CHAPTER 5 STATEWIDE GEOSPATIAL INDICES OF URBAN SPRAWL

I. Introduction:

Sprawl at a Statewide Scale

The patch-level GIUS measures developed in chapter 3 present a unique characterization for urban growth at the level at which it occurs – the development tract. In chapter 4, these patch-level measurements were scaled up to up to the municipality to explore the nuances between distinctly different trends of growth occurring from municipality to municipality within Hunterdon County. Some of the data that was utilized in the patch-level GIUS measures of chapter 3 and the municipal-level GIUS measures of chapter 4 such as parcel mapping and community node location is not universally available statewide. There are also different emphases of concern at a statewide level than at the local-level such as the state's responsibility for protection of important land resources. This chapter presents a statewide analysis of sprawl utilizing a GIUS approach but focuses solely on the impacts of sprawl on critical environmental resources. A variation of the Environmental Resource Impact GIUS indices (the last four of the twelve) is developed to identify New Jersey municipalities that were experiencing an excessive impact on land consumption, farmland loss, forest habitat loss, wetlands loss and impervious surface increase.

The complexity and magnitude of landscape change presents land managers and policy makers with a great need for simplifying and synthesizing land use/land cover change data to provide useful information. Within the environmental management literature, these simple metrics for analyzing, monitoring and communicating information about change are often known as *environmental indicators* (ERMS 2000; Jones and Simmers 2001). There has been a great push by the U.S. federal agencies to develop land cover data sets and indicators that are suitable for measuring and monitoring land cover and associated environmental change at broad regional scales (Jones et al., 1997; USEPA, 1998). However, there are fewer indicators that specifically focus on characterizing the magnitude and spatial patterns of urban growth and more specifically, urban sprawl.

II. State-level Indicators of Land Change in New Jersey

As in many other places throughout the nation and around the world, urban sprawl has become an important issue facing the state of New Jersey. Smack in the middle of the larger Boston-Washington megalopolis, New Jersey shows a bipolar distribution of population with dense urban centers adjacent to the New York City in the northeast and Philadelphia in the southwest (Figure 5-1a, b). Outside of this 'inner ring' of dense urban areas (both north and south) is an 'outer ring' of medium density suburban areas (e.g., population density of < approx. 5-14 people per hectare) that also spans the central neck of the state and extends along the Atlantic coast and low density rural or exurban areas (e.g., population density of < approx. 5 people per hectare) in the northwestern, central western, southwestern and Pinelands areas of the state. Examination of recent U.S. Census data reveals the classic symptoms of urban sprawl with stagnant population growth in these older 'inner ring' urban centers and moderate to high growth in the 'outer ring' suburbs, as well as hotspots of high growth in some exurban areas (Figure 5-1c).

a) location	*b) population density*	*c) population change*

Figure plate 5-1 New Jersey's land development pattern *is largely attributable to its location (a) between the Philadelphia and New York metropolitan areas. The highest densities of urbanization (b) occurs in the realms of these major metropolises. However, the majority of urban growth (c) is occurring in the rural suburbs while the inner-ring suburbs are stagnating and even loosing population.*

Even as the most densely populated state in the nation, New Jersey still has significant natural resource areas worthy of conservation and protection. In an effort to limit the negative consequences of poorly planned and implemented development, the New Jersey Office of State Planning has been developing a statewide management plan (NJOSP 2001). The state government has gone even further and supported the Sustainable State Project with the goal of achieving an efficient economy, a healthy environment and a just society to achieve a sustainable state for future generations (NJ Future 1999). In trying to move New Jersey towards a sustainable future, the first step was articulation of 11 goals ranging from promoting economic vitality, public health and social equity to efficient land use, and protecting ecological integrity and natural resources.

To gauge progress in achieving these goals, 41 different statewide indicators were selected ranging from income levels to high school graduation rates to beach closings to hectares of farmland lost (NJ Future 2000). Three statewide indicators adopted by the NJ sustainable state initiative deal directly with land use/cover change such as, hectares of freshwater wetland loss, farmland loss and amount of preserved vs. developed land; many others are associated with urban sprawl (e.g., vehicle miles traveled and air pollution). All of these indicators, however, are examined statewide and several could be enhanced through characterization at finer geographic scales. Similarly, since 1995, the New Jersey Department of Environmental Protection (NJDEP) has embraced a results-based management system that relies on indicators to ascertain progress toward environmental goals (Kaplan and McGeorge 2001). NJDEP employs a stressor-condition-response model of indicators which is coupled to adaptive management measures. Many of the NJDEP measures are statewide, yet where applicable, are stratified to finer watershed scales (NJDEP 2000, 2001).

Recognizing that human land use is one of the driving factors controlling water quality as well as related to aquifer recharge and baseflow to streams (i.e., water quantity), the NJDEP has included measures of land use change as environmental indicators to assess the degree to which the state is meeting its goals for land, natural resources, and water related key issue areas. For example, land use change data are being used to assess whether the state is meeting its milestone of a net increase in wetlands quantity or no net loss of forested land statewide, as well as, for each of the state's watershed management areas. Impervious surface cover is also used as an additional indicator of the intensity of urban/built-up land use due to its relationship to water quality (Kaplan and Ayers, 2000). However, only recently has the multi-temporal land use/land cover data set needed to calculate and map these indicators become available statewide, allowing the state to move from the conceptual development phase into implementation.

Statewide Land Resource Impact Indices of Urban Sprawl

In order to identify the relationship between statewide patterns of urbanization and its impact on the integrity of New Jersey's remaining land resources, the percent as well as per capita amount of urban growth and change for selected land resources were examined for each of New Jersey's 566 municipalities. The LRI indicators were developed for identifying the impact of new development on five specific critical land resources including: 1) efficiency of land utilization (i.e. density); 2) prime farmland; 3) forest core area; 4) natural wetlands; and 5) impervious surface.

The vector LU/LCC coverage was rasterized to facilitate spatial tabulations at both the statewide and municipal level. The grid cell size selected was 25 meters rendering a spatial resolution for the state of 10,783 rows by 5,680 columns. Municipal population estimates were calculated from 1980, 1990 and 2000 census counts (NJ SDC 2001) by linear interpolation for 1986 and 1995 to coincide with the dates of the LU/LCC dataset delineations.

***1) Density* -** Land is a limited resource, especially in a densely populated state such as New Jersey. Sprawl development is highly consumptive of land when compared to pre-sprawl-era urban patterns or more recent compact design trends proposed by "New Urbanists" (Duany Platter-Zyberk, 1991; Calthorpe, 1993; Nelessen, 1995). The density index provides a measure of land consumption for new urban growth.

Percent population change ($Pop\Delta_{pct}$) was calculated by comparing the difference in population between 1995 and 1986 over the population in 1986. The urban density LRI indicators were generated by tabulating area of all non-urban land use categories in 1986 that became urbanized by 1995 within each municipality. The percent growth metric (UG_{pct}) was calculated by normalizing the area of new growth by the total municipality area. The per capita metric (UG_{percap}) was calculated by normalizing the area of new growth by the concurrent change in population. Larger per capita consumption of land indicates a greater degree of sprawl.

$$UG_{pct} = \frac{A_{nu}}{A_{pu}}$$

and

$$UG_{percap} = \frac{A_{nu}}{Pop\Delta}$$

Where: UG_{pct} = percent urban growth LRI

UG_{percap} = per capita urban growth LRI

A_{nu} = area of new urban growth within unit of analysis

A_{pu} = area of pervious urban extent within unit of analysis

$Pop\Delta$ = population change within unit of analysis

2) Farmland Loss – Agriculture is a major activity in the Garden State. When all farming and food related activity is considered, agriculture is the third largest segment of the New Jersey economy contributing $56 billion (NJDA 2001). However, soaring land values and operating costs coupled with multiple conflicts stemming from the incompatibility of farming adjacent to new residential areas make it difficult to farm successfully in New Jersey (Adelaja and Schilling 1999). Of particular concern for the long-term competitiveness and sustainability of agriculture is the loss of the prime farmlands. These are agricultural areas endowed with Class I and Class II prime soils which are suited for long-term agricultural viability.

The prime farmland loss LRI indicators quantify the amount of prime farmland loss to urban growth. The indicators were developed by first creating a map of prime farm soils from NRCS SSURGO digital soils data utilizing the prime farm soils attribute of the map unit lookup table (NJ NRCS 2001). NJDEP soils datasets were utilized for several counties that have yet to complete SSURGO datasets. This statewide prime farm soils map was then intersected with the agricultural categories of the NJDEP LU/LCC dataset to produce a digital *prime farmland* map.

The prime farmland loss LRI indicators were generated by tabulating area of all prime farm land use categories in 1986 that became urbanized by 1995 for each unit of analysis, in this case municipalities. Percent prime farmland loss (PF_{pct}) was calculated by normalizing the area of prime farmland that converted to urban land by the starting area of prime farmland (as of 1986). The per capita metric (PF_{percap}) was generated by normalizing the amount of prime farmland loss by the concurrent increase in population. Larger per capita prime farmland loss values indicate a greater degree of sprawl.

$$PF_{pct} = \frac{A_{pfl}}{A_{ppf}}$$

And

$$PF_{percap} = \frac{A_{pfl}}{Pop\Delta}$$

Where: PF_{pct} = percent prime farm loss LRI

PF_{percap} = per capita prime farm loss LRI

A_{pfl} = area of prime farm loss within unit of analysis

A_{ppf} = area of previous prime farmland within unit of analysis

$Pop\Delta$ = population change within unit of analysis

3) Forest Core Habitat Loss – Forest habitat loss is of concern throughout the state but particularly in the ecologically sensitive Pine Barrens and the Highlands (Niles and Valent, 1999). Dispersed sprawling development both removes forest habitats and fragments the remaining forest areas into smaller pieces. While the loss of all forests is significant, the loss of interior or core forest area has significant implications for wildlife habitat sustainability and forest land management. Despite their inherent natural resource values, core forest areas are not specifically protected by any state regulation.

Forest core areas were generated for 1986 by extracting all mature upland and wetland forest land use/land cover categories from the NJDEP dataset while excluding the transitional wooded categories (e.g., scrub/shrub). The 1986 mature forested land use patches were then buffered 100 meters interior from the periphery of all human altered land use classes including all urban, all agriculture and several human-altered barren classes. The forest core loss was generated by intersecting the 1986 forest core map with a 100 meter buffer from all new 1995 urban growth. The percent forest core loss LRI indicator (FC_{pct}) was generated by normalizing the area of forest core loss by the area of previous forest core for each unit of analysis (i.e. the amount of forest core in 1986). Per capita forest core loss (FC_{percap}) was generated by normalizing the area of forest core loss by the population increase for each unit of analysis.

$$FC_{pct} = \frac{A_{fcl}}{A_{pfc}}$$

and

$$FC_{percap} = \frac{A_{fcl}}{Pop\Delta}$$

Where: FC_{pct} = percent forest core loss LRI

FC_{percap} = per capita forest core loss LRI

A_{fcl} = area of forest core loss within unit of analysis

A_{pfc} = area of pervious forest core within unit of analysis

$Pop\Delta$ = population change within unit of analysis

4) Natural Wetlands Loss – Once thought of as swampland or wasteland, wetlands have become recognized as critical for the ecological and hydrological health of a landscape. Loss of wetlands has implications for water quality/quantity and wildlife habitat. The wetlands LRI indicators were developed by extracting the wetlands categories from the dataset (i.e. 6000 level) that had converted to urban land uses. Only comparatively un- or minimally altered wetlands (i.e., excluding agricultural, urban or disturbed wetlands or wetlands rights-of-ways) were used in the analysis. The percent wetlands loss value (WL_{pct}) was generated by normalizing the area of wetlands that became urbanized by the original area of wetlands (as of 1986). The per capita wetlands LRI indicator (WL_{percap}) was generated by normalizing the area of wetlands lost to urbanization by the population growth within the unit area of analysis. Greater loss of wetlands per capita indicates a more sprawling development pattern under this measure.

$$WL_{pct} = \frac{A_{wll}}{A_{pwl}}$$

And

$$WL_{percap} = \frac{A_{wll}}{Pop\Delta}$$

Where: WL_{pct} = percent wetlands loss LRI

WL_{percap} = per capita wetlands loss LRI

A_{wll} = area of wetlands loss within unit of analysis

A_{pwl} = area of pervious wetlands within unit of analysis

$Pop\Delta$ = population change within unit of analysis

Impervious Surface Increase – Impervious surface is becoming an important indicator of water quality degradation within a watershed (Arnold and Gibbons 1997). Impervious surfaces created by parking lots, road ways and building footprints prevent ground water infiltration, increase stream surges and channel non point source pollution directly into water bodies. Estimates of impervious surface are included for each land use polygon in the NJ LU/LCC data set and were summarized for areas of new urban growth within the unit area of analysis. The percent impervious surface increase metric (IS_{pct}) was generated by normalizing the area of impervious surface estimated for new development by the impervious surface estimated for previously existing urban areas. The per capita impervious surface metric (IS_{percap}) was tabulated by normalizing the estimated area of new impervious surface by the population growth within the unit area of analysis. Higher per capita amounts of newly created impervious surface are considered more sprawling under this measure.

$$IS_{pct} = \frac{A_{nis}}{A_{pis}}$$

And

$$IS_{percap} = \frac{A_{nis}}{Pop\Delta}$$

Where: IS_{pct} = percent impervious surface increase LRI

IS_{percap} = per capita impervious surface increase LRI

A_{nis} = area of new impervious surface within unit of analysis

A_{pis} = area of pervious impervious within unit of analysis

$Pop\Delta$ = population change within unit of analysis

III. Results

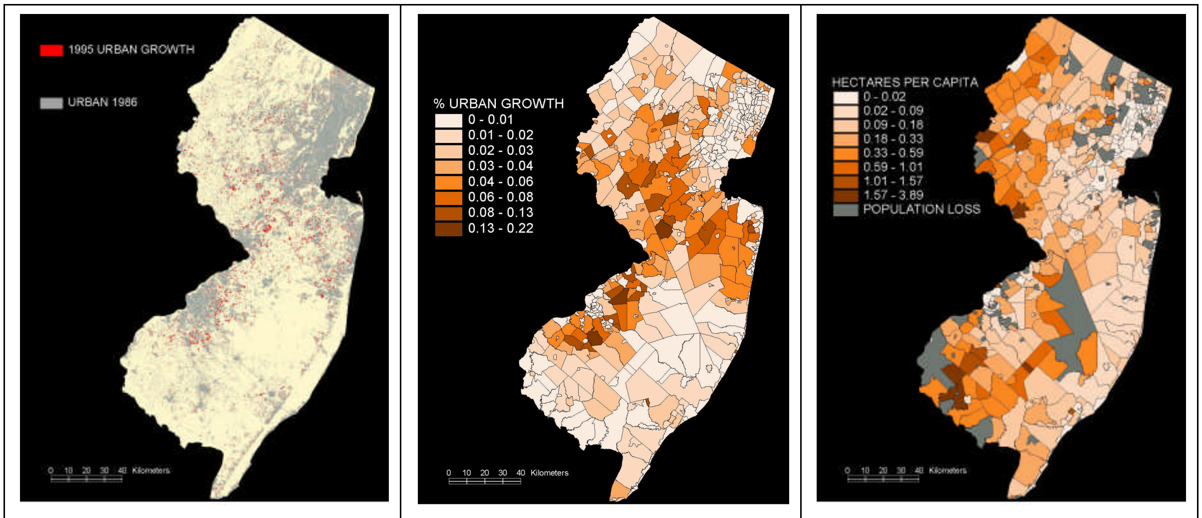
While the LRIs are designed to gauge land resource impacts against population growth, a significant number of municipalities actually lost population during the period of analysis requiring separate treatment in the analysis (Figure 5-1c). Population losers fell into two camps. Most were older urban and inner-ring suburban communities experiencing out-migration of populations to the growing outer-ring suburbs. Although urban and suburban decay are intimately connected to issues surrounding suburban sprawl, these communities are for the most part already built-out and therefore do not incur major additional impacts to land resources. However, a number of rural municipalities also lost population but actually developed significant tracts of new land. These municipalities exemplify shifting internal urban land use patterns and suggest problematic sprawling conditions where older urban centers in these rural towns are abandoned for new housing in the periphery. The population losing municipalities were removed from the per capita land use change analysis due to the nonsensical nature of the resulting metric value (i.e. negative value).

Table 5-1 provides summary statistics for the LRI values by municipality for localities that experienced population growth. Upon examination of municipalities that increased in population in New Jersey between 1986 and 1995, we find that on average for each additional new resident: 0.23 hectares of land was consumed; 0.05 hectares of prime farmland, 0.10 hectares of forest core habitat and 0.02 hectares of natural wetlands were lost; and 0.05 hectares of impervious surface were created.

Table 5-1 - Summary Statistics for LRI indicators for municipalities that gained population.

	$Pop\Delta_{pct}$	UG_{pct}	PF_{pct}	FC_{pct}	WL_{pct}	IS_{pct}
Mean:	*12.2*	*13.0*	*9.4*	*11.7*	*3.1*	*11.2*
Median:	*8.1*	*8.8*	*2.4*	*5.8*	*1.0*	*7.9*
Max:	*70.7*	*78.6*	*100.0*	*100.0*	*100.0*	*70.4*
		UG_{percap}	PF_{percap}	FC_{percap}	WL_{percap}	IS_{percap}
Mean:		*0.232*	*0.053*	*0.103*	*0.014*	*0.052*
Median:		*0.109*	*0.004*	*0.020*	*0.005*	*0.030*
Max:		*3.823*	*1.769*	*3.000*	*0.646*	*1.183*

Urban growth during the period between 1986 and 1995 follows an S-shaped curve starting in the northern part of the state swinging west then east across the central neck of New Jersey and then south and west (Figure 5-2a). In southern New Jersey the pattern diverges around the Pinelands National Reserve with growth lining the Atlantic coastal region and in an arc fringing the Philadelphia-Camden suburbs. Whereas the % urban growth map (Figure 5-2b) shows how extensive growth is across the state with a large number of municipalities experiencing significant growth rates (e.g., > 6% increases in urban area). The per capita urban growth map (Figure 5-2c) highlights the urban growth that has occurred in the more exurban areas of the state. It is in these relatively rural municipalities that large lot development is rapidly consuming large land areas. Areas of negative population growth (shown as gray in Figure 5-3c) are shown centered around the inner ring of New York City suburbs in northeast NJ, the older urban centers along the southern Delaware River valley (e.g., Camden and Salem areas) and the south central Pinelands region which is home to Fort Dix Military Reservation and McGuire Air Force Base.

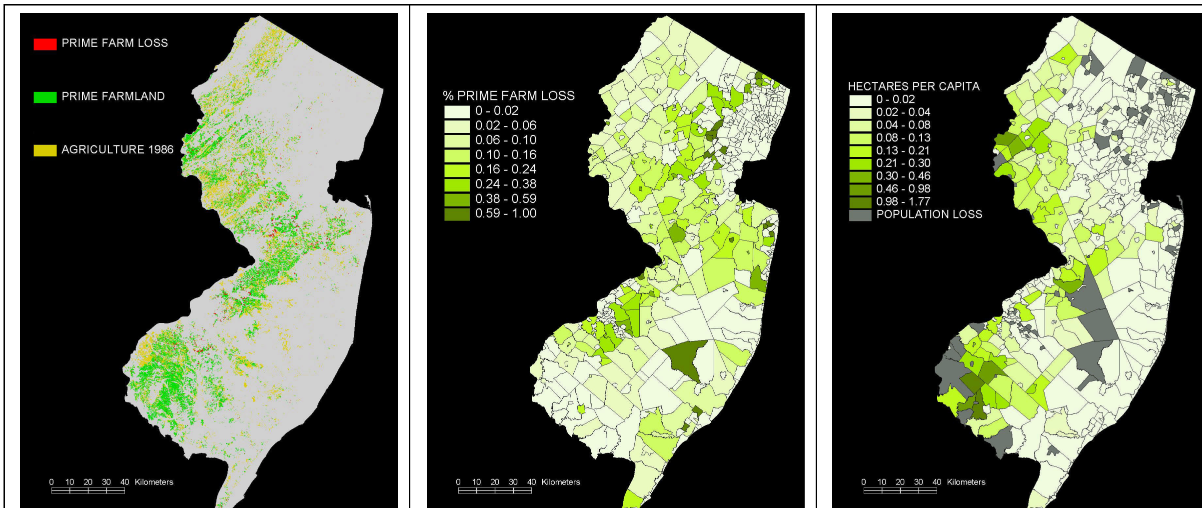


(a) 1986 –1995 urban growth	*(b) percent urban growth*	*(c) per capita urban growth (density)*

Figure plate 5-2 Statewide patterns of urban growth.

During the 1986 to 1995 study period, 23,314 hectares of farmland were lost directly to new urban growth. What is perhaps more significant is the loss of prime farmland (Figure 5-4a). While prime farmland accounted for 53% of all farmland under the plow in 1986, it accounted for 60% of the development that occurred on farmland. This loss suggests that prime farmland is more vulnerable to urbanization than non-prime farmland. The % prime farmland loss indicator shows the greatest hotspots of farm loss were in those municipalities adjacent to the urban cores of northeast, central and southwest New Jersey (Figure 5-4b).

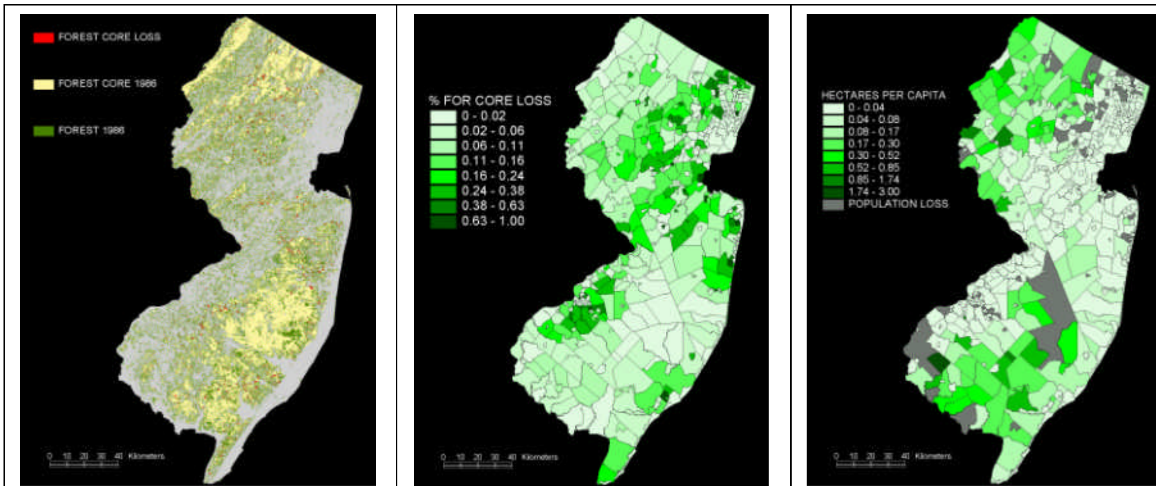
While the absolute magnitude were not necessarily the largest, these municipalities lost high percentages of their existing available prime farmland (using the amount of prime farmland in 1986 in each municipality as the basis). In comparison, the per capita farmland loss shows a dramatically different pattern with the highest values occurring in what have been largely rural farming areas of northwestern and southwestern New Jersey. The % prime farm loss indicator shows where farming is on its last legs by highlighting areas where the last remaining prime farmland is being lost. The per capita indicator shows prime farmland loss from a different perspective by highlighting those communities where farmland is being consumed at a comparatively high per capita rate.



(a) prime farmland loss	*(b) percent prime farmland loss*	*(c) per capita prime farmland loss*

Figure Plate 5-3 Statewide prime farmland loss.

The largest single type of landscape change that occurred to development growth in New Jersey over the last decade was the urbanization of forested lands. A total of 27,158 hectares of forested land were converted to urban land uses during the nine-year period of analysis. The % forest core indicator map shows a pattern similar to that of the % prime farmland loss with the hotspots of loss centered around the outer ring of northeast, central and southwest suburbs but also additional hotspots along the Atlantic coastal plain. The per capita indicator highlights the greatest losses in the still largely forested regions of northern and southern New Jersey.



(a) forest core loss	*(b) percent forest core loss*	*(c) per capita forest core loss*

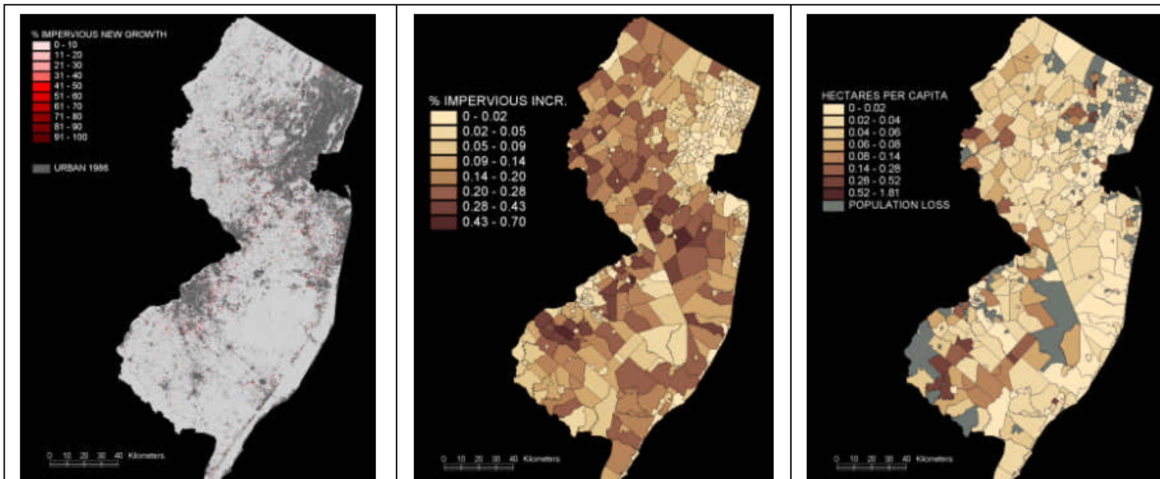
Figure Plate 5-4 Patterns of forest core loss to urbanization.

Whereas the statewide analysis reported changes in total wetlands, the LRI focuses more specifically on unaltered wetlands. A total of 10,433 hectares of unaltered wetlands were lost from 1986 to 1995, generally in small patches (Figure 5-5a). The % wetland loss map shows the greatest % losses of the remaining stock of undisturbed wetlands occurred in the urban and more densely settled suburban municipalities where wetlands often represents the last remaining areas of undeveloped land. The per capita wetlands loss map (Figure 5-5c) shows a more scattered pattern with the highest values found in some of the more established but still expanding suburban areas in central NJ as well as more rural areas that are on the outer fringes of expanding suburban development in both southern and northern NJ.

(a) wetlands loss	*(b) percent wetlands loss*	*(c) per capita wetlands loss*

Figure plate 5-5 statewide wetlands loss.

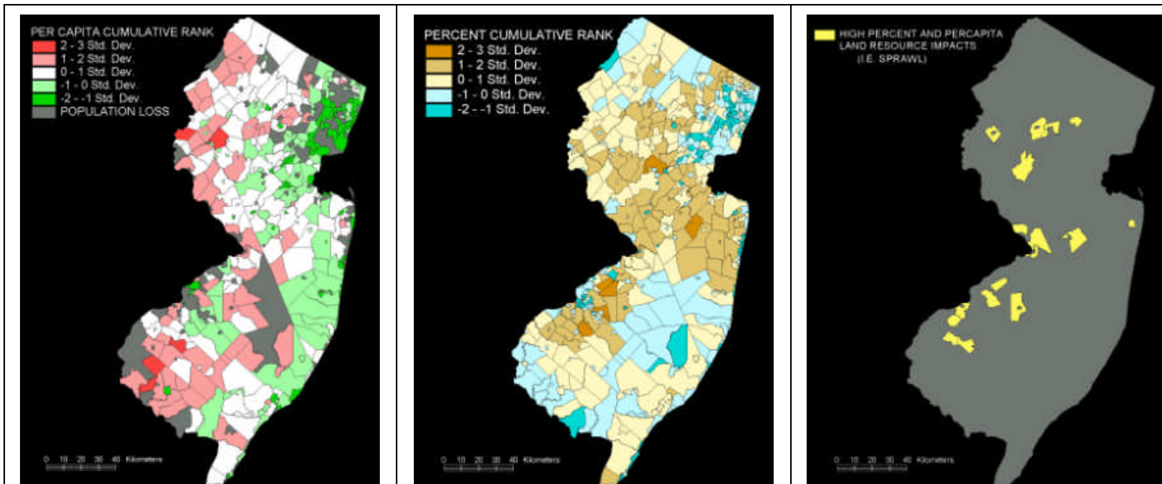
As expected the impervious surface increase map (Figure 5-6a) closely matches the spatial pattern of the urban growth map (Figure 5-3a). Impervious surface has increased in a comparatively consistent basis across the state with the exception of the already “built-out” urban core and a handful of rural municipalities (Figure 5-6b). Per capita impervious surface increase (Figure 5-6c) shows a more localized pattern highlighting a comparatively small number of municipalities as being hotspots of large per capita impervious surface gains.



(a) impervious surface increase	*(b) percent impervious surface increase*	*(c) per capita impervious surface increase*

Figure Plate 5-6 Statewide patterns of impervious surface increase

The individual LRI indicators provide useful metrics for focusing in on individual resource impacts. To locate more problematic overall trends of land resource impacts attributable to sprawling urban growth, the 5 LRI indicators were ranked by municipality and summed to provide a meta-LRI indicator. Figures 7a and 7b depict the percent cumulative rank and the per capita cumulative rank as standard deviations from the mean. The municipalities with a percent change meta-LRI above the mean were generally those in or directly adjacent to the more established 'outer ring' suburbs. While the municipalities with a per capita meta-LRI above the mean were generally those in the more rural exurban areas.



(a) Per capita cumulative rank in mean standard deviations. Red munis had greater than average cumulative per capita LRI and green munis had lower than average cumulative LRI's	*(b) Percent cumulative rank in mean standard deviations. Brown munis had greater percent cumulative LRI's and Blue munis had lower than mean cumulative LRI's.*	*(c) Municipalities with greater than +1 STDEV percent LRI's and +1 STDEV per capita LRI's. In other words towns which impacted a significant percentage of land resources in while housing relatively fewer new residents*

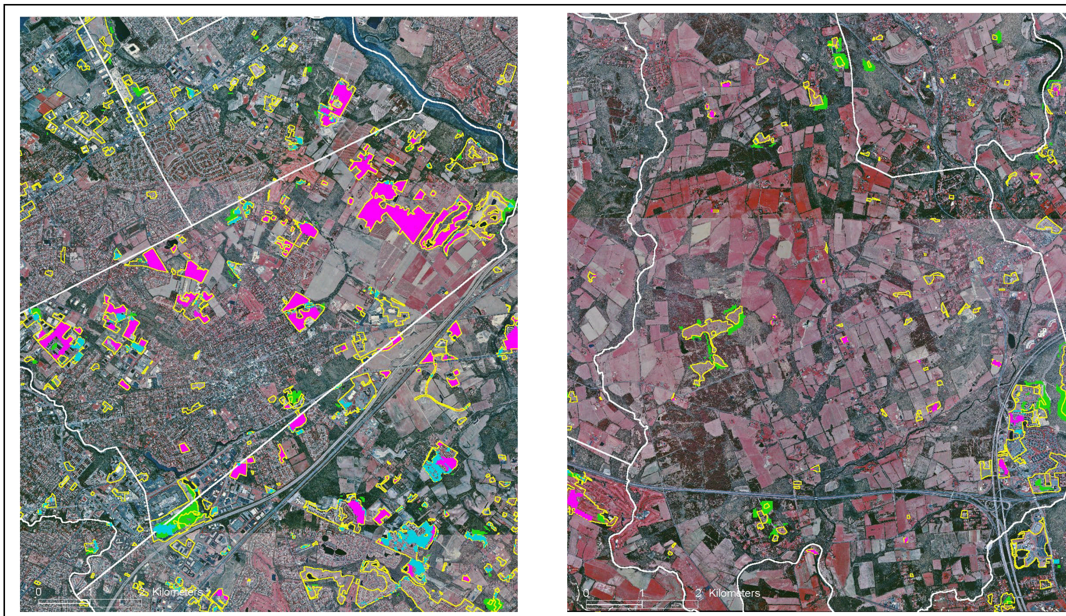
Figure plate 5-7 Identification of Municipalities with High Cumulative Land Resource Impacts

Combining the two meta-LRI indicators provides a means of identifying those municipalities that had a significant percentage LRI while also exhibiting a high impact on a per capita basis. Figure 5-7c highlights those municipalities that experienced above average percent impact as well as above average per capita impact. In other words, municipalities that incurred substantial degrees of impact to the land resource with comparatively fewer residents added to the population. It is our contention that it these municipalities exhibit the most wasteful patterns of urban growth (i.e. sprawl) regarding land resource impacts characteristics attributable to sprawling development.

Two municipalities were selected to illustrate application of the various indicators separately and combined for Moorestown, Burlington County and Bedminster Township, Somerset County (Table 5-2). Figure 5-8 displays these LRI indicators overlain on orthophotos of the municipalities to demonstrate contrasting development patterns and the subsequent land resource impacts. Moorestown (Figure 5-8a), exhibits a high percent and per capita impact to land resources denoting a sprawling development pattern. Bedminster Township, Somerset Township (Figure 5-8b), exhibited significantly lower LRI values while actually growing more than Moorestown in population. The spatial configuration of Moorestown's new development is more scattered and consumptive of land resources, especially prime farmland, whereas Bedminster's new growth occurred in several high-density clusters leaving agricultural regions largely intact. Clearly there are different geographical, political and economic processes steering development within these two communities. The LRI indicators provide an empirical approach for identifying, comparing and contrasting development patterns for further investigation of the underlying processes at play.

Table 5-2 - LRI indicators for two selected municipalities.

Moorestown Township, Burlington County					*Bedminster Township, Somerset County*			
	1986	*1995*	*pop*	*%*	*1986*	*1995*	*pop*	*%*
Population	*15,908*	*17,567*	*1,659*	*10.4*	*5,239*	*7,694*	*2,455*	*46.9*
LRI metrics								
	Hectares	*%*	*Per cap*		*Hectares*	*%*	*Per cap*	
New urban growth	*446.9*	*25.5*	*0.269*		*186.1*	*20.8*	*0.076*	
Prime farm loss	*239.9*	*23.7*	*0.145*		*12.5*	*1.0*	*0.005*	
Forest core loss	*27.2*	*27.1*	*0.017*		*76.2*	*12.3*	*0.031*	
Wetland loss	*30.1*	*7.0*	*0.018*		*1.4*	*0.4*	*0.000*	
Impervious Surface inc.	*106.6*	*18.7*	*0.064*		*59.0*	*23.6*	*0.024*	



(a) Moorestown, Township Burlington County *(b) Bedminster Township, Somerset County.*

Figure Plate 5-8 Orthophotos of selected municipalities *demonstrating contrasting LRI indicators for urban sprawl. Moorestown, Burlington Co. (left) exhibits a high percent and per capita impact to land resources denoting a sprawling land use pattern for new growth regarding land resource impacts. Bedminster Township, Somerset County, (right) exhibited significantly less LRI while growing substantially in population. Yellow outline delineates new urban growth, blue delineates wetlands loss, pink delineates prime farmland loss and green delineates forest core loss.*

IV. Discussion

The NJDEP LU/LCC data set provides a rich data set with which to examine the subtleties of New Jersey's dynamic landscape and the impact of sprawling urban growth. However, one can easily get lost in the complex dynamics and multiple transitions between numerous LU/LC categories; thus the need to clarify the picture through the use of comparatively simple indicators. The absolute and/or percent change measures provide indicators of the magnitude of change at both statewide and municipal scales. The NJDEP has adopted a series of LU/LCC measures as indicators of achievement towards statewide, and where applicable, individual watershed milestones of no net loss of forests and a net increase in the quantity and quality of wetlands (NJDEP 2000, 2001). As shown by our results of our statewide level analysis, New Jersey has yet to achieve these ambitious goals.

The suite of additional LU/LCC-based indicators, what we term Land Resource Impact (LRI) indicators, provide an alternative and more sophisticated means of quantifying the impact of spatial patterns of urban growth on these important land resources. Recognizing that not all urban growth has equivalent impact, our LRI indicators attempt to further restrict the possible set of land use/land cover changes and focus only on those aspects of urban growth that we consider especially significant in terms of their stresses on land and natural resources. For example, the Prime Farm LRI measures only the loss of farmland on the prime farm soils, the soils that are most critical to the long-term sustainability of agriculture in the state. Likewise, the Forest Core LRI attempts to focus efforts on the core or interior forest habitat, the habitat that is most critical to the long-term preservation of forest-dependent wildlife that are threatened or endangered within the state. While derived from the NJDEP LU/LCC data set, they require either additional GIS data sets (e.g., the prime farm soils coverage) or additional spatial analysis (e.g., edgebuffering to determine interior forests). This additional data or processing is not prohibitive and easily accomplished at a statewide scale, as we've demonstrated.

While sheer magnitude of new growth is often pointed to as sprawl, we propose that it is necessary to de-couple the amount of growth from the problematic or dysfunctional characteristics imparted by sprawling growth. In considering long-term sustainability of development, it is important to consider the efficiency of new development (i.e., hectares of new development in relation to number of people supported). Under this reasoning, sprawl is considered inefficient new urban growth, while more efficient land utilization is labeled Smart Growth. In an attempt to quantify this aspect of urban sprawl, we also calculated our five *LRI indicators* on a per capita basis. It is our contention that the straight % and the per capita measures provide complementary information with which to examine the spatial patterns of land use/land cover change. The percent change indicators measure the impact on the selected geographic unit's remaining land resources; while the per capita indicator provides a measure of land use efficiency of the new urban growth. In combination, the LRI indicators provide a means of identifying localities (e.g., municipalities) where the least efficient and most highly impacting forms of urban growth were occurring.

Whereas the absolute and percent measures of LU/LC change are comparatively straight forward to calculate and interpret, the per capita measures can be more problematic. One, the per capita measures rely on population census data that may not be concurrent in time or correspond to the same geographic units as the LU/LCC data. Certain assumptions are then necessary in order to bring the two data sets to a comparable framework. Two, negative population growth becomes difficult to handle. We did not attempt to further correct for negative population numbers but instead flagged those municipalities as population losers and did not calculate a per capita indicator value. Three, the per capita measures (as we have calculated them) do not explicitly account for commercial/industrial development separate from residential development. This distinction might be useful in examining the relative balance between these two types of development.

Finally this statewide level analysis illustrates that issues of scale are central to geospatial analysis of urbanization. This study examined the LU/LC change calculated by municipality to a statewide extent. Due to the sometimes arbitrary nature of municipal boundaries, somewhat different results would most likely be obtained had a different geographic unit been chosen on which to base the analysis (i.e. the modifiable area unit problem, Openshaw, 1984a). Other spatial units such as census tracts, zoning regions, counties, watersheds or even parcels could be easily utilized for analysis of land resource impacts at alternate scales so long as concurrent population data were available at the same unit of measurement. However, as there is a close correspondence between municipal units and New Jersey's locally-controlled land use decision-making system, a strong argument can be made for the appropriateness of municipalities as the geographic unit of choice. At all scales of analysis care must be exercised not to assume that all sub units of urban growth within the unit of analysis have the same value as the overall unit of analysis (Openshaw, 1984b). Substantial variation is likely to occur within the unit of analysis as is suggested by the rural municipalities that lost population but still developed significant areas of land. A parcel level analysis would be required to calculate a truly per capita ecological footprint rather than the municipal average as presented here. Nonetheless, municipal summaries provide a powerful means of identifying localities with overall wasteful or inefficient patterns of land development especially in localities with local land use control. Analysis of these data at the municipal level enables local decision-makers and citizens a window into what has been occurring in their communities over time.

V. Conclusion

The statewide GIUS analysis demonstrates that a geospatial approach to urbanization is useful at a broader scale than the site or town level albeit different constraints including data unavailability and processing limitations required a somewhat different approach on the state level than on the municipal level. Nonetheless the statewide analysis revealed patterns of land development inefficiency and environmental impacts to land resources that identify the most dysfunctional localities regarding overall patterns of development. The most significant difference between the two scales of analysis was the site-specific population data inferable from the parcel mapping of Hunterdon County which was not available statewide. Municipal-wide averages of the GIUS measures are not the exact equivalent of housing-unit summaries that are possible with digital parcel mapping. The statewide metrics provides a measure of overall average GIUS values for each municipality but does not provide an easy means of rescaling without running into the rescaling issues discussed in depth in chapter 4. The elegance of digital parcel mapping for GIUS measurements is that the parcel scale, in essence, atomizes the GIUS values so that they can be summarized by any geographic unit of analysis. The concluding chapter utilizes this rescaling advantage of parcel-based measures to explore the relationship of several socioeconomic variables to patterns of urban sprawl including development size, sewer service, the state plan and impervious surface.