LOOKING FOR THE RELATIONSHIP BETWEEN SPRAWL AND WATER QUALITY: A CASE STUDY OF GLOUCESTER COUNTY, NJ

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ABSTRACT: *It has been argued that sprawl (low density, dispersed and land-consumptive development) imposes greater consequences to the environment than Smart Growth development (compact, mixed-use, pedestrian friendly, etc). This analysis explores the relationship of sprawl/smart growth to one very widely used indicator of water quality, impervious surface. The research utilizes Gloucester County as a case study. The study first grades residential development in the county for the degree of sprawl utilizing a housing-unit population density sprawl metric. The analysis then evaluates impervious surface at the basin, watershed, and sub-watershed level. A correlation evaluation is then made between the residential density, population, and percentage amounts of impervious surface within each watershed extent. The results indicate that while sprawl development actually has less intense impervious surface coverage per acre due to its dispersed nature, the total impervious surface contributed by sprawl is substantially higher than contributed by smart growth when calculated on a per-capita basis. The study supports the contention that Smart Growth is locally more impacting to water quality at the site-level due to its compact nature but overall less impacting on the regional-level due to its smaller total footprint compared to low-density sprawling patterns of development.*

Keywords: *Impervious surface, Sprawl, Water quality, GIS*

INTRODUCTION

Rapid urbanization is occurring throughout many regions in the United States and the world. According to the U.S. Natural Resources Conservation Service (NRCS, 2006) Natural Resource Inventory, 35.2 million acres of developed land has been added to the United Sates over the last two decades, a land area roughly equivalent to the state of New York (34.9 million acres). The NRCS states that 2.9 million acres of developed land has been added to the U.S. between the years 2001 and 2003 alone. As land becomes urbanized there are implicit environmental impacts. One of the most significant environmental impacts is the creation of impervious surface and its relationship to development patterns.

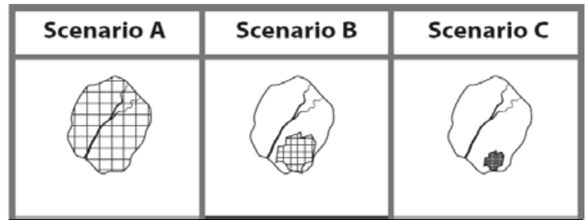
The relationship between water quality and urbanization is complex. Urbanization is not a single, homogenous phenomenon and water quality may be affected by numerous factors in addition to urbanization such as agricultural practices or environmental stresses. Different forms of urbanization have varying interactions with the hydrology of a region. Factors such as the intensity of development and vegetative cover are variable in different locations of a metropolitan region. One of the more challenging questions about this relationship is whether sprawl (dispersed, scattered, low-density development) impacts water quality more or less than compact development. This question is further complicated by the scale of analysis and the magnitude of residential population. In order to explore this relationship between water quality, impervious surface, and sprawl, this paper develops an empirical framework for examination of housing density patterns and impervious surface using several levels of watershed scale.

BACKGROUND

Impervious surface is human-created land cover that reduces or eliminates the capacity of the underlying soil to percolate water thus impeding the natural infiltration of precipitation into the ground. Not only does impervious surface impact water quality, but it can also alter the hydrologic cycle, change local energy balance, cause habitat degradation, fragmentation and loss, and change stream and landscape aesthetics (Barnes et al., 2001). One of the most significant impacts associated with impervious surface is nonpoint source pollution. According to the U.S. Environmental Protection Agency (USEPA, 1994), nonpoint source pollution is the number one cause of water quality impairment in the United States. This relationship of impervious surface to water quality relationship has resulted in impervious surface becoming one of the most significant environmental indicators in land and environmental management (Brabec et al., 2002; Barnes et al., 2001; Kaplan and Ayers, 2000; Arnold and Gibbons, 1996).

Not only does urbanization consume land and create impervious surface, the pattern of land development and the configuration of impervious surface within the landscape can also be a significant factor. Development patterns can vary widely from smart growth (compact, mixed-use, pedestrian friendly, etc) to sprawl (low density, dispersed, and land-consumptive development). It has been argued that sprawl imposes greater consequences to the environment than smart growth development. (Hasse and Lathrop, 2003a; Kahn, 2000). A number of planners and land managers suggest that the best way to minimize impervious surface on a watershed level is to concentrate or cluster development in existing village centers or high density clusters (Schueler, 1994). Studies have shown that an area's population density is correlated with its percentage of impervious cover (Stankowski, 1972).

However, land development patterns and their relationship to impervious surface are complicated. It was once thought that low-density development would better protect water quality (Arnold and Gibbons, 1996). More recent research has countered that contention by arguing in favor of high-density development as a means of protecting water quality. A major study by the USEPA (2006) modeled several residential density levels and their impacts on water quality. The study used three scenarios, one house per acre, four houses per acre, and eight houses per acre and examined the impact at several scales from the single lot to an entire watershed (Figure 1). The study focused on residential growth only, excluding commercial or industrial growth. The assumption was taken that more runoff would contribute more pollutants into waterways. The study's findings indicated that less runoff per housing unit would be present with higher-density development. Therefore, adjusting for population, higher density development results in less total impervious surface and thus in less water quality impact than low-density sprawl development. Overall impervious cover for the watershed decreases as site density increases (USEPA, 2006).



10,000 houses built on 10,000 acres produce:	10,000 houses built on 2,500 acres produce:	10,000 houses built on 1,250 acres produce:
10,000 acres x 1 house x 18,700 ft^3/yr of runoff =	2,500 acres x 4 houses x 6,200 ft^3/yr of runoff =	1,250 acres x 8 houses x 4,950 ft^3/yr of runoff =
187 million ft^3/yr of stormwater runoff	62 million ft^3/yr of stormwater runoff	49.5 million ft3/yr of stormwater runoff
Site: 20% impervious cover	Site: 38% impervious cover	Site: 65% impervious cover
Watershed: 20% impervious cover	Watershed: 9.5% impervious cover	Watershed: 8.1% impervious cover

Figure 1. Image showing the three EPA scenarios (from EPA, 2006).

Exploring Sprawl and Impervious Surface in Gloucester County, NJ

The modeled scenario conducted by the EPA provided the theoretical framework for exploring the relationship between urban patterns, impervious surface, and water quality. In this study, we attempt to test their theory by exploring real-world patterns using several different scales within an existing metropolitan area. Gloucester County, New Jersey was selected as a pilot study area for this analysis.

Our study was interested in several driving questions: (1) Does sprawl create more or less intense impervious surface than high-density growth. In other words, does development with sprawling characteristics result in a lower proportion of land covered with impervious surface than higher density, smart growth developments? If so, at what scale? (2) Does sprawl create more or less total impervious surface per capita? In other words, does the same number of people housed by high-density, smart growth create less total impervious surface than if those people were accommodated by sprawling growth? If so, at what scale?

The issue of scale is important. The proportion of impervious surface within a particular land area is dependent on the size of the land area being examined. The same quantity of impervious surface may contribute a different proportion of coverage when considered over different areal scales. Three scales were chosen for the analysis including two standard US Geological Survey (USGS) watershed delineations, USGS HUC (Hydrologic Unit Code) 11 and HUC 14. A third, smaller scale watershed, created by the authors utilizing the "watershed tool" of ArcGIS and a digital elevation model (DEM), was utilized to explore correlation at a scale smaller than HUC 14. For the purpose of simplifying the nomenclature, we designate HUC 11 as "basin" and HUC 14 as "watershed" and our newly created scale, "sub-watershed."

Sprawl is a multidimensional phenomenon. There are different approaches that one can take in measuring sprawl. Galster et al. (2001) compiled a list of eight characteristics in spatial patterns attributable to sprawl. Hasse (2004) developed a set of 12 geospatial indices of rural sprawl. While this literature demonstrates that sprawl can have one or more of these multiple spatial characteristics, our study focused on only one, *density*. Low density is arguably the most significant characteristic of sprawl (Ewing, 1997) and relatively straight forward to calculate. However, creating a density metric that can be measured across different watershed scales is more challenging.

METHODS

In order to create a density metric that could be summarized to different spatial scales, this study evaluated urban patterns at the housing unit level (Hasse and Lathrop, 2003b). This novel approach to characterizing sprawl provides a sprawl measurement for each housing unit facilitating summation by any geographical extent (Hasse, in press). Residential housing units were located as a point layer within a GIS utilizing a combination of property parcel centroids and heads-up digitizing. The housing points were then overlaid with US CENSUS tract data. The number of housing points was summarized within each census tract and divided by the tract population to derive an average number of residents for each housing unit. This method of allocating population to housing units was taken because the number of housing points generated in the GIS differed from the number of households as indicated by the census due to multi-family housing. Since population is not homogeneously dispersed, this method better distributed the population to the identified housing location. A raster density surface was then created in ArcGIS Spatial Analyst utilizing average housing population per unit and a radius of 660 feet, (the radius of a one-acre circle). The raster density layer value was then assigned back to the housing points. This resulted in each housing unit having a population density value approximately equivalent to the number of people within a one-acre circumference of each housing unit. This density value provided a visual representation of just how dense each area was in relation to its surrounding housing units. This density measure is our "sprawl index" for this study. The areal size, total population, total impervious surface as well as average sprawl value was then evaluated for each watershed at the three scales; USGS HUC 11 (basin), HUC 14 (watershed) and the author-generated sub-watersheds. The statistics were calculated by summarizing the sprawl values for all housing units in each watershed unit.

Study Area

The analysis was performed on Gloucester County, NJ (Figure 2) located on the southeast sector of the Philadelphia metropolitan region. The county was selected due to its gradient of development patterns going from intensely suburbanized in the north to largely rural in the south. This pattern can be easily identified within a map of impervious surface density of the county (Figure 3). The juxtaposition of the county provided a good cross-section of development levels. The county was also chosen because of the availability of digital parcel data, a geographic layer vital to the housing unit methodology.

The study began with the digitization of residential units within a study area including Gloucester County and a one-mile buffer around the county. This resulted in approximately 70,000 housing point locations. The impervious surface value was derived from a digital land use/land cover layer developed by the New Jersey Department of Environmental Protection (1995). This data layer contains estimates of impervious surface for each land use calculated to a minimum mapping unit of 1 acre. The impervious value was converted to a raster layer to facilitate summation by the various watershed extents. Summations were made county-wide at the *basin*, *watershed, and sub-watershed* scale (Figure 4).

RESULTS

The results provide an indication that a relationship does exist between sprawl and impervious surface, though it is complex. Part of the challenge is identifying the appropriate scale at which

Figure 2. Location of Gloucester County, NJ, one of the suburban counties of the Philadelphia metropolitan area.

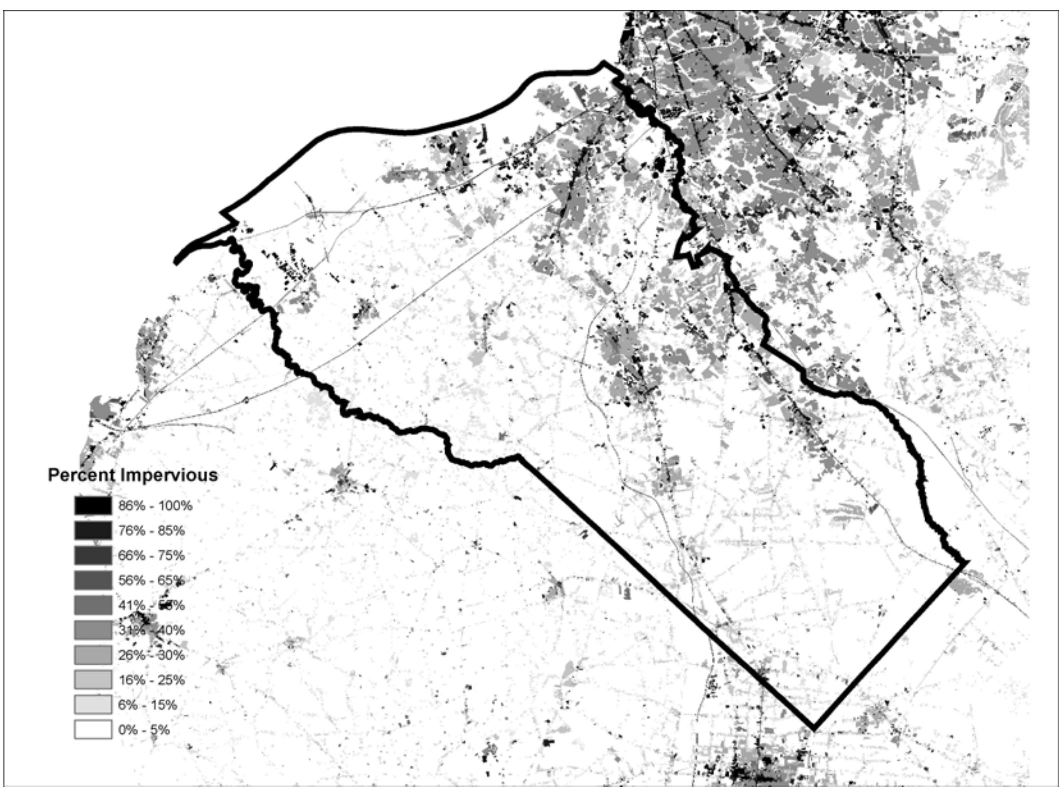


Figure 3. Map of impervious surface intensities for Gloucester County, NJ derived from the NJDEP digital land use/land cover dataset.

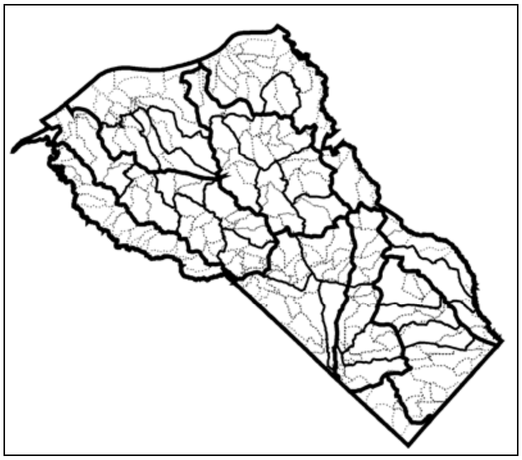


Figure 4. Map depicting the three area subdivisions utilized in the study: *Basin* (solid lines), *Watershed* (dashed lines), and *Sub-watersheds* (dotted lines).

the relationship is most meaningful. The multi-scale analysis of this study ran from the *basin*, which averaged 22,700 acres, an area spanning multiple municipalities, to the *sub-watershed*, which averaged 1,800 acres, roughly spanning the size of a large neighborhood. The number of housing units, total impervious surface, total population, and average density sprawl index were generated for each *basin*, *watershed*, and *sub-watershed* (Table 1). The total number of areal units for the *basin*, *watershed*, and *sub-watershed* was 10, 49, and 120, respectively.

Correlation coefficients were calculated for each geographic extent between percent impervious surface and residential density as well as per capita impervious surface and residential density. Figures 5a through 5f portray scatter diagrams of the percent impervious versus average housing density and per capita impervious surface versus average housing density. A positive correlation existed between percent impervious surface and the density measure ranging from R^2= 0.70 at the basin scale to 0.58 at the sub-watershed scale. There was also a weaker negative correlation for per capita impervious surface ranging from R^2=0.05 to 0.43.

DISCUSSION

Sprawl and water quality share a complicated connection that is not easily defined. One of the most significant connections is impervious surface. Development of any kind creates impervious surface, however one must consider more than simply the total amount of imperviousness. The level of impact to the environment can depend on the intensity and location of this impervious surface. The findings demonstrate that sprawling development does create lower intensities of impervious surface. Examination of the individual polygons of the land use data revealed that residential housing at one-acre per unit will typically have 5 to 10% impervious cover whereas housing at 4-5 units per acre will typically have 25% impervious cover while multi-unit urban housing may have more than 75% impervious cover. This suggests that sprawl has less of an impact to water quality than higher density development. This is true when examining a particular development site. However, this relationship is very different when viewed on a watershed basis. While creating less impervious cover at a building site, sprawling development consumes much larger amounts of land in order to house the same number of people. Therefore, within a watershed, more total impervious surface is generated with sprawling development patterns than higher density.

The results of this analysis confirm that sprawling development results in watersheds with less intense impervious surface which is strongest at *basin* level with a correlation coefficient of R^2= 0.70. The results also show a correlation between sprawling development patterns and per capita impervious surface generated within a watershed. However, this relationship is significantly weaker with the strongest relationship at the sub-watershed level with a correlation coefficient of R^2 = 0.43. The relationship is complicated by the heterogeneity of land use patterns within the watersheds and the geography of the watershed boundaries. Any given watershed unit may have many different types of land uses, some more sprawling than others. Also, the watershed boundaries do not readily coordinate with the boundaries of development patterns.

Several other factors may also help explain the weaker relationship between sprawl and per capita impervious surface. The metric utilized in this study looked only at residential density. Some of the areas with the most intense impervious cover within the study area are commercial and industrial land uses that have few residential units. To compensate for nonresidential areas the study could be limited to watersheds with primarily residential land uses or the additional impervious surface could be better accounted for with a more effective sprawl metric that accounted for non-residential components.

Another important consideration in this analysis is that water quality was not directly measured. While it is well established that impervious surface is associated with water quality impact, the study relied solely on impervious surface measurement as an indicator of water quality. It may

Table 1. Statistical Results of Correlation Analysis

Geographic Extent	Number of Watersheds	Average size in Acres	Average Population	R^2 -% I.S. v-Density	R^2 – Per capita I.S. v-Density
Basin (HUC 11)	N= 10	21,551	22,701	0.70	0.05
Watershed (HUC 14)	N= 49	4,133	4,611	0.67	0.35
Sub-watershed	N= 120	1,850	1,926	0.58	0.43

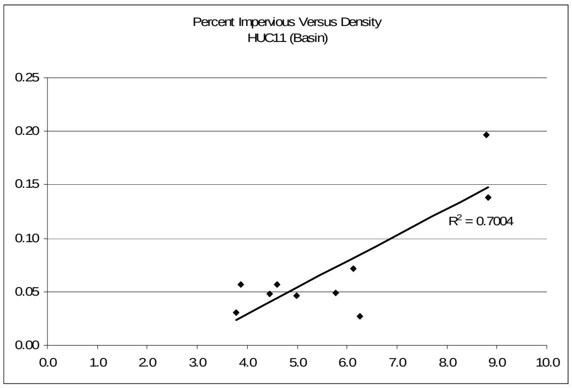


Figure 5a. Basin percent impervious versus average density.

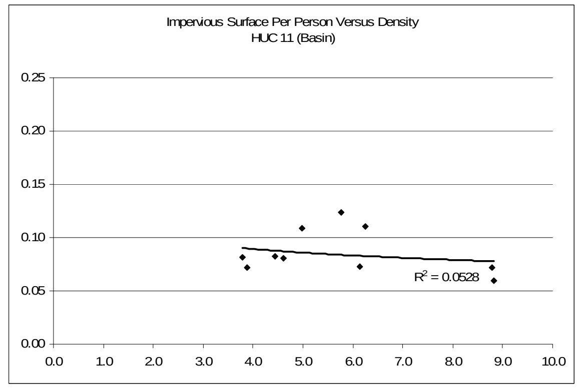


Figure 5b. Basin impervious surface per capita versus average density.

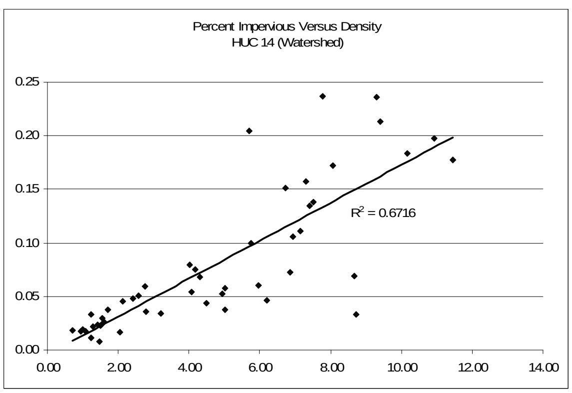


Figure 5c. Watershed percent impervious surface versus average density.

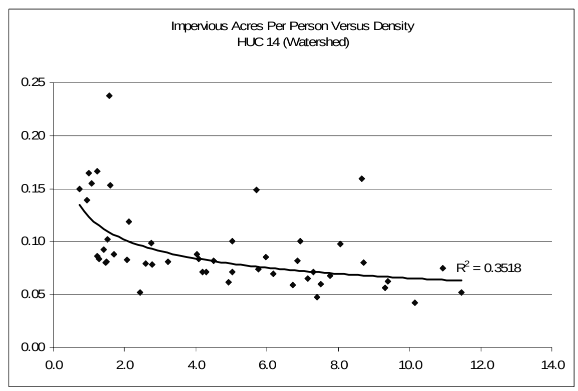


Figure 5d. Watershed impervious surface per capita versus average density.

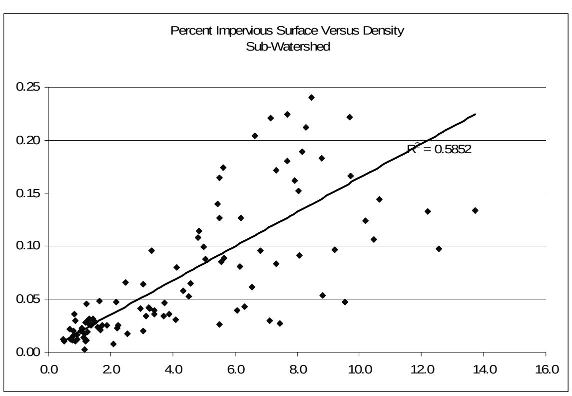


Figure 5e. Sub-watershed percent impervious surface versus average density.

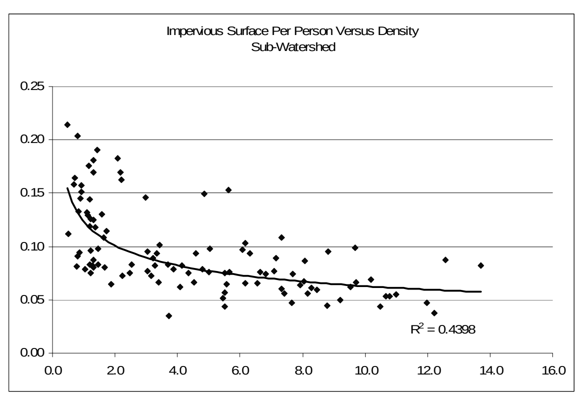


Figure 5f. Sub-watershed impervious surface per capita versus average density.

be possible that absence or presence of best management practices (BMP's) for storm water management may play a significant role on the degree to which water quality is impacted by urbanization. Land use activities other than urbanization such as agriculture can also have a dramatic affect of water quality while contributing little impervious surface. Nonetheless, in the absence of a direct monitoring of water quality at each individual watershed, a monumental task, impervious cover provides a credible indicator.

The findings of this study also need to be viewed in a temporal context. Sprawling areas are many times located along the urban/rural fringe and may be interspersed with undeveloped parcels. Many of these sprawling areas are located within watersheds that can receive more development in the future and can thus expect to have increasing amounts of total impervious surface. Sprawling watersheds may therefore degrade further with future growth whereas high density developments in the study area are more often in watersheds nearing build-out and therefore are more stable with less propensity for further degradation.

A number of other issues limited the scope of this study which could also be potentially improved upon in future research. For example, this study examined sprawl and impervious surface for only one county in New Jersey. An analysis of other counties throughout the state as well as other regions would provide insight into whether this pattern is unique to the study area or whether similar relational patterns exist in other areas. This study was also limited by an overly simplistic measurement of sprawl. A more sophisticated measure of sprawl that incorporated some of the other characteristics of urban form related to sprawl such as lack of mixed land use and leapfrogging patterns, etc. may offer a more nuanced and meaningful analysis of the connection between sprawl and water quality.

CONCLUSION

As development rapidly increases across the nation and around the globe, the realization of its environmental impacts becomes more evident. Planning how and where development occurs both at the local and national level is crucial in the reduction of impervious surface and thus the minimization of water quality impact. Analyzing patterns of urbanization for its associated impervious surface and the corresponding effects on the land and watersheds can be challenging. Sprawling development may not be thought of as a primary contributor to water quality problems. However, this analysis has demonstrated sprawl and impervious surface do have a complex relationship that is significant when viewed at the watershed level.

This study has taken a preliminary look at sprawl and water quality in order to provide data that can help to better delineate this relationship. The results demonstrate that this correlation can be explored through geospatial analysis. By analyzing a specific county at different scales, a better grasp on the complexities of the issue has been revealed. Future research and additional analysis will help to further clarify the multifaceted relationship between sprawl and water quality.

REFERENCES

Arnold, C.L. and Gibbons, C.J. 1996. Impervious Surface Coverage: The Emergence of a Key Environmental Indicator. *Journal of the American Planning Association* 62(2):243-258.

Barnes, K.B., Morgan, J.M. III, and Roberge, M.C. 2001. *Impervious Surfaces and the Quality of Natural and Built Environments.* Baltimore, MD: Department of Geography and Environmental Planning, Towson University.

Brabec, E., Schulte, S., and Richards, P.L. 2002. Impervious Surfaces and Water Quality: A Review of Current Literature and Its Implications for Watershed Planning. *Journal of Planning Literature* 16(4):499-514.

Ewing, R. 1997. Is Los Angeles-style Sprawl Desirable? *Journal of the American Planning Association* 63(1):107-126.

Galster, G., Hanson, R., Ratcliffe, M.R., Wolman, H., Coleman, S., and Freihage, J. 2001. Wrestling Sprawl to the Ground: Defining and Measuring an Elusive Concept. *Housing Policy Debate* 12(4):681-717.

Hasse, J.E. in press. Utilizing GIS and Remote Sensing to Identify Sprawl, *Integration of GIS and Remote Sensing,* ed. Victor Mesev.

Hasse, J.E. 2004. A Geospatial Approach to Measuring New Development Tracts for Characteristics of Rural Sprawl. *Landscape Journal* 23(1):52-67.

Hasse, J.E. and Kornbluh, A. 2004. Measuring Accessibility as a Spatial Indicator of Sprawl. *Middle States Geographer* 37:108-115.

Hasse, J.E. and Lathrop, R.G. 2003a. Land Resource Impact Indicators of Urban Sprawl. *Journal of Applied Geography* 23:159-175.

Hasse, J.E. and Lathrop, R.G. 2003b. A Housing Unit Approach to Characterizing Residential Sprawl. *Photogrammetric Engineering & Remote Sensing: Journal of The American Society for Photogrammetry and Remote Sensing* 69(9):1021-1029.

Hasse, J.E., Misner, J., and Reiser, J. 2003. Characterizing the Land Use/Land Cover Conditions of Two New Jersey Watersheds. *Middle States Geographe*r 36:146-154.

Kahn, M.E. 2000. The Environmental Impact of Suburbanization. *Journal of Policy Analysis and Management* 19(4):569-586.

Kaplan, M.B. and Ayers, M. 2000. *Impervious Surface Cover: Concepts and Thresholds. Basis and Background in Support of the Water Quality and Watershed Management Rules.* Trenton, NJ: New Jersey Department of Environmental Protection; W Trenton, NJ: USGS-Trenton District Office.

Natural Resources Conservation Service. 2006. *Natural Resources Inventory 2003 Annual NRI*. Washington D.C. Available on-line at http://www.nrcs.usda.gov/technical/land/nri03/Landuse-mrb.pdf.

NJ Department of Environmental Protection. 1995. Land Use/Land Cover digital data–source. Available on-line at www.state.nj.us/dep/gis.

Schueler, T. 1994. The Importance of Imperviousness. *Watershed Protection Techniques* 1(3):100-111.

Stankowski, S.J. 1972. Population Density as an Indirect Indicator of Urban and Suburban Land-Surface Modifications. *U.S. Geological Survey Professional Paper* 800-B: B219-B224.

United States Environmental Protection Agency. 2006. *Protecting Water Resources with Higher-Density Development.* Available on-line at http://epa.gov/smartgrowth/pdf/protect_water_higher_density.pdf.

United State Environmental Protection Agency. 1994. *The Quality of our Nation's Water.* #EPA-841-S-94-002. Washington, D.C. USEPA Office of Water.