urbanization at the housing unit level. For example much of the variability in development patterns between different municipalities can be explained by differences in overall extent, stage of previous settlement, available road and service infrastructure, geographic location and socioeconomic and political setting. Some of these parameters such as socioeconomic setting and geographic location are more regional in nature and will affect neighboring localities in a similar manner. Other parameters such as infrastructure may be variable within a municipality. In a rural-suburbanizing region such as Hunterdon County, NJ, variability of site-specific patterns of development within a municipality would be more fully explained by zoning regulation and service infrastructure than regional variation in socioeconomic and geographic differences. These various factors influence the processes of urbanization differently at different scales and extents. Characterizing sprawl at the municipal level from measurements calculated at the housing unit-level requires careful consideration of scale related issues.

Working Across Scales with Spatial Data

Unfortunately the term *scale* is utilized for a number of divergent meanings including the resolution of the spatial data elements, the extent of the region depicted, the scope of a phenomenon and the size ratio between a model and the real-world event (Goodchild and Proctor 1997). Analytical approaches to scale have been developed in several research disciplines including landscape ecology, urban planning and geography. Landscape ecologist focus particular attention on the relationship between spatial patterns of the ecosystem and the scale of the phenomena of interest (Urban et. al. 1987, Levin 1992). Landscape patterns and process interact in a symbiotic association as process affects pattern which in-turn affects process (Turner 1989). Therefore the scale of the pattern and the process are intimately interconnected. Particular emphasis is placed on various quantifications of landscape spatial pattern in order to capture the underlying processes (Gustafson 1998). In non-urban landscapes, ecological processes develop into a hierarchy of self-organizing systems at various interconnected scales (Perry 1995). For the landscape phenomena to be adequately understood on an ecological basis, the appropriate scale must be utilized for analysis (Levin 1992). A fundamental objective for spatial analysis in landscape ecology is to utilize the most appropriate scale of analysis that best reflects the underlying process in its temporal, geographic and spatial resolution (i.e. grain).

The issue of scale has also been widely developed in the discipline of geography as it presents fundamental challenges for spatial analysis. For decades geographers have understood the sensitivity of spatial data to the scale at which the phenomenon is measured (Harvey 1969). A multiple scale approach has long been employed to gain insight the scale of analysis (Stone 1972). More recently, rapidly advancing geospatial technologies such as GIS and remote sensing are requiring continued development of knowledge for many issues of spatial scale (Quattrochi and Goodchild 1997) leading to questions regarding selection of the appropriate sampling scale necessary to properly capture the phenomenon of interest (Davis et al. 1991). For example one could imagine a sampling framework in which a transect of land use was made across a city with a gridded road network. If the sampling interval inadvertently occurred at exactly the same interval as a city street, the resulting sample would indicate that land use of the entire city consisted of streets. The inadequacy of the chosen sampling interval for the scale of the phenomenon of interest demonstrates issues related to the scaling problem (Harvey 1969) or dichotomies of scale (Mark 1980). Not only is an understanding of the scale of a phenomenon fundamental to appropriate spatial analysis, but an understanding is also needed of how the scale of the sampling framework affects observable variation (Atkinson and Tate 1999). Recent research is approaching the problems defining optimal spatial scale though geostatistical techniques (Atkinson and Tate 2000).

Selecting an appropriate regional scale for sprawl analysis is dependent on the particular phenomenon of interest. Analysis of the relationship of sprawl to zoning regulations would require scaling the housing unit-level GUIS measures to a zoning map sampling framework. Three acre zoning could be compared to 5 acre zoning within and among municipalities. Likewise, scaling to a census tract level scale would be appropriate for analyzing the socioeconomic relationships to various GUIS measures as census data is available for many socioeconomic variables. The level of scale explored in this chapter is the municipality due to the significance of New Jersey's municipal home-rule for land use regulation. Policy at the municipal level is arguably the most significant factor affecting land use development and therefore the degree to which development is sprawling.

Scaling from housing unit-level GIUS to municipal-level GIUS measures not only provides a characterization of sprawl at the relevant political spatial extent but also provides the ability to incorporate various socioeconomic variables that are only available at extents larger than the patch level. Ancillary data such as population census, agricultural census, socioeconomic and zoning data among others can be easily integrated into a municipal analysis through map overlays. However, data integration must be approached with care for a number of reasons. First, the accuracy of the least accurate data will determine the level of confidence of the analysis (Gersmehl 1981). Regardless of the number or precision of other input data, the output will only be as accurate as the least precise input layer. A second concern is the modifiable areal unit problem (MAUP) (Openshaw 1984a). MAUP arises when the data available for an area is aggregated into regions (for example mean housing values within census tracts). The spatial pattern of the aggregated data can appear substantially different by simply changing the location of where the zonal boundaries are delineated. The effect of MAUP is exemplified each time a congressional district is reclassified after a decennial census in a process know as *gerrymandering*. The political party in control of redistricting usually carefully delineates the new boundaries to create a district in which a constituency of their interest is maintained.

A third consideration for the integration of spatial data is the problem of *ecological fallacy* (Openshaw 1984b). Ecological fallacy is an erroneous assumption that the value of a variable for an individual element within a region can be determined by the region summary value for that variable. For example, if it is assumed that that the income of a resident within a census tract is the same as the average income within the tract then an *ecological fallacy* has been committed. The only information that can be known about an individual in that tract is that they live in the census tract with a particular average income. Fourth is the question of spatial autocorrelation (Goodchild 1987, Tobler 1970). Spatial autocorrelation is a uniquely geographical phenomenon that arises when elements of observation are influenced by their proximity to one another. Standard statistical methods behave differently with spatial data because of the effect of spatial autocorrelation. However, the unique properties of spatial autocorrelation for geographical analysis can also be exploited for developing particular geostatistical methods such as such as kriging which incorporate statistical spatial trends in data to better model a variable surface (Isaaks and Srivastava 1989).

This discussion illustrates a number of the key issues involved in changing scale and the need for carefully developing an appropriate approach to the integration of multiple datasets in spatial analysis. The following analysis demonstrates the scaling of housing unit-level GIUS measurement to the municipal level to gain insight into the patterns of sprawl between municipalities.

III. Calculating Twelve GIUS Measures within a GIS

Methods

As theorized and substantiated in chapter 3, each GIUS measure was developed as an indicator that reflects important spatial characteristic of sprawl culled from a broad exploration of the literature. The GIUS metrics provide information on what is problematic, inefficient or dysfunctional about a particular pattern of growth. The automated methods as presented perform a reasonable calculation of GIUS measures within the constraints and limiting factors of the research. Limiting factors include data availability, resource limitations as well as the technical feasibility of conducting the delineation of the indices within a desktop GIS environment. Each of these will be discussed as they were encountered.

The twelve GIUS measures are grouped into 3 categories; 1) Land Use Spatial Patterns, 2) Transportation Spatial Patterns, and 3) Environmental Impact Spatial Patterns. The GIUS measures for the three individual selected development tracts discussed in the previous chapter proved relatively easy to calculate with the assistance of simple on-screen tools provided by Arcview GIS such as the measure tool and buffer wizard. Other ancillary information including digital orthophotography, infield observation and a detailed county map showing locations of parks, transit stops and many community nodes such as schools and municipal facilities also greatly facilitated the tract-level calculation of GIUS measures. Countywide automation of the GIUS measures proved much more challenging. The following section details the methods taken for automation of each indicator in this municipal study. While substantial time was invested and innovative techniques were developed the methodological approach taken is experimental and not intended to be a rigid proscription for automated methods of GIUS calculation. There are conceivably many other quantitative approaches that may be more appropriate depending on the needs, objectives and available data. The aim is to produce meaningful information about spatial characteristics and patterns that each index intends to convey.

Calculating Housing Unit GIUS Measures

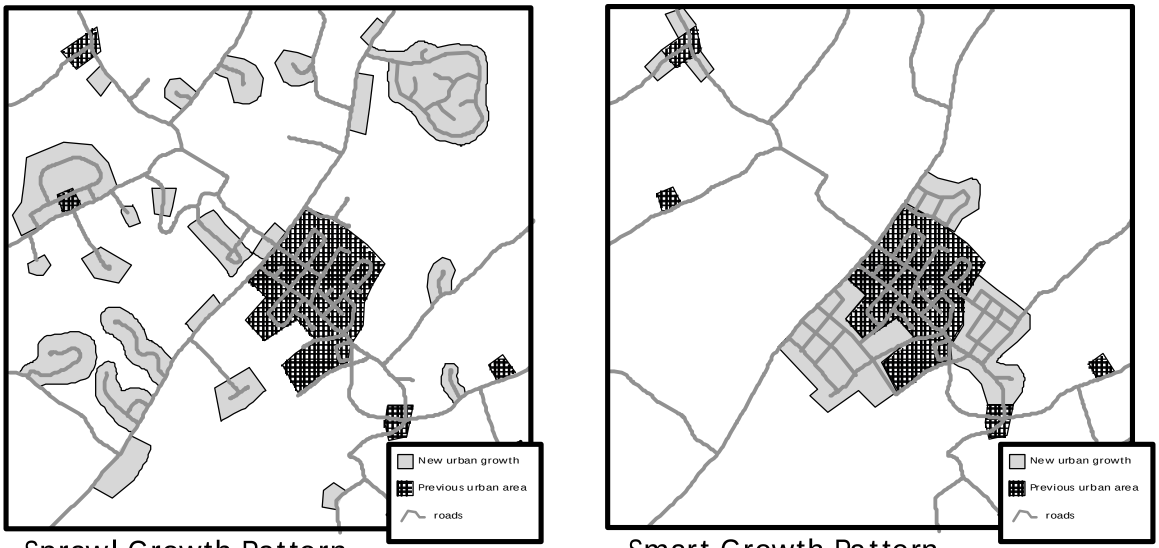
Many of the GIUS indices provide a measurement of sprawl on a per capita basis. For example the *density*, *road infrastructure* as well as all the *land resource impact indices* provide a measure based on the number of residents impacting the landscape in order to provide an indication of the cost-benefit efficiency for the development tract. Since the actual population of any given residential unit is not publicly available information, the analysis utilized housing units as a proxy for population. A reasonable estimate of the population for any given tract of development could be calculated by simply multiplying the number of units within a development tract by the average number of residents per household. Therefore, since the number of housing units within a patch of new development could be delineated within a GIS, it is used as a proxy for population throughout the analysis.

The number of units within a patch can be easily identified within an orthophoto. However, on-screen demarcation of each new housing unit is impractical at a county-level basis. Patches of new residential development that occurred from 1986 to 1995 were easily extracted from the land use/land cover dataset by querying for non-residential polygons in 1986 that had changed to residential in 1995. Since there were 4 categories of residential land use, adjacent but contiguous residential polygons of different sub-class were dissolved into a single general residential polygon. An automated demarcation of housing units was developed by intersecting polygons of new residential development patches with a countywide digital parcel coverage.

This created an output coverage in which each development patch was subdivided into its individual property parcels. Sliver polygons where then eliminated. Since each property parcel in a rural county such as Hunterdon, is generally restricted to only one single housing unit (with the exception of certain special cases such as condominiums), the number of subdivided parcels within a patch represents the number of housing units. The subdivided polygons were converted to polygon centroids. A "point in polygon" method was utilized to sum the number of parcel centroids within each original development patches to provide an estimate of the number of housing units contained by each new urban patch.

Land Use Pattern GIUS Measures

1) Urban Density - The urban density indicator provides a measure of per housing unit land use efficiency. Figure 4-1 provides a schematic illustration of the density calculation for an idealized sprawl versus smart growth development pattern. The area of each new urban patch is calculated then normalized by the number of housing units to delineate a per-unit quantity of land developed. Lower density indicates sprawl for the density measure whereas higher density signifies smart growth.



Sprawl Growth Pattern

Smart Growth Pattern

***Figure 4-1 Urban Density**- a schematic diagram of the Urban Density index for sprawl versus smart growth. While both diagrams receive an equivalent population growth, the Diagram on the left depicts an extreme sprawling pattern whereas the diagram on the right depicts an idealized smart growth pattern. The Density index provides a measure of per capita land consumption. The sprawling example uses a much larger amount of land to house each person than the smart growth example.*

Calculating Urban Density – Polygons of urban growth that occurred in the county between 1986 and 1995 were extracted from the NJDEP digital Land Use/Land Cover dataset. These new urban patches were then intersected with a digital parcel map of the county. The resulting output was a map of new urban growth subdivided into property parcels. After some data cleaning to remove inconsistencies and sliver polygons, centroids were generated for each polygon effectively representing a housing unit within a new development patch. Each housing unit centroid point was assigned the area value of it’s “parcelilzed” patch utilizing the *spatial join* function of the Geoprocessing Wizard. The area of each parcelized patch represents the density for each housing unit. The housing centroids were also assigned a municipal name field in the same manner. The average municipal housing unit value for urban density (UD_{mun}) was calculated by utilizing the *summarize* function on the *municipal name* field of the residential unit table.

$$\mathrm{UD}_{mun} = \frac{\sum_{mun} \mathrm{DA}_{unit}}{\sum_{mun} N_{unit}}$$

Where:

UD_{mun} = Urban Density index for new urban growth within a municipality
DA_{unit} = developed area of each unit
N_{unit} = number of new residential units

***2) Leap-Frog* -** A dispersed development pattern results in an increasingly fragmented land use pattern. This leads to many significant land use implications such as elevated transportation requirements and fragmentation of agricultural land and wildlife habitat among others. Figure 4-2 provides a schematic illustration of the leapfrog calculation for extreme sprawl versus an idealized smart growth development pattern. Patches of growth that occur at a significant distance from previously existing settlements are considered *leapfrog*. Municipalities with patches of new growth with high average leapfrog values are considered sprawling whereas low ratios are considered smart growth.

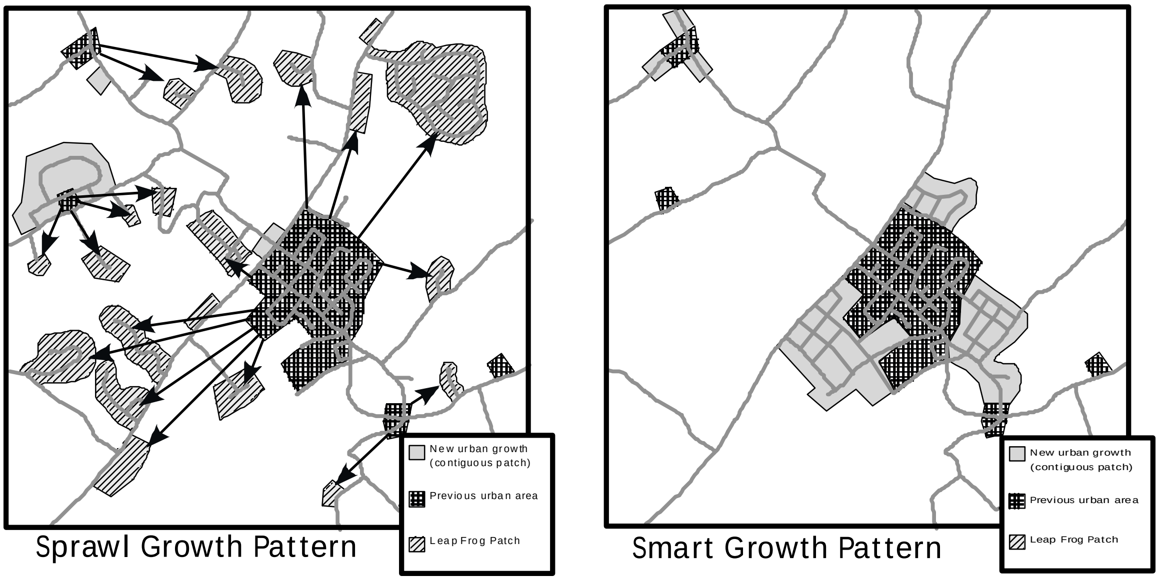


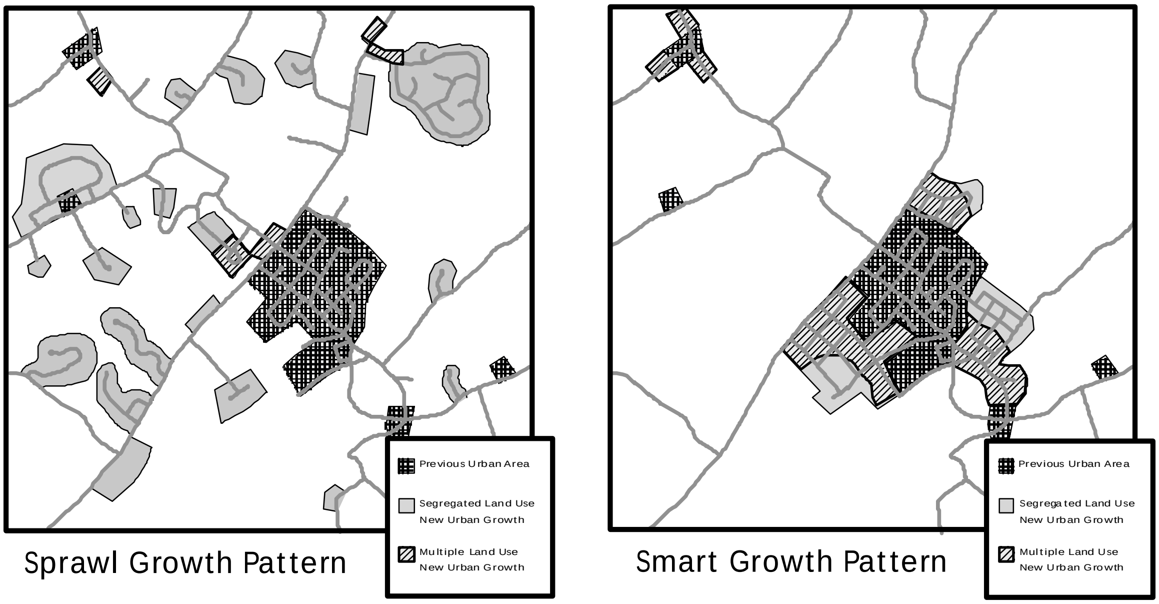
Figure 4-2 Leapfrog Index *-The leapfrog index measures the degree to which new development spreads beyond previously existing urban areas. The above diagram depicts the leapfrog index for a region of extreme sprawl versus a region of idealized smart growth. Patches of new growth that occur closer to previous development are considered contiguous and indicate smart growth. Patches that occur at a significant distance are considered leapfrog patches and an indicator of sprawl for the leapfrog measure.*

Calculating Leap-Frog - The leapfrog indicator was calculated by measuring the patch distance to previous settled areas. The previous settlements were delineated as patches of urban land use existing in 1986 that corresponded to designated place names on a USGS quadrangle maps or existing patches larger than 50 acres. This eliminated smaller non-named patches of 1986 urban areas that had already leapfrogged from settled areas (see chapter 3 for a more thorough discussion). A straight distance grid was generated from these "previously settled" patches within Arcview Spatial Analyst and then value was assigned to each new housing unit. The municipal leapfrog index (LF_{mun}) was calculated by summarizing the leapfrog field value of the housing unit shapefile by municipality.

$$\mathrm{LF}_{mun} = \frac{\sum_{mun} \mathrm{Dlf}_{unit}}{\sum_{mun} N_{unit}}$$

Where: LF_{mun} = Leapfrog Index for new urban patches within a municipality
Dlf_{unit} = leapfrog distance for each new unit
N_{unit} = number of new residential units

3) Segregated Land Use - A third characterization of sprawl is segregated land use. Single use zoning results in large regions of strictly segregated residential, commercial or industrial land uses. The segregation of land use single-use zones forces excessive automobile travel between zones, monotonous landscapes and a lack of community cohesion. Since mixed land use areas may look segregated on a micro level the definition of segregated land use employed here is single urban land uses beyond reasonable walking distance to multiple other types of urban land uses. Figure 4-3 provides a schematic illustration of the segregated land use calculation for an idealized sprawl versus smart growth development pattern. New residential patches within the 1,500 ft pedestrian distance (Nelessen 1995) to multiple other types of urban land uses are considered *mixed* while areas with only a single land use within the pedestrian distance are *segregated*. New urban growth that exhibits higher degrees of segregated land use is considered more sprawling than a mixed land use pattern for this measure.



Sprawl Growth Pattern

Smart Growth Pattern

Figure 4-3 Segregate Land Use *- The segregated land use index measures the degree to which new development occurs in single land uses that are not within walking distance to multiple other types of urban land use. Patches of new growth that occur within walking distance to multiple other urban land uses are considered non-segregated or 'mixed'. Patches that occur beyond the walking distance to other urban land uses are considered segregated patches and indicate sprawl.*

Calculating Segregated Land Use **-** The segregated land use metric was calculated by converting the "urban" land use/land cover data layer to a grid. The *mixed-use* urban category of the dataset was recoded to a value of 3 (i.e. considered 3 different urban land uses) to compensate for the fact that although it is classified as a single category, it should be considered already mixed. The three different categories of "single unit residential" (*rural single unit*, *single unit low density* and *single unit medium density*) delineated in the dataset were recoded to a "single unit residential" class to compensate for their tendency of this very similar categories to skew the results toward higher land use mixture than warranted. A *neighborhood_variety* calculation was performed on the gridded urban land use in Arcview Spatial Analyst utilizing a radius of 1,500 feet to represent the pedestrian distance (Nelessen 1995). This produced a grid surface where every cell was enumerated to the variety or mixture of different urban land use categories within the search radius.

Since the other GIUS measures produce output in which higher values indicate higher sprawl, the *mixed land use* surface grid was converted to a *segregated land use* value where a higher value represents a greater indication of sprawl. This was accomplished by subtracting the mixed-use grid from a constant grid value 8 (the constant value 8 represents the most highly mixed value occurrence countywide). This produced a surface grid in which the most segregated housing units (i.e. within 1,500 feet to only one urban land use) would have a value of seven and the least segregated patches (i.e. most mixed) would have a value of one. The value of the segregated grid surface was then assigned to the housing unit centroid by a *grid2point* Arcview extension. *The* municipal-level segregated land use index (SL_{mun}) was calculated by averaging the segregated land use field of the new housing unit shapefild by summarizing on the municipality field.

$$\mathrm{SL}_{mun} = \frac{\sum_{mun} \mathrm{Seg}_{unit}}{\sum_{mun} N_{unit}}$$

Where:

SL_{mun}= segregated land use indicator by municipality
Seg_{unit} = 8 – number of different developed land uses with 1500 feet
N_{unit} = number of new residential units

4) Inconsistency to Regional Planning - Much of the haphazard and conflicting urban patterns of sprawl can be attributed to local planning agencies' disregard to the regional context of land planning. The regional plan inconsistency index captures the incongruence of new development with regional and state plans. Figure 4-4 provides a schematic illustration of the regional inconsistency calculation for an idealized sprawl versus smart growth development pattern. Patches of new development are assessed for the state planning area in which they fall. Each planning area is assigned a value for the appropriateness for development within the area. Patches of new development which fall in the most appropriate growth planning areas are recoded to a low value whereas patches which fall in planning areas designated as *sensitive* receive higher values. Municipalities with high proportions of development in sensitive versus planned growth areas are considered more sprawling in this measure.

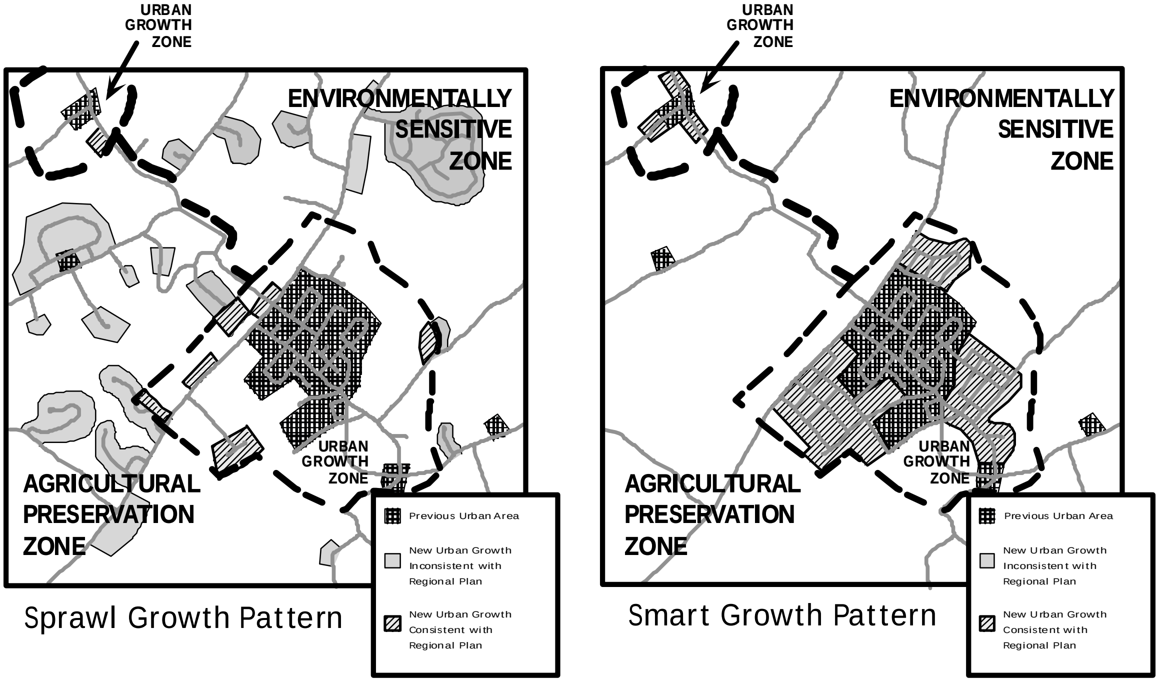


***Figure 4-4 Regional Planning Inconsistency** – This index measures the degree to which a local development pattern is in conflict with a larger-scale regional plan. The regional inconsistency index measures the proportion of urban growth that occurs in lands inappropriate versus appropriate for growth according to a regional plan.*

Calculating Inconsistency with Regional Planning - The New Jersey State Development and Redevelopment Plan (SDRP) delineates 5 planning regions ranging from urban through suburban to rural planning areas. Each planning area proscribes the type of land use deemed appropriate to accomplish the goals of the state plan. The SDRP also recognizes existing and planned centers as particularly important components to smart growth development. The index was calculated by gridding the SDRP planning areas map. A weight was assigned to each planning area corresponding to the appropriateness for development to occur within each particular planning area or center designated by the SDRP. The weighted planning area value was assigned to the new housing unit centroids using the *grid2point* extension. The municipal regional planning inconsistency index (RPI_{mun}) was calculated by summarizing the planning area-weighted value of the new housing unit shapefile by the municipality.

$$\mathrm{RPI}_{mun} = \frac{\sum_{mun} \mathrm{PAW}_{unit}}{\sum_{mun} N_{unit}}$$

Where:

RPI_{mun} = regional planning inconsistency indicator by municipality
N_{unit} = number of new residential units
PAW_{unit} = weight of planning area in which the unit is located such that:
PA1 (Metro) = 1
PA2 (Suburban) = 1
PA3 (Fringe) = 2
PA4 (Rural) = 5
PA4B (Rural/Env Sensitive) = 6
PA5 (Environmentally Sensitive) = 6

Within delineated center boundary = 1
Within 2000 feet of designated center point = 2

5) Highway Strip - Highway strip development is road-front growth typified by single-family housing units lining up along highways in long ribbons into the rural countryside as well as corridors of fast food restaurants and large ‘big-box’ retailers. Figure 4-5 provides a schematic illustration of the highway strip calculation for an idealized sprawl versus smart growth development pattern. The characteristic of highway strip is a binary measure. Development either is or is not highway strip. Development is considered highway strip if it occurs along rural highways outside of town centers. Development within a designated highway buffer is considered sprawling for this measure.

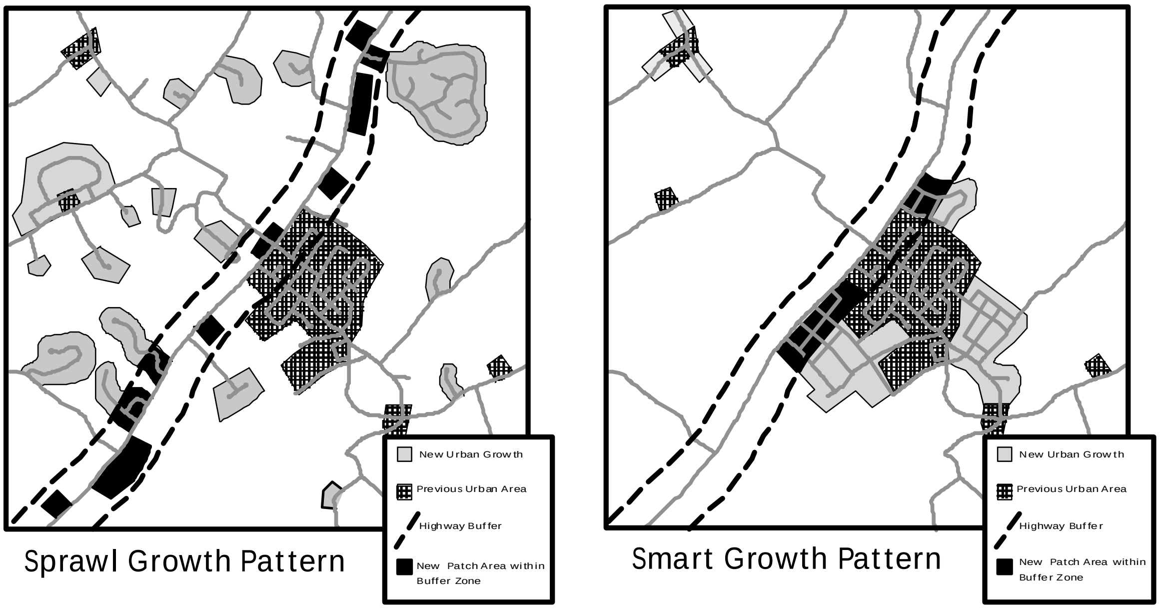


Figure 4 – 5 Highway Strip *- Highway strip development is a form of sprawl which results in ribbons of development stretching out into the countryside blocking vistas with housing units, strip malls and creating problems of highway access. The index is a measure of whether or not a new urban patch falls within a buffer of non-local roadways outside of town centers. Patches of new growth that occur within the buffer are considered sprawling for this measure.*

Calculating Highway-Strip Development - Characterization of highway strip development is challenging because the problematic qualities of strip development are a matter of urban design as well as location and configuration of land use. It is difficult to determine from a land use map the configuration of parking, the existence of sidewalks, on-street parking, non-auto accessibility and other more aesthetic qualities associated to highway strip development. These highway strip characteristics are best determined by in-field observation as the site level. Automating the highway strip metrics at larger spatial extents necessitates forgoing some of these design-specific characteristics of highway strip development.

For this study the highways were delineated from the dataset as all non-local roads outside of designated centers of the New Jersey State Plan. The buffer was set at 300’, a common depth for a 1-acre housing lot. The highway buffer was created in a gridded data format using Arcview

Spatial Analyst's *find distance* and *map query* functions. The *grid2point* extension was used to assign the highway buffer value to the housing unit shapefile. Units that fell within the buffer were coded to 1 and units outside the buffer were coded to zero. The municipal highway strip index (HS_{mun}) was calculated by summing the number of new residential units that occurred within the highway buffer and normalizing by the total number of new units that were developed within the municipality. This provided, in essence, a probability measure of highway strip occurrence for each municipality. Municipalities that experienced a higher ratio of highway strip development were considered sprawling for this measure.

$$HS_{mun} = \frac{\sum_{mun} HB_{unit}}{\sum_{mun} N_{unit}}$$

Where:

HS_{mun} = highway strip indicator by municipality
HB_{unit} = residential unit within 300' highway buffer
N_{unit} = number of new residential units

Transportation Related GIUS Measures

6) Road Infrastructure Inefficiency **-** One of the high profile negative impacts of sprawl that has led to public outcry is traffic congestion. Sprawling residential and commercial developments have less efficient road networks requiring greater lengths of new road creation, fewer intersections and more cul-de-sac than more efficient compact patterns of smart growth. Figure 4-6 provides a schematic illustration of the road efficiency calculation for an idealized sprawl versus smart growth development pattern. The new roadway efficiency metric measures the per unit increase in new road length, road intersections and cul-de-sacs. Greater per housing unit amounts of new road infrastructure indicates sprawl.

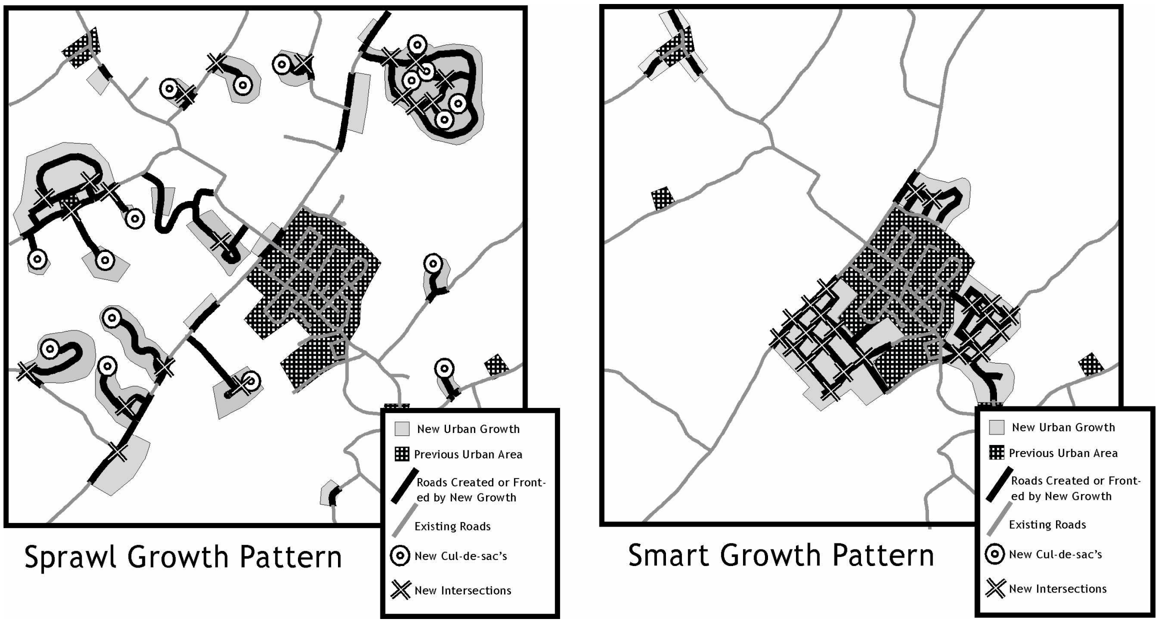


Figure 4-6 New Road Infrastructure Inefficiency *- The road efficiency index measures the spatial pattern of newly created or fronted roads which result from new development. The total length of newly created or fronted roads, new cul-de-sac's and number of intersections is normalized by population growth and summarized to produce a per housing unit new road efficiency measure.*

Calculating New Road Infrastructure Inefficiency - The new road efficiency metric was calculated by buffering new urban patches by 20 feet to incorporate roads along edges of new development. The buffered polygons were then used to clip the roads data layer resulting in a data layer of roads, intersections and cul-de-sacs within or adjacent to new development. The totals for each of these sub-measures was then assigned to each new development patch. The per unit length of new road was calculated by normalizing the total length of road within each new development patch by the number of units within the patch and assigning this back to the housing unit point shapefile. The cul-de-sac and intersection counts proved difficult to integrate into a single measure at the unit level. In order to simplify the index the final new road infrastructure inefficiency measure (RI_{mun}) as calculated in this analysis focused only on the length of new roads. This provided a measure of the average length of new road created in conjunction with each residential unit. Units that occurred in patches with longer lengths of road per unit are considered sprawling.

$$\mathrm{RI}_{mun} = \frac{\sum_{mun} \mathrm{Lnr}_{unit}}{\sum_{mun} N_{unit}}$$

Where:

RI_{mun} = road efficiency index by municipality
Lnr_{unit} = length of newly created or fronted roads per unit within a patch of new development
N_{unit} = number of new residential units

7) Transit Inaccessibility - Suburban sprawl is primarily oriented around the private automobile as the sole means of transport neglecting pedestrian, bicycle and public transportation modes. The alternate transit accessibility indicator measures the average road distance of each new housing unit to the nearest transit stop or bus route. Figure 4-7 provides a schematic illustration of the alternate transport accessibility calculation for an idealized sprawl versus smart growth development pattern. New urban growth with higher average distances to transit are considered more sprawling.

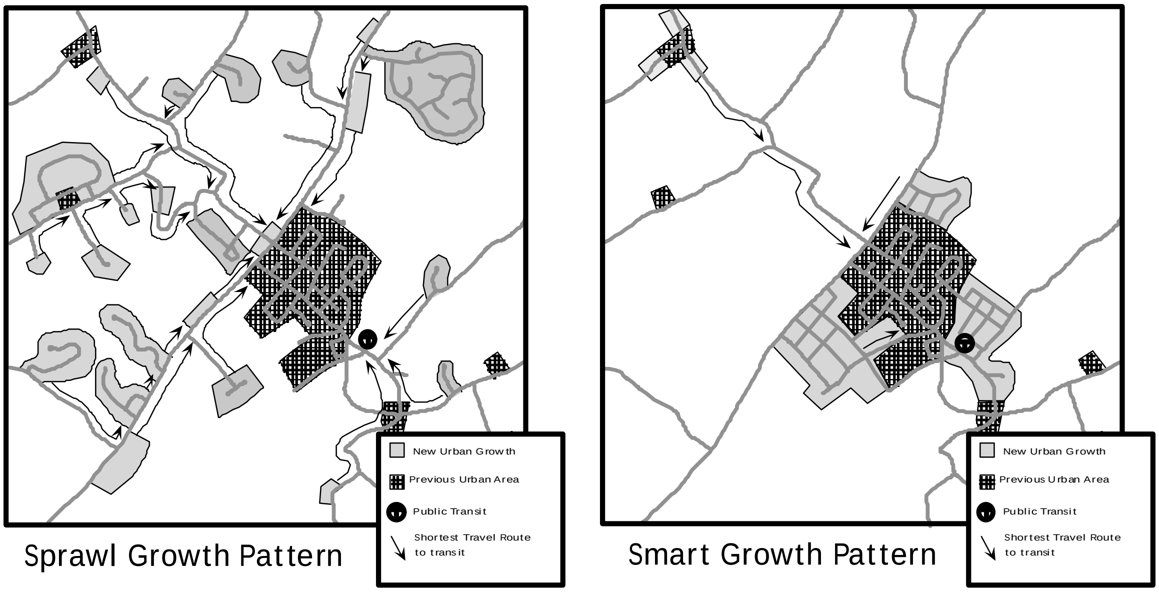


Figure 4-7 Transit Inaccessibility *-The public transportation accessibility factor measures the degree to which patches of new urban growth are accessible to public transportation. The factor was calculated by measuring the shortest road distance for each patch of new urban growth to the closest public transit.*

Calculating Transit Inaccessibility **-** New development patches are analyzed for their network distance to the nearest Bus lines and transit stations. This was accomplished by gridding the road coverage, and merging it with a gridded mask of new urban growth. This in essence, created a grid layer in which all patches of new urban growth were connected to the transit routes via the Hunterdon County road network. Isolated patches of new urban growth which did not intersect the gridded roads were connected to the road network by creating a shortest straight-line path using a *costdistance* function in Arcview Spatial Analyst on a distance from road grid.

Finally, a costdistance calculation was performed from the transit and bus routes across the road network/new urban patch mask. The result produced a grid layer in which every cell had the value of the shortest distance across the road mask to the nearest transit. The distance value was then assigned to the new housing unit centroid shapefile using the *grid2point* extension and summarized by municipality to produce the municipal transit inaccessibility (TI_{mun}) index.

$$\mathrm{TI}_{mun} = \frac{\sum_{mun} \mathrm{DT}_{unit}}{\sum_{mun} N_{unit}}$$

Where:

TI_{mun} = transit inaccessibility index by municipality
DT_{unit} = road distance of new unit from transit route.
N_{unit} = number of new residential units

***8) Community Node Inaccessibility* -** Sprawling land use patterns spread growth haphazardly throughout a landscape. This scattered land use pattern impairs accessibility to important community centers such as schools, libraries, fire/rescue, police, recreational facilities etc. This results in an inefficient transportation pattern, increase in vehicle miles traveled and lack of definable local town identity. It also has implications for public safety as emergency response time is directly related to urban spatial efficiency. Figure 4-8 provides a schematic illustration of the community node accessibility calculation for an idealized sprawl versus smart growth development pattern. The community node accessibility index measures the average distance of new development to a set of nearest community nodes. Sprawling land use patterns have significantly higher average distance between new urban patches and the selected community nodes.

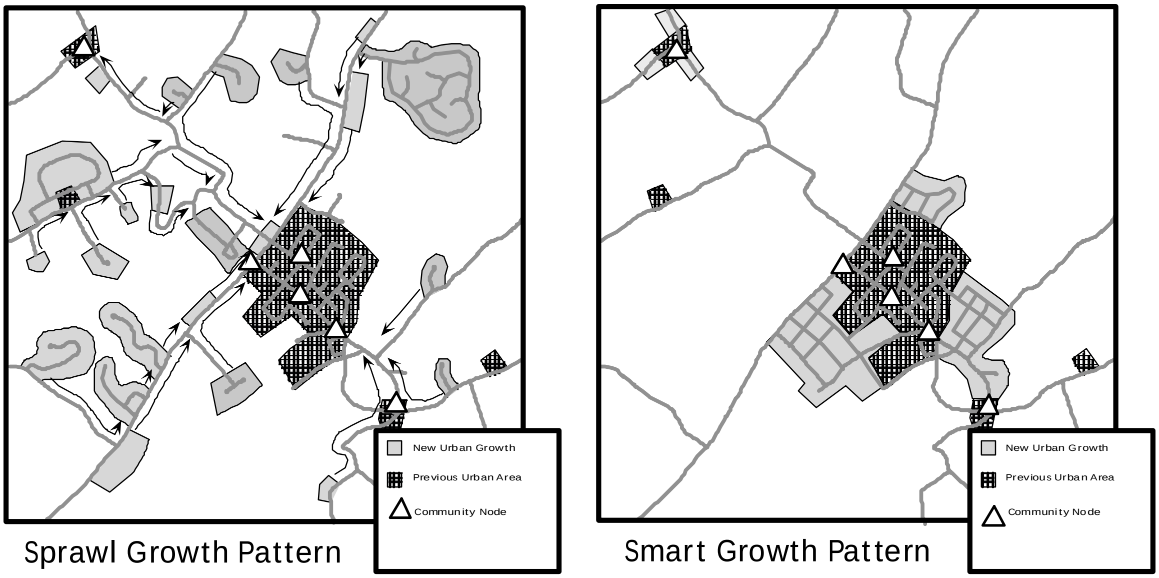


Figure 4-8 Community Node Inaccessibility *- Community node inaccessibility measures the degree to which new growth is accessible to important community centers. Community centers may include schools, libraries, recreation facilities, churches, town halls among other community focal destinations. The measure can be calculated by averaging the road distance from new development to each of the selected community centers.*

Calculating Community Node Inaccessibility - The first step of the community centrality metric is to define appropriate community centers. The centers chosen in this analysis included schools, libraries, post offices, municipal halls, fire and ambulance buildings. The centers were chosen to reflect likely destination for residents within a community as well as the availability of data for center locations. Other combinations, however, could certainly be employed. Each node was identified in the countywide digital parcel map utilizing the owner information as well as interpretation of digital orthophotos and hard-copy county maps.

A gridded road network/new urban patch mask was created in a similar manner as describe in the preceding transit inaccessibility measure. The road distance was calculated across the road network/new urban patch mask for each community node utilizing the costdistance function. The distance grids calculated for each individual community node were averaged by utilizing the *cell* *statistics* function. The community node inaccessibility index (CNI_{mun}) was calculated by summarizing the new housing unit community node distance values by municipality.

$$\mathrm{CNI}_{mun} = \frac{\sum_{mun} \overline{D\mathrm{cn}}_{unit}}{\sum_{mun} N_{unit}}$$

Where:

CNI_{mun} = community node inaccessibility index by municipality

$\overline{D\mathrm{cn}}_{unit}$ = average distance of new residential unit to community nodes

N_{unit} = number of new residential units

Environmental Resources Impact GIUS Measures

9) Consumption of Important Land Resources - Urban sprawl has been characterized as highly consumptive of important agricultural and natural land resources. The loss of land resources is in many cases an irreversible impact of sprawl. Figure 4-9 provides a schematic illustration of the important land resource impact calculation for an idealized sprawl versus smart growth development pattern. Areas of prime farmland, wetland and critical habitat loss due to urban development are delineated, summed for the unit of analysis and normalized by the number of housing units to produce a per unit loss of important land resources. Areas of new urban growth that consume considerable amounts of farmland, wetlands and critical habitat are considered sprawling for this measure.

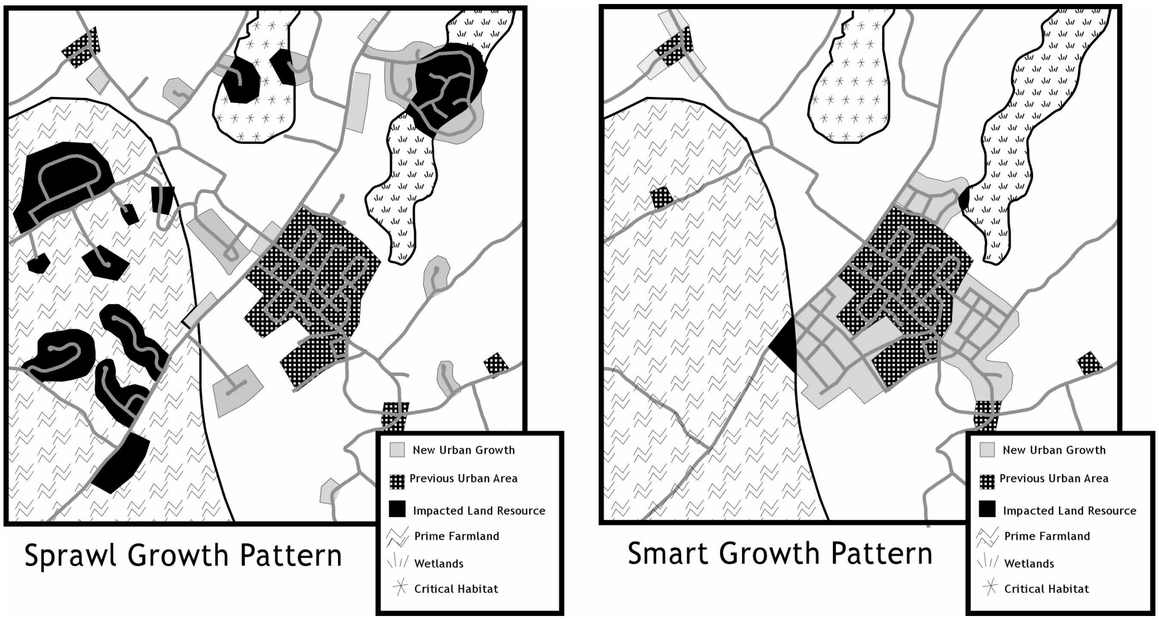


Figure 4-9 Land Resource Consumption *- The land resource consumption factor measures the degree to which new urban growth consumes or impacts important land resources. Resources may include prime farmlands, wetlands and critical habitat among others. The total area of land resource lost was normalized by population growth to produce a per capita land resource impact for this index.*

Calculation of Land Resources Consumption - The land resource consumption index measures the loss of prime farmland, critical habitat and wetlands. The metric sums the total area of loss to development for prime farmland as indicated by class A1 soils, fresh water wetlands as delineated by the New Jersey Department of Environmental Protection and critical wildlife habitat as delineated by the New Jersey Natural Heritage Database. The farmland, habitat and wetlands data layers were intersected with the new urban growth data layer to produce a grid of land resources loss to new urban growth. The acreage of resource lands loss for each patch was then summarized back to the new urban growth patch shapefile to provide a density of land resource loss per new development patch and normalized by the number of new units within each patch. The average per unit municipal land resource loss (LR_{mun}) index was calculated by summarizing the land resource per unit field of the new housing unit shapefile by the municipality field.

$$\mathrm{LR}_{mun} = \frac{\sum_{mun}\left(\mathrm{Apfl}_{unit} + \mathrm{Awl}_{unit} + \mathrm{Achl}_{unit}\right)}{\sum_{mun} N_{unit}}$$

Where:

LR_{mun} = land resource indicator by municipality
Apfl_{unit} = area of prime farmland loss per unit
Awl_{unit} = area of wetland loss per unit
Achl_{unit} = area of critical habitat loss per unit
N_{unit} = number of new residential units

10) Sensitive Open Space Encroachment - Continued urban land conversion challenges communities to provide adequate protected open space for active and passive recreation, maintenance of environmental quality, habitat preservation and farmland preservation. While any preserved open space is probably a positive amenity to a landscape, the juxtaposition of new development to open space can have widely divergent impacts. New development that is near recreational open space provides a positive benefit because the open space is accessible and an amenity for the residents. Conversely, new urban growth that is near sensitive open space such as wildlife management areas and farmland preservation can have a detrimental impact to these sensitive types of open space. Since the GIUS measures are designed to distinguish the dysfunctional characteristics of urban growth, they focus on the negative impacts of urban growth to sensitive open space preservation rather than the amenity that non-sensitive open space provides to nearby residences.

Figure 4-10 provides a schematic illustration of the open space preservation calculation for an idealized sprawl versus smart growth development pattern. The measure summarizes the inverse distance of each new housing unit to sensitive open space. A grid map of sensitive open space was created by overlaying a map of preserved open space with map of threatened and endangered species habitat as delineated by the New Jersey Fish, Game and Wildlife. This map of preserved patches of habitat was then unioned with a map of farmland preservation parcels. Urban growth that is closer to these sensitive open spaces is considered more sprawling than growth occurring at a greater distance to sensitive open space.

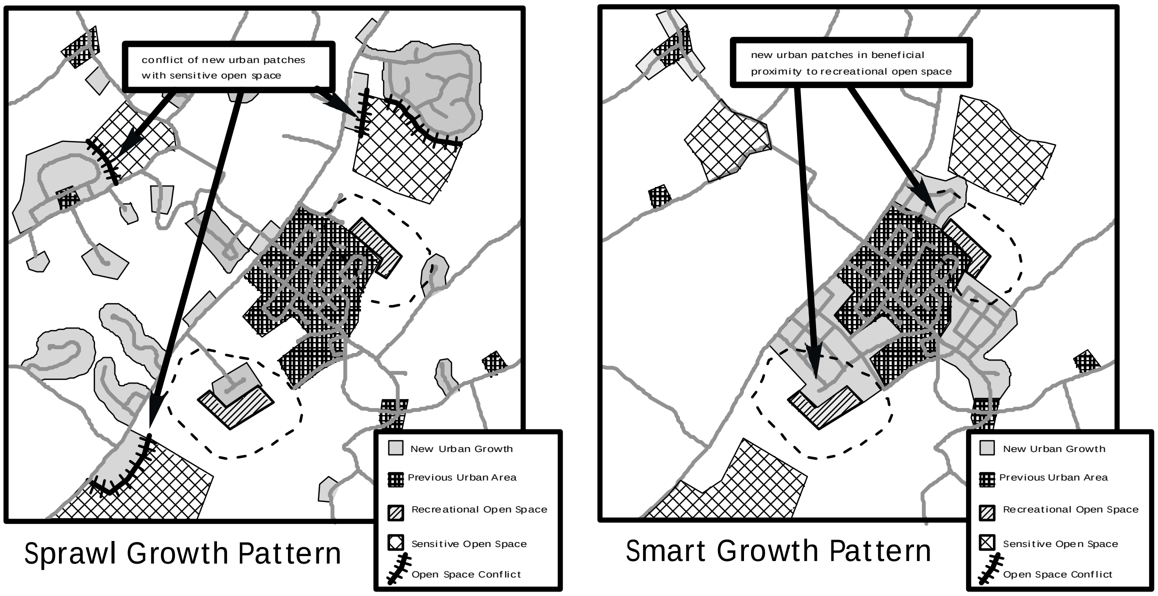


Figure 4 - 10 Sensitive Open Space Encroachment *- Open space preservation is important for environmental, aesthetic and recreational purposes. The open space impact index measures the degree to which new urban growth encroaches upon sensitive open space such as wildlife habitat and farmland preservation. New urban growth that encroaches on sensitive open space is considered more sprawling than growth with little or no open space encroachment.*

Calculating Open Space Encroachment **-** The open space encroachment index was calculated by intersecting parcels of preserved open space within the county with category 4 and 5 habitat patches of threatened and endangered species as delineated by the NJDEP Landscape Project (Niles, et. al. 2002). The produced a map of preserved open space that also contained habitat of important wildlife species. This map was then subsequently intersected with a map of preserved farmland parcels to produce a map of sensitive open space. A *distance* grid was generated from the parcels of sensitive open space and the distance value was assigned to the residential housing unit centroids using the *grid2point* extension. The municipal open space encroachment (OSE_{mun}) index was calculated by averaging the distance to sensitive open space by housing unit on the municipality field, inverting and multiplying by 1000 to adjust the magnitude of the index for manageability.

$$OSE_{mun} = \frac{\sum_{mun} Dsos_{unit}}{\sum_{mun} N_{unit}}$$

Where:

OSE_{mun} = open space impact by municipality

$Dsos_{unit}$ = distance from housing unit to preserved farmland and preserved parcels of threatened and endangered wildlife habitat.

N_{unit} = number of new residential units

11) Increased Impervious Surface (Per Housing Unit) **-** The amount of impervious surface within a watershed has direct implications for environmental quality particularly for water quality of local streams and ground water aquifer recharge potential. While urban sprawl patterns of development may have a locally lower percentage of impervious surface, this is more than compensated by the much larger amounts of land that are consumed. Figure 4-11 provides a schematic illustration of the impervious surface calculation for an idealized sprawl versus smart growth development pattern. The impervious surface index measures the efficiency of newly created impervious surface created by each additional resident added to the landscape. High per unit amounts of newly created impervious surface are considered more sprawling under this measure.

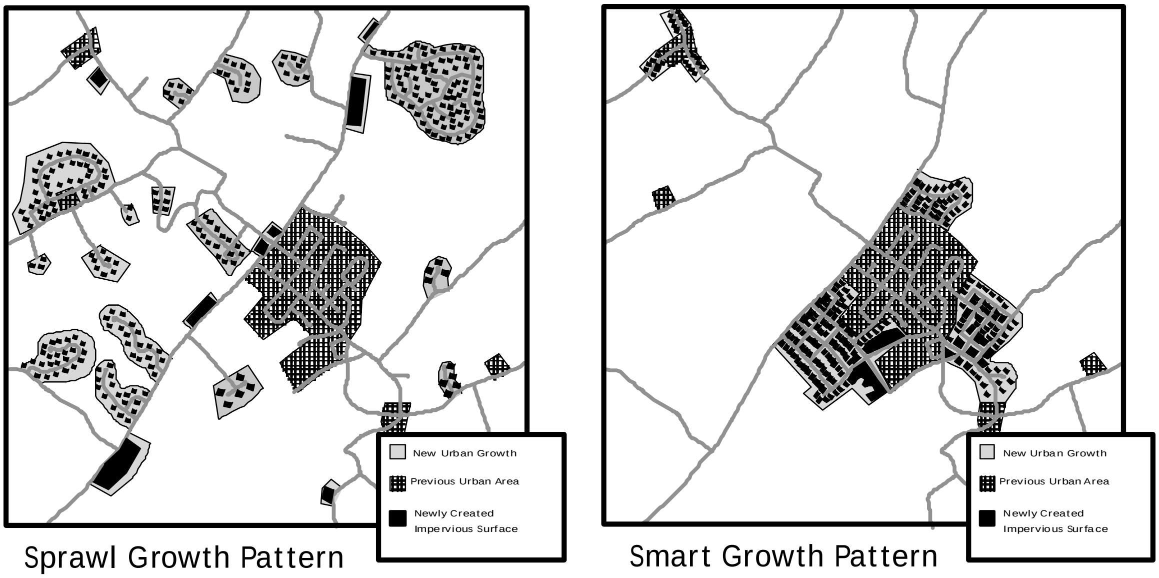


Figure 4-11 Increased Impervious Surface *- Impervious surfaces created by urban growth can have an important environmental impact. The impervious surface index measures added acres of impervious surface created by new urban growth. While the spread out pattern of sprawl may have lower percentage impervious surface per patch, when normalized by the population associated the growth, sprawling growth has more per capita impervious surface.*

Calculating Impervious Surface Index - Each patch of new urban growth contained information about the percent of impervious surface occurring within the patch. The estimation was derived from the NJDEP land use data set, which includes estimated impervious surface as an integrated attribute field. The areas of each new urban polygon were multiplied by the estimated percentage of impervious surface to determine the acres of impervious surface for each new unit. This produced a measure of impervious surface contributed by each housing unit. The municipal average impervious surface index (IS_{mun}) was calculated by summarizing the per unit acres of impervious surface by municipality.

$$IS_{mun} = \frac{\sum_{mun} Ais_{unit}}{\sum_{mun} N_{unit}}$$

Where:

IS_{mun} = impervious surface indicator by municipality

Ais_{unit} = area of newly created impervious surface within a municipality

N_{unit} = number of new residential units

12) Growth Trajectory **-** Sprawl can be associated with explosive patterns of growth. Unchecked development eventually consumes all available land reaching a build-out condition. When a locality reaches build-out it often finds itself with a mosaic of haphazard land use patterns and subsequent loss of definable town center or rural hinterland to separate town from town. Such explosively growing towns are strained to provide services such as fire and police as well as maintain schools and other municipal obligations. A measure of urban growth rate, municipal growth rate and consumption of available remaining land provides an indication of how development contributes to the trajectory of growth for a municipality. Figure 4-12 provides a schematic illustration of the growth trajectory calculation for an idealized sprawl versus smart growth development pattern. The index consists of three sub-measures that capture the rate of urban land area growth, the rate of growth in relation to the size of the municipality and the rate of loss of available land imparted by new development. High growth trajectory values are considered sprawling.

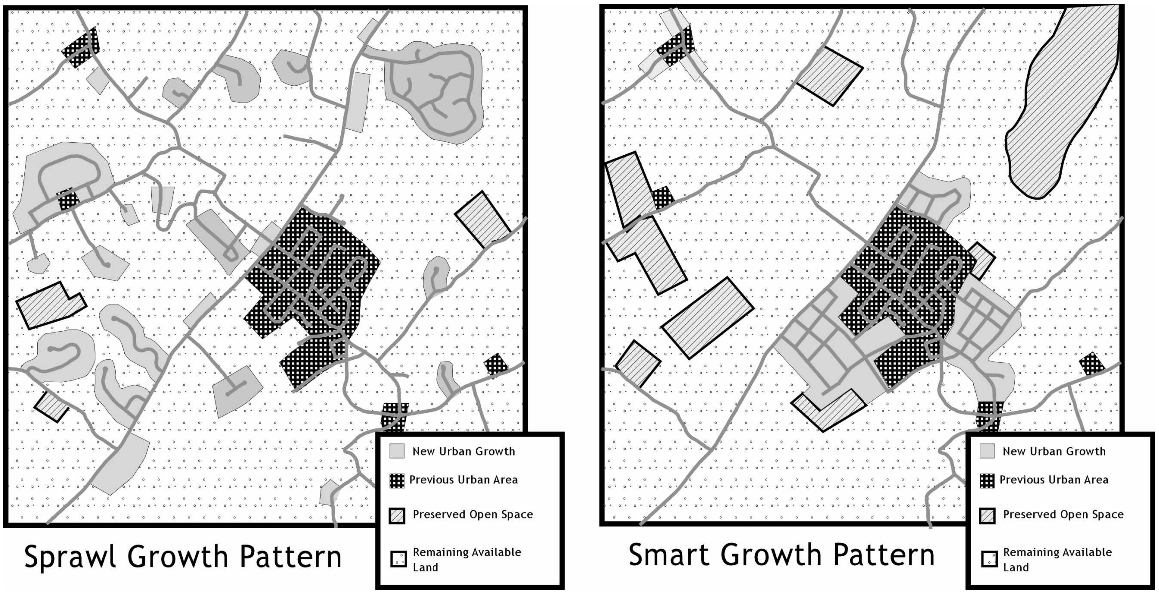


Figure 4-12 The growth trajectory index *measures the rate of urban growth, municipal growth and the rate of consumption of remaining available land within an area of analysis. The rate of growth and loss of available land provides an indication of the regions position of urgency for addressing urban growth issues. Regions with explosive growth and/or rapid loss of available land are considered sprawling.*

Calculating Growth Trajectory - The amount of land available for development was delineated through grid overlay by masking non-developable lands including; already urban lands, roads, parklands, preserved and protected lands, wetlands, steep slopes, etc. The three sub-measures were calculated for each patch of new growth by normalizing the size of the new patch by: a) the number of acres of developed land within each municipality in 1986; b) the area of the municipal territory, and c) the area of available land remaining in the municipality at the time the development was initiated. The sub-measure values were generated at the housing unit-level by normalizing the *acres/per unit* field of the new housing unit shapefile by the municipal values for urban land 1986, municipal size and remaining available lands. The sub-measures were mathematically added to produce the growth trajectory value by housing unit and then summarized by municipality to produce the municipal-level growth trajectory (GT_{mun}) index.

$$GT_{mun} = \sum_{mun} (MG_{unit} + UG_{unit} + AL_{unit})$$ Where:

GT_{mun} = growth trajectory indicator by municipality
MG_{unit} = unit contribution to growth as a percentage of municipal size.
UG_{unit} = unit contribution to growth as a percentage of pervious urban area
AL_{unit} = unit contribution to the loss of available land as a percentage of the remaining available land

IV. Operationalizing Municipal-Level GIUS: A Case Study

In order to develop and operationalize an automated GIUS calculation, a municipal-level GIUS analysis was performed on Hunterdon County, New Jersey. This once rural county has experienced significant suburbanization in recent decades and was chosen as the study area due to many qualities that exemplify the problems of sprawling urban growth along the rural-urban fringe. Hunterdon County is located in a traditionally agricultural region of western New Jersey, approximately 50 miles west of Manhattan and 50 miles north of Philadelphia. This puts the entire county within ‘acceptable’ commuting distance to these major metropolitan areas. It is traversed by interstate I78, a major highway running East-West providing access to Newark international airport and downtown New York City. North-South highways include Route 202 and Route 31, which leads to the State capitol of Trenton as well as interstate 95 to Philadelphia.

Hunterdon County’s demographic setting also makes for an interesting analysis of suburbanization as it has experience significant population growth over the last few decades rising from 69,718 in 1970 to 121,989 by 2000, a 75.2% increase in population (US Census Bureau 2001). Although the county’s population is relatively low when compared with other New Jersey suburban counties, Hunterdon’s rate of growth is outstripping the state as a whole. The increase in county population from 1990 to 2000 was 13.1% compared to the 8.6% statewide growth. The growth in population in the 1980’s and 1990’s along with an increase in educational attainment has shifted the demographic makeup of the county from a largely rural/ blue-collar workforce to a growing corporate white-collar labor force. In recent years, several major corporate centers have located in the county providing attractive employment opportunities. The gently rolling bucolic rural landscape and relatively low cost of living all combine to drive up the demand for residential development and the commercial development that follows. These geographic factors and growth pressures along with Hunterdon County’s proactive open space and land conservation programs, which are striving to incorporate many principles of smart growth, make the county the ideal case study for measuring geospatial patterns of urban sprawl on the rural fringe.

Data and Processing

The GIUS approach to urban growth analysis requires extensive geospatial data. Hunterdon County enjoys a wide variety of available geospatial data providing a wealth of source data for experimentation and development of GIUS methodology. An assortment of socioeconomic and biophysical sources of data were utilized for the analysis including land use/land cover, roads, tax parcels, State planning areas, census block data for 1980 and 1990, prime farmsoils, 1995/97 orthophotography and transit routes among others.

The most significant data to make this study feasible was digital land use\land cover. New Jersey has developed a detailed land use/land cover vector-based GIS database for the entire state (NJDEP 2000). The data was first compiled using 1986 Color Infrared aerial photography and has recently been updated through screen digitizing of 1995/97 color infrared digital orthophotography. The updated data retains the 1986 land use for land change analysis and is compiled to an Anderson Level III classification slightly modified for New Jersey. The minimum mapping unit is 1 acre. Linear accuracy is +- 20 ft. The land use/land cover was produced in ESRI shapefile format and also incorporates wetlands delineation generated under the New Jersey Freshwater Wetlands Mapping Program and impervious surface estimates photo interpreted for the 1995/97 land use designation.

A second vital database utilized in the analysis included the Hunterdon County Digital parcel map. This coverage provided parcel boundaries and attribute information for Hunterdon's +

50,000 parcels. The parcel mapping was produced in-house by the Hunterdon County Planning Department using the GPS road centerlines as the spatial reference for map conflation.

V. Results

Countywide Analysis

The automated GIUS analysis resulted in the delineation of 9,339 new residential units developed in Hunterdon County between 1986 and 1995. The individual GIUS measures were calculated for the housing unit centroid shapefile. The countywide summary statistics provided in Table 4 – 1 present a measure of the "average" characteristics of sprawl for all new residential growth within Hunterdon County during the period of analysis. The land use measures indicate an average development density of 0.835 acres developed for every unit; an average leapfrog distance of 2,035 feet; a segregated land use index value of 5.01 signifying an average of 2.99 different land uses within 1500 feet of each new residence; a regional planning congruency index of 3.475 where 1 is most congruent and 6 is least congruent; and a highway strip measure of 0.058 indicating that approximately 6 out of 100 new residential units exhibited the highway strip characteristic.

The county average new housing unit transportation measures indicate that 94 feet of new roadway was created per housing unit; public transit was located an average distance of 10,261 feet from each unit; and important community nodes where located an average of 13,418 feet from each residential unit. The average land resource impact measures indicate that for each unit built, 0.415 acres of important land resources were built upon; an open space encroachment index of 0.928 indicated that housing was built on average 1,077 feet from sensitive open space; 0.124

acres of impervious surface were created; and each new residence contributed 0.048 percent to a municipalities trajectory of growth.

***Table 4-1County-level GIUS Statistics** for all new housing units built in Hunterdon County between 1986 and 1995. N=9339.* [UD_{mun} = *urban density*], [LF_{mun} = *leap frog*], [SL_{mun} = *segregated land use*], [RPI_{mun} = *regional planning inconsistency*], [HS_{mun} = *highway strip*], [RI_{mun} = *road inefficiency*], [TI_{mun} = *transit inaccessibility*], [CNI_{mun} = *community node inaccessibility*], [LR_{mun} = *land resource consumption*], [OSE_{mun} = *sensitive open space encroachment*], [IS_{mun} = *impervious surface inefficiency*] and [GT_{mun} = *growth trajectory*].

	UD_{mun}	LF_{mun}	SL_{mun}	RPI_{mun}	HS_{mun}	RI_{mun}	TI_{mun}	CNI_{mun}	LR_{mun}	OSE_{mun}	IS_{mun}	GT_{mun}
Mean	0.835	2035	5.01	3.475	0.058	94	10261	13418	0.415	0.928	0.124	0.048
Stdev	0.848	2364	1.50	2.051	0.234	85	9272	5573	0.636	1.965	0.228	0.104
Min	0.001	0	1.00	1.000	0.000	0	104	2334	0.000	0.056	0.000	0.000
Max	15.643	17452	7.00	6.000	1.000	942	44927	36201	7.200	20.000	9.386	5.598

A cross correlation analysis (Table 4-2) demonstrates the degree to which each GIUS measure is correlated to each other. The results show that the 12 GIUS indices are substantially orthogonal, as no two measures are highly correlated. The measures which exhibited the highest correlation coefficient of 0.72 were *Transit Inaccessibility* and *Community Node Inaccessibility.* This correlation is not surprising considering that transit inaccessibility can be considered as a special case of community node. A housing unit that was located at a significant average distance from important community nodes would likely be also distant from transit locations. The next most significant correlation occurred between *impervious surface* and *urban density* with a coefficient of 0.666. This is also a logical correlation as a larger developed area for a housing unit is likely to entail larger building footprints, larger driveways as well as sidewalks and patios. The *community node inaccessibility* measure stands as the GIUS index most highly correlated to multiple other measures including *leapfrog, segregated land use, regional planning inconsistency* and *transit inaccessibility.* This is also a reasonable finding as the site-specific land use patterns inherent for a new residential unit will be linked to the accessibility of community nodes. The multiple correlation of the *community node inaccessibility* index suggests that a calculation of this index alone may be a useful proxy for several other characteristics of sprawl.

Table 4–2. GIUS cross correlation matrix *for all new residential units built between 1986 and 1997. N=9339* [UD_{mun} = *urban density*], [LF_{mun} = *leap frog*], [SL_{mun} = *segregated land use*], [RPI_{mun} = *regional planning inconsistency*], [HS_{mun} = *highway strip*], [RI_{mun} = *road inefficiency*], [TI_{mun} = *transit inaccessibility*], [CNI_{mun} = *community node inaccessibility*], [LR_{mun} = *land resource consumption*], [OSE_{mun} = *sensitive open space encroachment*], [IS_{mun} = *impervious surface inefficiency*] and [GT_{mun} = *growth trajectory*].

	UD_{mun}	LF_{mun}	SL_{mun}	RPI_{mun}	HS_{mun}	RI_{mun}	TI_{mun}	CNI_{mun}	LR_{mun}	OSE_{mun}	IS_{mun}	GT_{mun}
UD_{mun}	1.000											
LF_{mun}	0.276	1.000										
SL_{mun}	0.525	0.474	1.000									
RPI_{mun}	0.414	0.490	0.616	1.000								
HS_{mun}	-0.011	0.074	0.001	0.051	1.000							
RI_{mun}	0.403	0.162	0.382	0.223	0.068	1.000						
TI_{mun}	0.283	0.535	0.455	0.431	0.078	0.168	1.000					
CNI_{mun}	0.425	0.653	0.641	0.523	0.041	0.248	0.720	1.000				
LR_{mun}	0.351	0.091	0.302	0.093	0.009	0.368	0.140	0.261	1.000			
OSE_{mun}	-0.107	-0.121	-0.084	-0.101	0.006	-0.073	-0.074	-0.171	-0.062	1.000		
IS_{mun}	0.666	0.056	0.161	0.112	-0.015	0.133	0.070	0.111	0.106	-0.026	1.000	
GT_{mun}	0.431	0.107	0.166	0.211	0.005	0.157	0.118	0.113	0.094	-0.017	0.384	1.000

Municipal Level Analysis

A municipal-level summary was performed by averaging the individual housing unit GIUS values within each municipal boundary. Table 4-4 presents the municipal values in their average index value as well as in standard deviations from the norm (italicized type within gray box) for each measure. Municipalities that exhibited GIUS measurements more sprawling than the countywide average have positive standard deviations whereas negative standard deviation values indicate characteristics less sprawling than the county average. The range of the municipal-level GIUS averages demonstrate the diverse nature of residential growth from municipality to municipality.

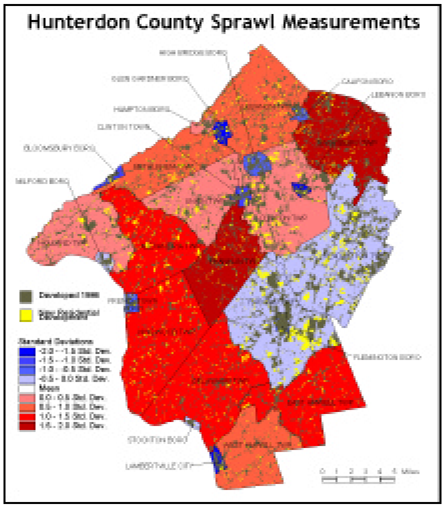
Some localities such as East Amwell Township exhibit growth patterns that are substantially more sprawling than the county average for all GIUS measures. Others such as Lebanon Borough are substantially less sprawling across all GIUS measures. Still other municipalities demonstrate a mixture of some characteristics more sprawling than average and others less sprawling than average.

Particularly interesting is Raritan and Readington Township which combined accounted for 47.7 percent of the 9,339 residential units built countywide. These towns exemplify the type of explosive recent growth often perceived as sprawl but examination of their GIUS measures finds them less sprawling than county average for most GIUS variables. An equally interesting characteristic (Table 4-4) is the number of housing units developed within each municipality for the period of analysis. Raritan, Readington, and Clinton Townships gained the most units and not surprisingly exhibited elevated *growth trajectory* measures. Many of the smaller towns and boroughs exhibited relatively fewer new units of residential growth but also exhibited elevated *growth trajectory* due to the relatively small size of boroughs and the limited amount of available lands within these smaller communities.

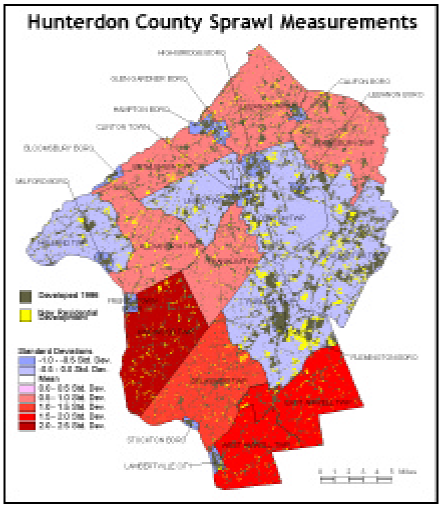
***Table 4-4 Municipal-Level GIUS measures** of Hunterdon County, NJ. Average measures are in regular typeface and standard deviations from the county average are italicized in the gray box.*

MUNICIPALITY	Housing Units	UD_{mun}	LF_{mun}	SL_{mun}	RPI_{mun}	HS_{mun}	RI_{mun}	TI_{mun}	CNI_{mun}	LR_{mun}	OSE_{mun}	IS_{mun}	GT_{mun}
ALEXANDRIA TWP	448	1.32	3406	6	5.2	0.078	140.2	21960	18976	0.541	0.627	0.164	38.54
		0.572	*0.580*	*0.660*	*0.841*	*0.085*	*0.544*	*1.262*	*0.997*	*0.198*	*-0.153*	*0.175*	*1.889*
BETHLEHEM TWP	287	1.1	3152	6	5.8	0.122	116	24835	14578	0.256	1.519	0.153	24.25
		0.313	*0.473*	*0.660*	*1.134*	*0.274*	*0.259*	*1.572*	*0.208*	*-0.250*	*0.301*	*0.127*	*0.625*
BLOOMSBURY BORO	14	0.35	213	1.7	1	0	271.6	26262	12113	0.625	0.102	0.101	4.62
		-0.572	*-0.771*	*-2.207*	*-1.207*	*-0.248*	*2.089*	*1.726*	*-0.234*	*0.330*	*-0.420*	*-0.101*	*-1.112*
CALIFON BORO	18	0.57	576	3.8	3.3	0.056	60	1355	9324	0.022	0.45	0.105	7.49
		-0.313	*-0.617*	*-0.807*	*-0.085*	*-0.009*	*-0.400*	*-0.961*	*-0.735*	*-0.618*	*-0.243*	*-0.083*	*-0.858*
CLINTON TOWN	88	0.26	231	4.1	1	0	78	2694	3392	0.41	0.146	0.086	11.01
		-0.678	*-0.763*	*-0.607*	*-1.207*	*-0.248*	*-0.188*	*-0.816*	*-1.799*	*-0.008*	*-0.398*	*-0.167*	*-0.546*
CLINTON TWP	921	0.87	980	5	2.9	0.089	102.3	5185	10894	0.271	0.599	0.134	28.48
		0.041	*-0.446*	*-0.007*	*-0.280*	*0.132*	*0.098*	*-0.547*	*-0.453*	*-0.226*	*-0.167*	*0.044*	*0.999*
DELAWARE TWP	304	1.38	4381	6.3	5.6	0.082	98.4	18827	17049	0.806	0.74	0.144	22.05
		0.643	*0.992*	*0.860*	*1.036*	*0.103*	*0.052*	*0.924*	*0.652*	*0.615*	*-0.096*	*0.088*	*0.430*
EAST AMWELL TWP	224	1.25	5038	6.3	5.2	0.147	134.7	15959	20856	1.531	2.473	0.13	17.29
		0.489	*1.270*	*0.860*	*0.841*	*0.380*	*0.479*	*0.615*	*1.335*	*1.755*	*0.786*	*0.026*	*0.009*
FLEMINGTON BORO	8	0.39	80	2.9	1	0	59.1	615	3805	0.062	0.181	0.115	1.56
		-0.525	*-0.827*	*-1.407*	*-1.207*	*-0.248*	*-0.411*	*-1.040*	*-1.725*	*-0.555*	*-0.380*	*-0.039*	*-1.382*
FRANKLIN TWP	171	1.48	3394	6.3	5.6	0.035	112.2	18871	17188	0.592	1.101	0.176	20.44
		0.761	*0.575*	*0.860*	*1.036*	*-0.098*	*0.214*	*0.929*	*0.676*	*0.278*	*0.088*	*0.228*	*0.288*
FRENCHTOWN BORO	13	0.53	473	4.8	4.2	0.308	154	2162	12922	0.046	0.139	0.092	5.68
		-0.360	*-0.661*	*-0.140*	*0.353*	*1.068*	*0.706*	*-0.873*	*-0.089*	*-0.580*	*-0.402*	*-0.140*	*-1.018*
GLENGARDNER BORO	215	0.17	272	3.6	5.9	0.005	32.3	2031	9076	0.015	0.382	0.055	22.93
		-0.784	*-0.746*	*-0.940*	*1.182*	*-0.226*	*-0.726*	*-0.888*	*-0.779*	*-0.629*	*-0.278*	*-0.303*	*0.508*
HAMPTON BORO	16	0.93	330	3.8	5	0.125	153.8	3517	8929	0.288	0.186	0.13	8.27
		0.112	*-0.721*	*-0.807*	*0.744*	*0.286*	*0.704*	*-0.727*	*-0.805*	*-0.200*	*-0.378*	*0.026*	*-0.789*
HIGH BRIDGE BORO	17	0.49	164	4.8	6	0.059	88	2710	8287	0.229	1.315	0.137	3.4
		-0.407	*-0.791*	*-0.140*	*1.231*	*0.004*	*-0.071*	*-0.814*	*-0.921*	*-0.292*	*0.197*	*0.057*	*-1.219*
HOLLAND TWP	372	0.95	1513	5.3	3.5	0.048	89.1	9258	14269	0.366	0.207	0.151	21.1
		0.136	*-0.221*	*0.193*	*0.012*	*-0.043*	*-0.058*	*-0.108*	*0.153*	*-0.077*	*-0.367*	*0.118*	*0.346*
KINGWOOD TWP	420	1.21	6648	6.4	5.1	0.117	113.1	17526	22585	0.375	0.219	0.118	33.57
		0.442	*1.951*	*0.927*	*0.792*	*0.252*	*0.225*	*0.784*	*1.645*	*-0.063*	*-0.361*	*-0.026*	*1.449*
LAMBERTVILLE CITY	110	0.15	249	4.1	1.3	0	66.9	1841	4505	0.066	0.205	0.078	10.09
		-0.808	*-0.755*	*-0.607*	*-1.060*	*-0.248*	*-0.319*	*-0.908*	*-1.599*	*-0.549*	*-0.368*	*-0.202*	*-0.628*
LEBANON BORO	103	0.11	42	2.2	1	0	37.7	723	9115	0	0.429	0.054	12.92
		-0.855	*-0.843*	*-1.873*	*-1.207*	*-0.248*	*-0.662*	*-1.029*	*-0.772*	*-0.653*	*-0.254*	*-0.307*	*-0.377*
LEBANON TWP	350	1.17	3607	5.9	5.7	0.031	106.8	10672	14066	0.206	0.693	0.154	20.03
		0.395	*0.665*	*0.593*	*1.085*	*-0.115*	*0.151*	*0.044*	*0.116*	*-0.329*	*-0.120*	*0.132*	*0.251*
MILFORD BORO	11	0.59	224	5.8	5.3	0	97.5	3641	9902	0.027	0.08	0.148	5.91
		-0.289	*-0.766*	*0.527*	*0.890*	*-0.248*	*0.041*	*-0.714*	*-0.631*	*-0.610*	*-0.432*	*0.105*	*-0.997*
RARITAN TWP	2383	0.63	1025	4.6	2.2	0.042	93.9	5339	10318	0.621	0.873	0.111	42.25
		-0.242	*-0.427*	*-0.273*	*-0.622*	*-0.068*	*-0.001*	*-0.531*	*-0.556*	*0.324*	*-0.028*	*-0.057*	*2.217*
READINGTON TWP	2074	0.65	1621	4.4	2.6	0.042	73.7	9775	14067	0.207	1.527	0.112	30.17
		-0.218	*-0.175*	*-0.407*	*-0.427*	*-0.068*	*-0.239*	*-0.052*	*0.116*	*-0.327*	*0.305*	*-0.053*	*1.148*
STOCKTON BORO	3	0.66	137	4.7	2	0	65.7	15192	9748	0	1.767	0.066	2.99
		-0.206	*-0.803*	*-0.207*	*-0.719*	*-0.248*	*-0.333*	*0.532*	*-0.659*	*-0.653*	*0.427*	*-0.254*	*-1.256*
TEWKSBURY TWP	325	1.45	3162	6	5.8	0.043	91.4	13795	17830	0.535	0.631	0.183	21.18
		0.725	*0.477*	*0.660*	*1.134*	*-0.064*	*-0.031*	*0.381*	*0.792*	*0.189*	*-0.151*	*0.259*	*0.353*
UNION TWP	327	0.85	1185	5.2	3.9	0.061	92.3	20513	12908	0.278	1.019	0.118	20.32
		0.018	*-0.360*	*0.127*	*0.207*	*0.013*	*-0.020*	*1.106*	*-0.092*	*-0.215*	*0.046*	*-0.026*	*0.277*
WEST AMWELL TWP		1.04	5642	6.2	5.7	0.145	121	10900	14250	0.12	0.265	0.109	10.34
	117	*0.242*	*1.526*	*0.793*	*1.085*	*0.372*	*0.318*	*0.069*	*0.149*	*-0.464*	*-0.337*	*-0.066*	*-0.606*

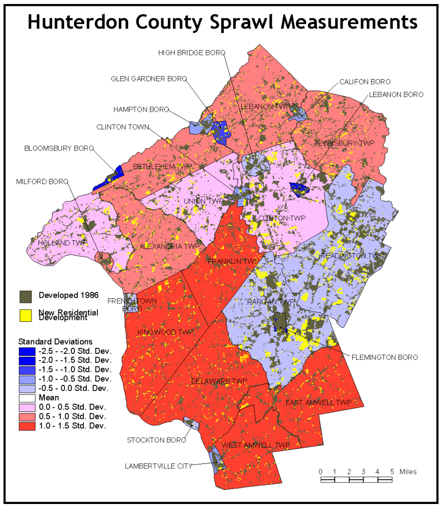
The average measures for each GIUS index are mapped in Z-scores (standard deviations) from the county mean by municipality in figure plate 4-13 and figure plate 4-14. The maps depict the municipal average measures for each index where shades of red indicate sprawling conditions greater than average and shades of blue indicate sprawling conditions lower than average. In order to show the spatial pattern of growth that is occurring in each of the municipalities, the choropleth maps are overlaid with a delineation of 1986 urban (i.e. previous development) in gray and new residential housing in yellow. The maps demonstrate the geographical variation of each measure from municipality to municipality. The spatial patterns of the individual GIUS measures are strikingly dissimilar supporting the conclusion of orthogonality demonstrated by the cross correlation analysis (Table 4-2).



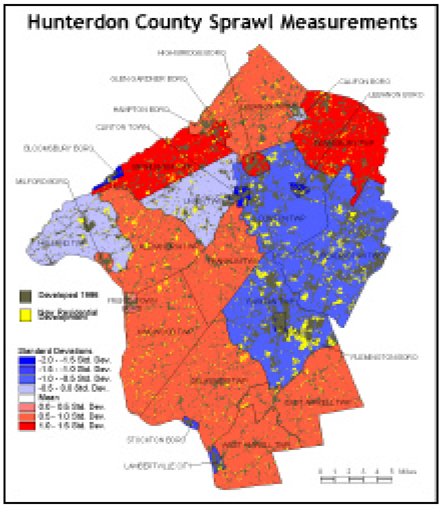
(a) Density



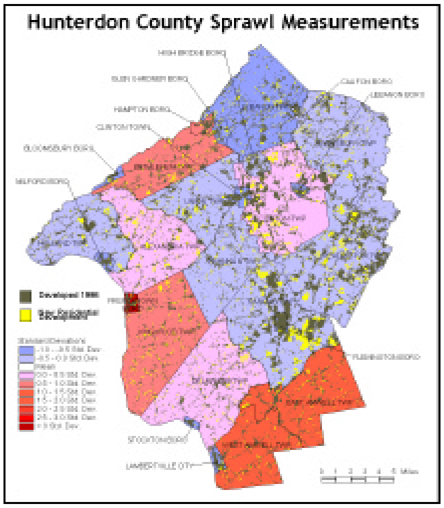
(b) Leapfrog



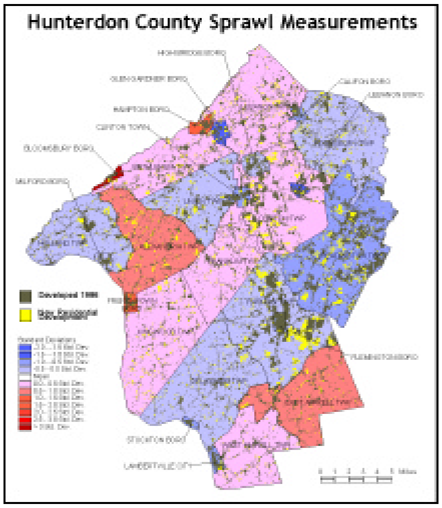
(c) Segregated Land Use



(d) Regional Planning Incongruence

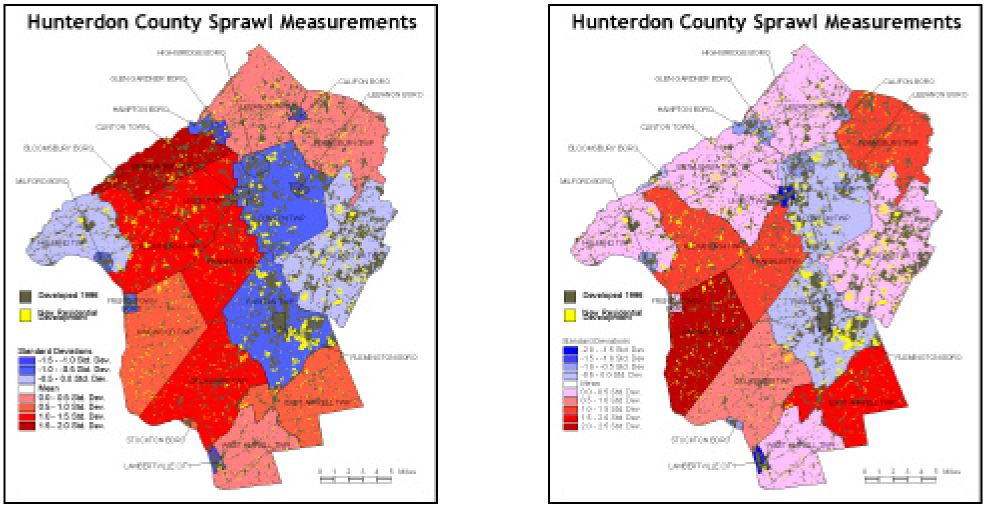


(e) Highway Strip



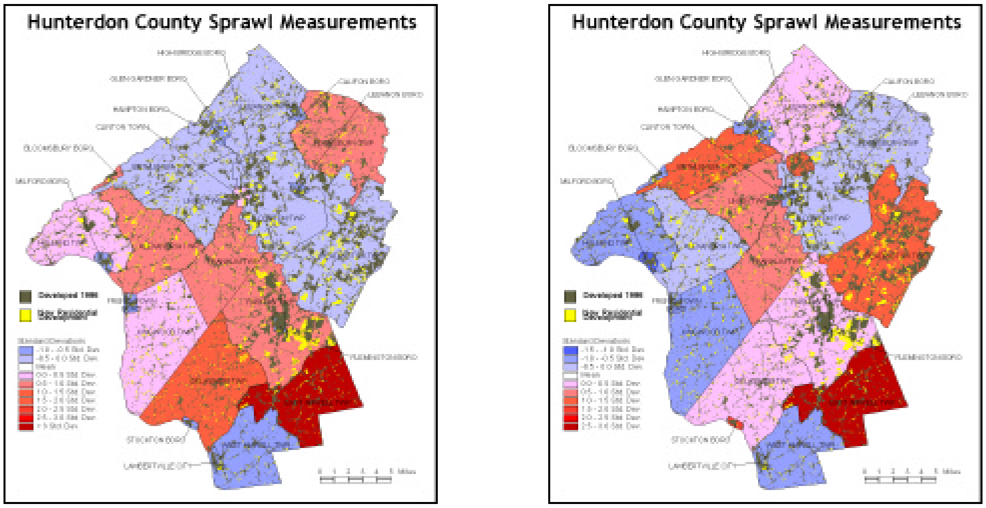
(f) Road Infrastructure Inefficiency

Figure Plate 4-13a. Municipal Average GIUS measures *in Z-scores from the county average. Reds indicated greater than average values (i.e. more sprawling) whereas blues indicate less than average. Overlays of gray indicate areas of previous development and yellow indicate new residential growth.*



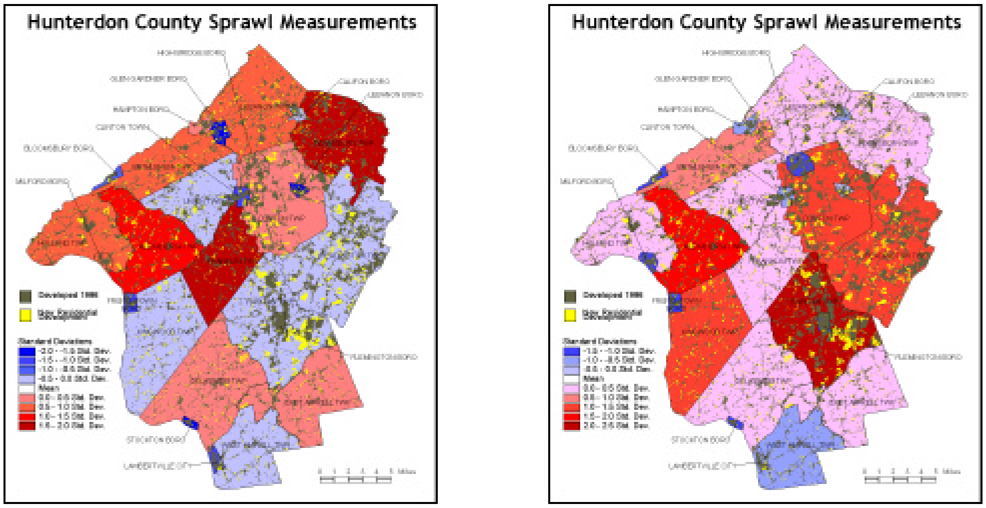
(g) Transit Inaccessibility

(h) Community Node Inaccessibility



(i) Land Resource Impacts

(j) Sensitive Open Space Encroachment



(k) Impervious Surface Inefficiency

(l) Growth Trajectory

Figure Plate 4-13b. Municipal Average GIUS measures (cont.) *in Z-scores from the county average. Reds indicated greater than average values (i.e. more sprawling) whereas blues indicate less than average. Overlays of gray indicate areas of previous development and yellow indicate new residential growth.*

Normalizing Municipal GIUS Measures

Each of the 12 individual GIUS measures reflects a particular geospatial characteristic of urban growth and provides useful analytical information. However, the measures are not standardized but reflect an appropriate measurement unit for each particular trait. For example, some measurements such as *leapfrog* are in feet, some such as *density* are in acres and yet others such as *growth trajectory* are in percent land use change. The diversity and range between these measurement units precludes comparison between measures. Normalization of the measures through percentile rank results in index values that can be cross-compared. Once the individual 12 GIUS measures are normalized to percentage ranks they can be summed together producing a single cumulative summary measure of sprawl or what can be characterized as a *Metasprawl Index* for each municipality. Figure 4-14 maps the metasprawl index and Table 4-5 is ranked in descending order placing the most sprawling municipality at the top.

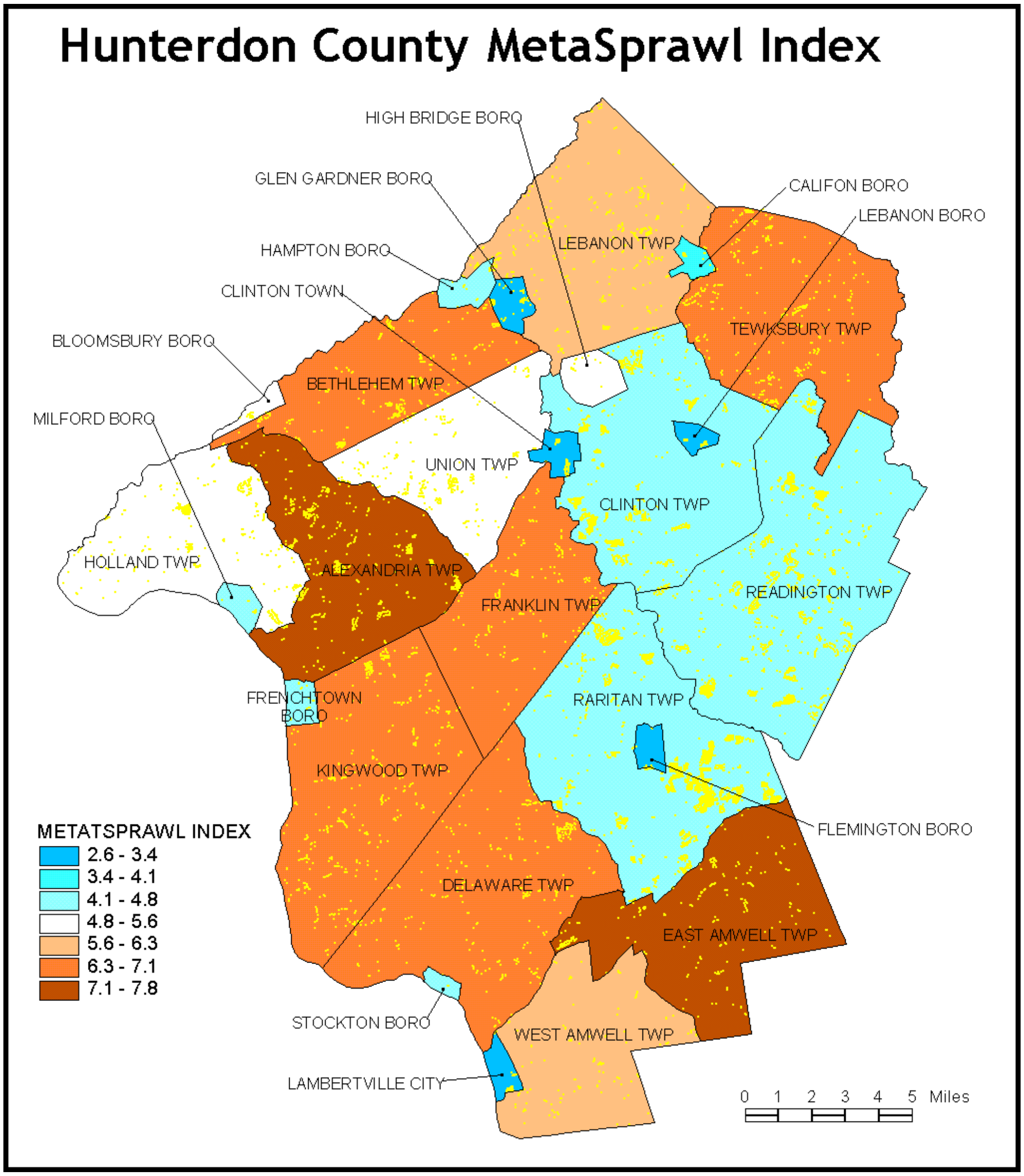


Figure 4-14 Metasprawl by municipality*. Map depicts the normalized combined GIUS measures for municipalities in Hunterdon County. Darker shades of red indicate higher combined sprawl values. Darker shades of blue indicate lower combined sprawl values. Yellow overlay indicates new residential growth.*

Table 4-5. Normalized Municipal GIUS Measures Ranked by Metasprawl Index

Municipality	UD$_{mun}$	LF$_{mun}$	SL$_{mun}$	RPI$_{mun}$	HS$_{mun}$	RI$_{mun}$	TI$_{mun}$	CNI$_{mun}$	LR$_{mun}$	OSE$_{mun}$	IS$_{mun}$	GT$_{mun}$	Meta sprawl Index
East Amwell Twp	0.680	0.784	0.627	0.579	0.139	0.581	0.695	0.821	0.822	0.729	0.581	0.759	7.796
Alexandria Twp	0.699	0.712	0.554	0.581	0.074	0.630	0.837	0.818	0.556	0.392	0.663	0.780	7.296
Franklin Twp	0.704	0.717	0.641	0.640	0.033	0.465	0.790	0.734	0.469	0.455	0.644	0.813	7.103
Delaware Twp	0.708	0.794	0.628	0.637	0.078	0.442	0.768	0.703	0.448	0.410	0.611	0.732	6.958
Bethlehem Twp	0.637	0.704	0.575	0.677	0.115	0.548	0.838	0.589	0.243	0.513	0.644	0.778	6.860
Kingwood Twp	0.661	0.883	0.672	0.559	0.110	0.512	0.693	0.875	0.379	0.192	0.539	0.751	6.824
Tewksbury Twp	0.716	0.693	0.545	0.673	0.041	0.405	0.640	0.759	0.427	0.474	0.693	0.697	6.762
West Amwell Twp	0.616	0.781	0.619	0.658	0.137	0.509	0.576	0.542	0.152	0.277	0.488	0.771	6.126
Lebanon Twp	0.653	0.679	0.541	0.660	0.030	0.467	0.554	0.537	0.170	0.445	0.635	0.669	6.040
Union Twp	0.473	0.378	0.435	0.408	0.058	0.453	0.788	0.487	0.241	0.637	0.455	0.575	5.388
Holland Twp	0.552	0.460	0.427	0.354	0.046	0.455	0.484	0.560	0.501	0.249	0.582	0.604	5.273
Bloomsbury Boro	0.353	0.154	0.044	0.000	0.000	0.955	0.925	0.446	0.696	0.048	0.483	0.972	5.077
High Bridge Boro	0.415	0.137	0.362	0.696	0.055	0.444	0.237	0.202	0.302	0.550	0.569	0.961	4.929
Clinton Twp	0.527	0.361	0.384	0.273	0.084	0.539	0.383	0.373	0.417	0.332	0.542	0.461	4.675
Readington Twp	0.396	0.503	0.290	0.242	0.040	0.426	0.495	0.543	0.272	0.727	0.416	0.263	4.612
Hampton Boro	0.517	0.218	0.204	0.569	0.118	0.682	0.299	0.254	0.162	0.221	0.553	0.899	4.697
Frenchtown Boro	0.432	0.243	0.334	0.461	0.290	0.602	0.197	0.485	0.057	0.136	0.458	0.990	4.684
Milford Boro	0.453	0.181	0.481	0.603	0.000	0.526	0.313	0.324	0.058	0.010	0.662	0.994	4.605
Raritan Twp	0.432	0.379	0.304	0.211	0.040	0.513	0.346	0.329	0.619	0.505	0.456	0.323	4.455
Stockton Boro	0.481	0.120	0.334	0.186	0.000	0.304	0.725	0.322	0.000	0.726	0.380	0.967	4.545
Califon Boro	0.444	0.242	0.174	0.356	0.052	0.388	0.127	0.266	0.037	0.530	0.500	0.976	4.091
Clinton Town	0.307	0.180	0.232	0.000	0.000	0.477	0.233	0.008	0.665	0.156	0.389	0.790	3.437
Lambertville City	0.278	0.198	0.232	0.038	0.000	0.457	0.182	0.023	0.372	0.241	0.308	0.587	2.916
GlenGardner Boro	0.141	0.093	0.136	0.679	0.004	0.252	0.194	0.269	0.020	0.480	0.151	0.395	2.815
Flemington Boro	0.352	0.069	0.040	0.000	0.000	0.423	0.057	0.010	0.321	0.225	0.517	0.690	2.703
Lebanon Boro	0.264	0.036	0.026	0.000	0.000	0.341	0.072	0.279	0.000	0.543	0.301	0.752	2.614

Cluster Analysis – Distinguishing the Families of Sprawl

The metasprawl index presented in the previous section provides an interesting single-value characterization of sprawl. It produces a single measure that generalizes in distinguishing the overall more sprawling from the less sprawling municipalities. Yet a metasprawl index is of limited value. In a number of ways the metasprawl index is an over simplified descriptor potentially concealing the most important nuances between different types of sprawl that may occur. In order to tease out these potentially different variations of sprawl, a cluster analysis was performed on the municipal GIUS values to categorize the data into discrete categories or “families” of sprawl at a municipal level. A hierarchical method of clustering was chosen to perform on the GIUS data because unlike partitioning algorithms, hierarchical algorithms produce a hierarchal structure displaying the order in which groups are merged or divided. An agglomerative hierarchical algorithm of cluster analysis begins with the entire data set as individual elements and combines statistically similar elements together into clusters by their statistical distance. The iterative processes proceeds in a successive manner combining all elements into clusters and eventually all clusters into one single cluster containing the whole dataset (Kaufman and Rousseeuw 1990). This *agglomerative* approach to hierarchal clustering contrasts with divisive approaches that begin with the entire set and divide until each observation is in a separate group (S-Plus 2000).

Cluster Results

An agglomerative hierarchical cluster analysis was performed on the municipal GIUS data set using a Euclidean dissimilarity measure to standardize the measures. Figure 4-15 depicts the resulting dendrogram of the clustering algorithm. The analysis revealed four distinct categories of sprawl at the municipal level. In order to convey a interpretive meaning for the cluster groups

I have provided a descriptive nickname in the following manner: 1) *Smart Towns*, 2) *Sensible Small Cities*, 3) *Ubiquitous Countryside Fragmentors*, and 4) *Explosive Rural Subdividers*. Each cluster group or “family” of sprawl has a different GIUS signature reflecting a different spatial pattern and thus a different underlying process of urban growth. Table 4-6 lists the cluster ember municipalities while Figure 4-16 maps the cluster allocation.

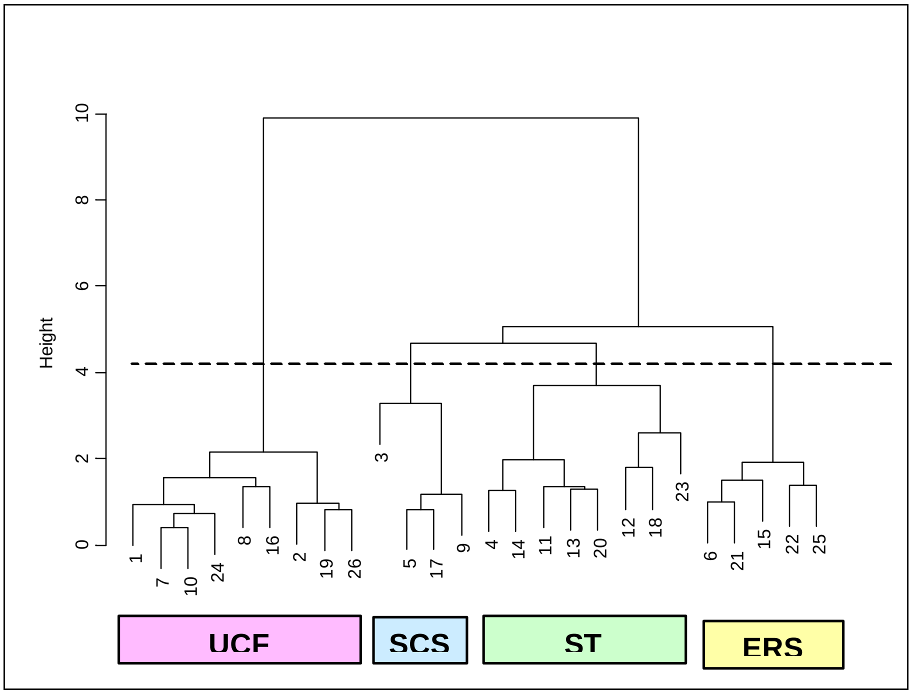


Figure 4-15 Dendrogram of Cluster Analysis

Table 4-6 Cluster Membership

	cluster	Label	Municipality
0.15	1	*Smart Town*	LEBANON BORO
0.17	1	*Smart Town*	GLEN GARDNER BORO
0.34	1	*Smart Town*	CALIFON BORO
0.39	1	*Smart Town*	STOCKTON BORO
0.40	1	*Smart Town*	MILFORD BORO
0.41	1	*Smart Town*	FRENCHTOWN BORO
0.42	1	*Smart Town*	HAMPTON BORO
0.44	1	*Smart Town*	HIGH BRIDGE BORO
0.16	2	*Sensible Small City*	FLEMINGTON BORO
0.18	2	*Sensible Small City*	LAMBERTVILLE CITY
0.25	2	*Sensible Small City*	CLINTON TOWN
0.46	2	*Sensible Small City*	BLOOMSBURY BORO
0.87	3	*Ubiquitous Countryside Fragmentor*	EAST AMWELL TWP
0.80	3	*Ubiquitous Countryside Fragmentor*	ALEXANDRIA TWP
0.77	3	*Ubiquitous Countryside Fragmentor*	FRANKLIN TWP
0.76	3	*Ubiquitous Countryside Fragmentor*	DELAWARE TWP
0.74	3	*Ubiquitous Countryside Fragmentor*	BETHLEHEM TWP
0.74	3	*Ubiquitous Countryside Fragmentor*	KINGWOOD TWP
0.73	3	*Ubiquitous Countryside Fragmentor*	TEWKSBURY TWP
0.63	3	*Ubiquitous Countryside Fragmentor*	WEST AMWELL TWP
0.61	3	*Ubiquitous Countryside Fragmentor*	LEBANON TWP
0.39	4	*Explosive Rural Subdivider*	RARITAN TWP
0.42	4	*Explosive Rural Subdivider*	READINGTON TWP
0.43	4	*Explosive Rural Subdivider*	CLINTON TWP
0.51	4	*Explosive Rural Subdivider*	HOLLAND TWP
0.53	4	*Explosive Rural Subdivider*	UNION TWP

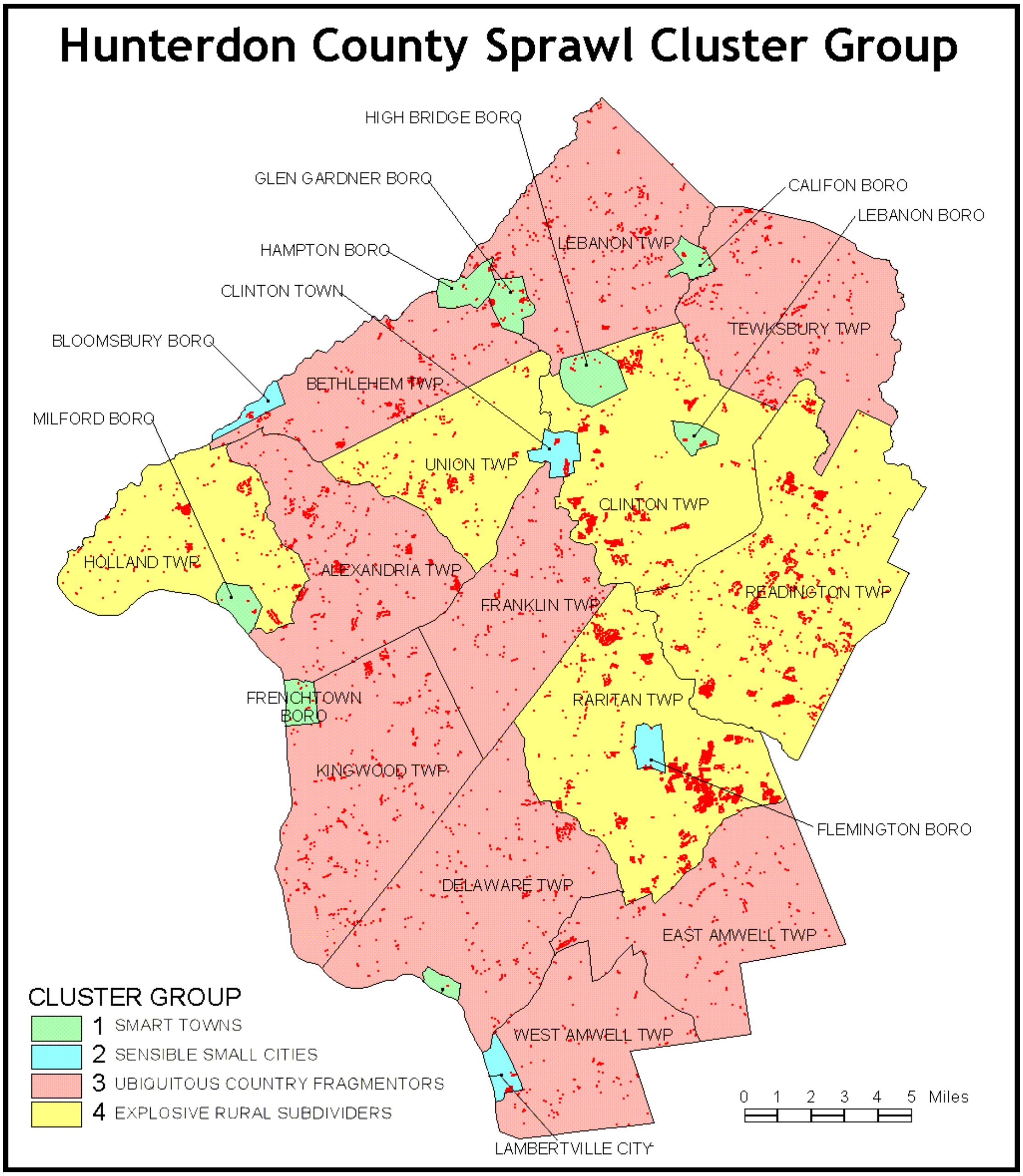


***Figure 4-16 Municipal Cluster Grouping Map**. Red patches depict the actual pattern of new residential development from which the cluster group GIUS summaries were calculated.*

Summarization of the housing unit GIUS values by cluster grouping (Table 4-7) provides insight into the different spatial characteristics of growth occurring in the different cluster member municipalities. Figure 4-17 depicts a graph of the cluster GIUS values normalized by average percentile rank to facilitate cross-index comparison. Together these data provide a means to profile the different spatial characteristics of sprawl inherent in different types of municipalities.

TABLE 4-7 Average GIUS Measures by Cluster Membership 1= Smart Town*; 2=* Sensible Small Cities*;*
3= Ubiquitous Country Fragmentors; and 4 = Explosive Rural Subdividers.

CLUST ID	*HOUSING UNITS*	UD_{mun}	LF_{mun}	SL_{mun}	RPI_{mun}	HS_{mun}	RI_{mun}	TI_{mun}	CNI_{mun}	LR_{mun}	OSE_{mun}	IS_{mun}	GT_{mun}
1 ST	*396*	*0.245*	*228*	*3.4*	*4.4*	*0.0227*	*48*	*1898*	*9212*	*0.033*	*0.424*	*0.067*	*69.6*
2 SSC	*220*	*0.216*	*234*	*3.9*	*1.1*	*0.0000*	*84*	*3691*	*4518*	*0.239*	*0.174*	*0.084*	*27.3*
3 UCF	*2646*	*1.272*	*4238*	*6.2*	*5.5*	*0.0850*	*115*	*17515*	*17895*	*0.538*	*0.852*	*0.150*	*207.7*
4 ERS	*6077*	*0.705*	*1260*	*4.7*	*2.6*	*0.0505*	*88*	*7886*	*12066*	*0.392*	*1.022*	*0.117*	*142.3*

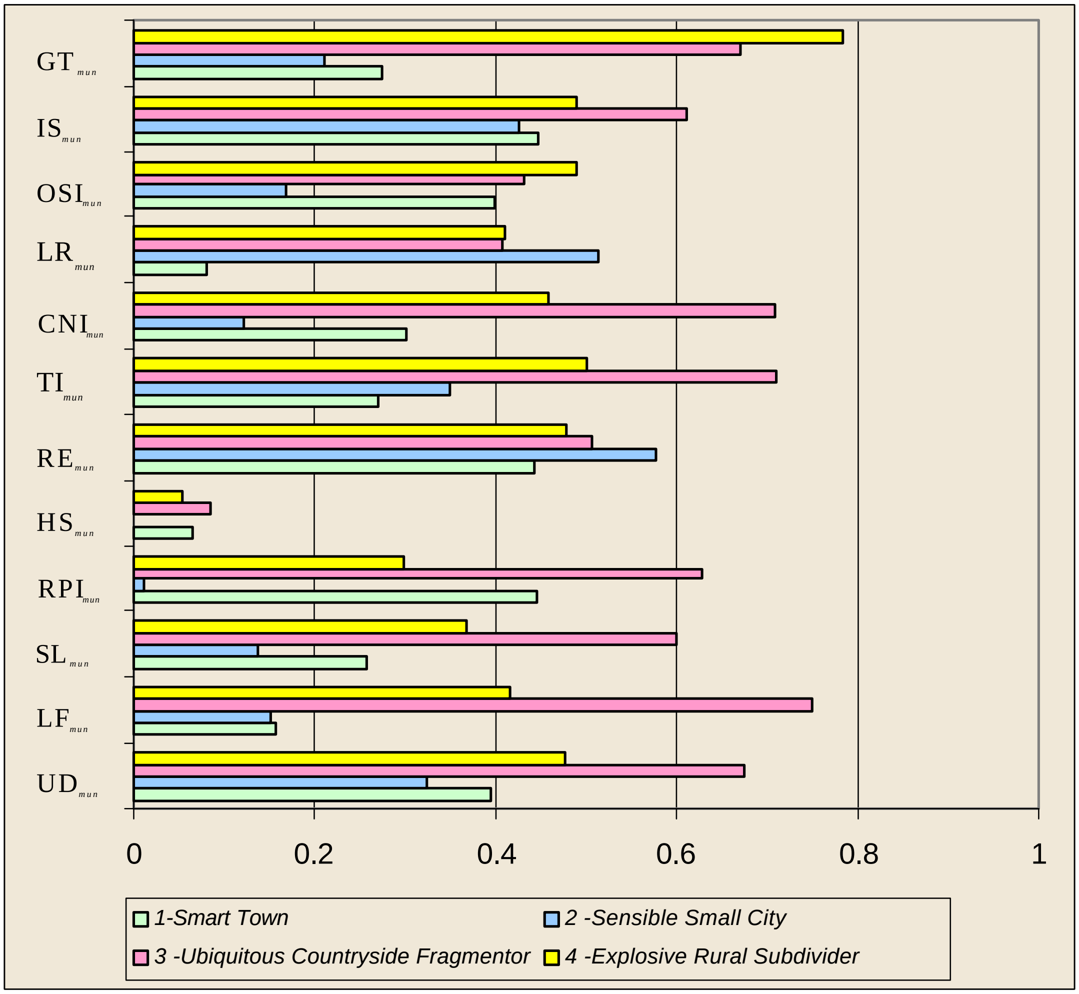


Figure 4-17 Average Percentile Rank Comparison Summarized by Cluster Group

Cluster Discussion

1) Smart Towns (ST) - epitomize the least sprawling municipalities in Hunterdon County. There are no large townships in the ST sprawl family. ST are made up of boroughs, which are generally small municipalities that began as villages and towns early in New Jersey's history. Growth in *Smart Towns* during the period of analysis on average used less land (0.245 acres per unit), provided better accessibility to community centers, low leapfrog distance values (228 feet) and substantial mix of land use with a segregated land use index of 3.4. Smart Town's are originally compact communities that have continued to develop in a compact pattern of growth during the study period.

2) Small Sensible Cities (SSC's) - consist of several of Hunterdon County's larger incorporated towns. The growth that occurred in these municipalities exhibited some of the least sprawling characteristics of residential growth in the county. Urban density was 0.216 acres per unit. The *regional planning incongruency* index was lowest of the cluster families indicating that the development largely occurred in accordance with the state plan. *Community node inaccessibility* distances are also the lowest for this family of sprawl indicating a more efficient pattern of transportation generated by the residents in these towns in comparison with the rest of the county. Nearly all residential units build in the SSC municipalities were serviced by public sewer allowing for a higher density development pattern.

3) The Ubiquitous Countryside Fragmenters (UCF) - are the most common GUIS municipal type in Hunterdon County representing 9 of the 26 municipalities. UCF municipalities are all large historically rural townships averaging 18,371 acres in extent and occupying 59% of the county territory. New residential growth is spreading haphazardly throughout the countryside at a low average density of 1.272 acres per unit. There is little pattern to the growth in UCF municipalities as the growth consists largely of individual home sites and to a lesser degree moderate disjointed smaller subdivisions on private septic systems. Leapfrog distances averaging 4,238 feet, and public transit and community node inaccessibility distances of 17,515 and 17,895 respectively make UCF municipalities the most spread out Hunterdon County communities. While the rural appearance of UCF municipalities where new housing units are many times tucked away in hidden corners may contradict the public perception of sprawl, high per capita land consumption as well as high land resource consumption and growth trajectory reveals the low efficiency and high impact of the growth in these municipalities.

4) *Explosive Rural Subdividers* (ERS) - are rapidly growing large municipalities situated along Hunterdon County's central growth corridor which follows interstate 78 east to west. While the sheer magnitude of growth in these towns accounts for the majority of the county's gross development, the pattern of growth imparted is less impacting on a per unit basis than the previous UCF category of municipal sprawl. ERS municipalities grew more compactly and with lower leapfrog measures than UCF municipalities. Land resource impact was also less although higher on a gross basis due to the sheer magnitude of growth. Accessibility to public transportation is reasonable in ERS municipalities when compared with others in the county but ERS perform poorly in the mixed land use measure.

The Dysfunctional Families of Sprawl

If the analogy can be made to sprawl as dysfunctional urban growth then the Ubiquitous Country Fragmentors and Explosive Rural Sudividers are the municipal dysfunctional families of sprawl. The most dysfunctional types of growth occurred in the UCF municipalities which imparted significantly greater impacts to the landscape on a proportional basis than the other municipalities (Table 4-7). While the 2,646 units of new residential that occurred in UCF municipalities represents only 28.3 % of total new housing, it was responsible for 43.2% of land consumption, 39.6% of prime farmland loss, 47.3% of the wetlands loss, 34.3 % of the new impervious surface created and 37,8% of the total estimated vehicle miles traveled by the new residents. The impact in travel accessibility and loss of land resources and fragmentation of farmland and habitat makes the UCF municipalities the most dysfunctional type of growth on a per capita basis albeit the overall magnitude of growth is less than other more rapidly-growing municipalities.

The five municipalities that make up the *Explosive Rural Subdividers* were responsible for the lions share (65.1%) of the residential growth (i.e. new housing units) that occurred in the county during the study period. ERS municipalities were less dysfunctional on a per unit landscape impact basis than UCF municipalities as the landscape impacts were more proportional to the percentage of growth that occurred. While the explosive nature of growth within the ERS municipalities carries many other problematic implications such as traffic and school over crowding, the impacts imparted to the landscape were less consumptive on a per housing unit basis than the UCF municipalities. However, the ERS municipalities grew significantly less efficiently than the *Smart Towns* and *Small Sensible Cities*.

Smart Towns and *Small Sensible Cities* are the model families of “smart” growth in Hunterdon County during the study period. While combined they only accounted for 6.6% of new residential units built, they imparted a proportionately smaller impact to the landscape consuming only 1.9% of the developed land, 2.1% of the prime farmland loss, and 3.9% of the new impervious surface created. Smart Towns and Sensible Small Cities maintained moderate growth, retained their efficient pattern of land use and were largely in line with the goals and objectives of the New Jersey state plan. Smart Towns and Small Sensible Cites are model municipal families for smart growth.

***Table 4-7 Cluster Group Impact Measures**. 1*= Smart Town*; 2*= Sensible Small Cities*;*
3= Ubiquitous Country Fragmentors; and 4 = Explosive Rural Subdividers.

CLUSTER	*Housing Units*	*% of New Housing*	*% of Acres Developed*	*% of Prime Farm Loss*	*% of Wetlands Loss*	*% o Heritage Lands Loss*	*% of Impervious Surface Created*	*% of New Road Miles Created*	*% of Est Vehicle Miles Traveled*
1 ST	*396*	*4.24%*	*1.24%*	*0.55%*	*0.46%*	*0.02%*	*2.31%*	*0.78%*	*2.91%*
2 SSC	*220*	*2.36%*	*0.61%*	*1.54%*	*6.79%*	*0.01%*	*1.59%*	*0.85%*	*0.79%*
3 UCF	*2,646*	*28.33%*	*43.18%*	*39.64%*	*47.25%*	*30.56%*	*34.31%*	*48.36%*	*37.78%*
4 ERS	*6,077*	*65.07%*	*54.97%*	*58.28%*	*45.50%*	*69.42%*	*61.78%*	*50.01%*	*58.51%*

VI. Conclusion

Evident in the cross-municipal sprawl evaluation as well as the cluster analysis is the distinct difference between municipality types. New Jersey has 4 category of municipality 1) city, 2) town, 3) borough and 4) township. Cities, towns and boroughs are the older communities usually incorporated as settlements and initially settled in many cases in the 19th century or earlier. Townships on the other hand were traditionally unincorporated rural jurisdictions with originally sparse settlement patterns. However, more recently townships have become the hotbeds for suburban growth accounting for 93.4% of all new residential units built in Hunterdon County during the 1986 - 1995 study period. Much of the growth in townships exhibit elevated GIUS values compared to the boroughs indicating the propensity for townships to sprawl.

Size matters in municipal distinctions. The size of boroughs, cities and towns taken together in Hunterdon County is on average 800 acres whereas the average township is 17,800 acres in size. Population growth is marginal and in some cases negative in Hunterdon cities, towns and boroughs averaging 6.2% as a group between 1986 and 1995 versus an average 13.7% population growth for the townships. Average urban land growth for the same years was 8.4% for towns, cities and boroughs versus 30.4% for townships. Clearly, if growth of low urban density were solely used as a sprawl indicator, townships are epitomizing low-density urban growth.

However, the GIUS measures provide a more sophisticated analysis of the growth that occurred during the time period. Care must be taken to ensure that the measures are not tautological. In other words larger municipalities may be defined as sprawling simply because they are large municipalities and have more available space to grow therefore the growth is more spread out which appears as more sprawling in the GIUS analysis. While this critique is valid for the *leapfrog* and *community inaccessibility* indices, it is not an issue for other significant sprawl indicators such as *density*, *land resource consumption*, and *segregated land use*. These characteristics of sprawling growth and their smart growth alternatives can occur just as readily in a large municipal townships as in small municipal boroughs. Calculating a number of the GIUS measures on a per unit basis also has the benefit of normalizing out the differences in municipal size.

What the GIUS analysis suggests is that there are other political and geographical factors that result in different manifestations of growth at the municipal level. Possible explanations for different expressions of sprawl revealed by the GIUS cluster analysis may include aspects such as the difference in municipal self image of townships versus boroughs which may lead to significantly different attitudes and policies toward land development. Rural townships zone large lots such as 3 acre to ‘maintain the rural quality’ of their locale while a small town mentality may result in higher density zoning and encouragement of appropriate mixed use developments that maintain their civic town atmosphere. Other factors may include the influence of infrastructure such as sewers, highway accessibility, state and county planning policy, major versus minor subdivision process and simply the overall age and pattern of the previously existing urban structure.

The results provided by the municipal level GIUS analyses support the contention that the spectrum of different sprawling patterns of growth is indeed a combination of geography and policy. The GIUS measures may also be summarized by different spatial extents to capture other patterns & processes related to urban growth. The following chapters explore some of these geopolitical questions associated with sprawl first at a statewide level and then back again in Hunterdon County by summarizing the GIUS measure at other scales and spatial configuration.