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CHARACTERIZING THE LAND USE/LAND COVER CONDITIONS OF TWO NEW JERSEY WATERSHEDS

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ABSTRACT: *This paper develops a set of landscape characterization indicators for assessing watersheds. The study focuses on two subwatersheds in the lower Delaware Basin, Chestnut Branch and Newton Creek. The indicators developed include: 1) land utilization and change profiles, 2) percentage impervious surface, 3) impervious surface increase, and 4) urban intensity. The selected subwatersheds are gauged against state-wide averages. The findings indicate that Newton Creek is substantially urbanized nearing a built-out condition. With a total impervious surface coverage of 38.9%, this watershed has experienced severe water quality degradation. Chestnut Branch subwatershed is characterized as a rapidly suburbanizing watershed with a total impervious surface of 18.9% and demonstrably impacted water quality. The characterizations help to provide insight into appropriate management strategies tailored for each watershed.*

INTRODUCTION

Over the past several decades, the watershed has become widely accepted as a logical spatial unit of ecological/environmental analysis and land management. Although watersheds exist at multiple scales from the smallest first order tributaries to the largest river basins, at any given scale of interest, a watershed provides a hydrologically self-contained functional system. Considering that the hydrological system is so intimately interconnected with the climatological, geological, biological, and anthropological systems and processes of a given land area, there is a logical rationale for viewing the watershed as the natural spatial unit for relevant land management (Brabec et al., 2002). This paper explores and develops land use and impervious surface-based indicators for assessing watershed conditions.

Watershed-based Management in New Jersey

As the watershed becomes more widely adopted as the ecological organizational framework for environmental analysis and human land management, the need is arising in governing agencies for development of tools and indicators for assessment of the conditions, similarities and differences among various watersheds. In trying to move New Jersey towards a sustainable future, the state has adopted a watershed-based approach to land and environmental management. 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 versus developed land; many others are associated with urban sprawl (e.g., vehicle miles traveled and air pollution). While many of these indicators have thus far been examined only at a statewide scale, a number of these indicators would be more beneficial calculated at finer geographic scales such as a watershed or subwatershed-level.

Since 1995, the New Jersey Department of Environmental Protection (NJDEP) has also embraced a watershed-based approach to environmental management 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. Recent work has combined land use change data with population change data to create indicators of problematic impacts to vital natural land resources including prime farmland, wetlands, and forest core areas based on per capita consumption (Hasse and Lathrop, 2003). This approach to land use change indicators provides a robust means of characterizing the conditions of watersheds in a manner meaningful to land managers.

Impervious Surface as a Primary Environmental Indicator

Impervious surface is human-created land cover that reduces or eliminates the capacity of the underlying soil to percolate water thus impeding the natural infiltration of precipitation into the ground. Impervious surface cover is emerging as a keystone indicator of the intensity of urban/built-up land use due to its relationship to water quality (Kaplan and Ayers, 2000). Other research has indicated that the overall environmental quality of water within a watershed is directly related to the amount of impervious surface within that basin (Alley and Veenhuis, 1983; Horner et al., 1996; Booth and Jackson, 1997). Important impacts such as changes in alkalinity, nutrient loading and chemical contamination can be associated with impervious surface coverage.

These vital associations to water quality are leading impervious surface coverage to become increasingly relied upon as a primary environmental indicator for effective land planning (Brabec et al., 2002). Analysis indicates two significant thresholds for the total amount of impervious surface within a watershed that have direct impacts to water quality. When a watershed reaches approximately 10% total impervious surface coverage the water quality begins to be demonstrably impacted and the stream ecology begins to show signs of stress (Arnold and Gibbons, 1996). When the watershed reaches 30% impervious surface, the stream can be considered degraded, as stream ecology can no longer adequately function in its original capacity (Arnold and Gibbons, 1996). The creation of impervious surface and its impact to water quality is arguably one of the most significant negative consequences of urban growth. Indicators based on impervious surface are subsequently emerging.

GIS Land Information Data for Watershed Indicators

As planning strategies for sustainable development require solid base-line data on natural resources and socio-economic conditions, GIS and remote sensing have emerged to play a pivotal role in environmental management (Skidmore et al., 1997). However, only recently have the multi-temporal land use/land cover data sets needed to calculate and map these indicators at the appropriate level of detail become available in New Jersey (NJDEP, 2003). The New Jersey land use/land cover datasets is one of the first statewide digital land databases developed to a highly detailed level of accuracy. This dataset was employed to characterize the conditions of the two study area watersheds.

The New Jersey Department of Environmental Protection contracted the production of the digital LU/LC data for the entire state utilizing multi-date digital ortho-photographic imagery (Thornton et al., 2001). This statewide data set contains LU/LC information from 1986 (time 1) and 1995/1997 (time 2) as well as estimates of impervious surface coverage for each land use map unit (i.e., polygon). The LU/LC dataset includes over 50 categories of classes utilizing a modified Anderson et al. (1976) classification system. The NJ dataset was produced from an original 1986 land use/land cover dataset delineated from 1986 orthophotoquads. The dataset was updated to 1995/97 and enhanced in spatial accuracy through "heads-up" on-screen digitizing and editing techniques. The 1995/97 digital imagery were color infrared USGS digital orthophoto quarter quads (DOQQs) (1:12,000 scale) with 1-meter grid cell resolution. Data were delineated to a spatial accuracy of +/- 60 feet (18.29m) in the original 1986 data and further adjusted in the 1995/97 update. A minimum mapping unit of 1-acre (0.4047 ha) was utilized for delineating features as well as a 60-foot (18.29m) minimum width for mapping linear features. The dataset is freely available for download at the NJDEP website (www.state.nj.us/dep/gis).

STUDY AREA

In order to assess, characterize and compare the conditions of watersheds in southern New Jersey, a pilot analysis was undertaken incorporating land use/land cover change analysis and impervious surface on two case-study watersheds. The assessment was conducted on two watersheds situated in the lower Delaware Basin; the Chestnut Branch of the Mantua Creek (Gloucester County) and Newton Creek (Camden County) (Figure 1).

DEVELOPING WATERSHED CHARACTERIZATION INDICATORS

Considering that both watersheds in our case study are located in relative close proximity to one another and within a similar geologic regime of the New Jersey Inner Coastal Plain, the major differentiating factor between watersheds is land use. The Chestnut Branch watershed is a semi-rural watershed that is experiencing rapid pressures for suburbanization, while Newton Creek watershed is intensely developed with industrial and residential land uses, and actually experiencing significant urban decay. The indicators that were developed for analyzing land use in the two study watersheds include, *land utilization and change profile,* and *impervious surface percentage, impervious surface*

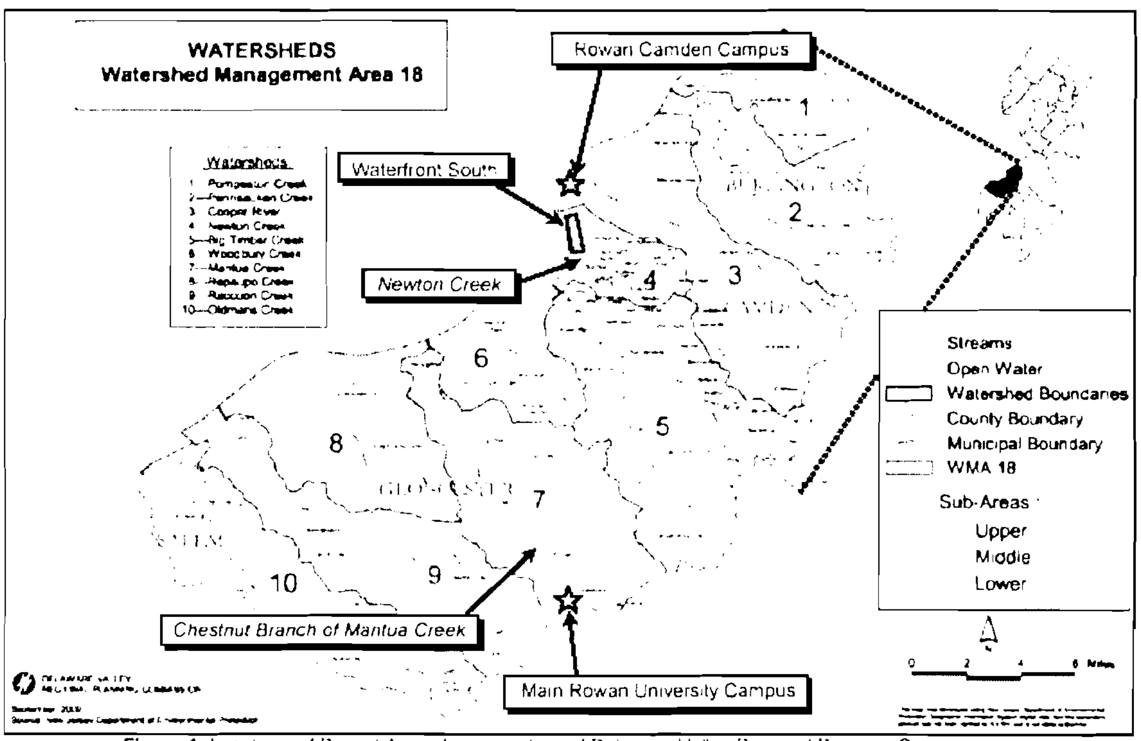

Figure 1: Locations of Project Areas (map courtesy of Delaware Valley Regional Planning Commission)

increase, and *urban intensity*.

Land Utilization Profile and Change

A land use/land cover analysis employing the NJDEP dataset reveals a profile of land utilization and change in the study watersheds. The data provides highly reliable detailed inventories of land use/land cover accurate to a minimum mapping unit of one acre (Lathrop and Hasse, 2002). Normalized into percentage values for direct comparison, the profile presents a graphic depiction of the types and proportions of land use categories found within the given watersheds.

Figures 2 illustrates the land utilization and change profile in how it describes the current land use patterns as well as the degree to which those patterns are changing. The land utilization profile presented herein has two sections: one for detailing the developed land use class and a second one depicting the general overall land category types. The top part of the chart communicates the detailed depiction of urban land use at Anderson Level II, while the bottom part of the graph provides the general Anderson Level I land category proportions. There are four bars for each category on the graph, depicting the land uses from time period 1 (1986) and time period 2 (1995) for Chestnut Branch and Newton Creek.

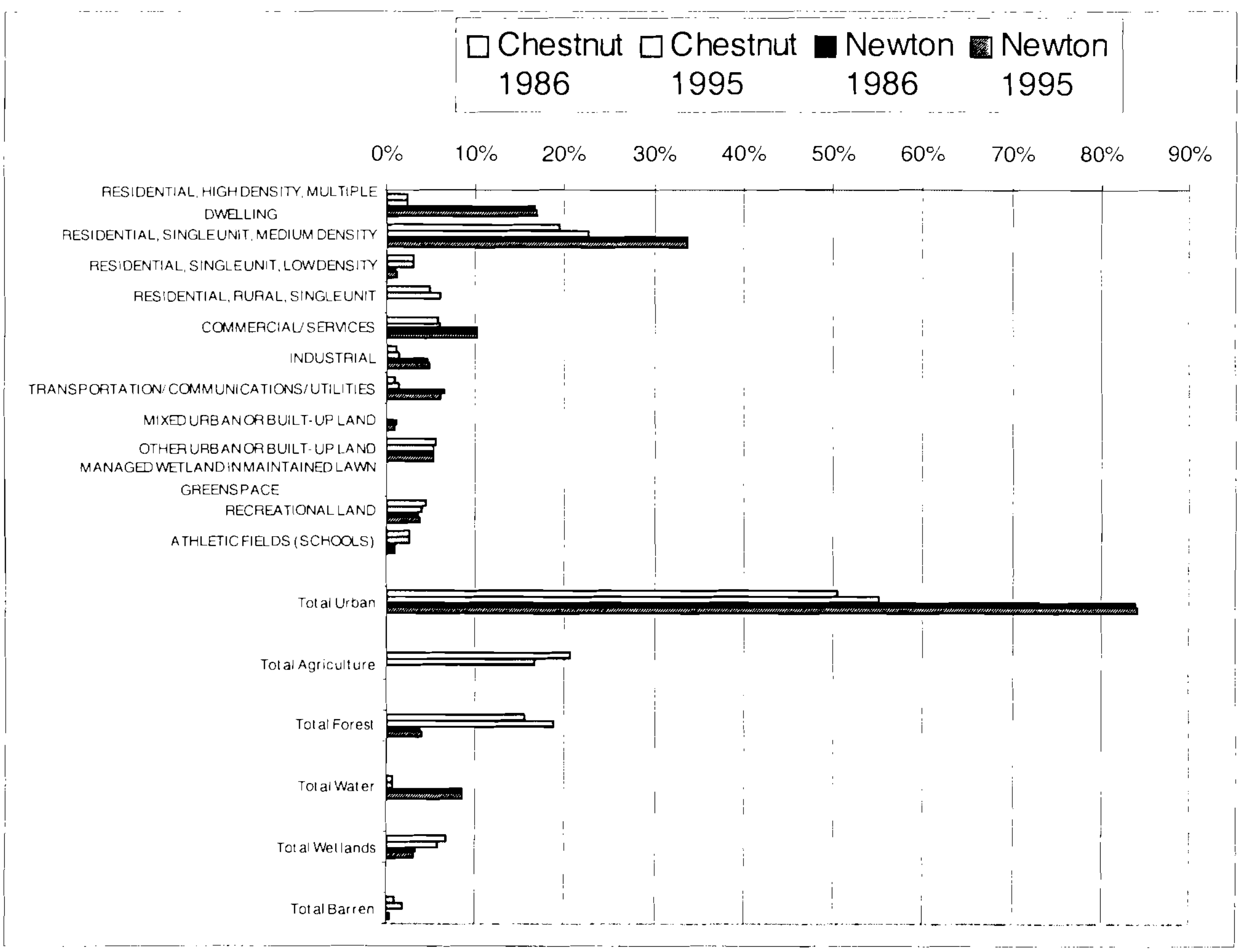

Figure 2: Land Utilization Profile and Change for Newton Creek & Chestnut Branch Creek.

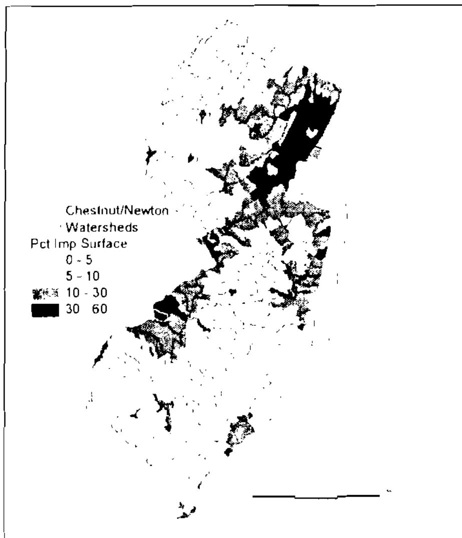

Figure 3a: percent impervious surface

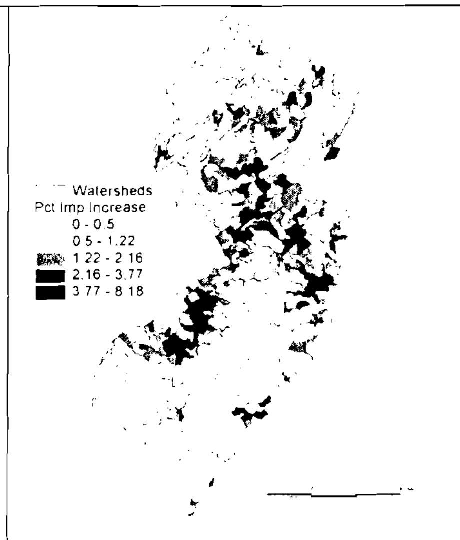

Figure 3b: impervious increase

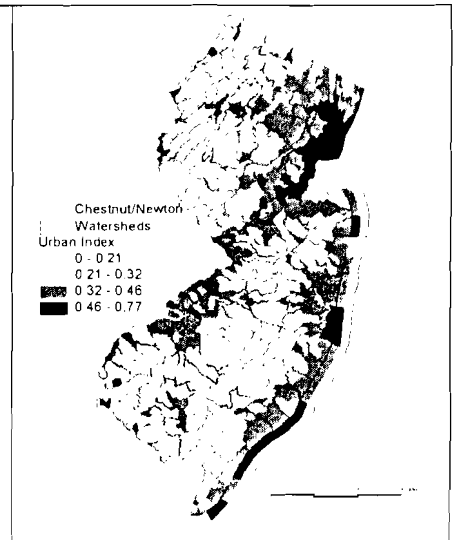

Figure 3: urban intensity index

Urbanization and Urban Intensity

The percent impervious surface measure provides the total amount of impervious surface within a watershed. However, with these numbers alone, the nature and pattern of the impervious surface in relationship to the urbanization patterns remains unknown. In order to capture the relationship of impervious surface to urbanization, we developed a new indicator by normalizing the percent impervious surface by the percent urbanization of a watershed. This metric provides a means of total impervious surface per urban land use capturing, in essence, the intensity of urbanization within a given watershed.

Impervious Surface and Impervious Surface Increase

The impervious surface indicator consists of estimating the total percentage of impervious surface within a watershed and the degree that impervious surface changes over time. The LU/LC dataset utilized in this analysis contains estimated impervious surface percentage for each land use polygon in 1995. Summation of polygon values provided total impervious cover for the watershed. In order to estimate the change in impervious between 1986 and 1995, the LU/LC polygons that indicated a change from undeveloped to developed categories between dates were summarized separately.

RESULTS

Statewide Watershed Ranking

In order to put Newton Creek and Chestnut Branch sub-watersheds into context within the state of New Jersey, a statewide ranking of land use, land use change and impervious surface was conducted. This was accomplished by merging the NJDEP watershed-based land use datasets into a single coverage and then converting it to a raster grid in order to facilitate watershed land acreage summaries. Maps portraying the statewide calculations of the indicators by subwatershed include Figure 3a *percent impervious surface*, 3b *percent impervious surface increase* and 3c the *urban intensity index*. Table 1 provides the statistical results of the pilot watersheds compared with the statewide analysis.

By examining the land utilization and change profile, a good indication of the nature of the pilot watersheds can be inferred. Newton Creek is a heavily developed watershed with 85% of its total land area urbanized. This puts Newton Creek in the top 3.5% (96.5% rank) of the most urbanized NJ watersheds. Considering that much of the remaining

Table 1. Pilot watersheds compared with statewide statistical summaries.

	% imperv	% is_incr	% urban	U.I.Index
Chestnut Branch	18.0%	1.7%	56.0%	0.32
percentile rank	81.0%	85.5%	82.8%	
Newton Creek	39.0%	0.2%	85.0%	0.46
percentile rank	97.0%	34.4%	96.5%	
NJ average	10.0%	0.82%	28	0.27
NJ range	0 - 60	0 - 8.18	0 - 99	0 - 0.73
NJ stdev	11	1	25	0.11

land use consists of water (8%), forest (4%), and wetlands (3%), Newton Creek can be described as virtually "built-out." The urban category section of the profile demonstrates that the majority of developed land is occupied by medium density (34%) and high density residential (17%). Commercial and industrial land uses comprise 11% and 7% of land area respectively. Relatively low change occurred in land use between time period 1 and time period 2. This is characteristic for a built-out watershed. In contrast, the residential land types of Chestnut Branch tended toward a lower density mix of housing with some single-unit rural compared to Newton Creek. Commercial land types only occupied about 7% of the land area, but woodlands and agricultural lands occupied 18% and 16% respectively in Chestnut while they were virtually non-existent in Newton.

Patterns of impervious surface differ between watersheds. Newton Creek was at 38.9% impervious surface in 1995 and added 0.2% of additional impervious surface between 1986 and 1995. Compared to subwatersheds statewide, Newton is within the top 3% of watersheds (97.0% rank) with the highest proportion impervious surface coverage and ranks at 34.4% statewide in terms of impervious surface increase. At 38.9% impervious surface, Newton Creek is well beyond the 30% threshold for degraded water quality. Utilizing impervious surface as a water quality indicator, Newton Creek is a severely impacted watershed due to the intensity of its urbanized land use. Chestnut Branch watershed increased total impervious surface from 794.8 acres (15.9% of the total watershed acreage) in 1986 to 879.4 acres (17.5% of the total watershed acreage) in 1995 creating a substantial 1.6% increase.

The urban intensity index for Newton Creek and Chestnut Branch is 0.32 and 0.46 respectively. These numbers can be interpreted as the average proportion of impervious surface per land area developed. Developed land in Newton Creek watershed is, in essence, 46% impervious surface whereas Chestnut Branch development is on average 32% impervious surface. Compared with subwatersheds statewide, both Newton and Chestnut Branch have a more intense urban pattern than the state average urban intensity index of 0.27.

In addition to the urban intensity indicator, Chestnut Branch contrasts markedly with Newton Creek in a number of factors evident in the land utilization and change profile. The most evident difference between Chestnut and Newton is urban makeup. As of 1995, Chestnut branch had urbanized approximately 56.0% of its land area putting it in the 82.8 % rank for urbanized watersheds in New Jersey The second area in which Chestnut Branch contrasted with Newton was in land change. Chestnut is a rapidly suburbanizing watershed. New residential units were created often at the expense of farmland and other land resources. The proportion of medium-density single unit residential increased from 19% of the total watershed area in 1986 to 23% in 1995.

The implications for water quality in the rapid development of Chestnut Branch are evident in the impervious surface analysis. Recent growth has pushed the watershed further into an impacted condition since the mid 1980's. At 17.5% impervious surface, Chestnut Branch is at the 81.0% rank against watersheds statewide and well beyond the 10% threshold for water quality impact. Chestnut Branch is also increasing impervious surface at an elevated rate 1.7% total watershed increase between 1986 and 1995. This places Chestnut in the top 15% statewide (85.0% rank) of the most rapidly degrading watersheds, as indicated by increasing impervious surface. At the current rate of 9.4 acres of new impervious surface per year, Chestnut Branch is rapidly progressing toward the 30% degraded water quality threshold.

DISCUSSION

In the development of environmental indicators, the primary concern is creating measures that are substantially meaningful for their intended use. Our intention with this research is to create a classification system that allows a simplified mechanism for assessing, comparing and characterizing the environmental conditions and the magnitude of change of any given watershed. In our pilot study of the Chestnut Branch and Newton Creek watersheds, four measures emerged as the most significant for our interest: *land use/land cover change profile, percent impervious surface, percent impervious surface increase, and the urban intensity index*. Each of these indicators provide important information, but each also carries certain inherent limitations.

The *land utilization and change profile* provides a means of graphically depicting the land use/land cover components of a given watershed. The general Level I category provides a means of gauging what proportions of a watershed are in agriculture, forest, water and wetlands as well as to what degree a watershed is progressing to build-out (i.e., urbanization). The percent urbanization indicates the proportion of land in a developed condition and thus, indirectly indicates the potential for further development and subsequent further water quality degradation. This assumption is limited, however, because the non-urbanized portion of a watershed is not necessarily entirely available for development for reasons such as public lands and wetlands. Nevertheless, the percent urban versus non-urban portion of the profile provides a window into the potential for further degradation and the significance for land management policies in a given watershed.

The *percent impervious surface* indicator provides a recognized measure of current water quality impact attributable to urbanization. As the most densely populated state in the USA, New Jersey's development patterns spread impervious surfaces deep into rural areas. The percent impervious surface indicator provides a means of gauging the water quality impact attributable to non-point source pollution associated to urbanization. One of the limiting factor of percent Impervious Surface is that it does not capture the spatial pattern or intensity of impervious surface within a watershed.

The *percent impervious surface increase* indicator provides a measure of the rate of water quality degradation. Watersheds with relatively high percent impervious surface change are at most risk for experiencing water quality degradation. However, the percent change must be gauged against the percent total impervious surface in order to better understand the indicator's significance for the given watershed. Relatively high percentages of impervious surface increase in watersheds that are nearing the 10% and 30% thresholds are most significant. For example, Chestnut Branch increased impervious surface by a substantial 1.7% leaving the watershed with a total of 18% impervious cover, whereas Newton Creek only increased 0.24%, but already had a total of 39% impervious cover therefore indicating that it is already degraded and the current change is less significant.

The *urban intensity index* is a measure of the degree to which the existing urban land area is of an impervious nature. This indicator normalizes the percentage of impervious area by the percentages of urban area to provide a measure of the intensity of urbanization regardless of the extent. Watersheds with a high urban intensity index contain development patterns that have intense urban development patterns regardless of the total amount urban cover within the watershed. In some respects, the *urban intensity index* provides an indicator of the degree to which development is dispersed (i.e., sprawled) within a watershed. Although the measure is limited as an indicator of sprawl in that it only captures the impervious nature of urbanization but has no direct relationship to the actual population density of the given urban structure nor does it compensate for residential versus non-residential land uses.

CONCLUSION

This preliminary study evaluated in detail two of New Jersey's 899 subwatersheds. The research makes a step in developing a comprehensive set of indicators by which watersheds can be evaluated, compared, contrasted, and characterized. Individually, each of the four indicators provided useful summary information of the existing conditions of our pilot watersheds. However, utilized together as a suite of measures, we feel that the four indicators provided a robust description and characterization of the current and dynamic conditions of our pilot watersheds for comparison to other watersheds throughout the region.

This research helps to lay the groundwork for future development of a standard system of classification for characterizing watersheds within a region of interest into a meaningful and helpful scheme. In continued research we intend to explore cluster analysis and principle component analysis as a means of summarizing these four indicators for all New Jersey sub watersheds. We foresee the development of these indicators into a "Claritas"-like categorization system of watershed types ranging from the least to the most intensely urbanized conditions. Other biological, ecological, and sociological land analysis may also benefit from land use-based watershed indicators. Our aim is to develop watershed characterization indicators widely useable to various stakeholders such as environment regulators and land managers. Ultimately, watershed-based indicators hold promise for supporting land use related policy and management decision, protecting water quality, mitigating sprawl, fostering smart growth and encouraging revitalization of already developed areas.

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