Final Report

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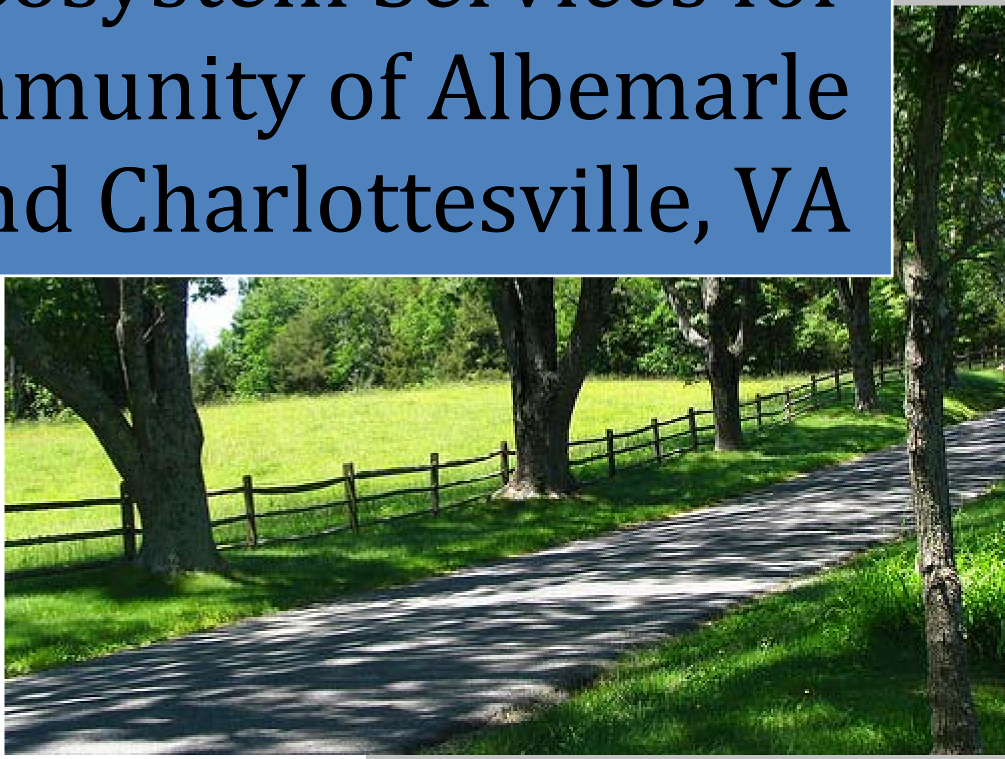
Estimating Impacts of Population Growth on Ecosystem Services for the Community of Albemarle County and Charlottesville, VA



Optimum Sustainable Population Size Project

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Executive Summary

This study is one of the main components of the Optimal Sustainable Population Size (OSPS) Project, begun in 2007 by the non-profit organization Advocates for a Sustainable Albemarle Population (ASAP) (see www.ASAPnow.org). The aim of the OSPS Project is to initiate research that can help estimate the biological carrying capacity and the socio-economic optimal size of this community, which has a current population of about 135,000. This study quantifies ecosystem services for Albemarle County and Charlottesville, VA, and investigates the impacts of potential population growth on these services.

The wide range of resources and processes supplied by natural ecosystems include benefits of immense value to human populations, from erosion and flood control to crop pollination. Population growth and the resulting land use changes pose threats to ecosystem services. This research used American Forests' CITYgreen software, data sets that include the National Land Cover Dataset, U.S. Census population data, and GIS datasets from Albemarle County and the City of Charlottesville to quantify a selection of ecosystem services, including water-related services (i.e. stormwater retention, water pollution removal) and air-related services (i.e. carbon sequestration and storage, air pollution removal).

For most of the ecosystem services analyzed, two population levels are observed where degradation accelerates. At a 50% increase in population (pop.186,429) services within the developing sub-study areas (i.e. Charlottesville, Crozet, and the Route 29 corridor) begin to decline markedly. Up to a 125% population increase (pop. 279,642), degradation of ecosystem services is contained within the developing sub-study areas; as population exceeds this threshold degradation becomes widespread, impacting all of the rural areas. It is important to emphasize that ecosystem degradation occurs unevenly across the study area. While ecosystem services at the level of the entire study area appear to be sustainable up to a 125% population increase due to the continued functioning of the rural areas, this masks the degradation that is occurring in the developing areas.

The results of this first OSPS Project study clearly indicate that if growth continues, planners will have to balance the needs of the human population with local ecosystem health. We note that while careful development can continue in the short term, it clearly cannot be sustained forever without sacrificing important ecosystem services. There are two main lessons that can be garnered from this research. First, one

of the key findings of this study is the importance of a development strategy that encourages growth and efficient use of land in the developing areas while preserving the rural areas. This kind of strategy has the best chance of offsetting the impacts of future population growth in the short term. A strong urban forestry program is also important for this approach so that residents in the more densely developed areas can benefit from the ecosystem services provided by trees. Second, even with these land use strategies in place, unabated population growth and the accompanying land development will negatively alter ecosystem services across the entire study area, suggesting that the identification and maintenance of an optimal population size should be a goal for local decision makers.

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1.0 Introduction

Research in the past two decades has produced compelling evidence that the natural biological resources around us, often taken for granted as components of scenic landscapes, provide essential functions for the maintenance of our lives, and do so at no cost. These "ecosystem services" include the pollination of crops, cleaning of air, protection of streams, and much more. Past research also shows that these essential resources are reduced, sometimes almost imperceptibly, as fields and forests are transformed into housing and commercial developments.

The community of Charlottesville and Albemarle County, Virginia has not escaped the pressures of growth and development. Though the city of Charlottesville itself has remained fairly stable over the past 50 years at roughly 40,000 residents, the county's rate of growth has led to a doubling of the population in the last 35 years and is now at about 95,000. The added people, and the homes, stores, offices, and recreational space they need, have reduced the environmental open space and ecosystem services in the community. For example, between 1992 and 2007, Albemarle County lost 16% of its farmland (USDA 2009). Local growth since the 2000 Census seems to have slowed slightly, likely as a result of the widespread economic slowdown, but the community's site, situation, and amenities make it poised for much more expansion.

This study examines the impacts of local population growth on ecosystem services in Charlottesville and Albemarle County and is one of the main components of the Optimal Sustainable Population Size (OSPS) Project. The aim of the OSPS Project is to initiate research that can help estimate the biological carrying capacity and the socio-economic optimal size of this 760 mi^2 (1,970 km^2) community, with a population of about 135,000 residents in 2008. Another main OSPS study, undertaken simultaneously, explores the ecological footprint of this same area. Smaller, forthcoming studies investigate the effects of local population growth on local stream health, on local groundwater supplies, and on local air quality. Research will then turn to socio-economic issues that help define the community's optimal size following these studies on local sustainability.

The ultimate goal of the OSPS Project is to help estimate a sustainable population size, recognizing that there are limits to growth even at a community level. The identification of such a limit could provide a new planning tool for local decision-makers responsible for ensuring the community's sustainable future.

A balanced ecosystem can be described as the complex interaction of living organisms and the physical environment existing together sustainably (Costanza et al. 1997). The wide range of resources and processes supplied by natural ecosystems, referred to as ecosystem services, include benefits of immense value to human populations, from erosion and flood control to crop pollination. The increasing awareness of global climate change has brought ecosystem services greater attention. In 2001 the United Nations set up the Millennium Ecosystem Assessment (MA) as an international project intending to calculate the role of ecosystem services over the entire globe and the implications of their lost value (Millennium Ecosystem Assessment 2005a). Among their many findings, the authors recognized the challenge of reducing impacts on ecosystems while demanding more from them in an increasingly populous world (Millennium Ecosystem Assessment 2005a, Section 8, p. 92). The City of Charlottesville and Albemarle County, like the rest of the world, face critical decisions over how best to use their finite natural resources and how to manage their human population.

A primary theme in ecosystem services research has been estimating their economic value. In a seminal study by Costanza and colleagues (1997), the total value of global ecosystem services was estimated to be $33 trillion each year. Now it is recognized that quantifying the value that ecosystem services provide can be complicated when the services do not provide direct commodities (Turner et al. 2007; Dodds et al. 2008). However, the United States Department of Agriculture (USDA) recently opened the Office of Ecosystem Services and Markets (OESM) to assist the emerging market for ecosystem services (USDA 2008, Release No. 0307.08). The USDA seeks a standardized format for valuing ecosystem services that will be eventually be sold and traded (USDA 2008).

Other studies, like this one, utilize the valuation of ecosystem services as a tool for understanding how human impacts on local ecosystems impact human lives (Zheng et al. 2008). Instead of attempting to estimate the economic value of those services, this study links a growing population to the degradation of local ecosystem services. In so doing, it quantifies the role of the natural environment in sustaining a hospitable local community.

Ecosystem services and sustainability are concepts that are already incorporated into local planning efforts. The Albemarle County comprehensive plan recognizes the importance of ecosystem services as being critical to the "economy, health, safety, and welfare, and quality of life" (Department of Community Development 2007a, p 1), specifically mentioning services such as the purification of air and water and flood mitigation. Furthermore, the County has committed to support several accords produced by the Thomas Jefferson Sustainability Council, including "Strive for a size and distribution of human population that will preserve the vital resources of the Region for future generations" and "Ensure that water quality and quantity in the Region are sufficient to support the human population and ecosystems" (Department of Community Development 2007a, p 4). This study begins to quantify these goals for the Albemarle County-Charlottesville community.

For this component of the OSPS Project, existing data sets and tools are used to identify and quantify locally influenced ecosystem services. The results are used to identify population levels where ecosystem services begin to significantly degrade. This provides a window into the current use of natural resources and aids in determining whether today's development patterns are sustainable. This project is timely: with 10% of the study area developed, Charlottesville area and Albemarle County have already begun to experience a degradation of air and water quality (City of Charlottesville 2008, VA DEQ 2002, VA DEQ 2007a) while the population continues to grow (U.S. Census 2008).

2.0 Objectives

Broadly, this study addresses four objectives:

1. Identify and quantify a set of ecosystem services that are locally influenced and from which residents in Albemarle County and the City of Charlottesville receive benefits. Ecosystem services that will be targeted for this study include those that protect air and water resources.
2. Create scenarios of county-wide population growth and land use change, and apportion this growth into homogeneous sub-areas within the county, recognizing that population pressure is not distributed evenly within the study area.
3. Quantify impacts of population growth and land use change on ecosystem services for each population growth scenario.
4. For each ecosystem service, identify when a population scenario results in declines in services given current land consumption patterns. Limits to growth can be identified based on the results of this final objective.

3.0 Data and methods

3.1.1 Overview

While the ultimate objective of this project is to suggest limits to growth based on population impacts on ecosystem services (objective 4), the intermediate objectives (objectives 1 – 3) indicate the complex methodology that was required to complete the analysis. After identifying a set of ecosystem services to be analyzed, and the tools that would be used to complete the analysis, we constructed a geographic database that consisted of a land cover data set and a dataset of developable lands. We then had to develop methods and datasets to link land use, population and ecosystem services. As discussed below, this required that the study area be divided into small units (sub-study areas) that could be linked to population data from the U.S. Census. For each sub-study area, the amount of developable land was calculated and the number of new residents that could be accommodated in each area estimated based on current rates of "land consumption." Scenarios of population growth were then applied to the study area, and the resulting land use changes were estimated. The impacts on these land use changes on ecosystem services were then quantified.

Figure 1 below provides a flowchart of the methods required to achieve each objective listed in section 2.0. Objectives 1, 2 and 3 are directly related to the data and methods used to complete our analysis and will be covered in detail in this section. Objective 4 will be revisited in the Discussion and Conclusions sections.

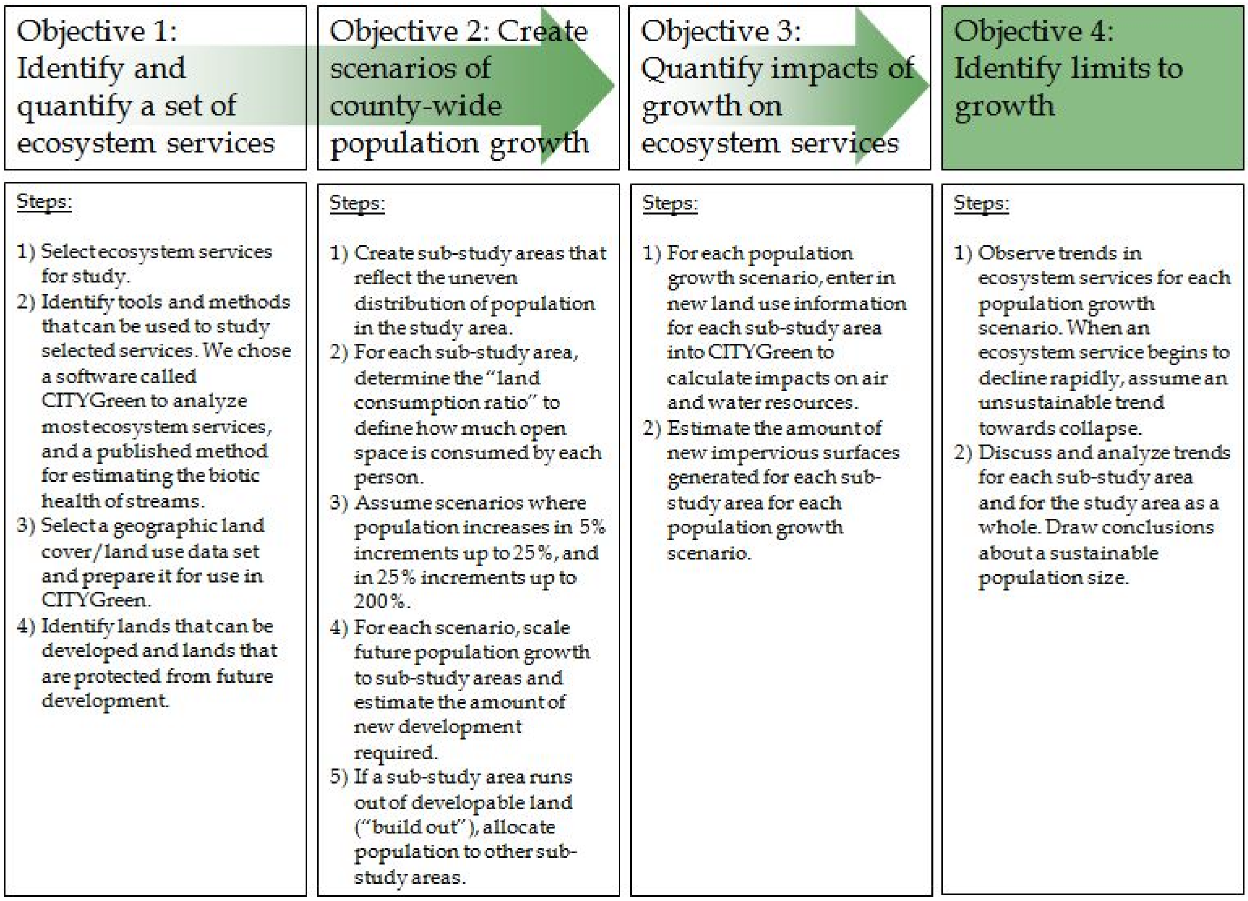

Figure 1. Flow chart of methods used to achieve each objective. These boxes will also be included as sidebars in the subsequent sections.

3.2 Objective 1: Identify and quantify a set of ecosystem services

3.2.1 Selection of ecosystem services for analysis

As noted above, our first objective was to identify ecosystem services for this study. A broad set of ecosystem services could be investigated, ranging from the natural stormwater management provided by vegetation to the pollination services rendered by insects and other animals. However, this study required a focus on ecosystem services that are locally influenced and for which existing data sets, tools and models existed to quantify them.

The services analyzed in this study were chosen based on the fact that they are influenced by local population growth and land use change. The selected services are also well documented, with existing methodologies for estimating their current and future status in the study area. Table 1 lists the ecosystem services that were analyzed for each of the population growth scenarios.

Objective 1: Identify and quantify a set of ecosystem services

Steps:

1) Select ecosystem services for study.
2) Identify tools and methods that can be used to study selected services. We chose a software called CITYGreen to analyze most ecosystem services, and a published method for estimating the biotic health of streams.
3) Select a geographic land cover/land use data set and prepare it for use in CITYGreen.
4) Identify lands that can be developed and lands that are protected from future development.

Table 1. Ecosystem services estimated in this study

Water related:	Atmosphere related:
• Stormwater retention • Mitigation of nitrogen, phosphorous, and suspended solids pollution • Mitigation of biological oxygen demand • Maintenance of stream biotic health	• Carbon stored and sequestered • Mitigation of carbon dioxide (CO_2), ozone (O_3), nitrogen dioxide (NO_2), particulates (PM_{10}), and sulfur dioxide (SO_2) pollution

3.2.2 Tools to measure ecosystem services

We identified the CITYgreen software as an existing and extensively used tool that was originally developed to quantify the economic and biologic value of the services of trees in an urban environment (American Forests 2002; 2004). We chose CITYgreen because it uses well established and rigorously documented methodologies (discussed in more detail in section 3.4) to evaluate the ecosystem services within a landscape, particularly those related to air and water purification. Additionally, CITYgreen interfaces directly with the ArcGIS geographic information software, which allowed us to take a spatially explicit approach in this research.

Most ecosystem services were analyzed using CITYgreen. The one exception is the maintenance of stream biotic health. Several studies have pointed to the declines in aquatic life that occur as more of the land within a watershed is paved. We were thus able to use impervious surface area (i.e. developed land) as a proxy to measure declines in stream biotic health (discussed in more detail in section 3.4.3).

3.2.3 Land cover dataset

The analysis of ecosystem services required accurate land cover or land use data. We selected the National Land Cover Dataset (NLCD) (Figure 2) to quantify current land use patterns in the study area[1]. The timing of the U.S. Census dataset, year 2000, was considered compatible with the NLCD's representation of circa 2001 conditions. CITYgreen has an internal land use classification scheme, but the land use classifications provided by the NLCD are comparable. Table 2 gives the NLCD classification and the corresponding CITYgreen land use classification (also see Appendix II).

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[1] See Appendix I for a discussion on the decision to use the NLCD over other land cover datasets

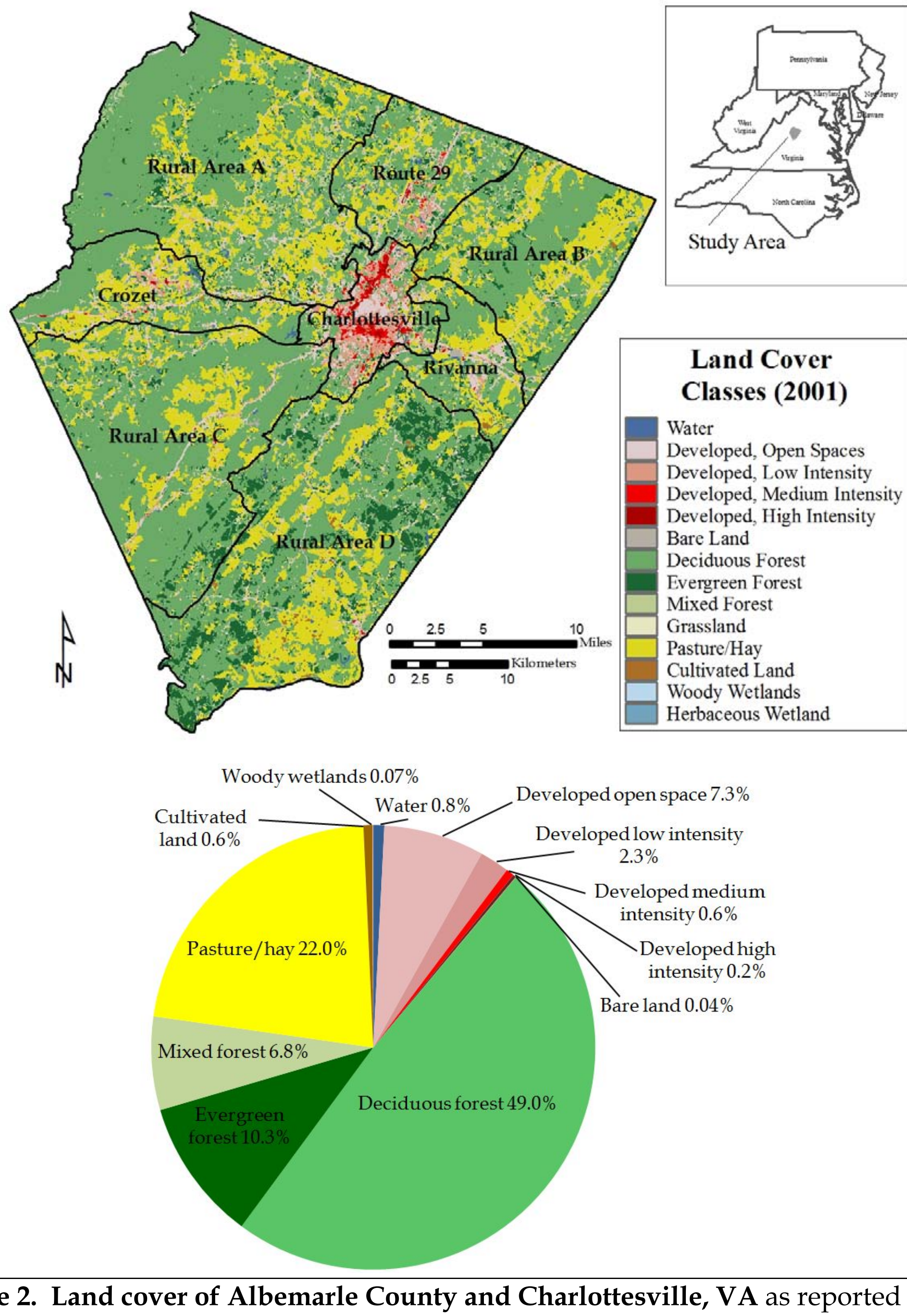

Figure 2. Land cover of Albemarle County and Charlottesville, VA as reported by the NLCD based on 2001 satellite imagery. The labeled sub-study areas in this figure and subsequent figures are discussed in section 3.3.1.

NLCD Classification	CITYgreen Classification	Area (acres)	Percentage of Total
Water	Water	3,749	0.80
Developed, Open Space	Urban: Residential: 1.0 acre	34,607	7.33
Developed, Low Intensity	Urban: Residential	10,196	2.16
Developed, Medium Intensity	Urban	2,718	0.58
Developed, High Intensity	Impervious Surfaces: Buildings	1,053	0.22
Bare Land	Urban: Bare	180	0.04
Deciduous Forest	Trees: Forest: Adequate	230,774	48.97
Evergreen Forest	Trees: Forest: Adequate	48,744	10.34
Mixed Forest	Trees: Forest	31,975	6.78
Shrub/Scrub	Shrub	0.00	0.00
Grassland	Open Space - Grass/Scattered Trees: >75%	0.99	<0.001
Pasture/Hay	Pasture/Range	103,888	22.04
Cultivated Land	Cropland: Row Crops	3,007	0.64
Woody Wetlands	Trees	353	0.07
Emergent Herbaceous Wetland	Shrub	15	<0.001
Totals		471,274	100.0

Table 2. NLCD land use classifications that occur in the study area and the respective CITYgreen classification used in the land use analysis of ecosystem services.

3.2.4 Determining developable land

This research uses current land development patterns as the basis for future land consumption. The amount of developable land is, therefore, fixed because we do not anticipate a significant change in development intensity. That is, we do not expect a dramatic shift in zoning that would allow, for example, the building of skyscrapers. In order to prevent the development of more land than is legally allowed or physically exists, we assembled a dataset of land *excluded* from future development. Land can be excluded due to zoning regulations (i.e. riparian boundaries and slope) or voluntary decisions to restrict development (i.e. conservation easements).

Lands deemed to meet at least one of the following criteria by Albemarle County or the City of Charlottesville were included in this 'Excluded Dataset'. For the purposes of this analysis we assume that these areas remain unchanged and that the local governments do not grant variances to restricted land uses.

- **Critical slopes**- land that has a greater than 25% grade.
- **Ragged Mountain Natural Area**- site of one drinking water reservoir.
- **Shenandoah National Park**
- **Water Protection Ordinance buffer**- the larger of either the 100-year floodplain or 100 feet from the streambank and a 200-foot buffer around water supply reservoirs' 100-year floodplain.
- **Conservation Easements**- those parcels that are under easements from a government and non-governmental organization.
- **Agriculture/Forest Districts**- participating parcels are restricted from more intense development because of their agricultural or forestal use. We acknowledge that the future status of these lands is in question: they could remain as they are, they could be converted into permanently protected lands through the adoption of conservation easements, or they could become developed. In this study we assume that land within agriculture and forest districts will remain undeveloped. While the inclusion of this land may alter the capacity of the study area to accommodate new population, it ultimately results in a more conservative estimate of impacts on ecosystem services.

These excluded datasets were merged to estimate the amount of developable lands in the study area, and to create a map of lands that are excluded from development within the study areas (Table 3 and Figure 3, and refer to Appendix III for a discussion of the methods). Re-development of land previously built on is not accounted for in this analysis; we assume that land that is already developed remains in its current land use and is thus unavailable for further development.

Study Area	Area ($mile^2$)	Developable Area ($mile^2$)	Percent Developable	Developed Area ($mile^2$)	Percent Developed
Charlottesville Area	33.8	10.2	30.2%	18.3	54.2%
Crozet	49.2	18.5	37.6%	7.1	14.4%
Rivanna	32.8	13.4	40.9%	4.9	14.9%
Route 29	48.5	27.2	56.0%	6.8	14.0%
Rural Area A	171.1	54.4	31.8%	12.0	7.0%
Rural Area B	83.8	33.7	40.3%	5.2	6.1%
Rural Area C	139.7	50.1	35.9%	9.9	7.1%
Rural Area D	177.8	89.2	50.2%	11.5	6.5%
Total	736.8	296.8	40.3%	75.8	10.3%

Table 3. Developable land and current levels of development by sub-study areas, discussed in detail in the next section (3.3.1). Urban areas are defined as all areas classified as 'Developed' in the NLCD (Table A1, Appendix I). 'Developable Areas' are defined as all areas currently under agricultural or forested land use and not part of the lands deemed excluded (Population data courtesy U.S. Census and land cover data courtesy USGS).

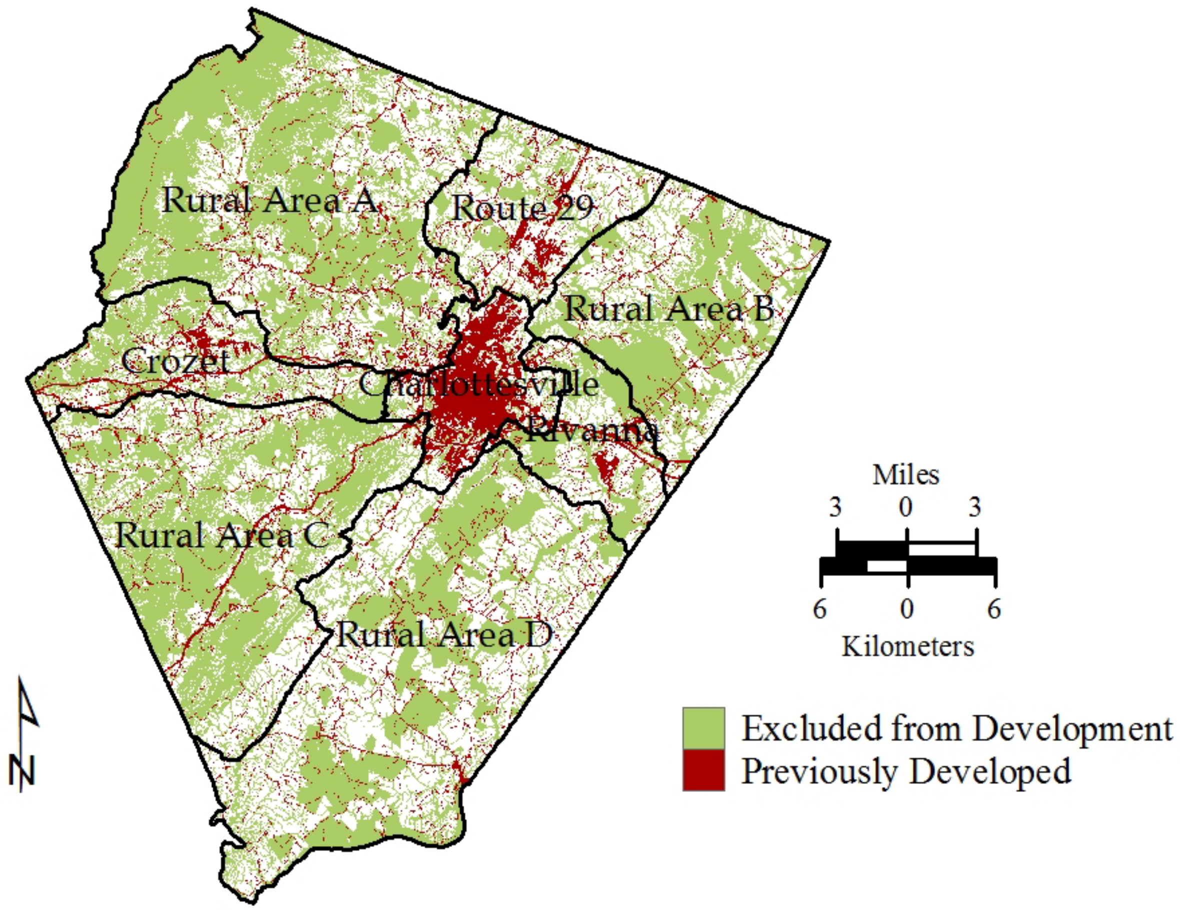

Figure 3. Lands that are excluded from potential development in population growth scenarios (exclusions are based on zoning, participation in voluntary conservation easements, and current land use). Lands are classified as developed based on the NLCD (Appendix I).

3.3 Objective 2: Create scenarios of county-wide population growth

Objective 2: Create scenarios of county-wide population growth

Steps:

1) Create sub-study areas that reflect the uneven distribution of population in the study area.
2) For each sub-study area, determine the "land consumption ratio" to define how much open space is consumed by each person.
3) Assume scenarios where population increases in 5% increments up to 25%, and in 25% increments up to 200%.
4) For each scenario, scale future population growth to sub-study areas and estimate the amount of new development required.
5) If a sub-study area runs out of developable land ("build out"), allocate population to other sub-study areas.

Section 3.2 focused on the development of the tools and base datasets that would be used in our analysis of land use patterns, land use change, and ecosystem services. At the same time, we needed to develop datasets and methods to create scenarios of county-wide population growth, and to link land use with population so that impacts of population growth on ecosystem services could be determined.

3.3.1 Subdividing the study area

Population density and land use patterns vary significantly across the Albemarle County-Charlottesville area. Future growth—and thus impacts on the environment—will therefore not occur uniformly in all parts of the community. To deal with this areal variation, the study area needed to be subdivided into units that share similar population density and land use patterns (referred to in this report as "sub-study areas"). Eight sub-study areas were established based on a combination of the county's planning areas and U.S. Census blocks[2] (Figure 4). Drawing the sub-study area lines along Census block lines preserved the relationship between the resident population and the area of land. This was critical for linking our population data to land development patterns.

Albemarle County's Master Plan encourages in-fill construction within developed areas through the use of the Neighborhood Model, referred to either as Communities, Neighborhoods, or Villages, depending on the planning area (Department of Community Development 2007b) (Figure 4a). By emphasizing growth in these areas, the rural areas of the county can theoretically remain undeveloped. The master plan-designated growth `Communities‘ and the Rivanna planning `Village‘ (shown in purple and green respectively in Figure 4a) are along the major highways that serve the region. We expanded these areas to create sub-study areas that would accommodate potential future growth along their respective transportation corridors.

[2] U.S. Census blocks are the smallest units with population data that are publicly available.

Except for the City of Charlottesville, these areas are the most urbanized regions in the study area (Figure 2).

The City of Charlottesville was grouped with Albemarle County's `Neighborhood' planning areas to reflect the urban areas around the city and account for growth within the entire metropolitan area, again particularly along the highway corridors (Albemarle County Community Relations Office 2007). Four rural sub-study areas (A-D) occupy the remainder of the county. These are similar to the master plan-designated rural areas 1 – 4, but the boundaries are not identical (with the exception of the boundary between Rural Areas C and D, which was adopted from the boundary between the county's rural areas 1 and 3).

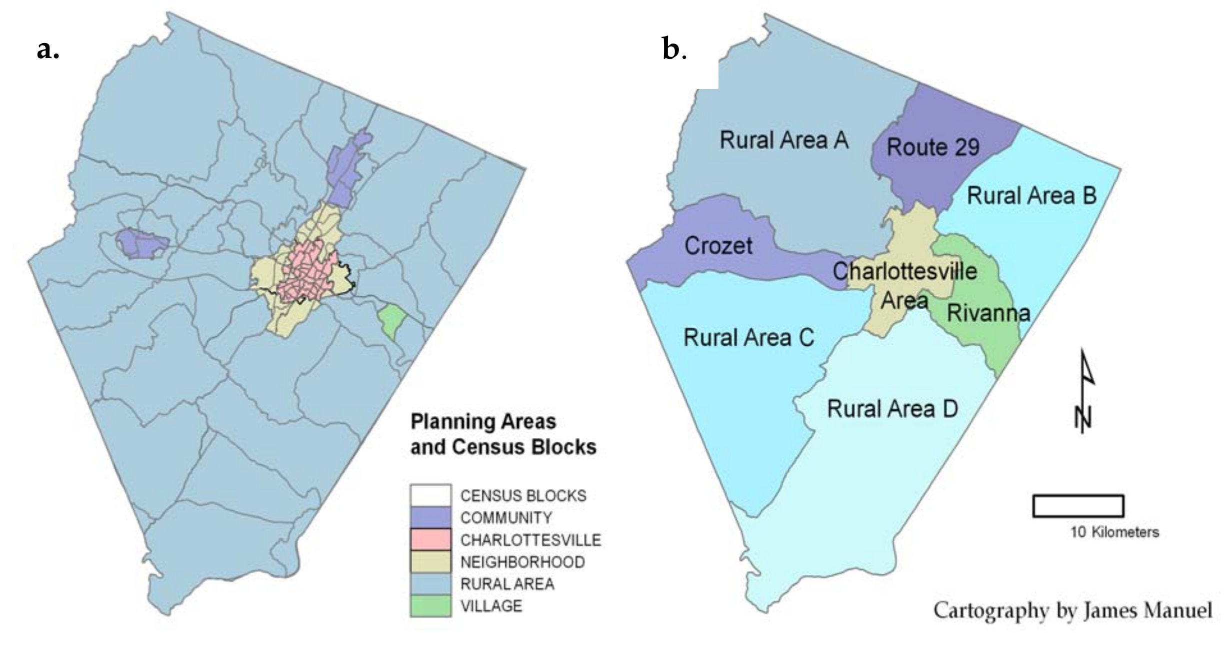

Figure 4a. Albemarle County and Charlottesville, VA are divided in color by the planning areas defined by the county comprehensive plan and then those regions are divided based on U.S. Census Blocks.
Figure 4b. This map shows the demarcation of the eight sub-study areas based on planning and Census boundaries for the ecosystem services analyses. Note that the City of Charlottesville is merged with all of the county's 'Neighborhood' planning areas in order to facilitate growth projections. (Data from U.S Census Bureau and Albemarle County)

While CITYgreen does not include guidelines for study area size, one of the models employed by CITYgreen (TR-55) encourages users to cap study areas at 16,000 acres. Thus the developing sub-study areas (Charlottesville, Crozet, Rivanna, and Route 29) were further divided into units of less than 16,000 acres (Figure 5). This provided a finer scale of analysis for those regions experiencing the greatest amount of development, although most results will be reported at the sub-study area scale. The division of the developing study areas again followed Census block lines in order to preserve the ability to link population data to land use. We were unable to subdivide the rural sub-study areas because the Census blocks in these areas are greater than 16,000 acres.

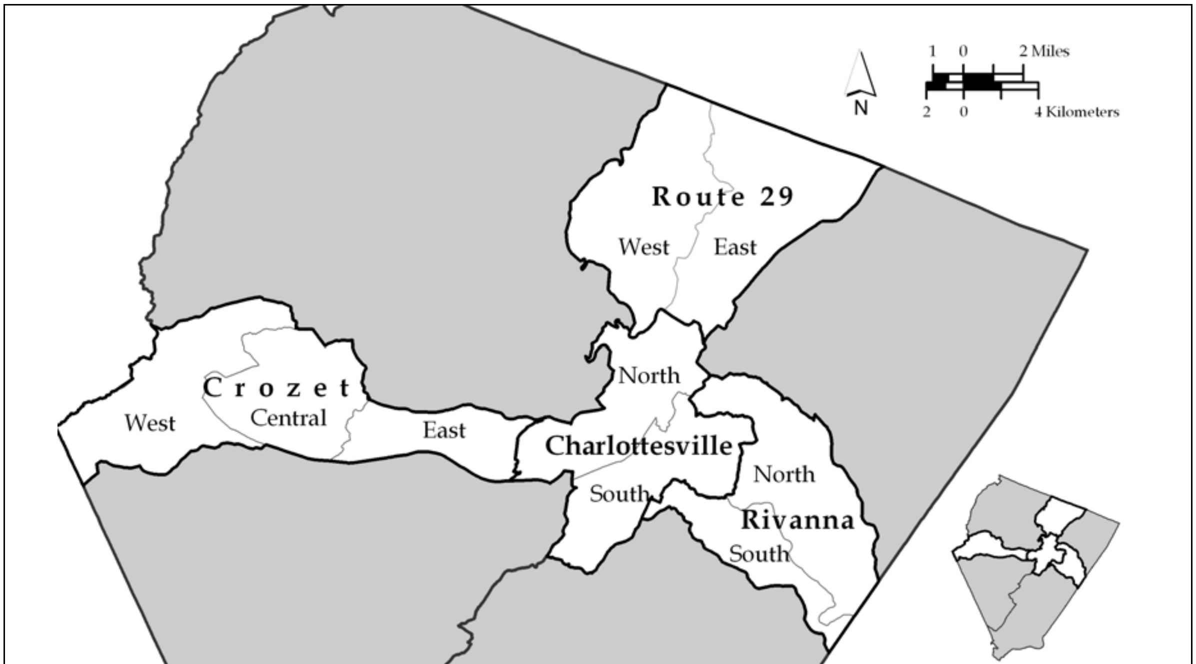

Figure 5. The divisions the developing sub-study areas were further divided. These regions provided a finer resolution for analysis with the CITYgreen software.

3.3.2 Linking population and land use using a "land consumption ratio"

In order to identify population levels that would cause significant degradation of ecosystem services, population must be linked to land use. The sub-study areas are used to recognize the different land use and population density patterns across the study area (Figure 6). For example downtown Charlottesville is more intensely developed than the land adjacent to Shenandoah National Forest. A "land consumption ratio" for each sub-study area was developed to determine how much land is consumed with every additional person, and is calculated by simply dividing the area of developed land by the number of people (Table 4). The "land consumption ratio" is thus a measurement of the number of people associated with each acre of urbanized land and is a reflection of existing urbanization patterns; more densely developed sub-study areas (e.g. with higher density zoning) will have a higher ratio, indicating more people per developed area, and more dispersed development (e.g. with a lower density zoning) will have a lower ratio, indicating fewer people per developed area.

'Developed land' is defined according to the 2001 NLCD developed land use classes (and their corresponding CITYgreen land use classes): low, medium, and high intensity developed (urban-residential, urban, and impervious-buildings); developed open spaces (urban-residential-1.0 acre); and bare land (urban bare) (Table 3, see also Table A1, Appendix I). All categories of developed lands are used in this ratio because they include all of the infrastructure that goes into supporting the population (e.g. transportation networks, shopping, industry and housing).

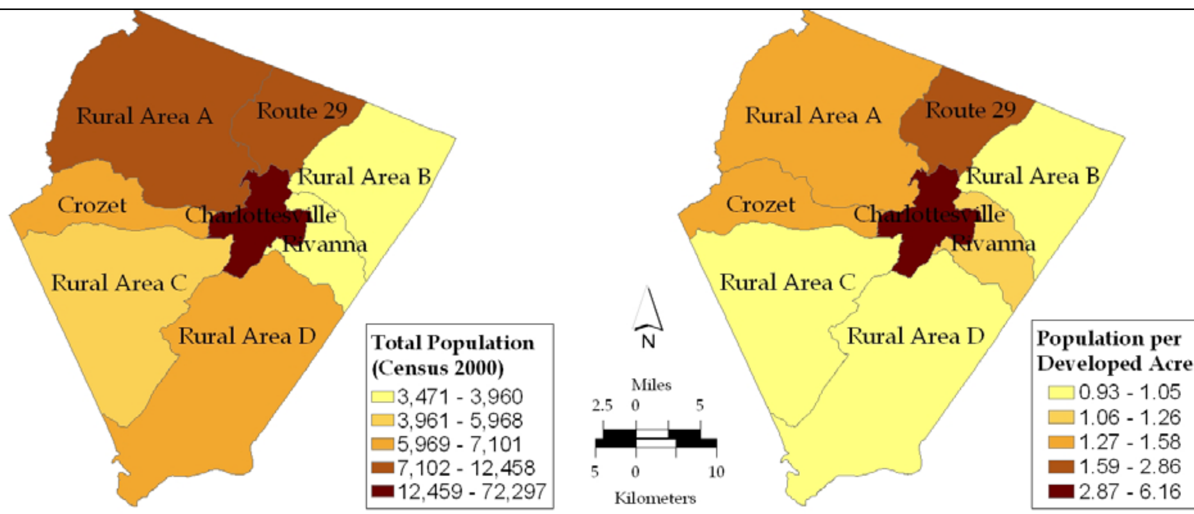

Figure 6a. Total population in Albemarle County and Charlottesville, VA in 2000 based on the eight study areas drawn in Figure 4 (from U.S. Census).

Figure 6b. Population per developed land in Albemarle County and Charlottesville, VA based on the eight study areas drawn in Figure 4b. Lands are defined as "developed" based on the NLCD developed land use categories (see Figure 2 and Table A1) (from U.S. Census; USGS).

Study Area		Total Area	2001 Developed Area (% of total)	2000 Population	Land Consumption Ratio
Charlottesville	North	10,965	6,272.1(57%)	43,128	0.14543
	South	10,669	5,449.5 (51%)	29,169	0.18682
	Total	*21,634*	*11,721.6 (54%)*	*72,297*	*0.16213*
Crozet	West	13,976	1,640.6 (12%)	1,087	1.50933
	Central	10,615	2,094.3 (20%)	4,542	0.46111
	East	6,855	808.6 (12%)	1,472	0.54935
	Total	*31,446*	*4543.5 (14%)*	*7,101*	*0.63983*
Rivanna	North	14,282	2,516.7 (18%)	3,157	0.79717
	South	6,728	738.6 (11%)	803	0.91979
	Total	*21,010*	*3,255.3 (15%)*	*3,960*	*0.82204*
Route 29	West	15,218	1,576.2 (10%)	3,438	0.45845
	East	15,830	2,782.9 (18%)	9,020	0.30853
	Total	*31,048*	*4,359.1 (14%)*	*12,458*	*0.34990*
Rural Area A		109,513	7,697.7 (7%)	12,146	0.63376
Rural Area B		53,639	3,305.8 (6%)	3471	0.95239
Rural Area C		89,366	6,418.0 (7%)	5968	1.07541
Rural Area D		113,799	7,363.0 (6%)	6884	1.06958
Total		***471,455***	***48,665 (10%)***	***124,285***	***0.39151***

Table 4. Land consumption ratio for each sub-study area. Area measurements are provided in acres. Baseline U.S. Census 2000 population figures are listed by study area for Albemarle County and Charlottesville, VA. Baseline developed lands are defined by NLCD developed land use categories (Table A1, Appendix I). The land consumption ratio is equal to the amount of developed acres per individual person—so, for example, the Charlottesville North study area has a land consumption ratio of 0.15 people per acre of developed land.

When allocating additional people to sub-study areas, the amount of each *type* of development was allocated based on its share of developed land in a sub-study area (see Table 5 for an example from the Route 29- East sub-study area). The land consumption ratio provided the necessary rate of land use change based on an increasing population. Similarly, the type of open space that will be developed for each population growth scenario is also based on the current existing distribution of open space (Table 5).

Table 5. Example of the calculation of the land consumption ratio (Route 29- East, population 9,020). Land cover types in this table reflect the CITYgreen land use classification scheme. The "Developed percentage" is the percentage of the area that is occupied by each developed land cover type. The "Developed Percentage" is multiplied by the population resulting in the number of developed acres (of a particular type) per person.

Land Use	Area (acres)	Post-Exclusion Area (acres)	Developed Percentage	Land Consumption Ratio	Open Space Percentage
Cropland: Row Crops	74.7	53.6			0.6%
Open Space-Grass/Scattered Trees	0.0	0.0			0.0%
Pasture/Range	2,596.1	1,886.8			20.2%
Shrub	2.0	0.0			0.0%
Trees	29.1	2.7			0.0%
Trees: Forest Litter Understory	1,913.8	1,530.1			16.4%
Trees: Forest: Adequate Soil Coverage	8,316.4	5,880.7			62.9%
Water Area	115.0	27.6			
Impervious-Buildings	28.9	27.1	1.0%	0.00321	
Urban	156.3	141.9	5.6%	0.01733	
Urban: Bare	0.0	0.0	0.0%	0.00000	
Urban: Residential	981.9	864.7	35.3%	0.10886	
Urban: Residential: 1.0 acre lots	1,615.7	1,331.1	58.1%	0.17913	
Totals	15,830.0	11,746.3	100.0%	0.30853	100.0%

3.3.3 Population growth scenarios

Having developed a method to estimate the land use change associated with population growth, the next step was to develop a set of population growth scenarios and allocate that new growth to the sub-study areas. Study area-wide population increase scenarios were run at 5% intervals up to 25% and then at 25% intervals up to a 200% population increase. The population scenarios at the 5% interval provide a planning tool for the immediate impacts of continued growth, while the 25% intervals are used to identify a population range where ecosystem services begin to experience serious degradation. We note that this study does not seek to identify when (or if) certain population figures will be met.

To allocate study area-wide population growth to sub-study areas, the population in each sub-study area was increased at the same rate as the study area's for a particular scenario. For example, for the 5% area-wide increase, the population in each sub-study area was increased by 5%. Then, the amount of land required to undergo development to accommodate each new person was estimated using the land consumption ratio, which differs for each sub-study area (Table 4). This approach of equal allocation was used until a particular sub-study area reached build-out, a situation described in the next section.

3.3.4 Growth scenarios resulting in build-out

As noted in section 3.2.4, each sub-study area had a fixed amount of developable land due to the presence of protected lands and the assumption that development intensity does not change. Some population growth scenarios therefore resulted in a situation where a sub-study area reached its development capacity, a scenario termed "build-out." When this occurred, the excess population needed to be re-allocated to another sub-study area. In our case, the amount of land available for development in a sub-study area is determined by our excluded dataset (Table 3 and Figure 3) and the land consumption ratio (Table 4). We note that this approach is different from using a parcel-based method, where developable property parcels would be identified and enumerated.

Because it is county policy to encourage residential development in the designated growth areas, excess population was focused on the development sub-study areas first: Charlottesville, Crozet, Rivanna and Route 29. Whenever an area reached build-out the excess population was re-distributed equally to the remaining growth sub-study areas first (Figure 7). Only after the Crozet, Rivanna, Route 29 and

Charlottesville sub-study areas were all at build-out was excess population allocated to the rural areas. A sub-study area was required to accommodate the new development associated with the new population prior to receiving overflow population. In the 75% scenario, for example, the Route 29 sub-study area had to accommodate its 75% additional people before receiving overflow people from the Charlottesville Area. When all four of the developing sub-study areas reached build-out, the rural areas received the re-allocated populations equally. In Table 6, we show the population at build-out for each of the sub-study areas and the population growth scenario where build-out is reached.

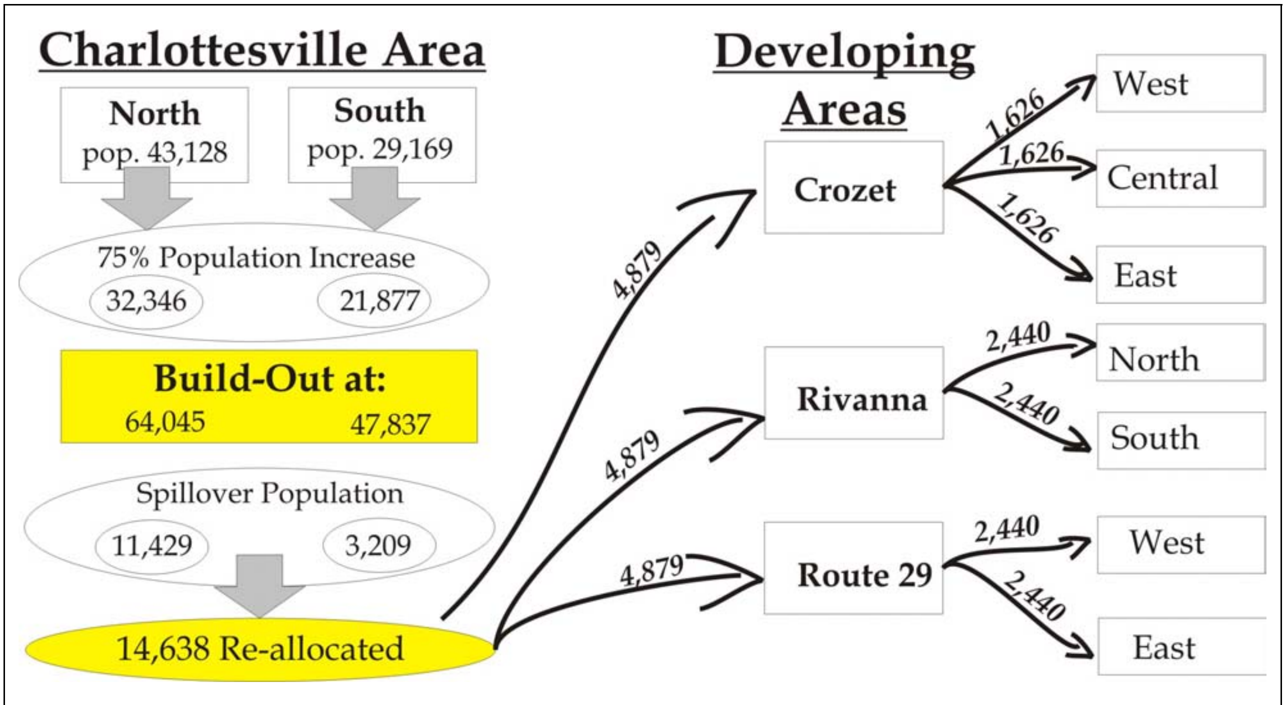

Figure 7. Flowchart describing the re-allocation process due to a sub-study area reaching build-out. In this example from the 75% population increase scenario both sections from the Charlottesville Area reached build-out with an extra 14,638 persons. This spillover population is divided equally among the remaining developing areas that have not reached build-out. The receiving sub-study areas then distribute the additional 4,879 persons equally among their respective divisions, again assuming each has first satisfied its 75% population increase without reaching build-out.

Sub-study area	2000 population	Population at build-out	Growth scenario where/if build-out is reached
Charlottesville area	72,297	111,882	50 - 75%
Crozet	7,101	25,106	100 - 125%
Rivanna	3,960	14,205	100%
Route 29	12,458	60,310	125%
Rural A	12,146	67,082	--
Rural B	3,471	26,141	175 - 200%
Rural C	5,968	35,763	175 - 200%
Rural D	6,884	60,258	--
Total	*124,285*	*400,747*	

Table 6. The population at build-out for each of the sub-study areas and the population growth scenario where build-out is reached. Some sub-study areas reach build-out in-between scenarios. Charlottesville, for example, reaches build-out with a 55% increase in population, meaning this sub-study area was able to accommodate a 50% increase, but had an overflow population in the 75% scenarios. The "--" for rural areas A and D indicate that these areas do not reach build-out by the 200% population growth scenario. The build-out population was thus estimated by dividing the amount of developable land in acres (Table 3) by the land consumption ratio (Table 4).

A sub-study area reaching build-out resulted in important changes in the growth rates of other sub-study areas. For example, the Charlottesville area was the first sub-study area to reach build-out (after a > 50% population increase). For the successive scenarios the other three developing sub-study areas experienced rapid population growth; Rivanna, for example, had a population increase of 189.1% while the entire study area was experiencing a 75% population increase (Figure 8). The Crozet and Route 29 sub-study areas had similar increases in population during the 75 – 125% scenarios due to the re-allocated populations from Charlottesville (Table A3). After the 125% population increase scenario all re-allocated populations were directed to the rural sub-study areas. In the 200% population increase scenario, rural areas B and C reached build-out, thus their excess populations were re-allocated equally to rural areas A and D. As will be discussed in section 5.0, these trends in population growth appear directly linked to increases in developed area and impervious surface area, and the observed patterns of the decline in ecosystem services.

We note that the Route 29 development area absorbed a tremendous population increase as compared to the other developing areas. This area had the second highest population in the entire study area and still grew its population by 384.1% before reaching build-out at a population of 60,310. This is attributed to the combination of a low ratio of developed land per person (second lowest only to the Charlottesville area) and size (48.5 mi.^{2}, nearly 15 mi.^{2} greater than the Charlottesville area). The implications for this substantial population increase are discussed section 5.0.

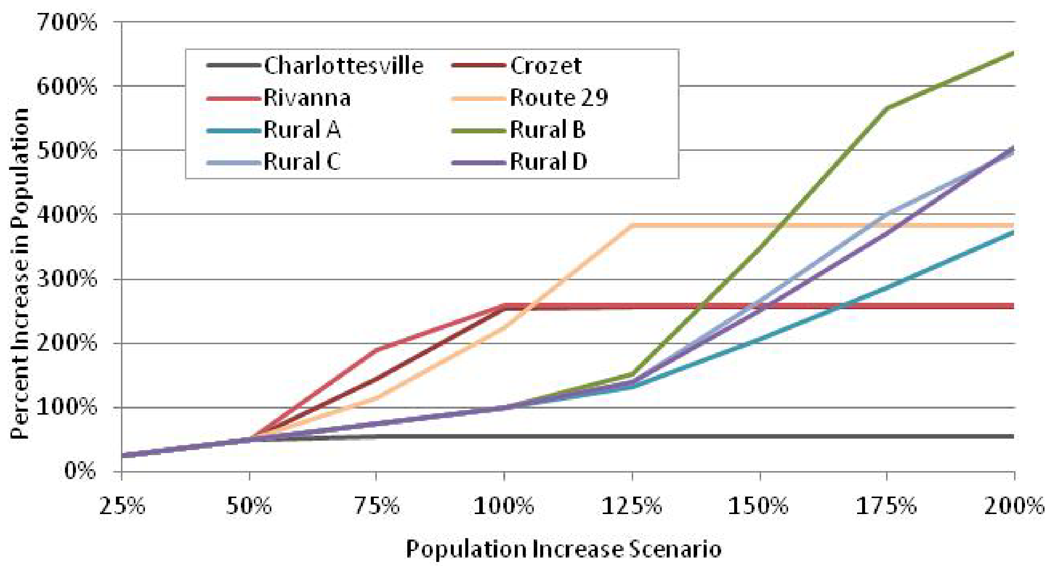

Figure 8. The rate of population increase by sub-study area for each scenario. Increases greater than 25% indicate sub-study areas that are receiving overflow population from an adjacent sub-study area that has reached build-out. In the graph above, a sub-study area has reach build-out when its population ceases to increase. Population data are based on the 2000 Census.

3.4 Objective 3: Quantifying impacts of growth on ecosystem services

Objective 3: Quantify impacts of growth on ecosystem services

Steps:

1) For each population growth scenario, enter in new land use information for each sub-study area into CITYGreen to calculate impacts on air and water resources.
2) Estimate the amount of new impervious surfaces generated for each sub-study area for each population growth scenario.

Objective 1 focused on the development of data sets for the analysis of ecosystem services, and objective 2 developed methods for modeling population growth and the associated land use changes. This section will describe how ecosystem services are analyzed, first addressing how air and water resources are assessed using CITYgreen and then presenting how impacts on stream biota are measured.

3.4.1 Measuring impacts on atmosphere-related services using CITYgreen

In CITYgreen, air quality change is predicted based on the area of tree canopy coverage in the study area and the software utilizes algorithms based on the U.S. Forest Service's Urban Forest Effects (UFORE) model (Nowak and Crane 2000). The role of trees in filtering air pollutants is calculated based on their ability to filter five airborne pollutants, total carbon stored and carbon sequestered annually (Table 1). The air quality analysis of urban forests is based on the closest representative city to the study area from a list of 55 United States cities. The nearest two cities to Albemarle County were Washington DC and Roanoke, VA. Given the prevailing westerly winds for the region, Roanoke was used for this research.

3.4.2 Measuring impacts on water-related services using CITYgreen

CITYgreen integrates several well-documented models to determine the hydrologic and water quality impacts of changing land use. The National Resources Conservation Service's (NRCS) Technical Review-55 software (commonly referred to as TR-55) was originally developed by the Soil Conservation Service (SCS). TR-55 is a foundational part of the CITYgreen analysis because it determines the amount of stormwater runoff that will be produced from the most common land covers. The SCS developed a system of runoff coefficients called curve numbers (CNs) to allow area-weighted averaging of landscapes that include a variety of different land cover types (Bedient et al. 2008). Essentially, the curve number is used to estimates a volume of stormwater runoff produced from any type of land use over a given area. This allowed us to compare the runoff production from, for example, today's pasture versus tomorrow's strip mall.

Together with the land cover type and the runoff coefficients (or curve numbers), CITYgreen uses the Long Term Hydrologic Impact Assessment (L-THIA) model to predict increased contaminant loading in streams based on land use change (Bhaduri et al. 1997). CITYgreen's analysis of stream pollutants has two main limitations. First, the algorithms used to calculate pollutant loading are designed to not fall below zero; thus where land cover change resulted in less runoff, CITYgreen does not report a commensurate reduction in pollutant loading. Second, CITYgreen reports contaminant loading in streams as a *percent increase* rather than a gross volume or weight. In order to estimate the actual level of these pollutants in watersheds, a current value for these variables is required. Actual stream measurement data sets for all pollutants are currently not available across the study area. However, as discussed below, we were able to estimate nitrogen and phosphorous loadings using modeled data provided by the Chesapeake Bay Program (USGS 2004).

3.4.2A Developing baseline N and P levels in streams with the SPARROW model

Developed by the USGS for the Chesapeake Bay, the **SPA**tially **R**eferend **R**egressions **O**n **W**atershed (SPARROW) model relates water quality measurements to sources of nitrogen and phosphorous (Preston and Brakebill 1999; USGS 2004). For baseline data (i.e. current levels of nitrogen and phosphorous in streams), this study utilized previously published SPARROW pollutant estimates for the sub-watersheds within the study area. We used estimates of nutrient loading generated locally, independent of the contributing load from upstream. In-stream losses of nutrients are dependent on individual reaches and are thus omitted from use in this analysis as well (USGS 2004). CITYgreen's estimates of increases in nutrient loading were then added to the SPARROW estimates for the sub-watersheds delineated by the USGS.

While SPARROW provided an important baseline data set for our analysis of water quality, it presented a new methodological challenge: the SPARROW results were generated for sub-watersheds, but our CITYgreen analysis was performed for the sub-study areas, creating a spatial mismatch between these two data sets. The CITYgreen projections for stream contaminant loadings therefore had to be allocated to the sub-watersheds used by SPARROW. In addition, sub-watersheds are a logical unit of analysis for water quality.

3.4.2B Distributing impacts to watersheds

Albemarle County—98% of which is part of the Middle James River basin—is comprised of ten different sub-watersheds. The majority of the sub-watersheds are part of the Rivanna River system (as defined by the U.S. Geological Survey (2004) (Figure 9). The projected pollutant loadings for each sub-study area were allocated to their respective watershed(s) based on area weighting. For example, 86.7% of the Charlottesville sub-study area is in the Rivanna River basin and 13.3% in the South Fork Rivanna River basin. Therefore 86.7% of the projected pollutants was allocated to the Rivanna River basin and the remainder to the South Fork Rivanna River basin.

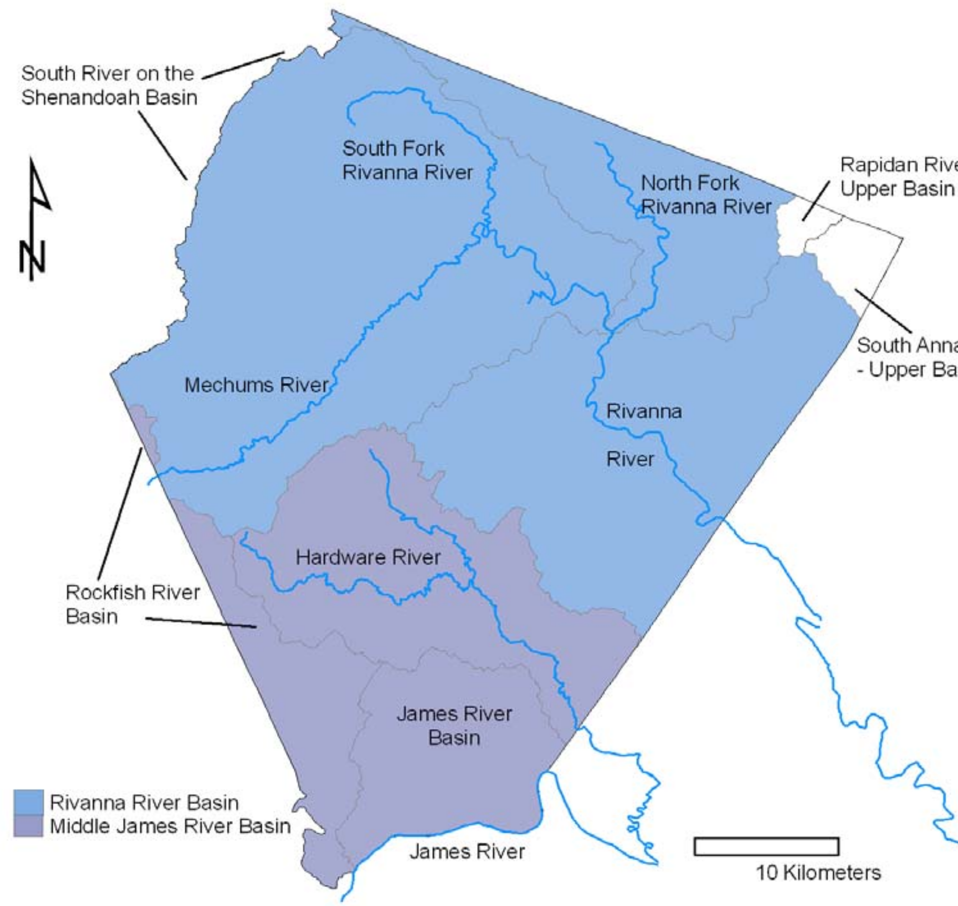

Figure 9. Map of the watersheds and sub-watersheds that make-up the Albemarle-Charlottesville area. The Rivanna River joins the James River southeast of Albemarle County to form part of the Middle James River Basin. Note that the South River on the Shenandoah Basin areas represent fractions of a percentage of the study area (Table 6) and are thus not visible but still accounted for above (USGS 2008).

3.4.3 Estimating Degradation of Stream Biota via Impervious Surface Area

Except for the maintenance of stream biotic health, all of the ecosystem services listed in Table 1 were analyzed using the CITYGreen software. The water-related elements analyzed in CITYGreen are either related to the physical functioning of stream systems (i.e. stormwater retention) or water quality (i.e. nitrogen and phosphorous pollution levels). The biotic health of streams, or the ability of streams to maintain aquatic life, is another important component of stream health. Biotic health is usually determined through the measurement of the diversity and abundance of aquatic species, including fish and insects.

As a local population grows, there is almost always an increase in developed land uses (i.e. roads, houses, shopping centers) and a reduction in agriculture and forest cover. These land use changes have well documented negative effects on stream biotic health, primarily due to the increase in impervious surface area (ISA)—or the increase in paved surfaces that prevent water from filtering naturally through the soil. Recent research suggests that there is a 10% threshold on ISA at which point streams and rivers become significantly impaired in terms of their ability to maintain aquatic life (Goetz and Fisk 2008). ISA was therefore estimated for all of the sub-study areas in the Albemarle County-Charlottesville Area for each of the population and land use change scenarios. The amount of ISA for each developed land use was based on the National Land Cover Dataset (NLDC) (2001) descriptions (Table 7).

Table 7. Land cover types represent different quantities of impervious cover based on NLCD (2001) descriptions. These percentages were used to estimate impervious surface area (ISA) to estimate degradation in streams.

Land Cover Class	Percent Impervious
Impervious Surfaces: Buildings/Structures	90.0%
Urban	65.0%
Urban: Bare	0.0%
Urban: Residential	35.0%
Urban: Residential: 1.0 ac lots	15.0%

4.0 Results

For most of the ecosystem services analyzed, two population levels are observed where degradation accelerates: 1) at a 50% increase in population (pop.186,429) services within the developing sub-study areas begin to decline markedly, and 2) at a 125% increase (pop. 279,642) ecosystem services decline across the study area. In nearly every variable projected by this study, degradation accelerated at this population increase, although it is important to note that degradation did not occur equally among the sub-study areas. In fact, when the results are viewed at the scale of the whole study area, a precipitous drop in ecosystem function is not immediately apparent, emphasizing the point that the decline in services in the developing sub-study areas is masked at the broader scale as long as the rural areas remain intact. The results of the analysis are presented first by the estimated land use change and then each ecosystem service is addressed individually.

4.1 Land use/land cover change associated with population growth

As noted in section 3.3.2, land use changes associated with each of the population growth scenarios were estimated using the land consumption ratio. In Figure 10, we show the projected trends for agriculture, forest and developed land given each population increase scenario. For the year 2000, the base year of study, undeveloped open space dominated the regional land cover (>88%). As population increases, developed land also increases at the expense of forests and agricultural lands, but the rate of change is non-linear (seen in Figure 10 as the slope of the 'Developed' line increases at the 125% scenario). The greatest increase in land consumption for developed land uses occurred after the developable land in the growth areas was exhausted due to the low-density settlements patterns (and thus higher rates of land consumption) in the rural sub-study areas.

Between the 25 – 200% population growth scenarios, the Albemarle County-Charlottesville area lost an average of 4.34% of the open space with every 25% increase in population. Impacts of development first become apparent in Crozet, Rivanna and Route 29 after the 25% scenario (Figure 11). All four rural sub-study areas began to experience more development at the 125% population increase scenario, the scenario that marks the beginning of the rural areas receiving overflow populations from other areas that had reached build-out.

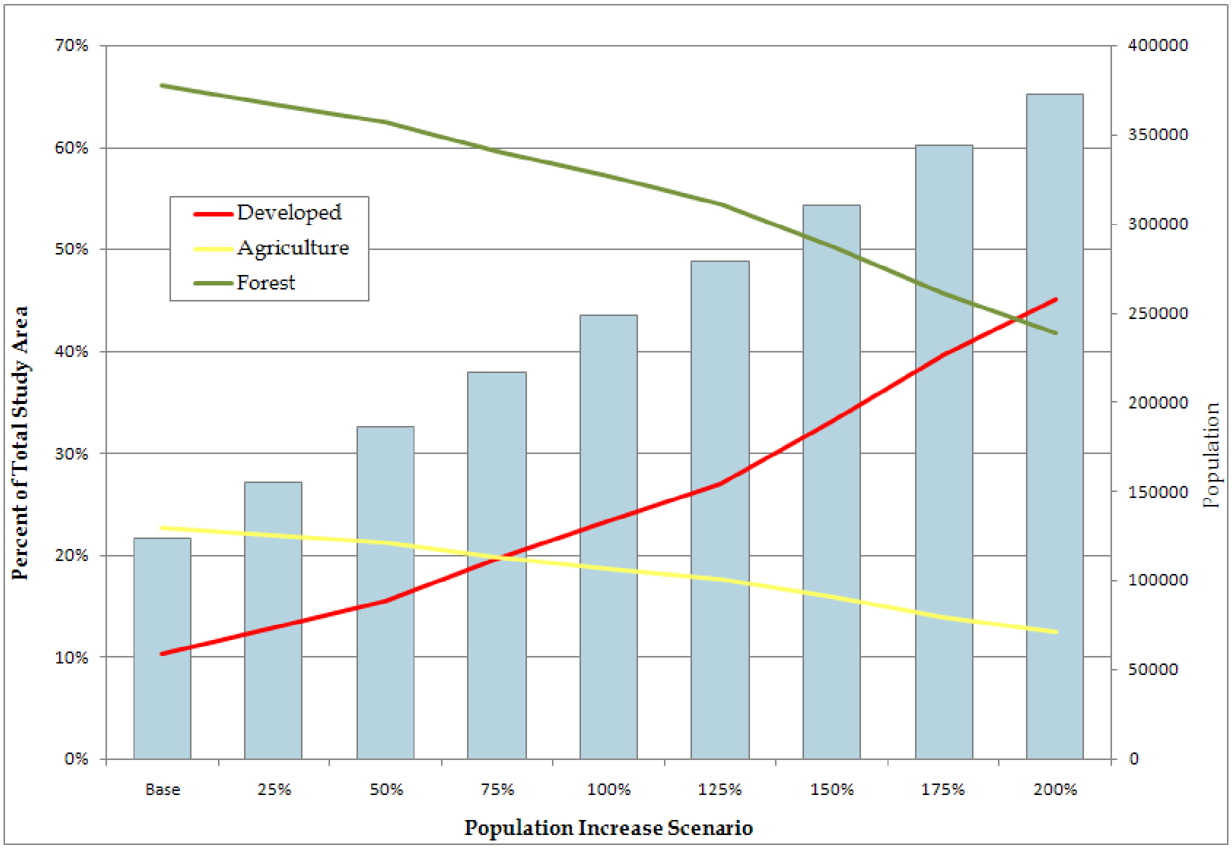

Figure 10. Land use trends for the population scenarios analyzed here compared to the study area's estimated population. Developed land uses include 'impervious surfaces' and the four 'urban' land classes discussed in section 3.2.3. Agricultural land uses are row crops and pasture. Wetlands or bodies of water were excluded from this analysis. Note that even though population growth is linear, increases in development are non-linear due to the land consumption ratio.

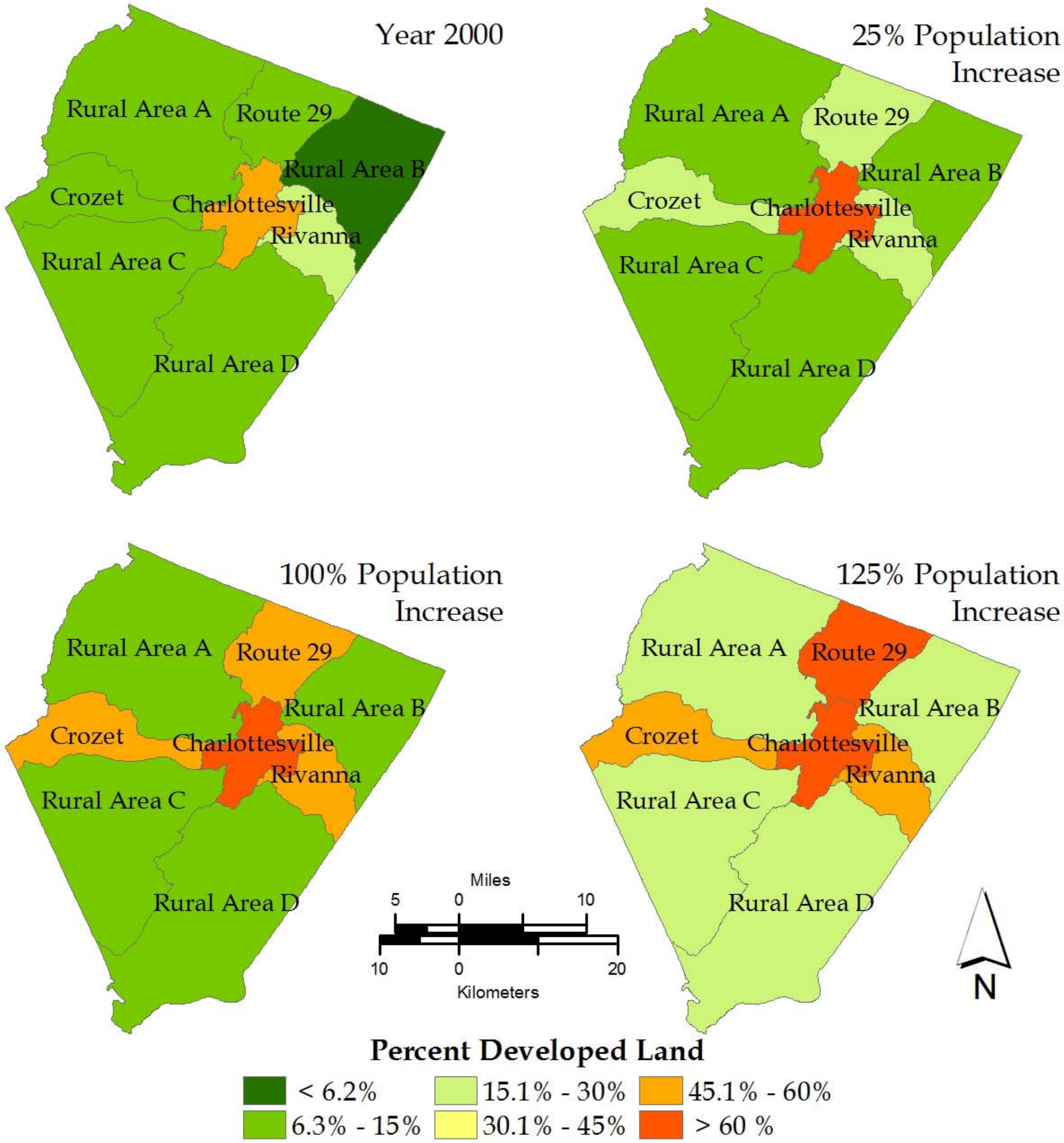

Figure 11. The amount of developed land in each sub-study area as a percentage of the total area for the base year, a 25% population increase, a 100% population increase and a 125% population increase. Note the expansion of developed land in the rural areas that occurs between a 100% and a 125% increase.

4.2 Impacts on atmosphere-related ecosystem services

The forests of the Charlottesville-Albemarle County community are undoubtedly one of the more important assets in terms of ecosystem services, providing the removal of atmospheric pollutants, such as carbon monoxide and ozone, and serving to store and sequester carbon. However, forest cover is reduced as the population in the area grows (Figure 10). We found that the ability of the tree canopy to provide atmosphere-related ecosystem services was severely degraded across the entire study area when the population increased by more than 125%, although the developing sub-study areas begin to experience declines much earlier. Below are the results related to specific pollutants.

4.2.1 Carbon storage

The increase in carbon dioxide (CO_2) emissions has had more influence on global climate change than any other greenhouse gas (MA 2005b), and is thus a major focal point for climate change research and policy. Ecosystems can serve as both carbon sources (i.e. carbon emission) and sinks (i.e. carbon absorption), but the ability of ecosystems to store and sequester carbon is most important in terms of the climate change issue. Carbon storage refers to the total amount of carbon stored in a landscape, both above ground in vegetation (particularly trees and forests) and below ground in the soil. In this analysis, we focused on the tons of carbon stored per acre, measured by the amount of forest, and how it declines with an increasing population.

The amount of carbon stored per acre for each scenario, beginning with base year 2000, is shown in Figure 12. Consistently, the rural areas have the highest rate of per-acre carbon storage, although we note that Route 29 and rural area B have an almost equal rate in 2000. The amount of carbon stored per acre for the study area declines rather consistently as the population increases (dashed line in Figure 12). However, this seemingly gradual decline at the broad scale masks finer scale trends that, for the developing sub-study areas, seem almost disastrous. For example, Charlottesville experiences a steep decline with just a 25% increase in population, and the other developing sub-study areas begin to experience steep declines after a 50% population increase. The collapse of this ecosystem service for the Route 29 area is especially dramatic, falling from roughly 27 tons/acre in 2000 to 9 tons/acre after a 125% increase in population—a decrease in carbon storage capacity of over 65%. After the 125% scenario the ability of the rural sub-study areas to store carbon is affected. Rural area C had the highest rate of carbon storage in the study area (30.4 tons/acre in 2000) until the

150% population increase scenario (25.6 tons/acre) when rural area A has the largest carbon storage rate.

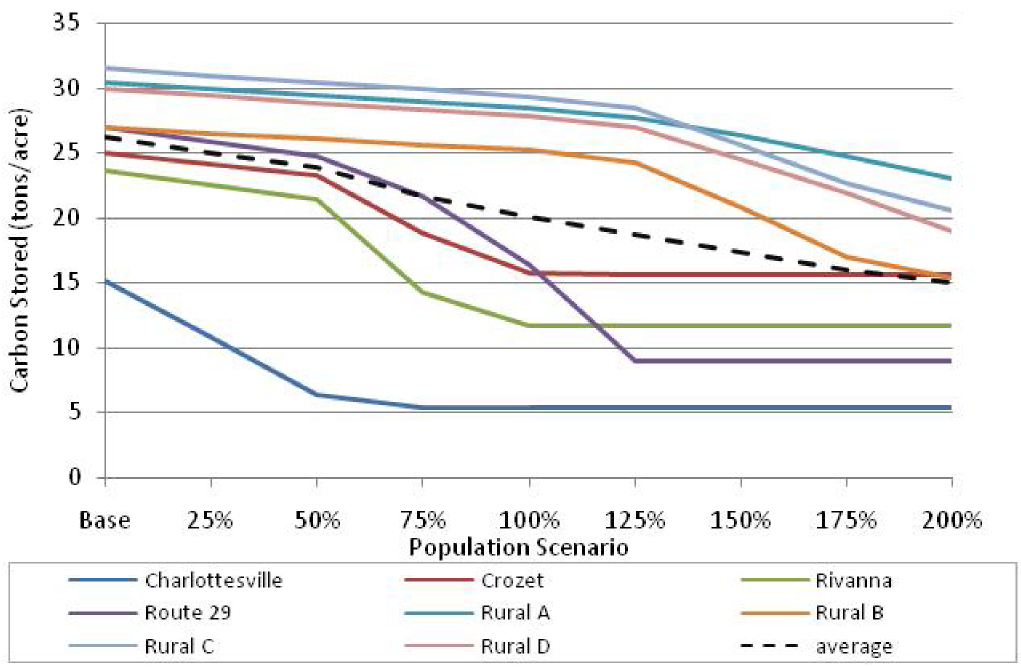

Figure 12. The amount of carbon stored in the tree canopies (tons/acre). The difference between 125% and a 150% population increase illustrates the impacts of increased development in the rural areas of the study area.

Spatially, these trends are illustrated in Figure 13. In 2000, per acre rates of carbon storage are lowest in Charlottesville and Rivanna, the two most developed sub-study areas. With a 125% increase, it is clear that the major declines in carbon storage remain confined to the developing sub-study areas, while with a 150% population increase, declines can be observed in the rural areas.

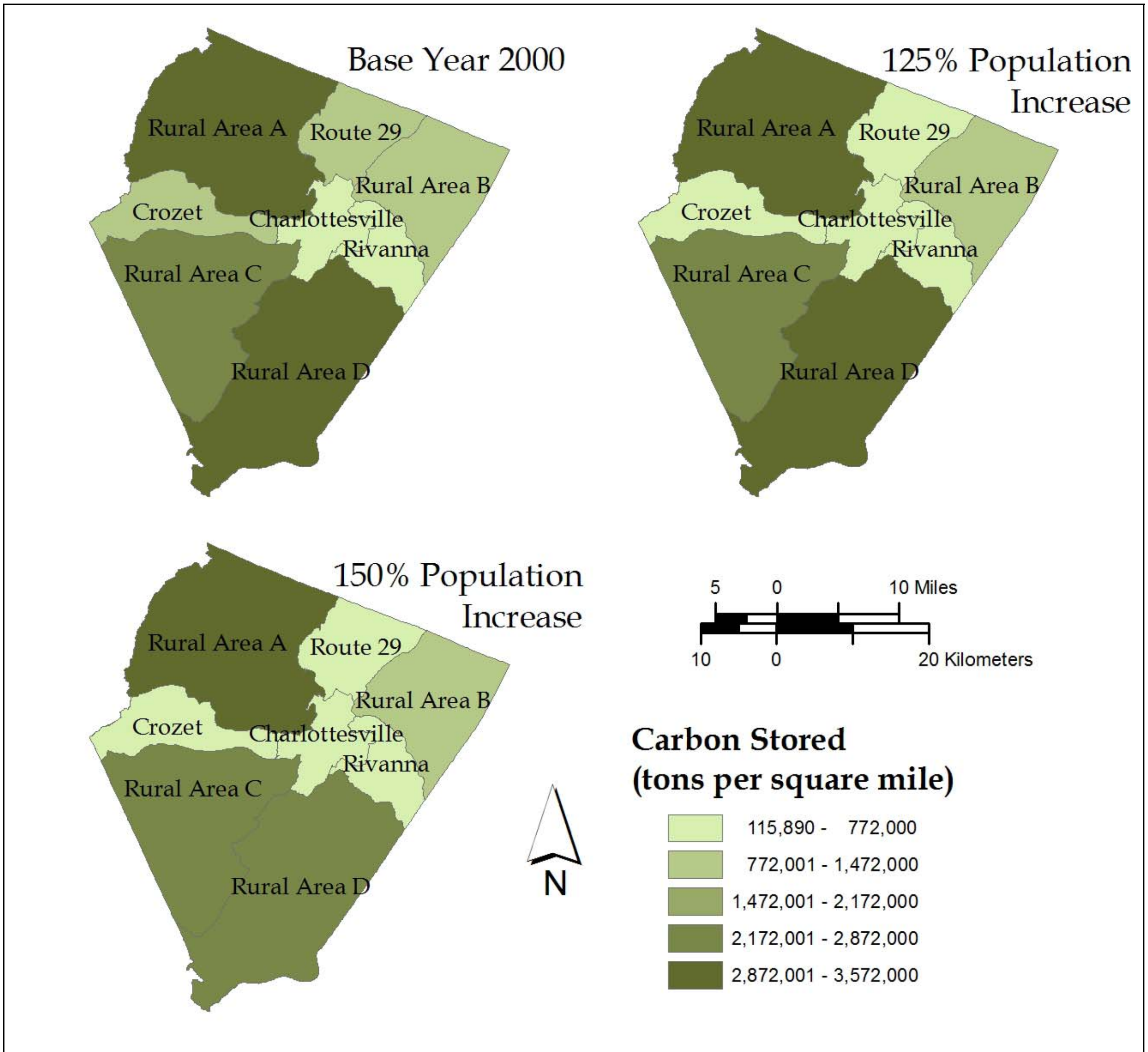

Figure 13. The quantity of carbon stored (tons per square mile) in the tree canopies by sub-study area. The difference between 125% and the 150% population increase illustrates the increased impacts of development in the rural areas of the study area.

4.2.2 Carbon sequestration

Carbon sequestration is another important component of an ecosystem's ability to manage carbon. Carbon sequestration refers to the removal of carbon from the atmosphere through physical or biological processes, such as photosynthesis, and is often expressed in tons of carbon sequestered per unit area per year. Like carbon storage, the analysis of carbon sequestration focuses on the role of forests in an area's ability to sequester carbon.

Trends in carbon sequestration are similar to carbon storage (Figure 14). The amount of carbon sequestered annually in the rural areas (especially A, C, and D) is consistently greater than the developing areas. These three rural areas account for 71.1% of the carbon sequestered annually in 2000. Rural area B's carbon storage and sequestration rates are lowest among the rural sub-study areas, likely due to having relatively lower forest cover and relatively higher coverage of pasture. At the 125% scenario these same areas sequester 78.0% of the carbon in the study area, reflecting the loss of carbon sequestration capacity in the developing sub-study areas and the importance of the rural areas for off-setting this loss. Rural area D sequesters the greatest amount of carbon annually until the 125% scenario when the carbon sequestration rate for this sub-study area drops steeply as it begins to receive overflow population from neighboring sub-study areas that have reached build-out. The amount of carbon sequestered by rural area A (well-forested and protected) is the highest among the sub-study areas beyond the 125% scenario.

In sum, we estimate that carbon sequestration rates were reduced 24.1% across the entire study area after a population increase of 150% (pop. 310,715). Even though the decline in carbon sequestration capacity appears gradual for the study area (dashed line in Figure 14), the developing areas experience rapid reductions in carbon sequestered due to lost forest canopy. As a whole the large tracts of forest in the rural areas makes up for these losses in the developing areas. However, continued development beyond the 125% population increase scenario (pop. 279,642) initiates a rapid decline in carbon sequestration in the rural areas.

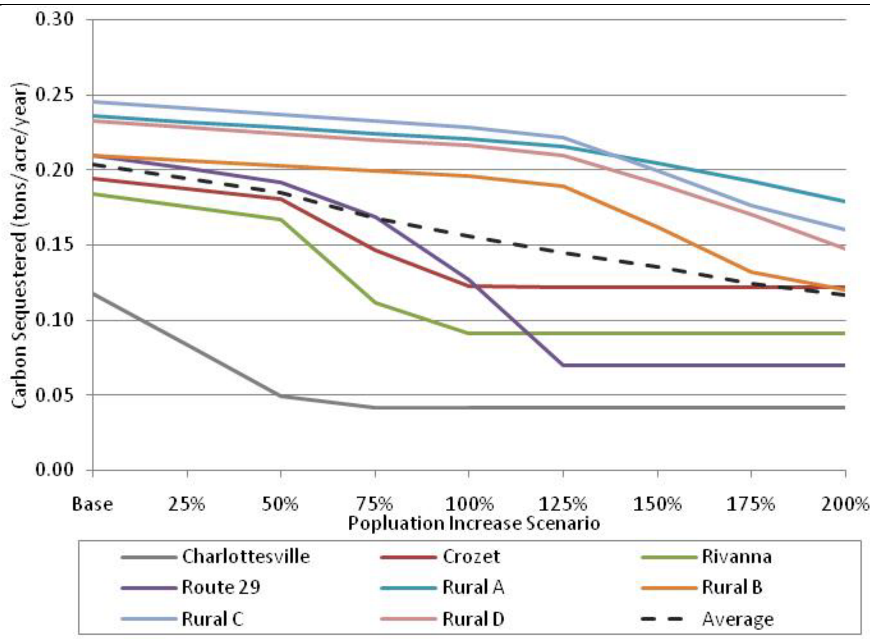

Figure 14. Tons of carbon sequestered per acre annually in the Albemarle County-Charlottesville Area based on estimations made with CITYgreen. For reference, mixed deciduous forests globally sequester 0.69 – 1.46 tons of carbon/acre/year (Watson et al. 2000).

4.2.3 Carbon monoxide

Carbon monoxide (CO) is a by-product of fossil fuel combustion and a primary source is motor vehicle exhaust. At high levels, CO has serious human health effects since it reduces the delivery of oxygen throughout the body. CO also contributes to the formation of smog. As with all atmospheric pollutants discussed here, trees remove carbon monoxide from the atmosphere by absorbing the gas through the surface of their leaves (EPA 2009).

Across the entire study area, carbon monoxide removal decreases by 4% during the 25 – 125% scenarios; for the 125 – 200% scenarios the rate of decrease is 6%. Beyond the 125% scenario the ability of the tree canopy to filter CO is reduced by more than 24% of the 2000 capacity. Again, the developing sub-study areas experience a decline in this ecosystem service first and the Route 29 sub-study area had the most rapid decline among all of the sub-study areas. Rural area B is the first of the rural sub-study areas to show diminished functioing of this ecosystem service (Figure 15). However, after the developing sub-study areas reach build-out declines in CO removal are widespread throughout the study area (Figure 15).

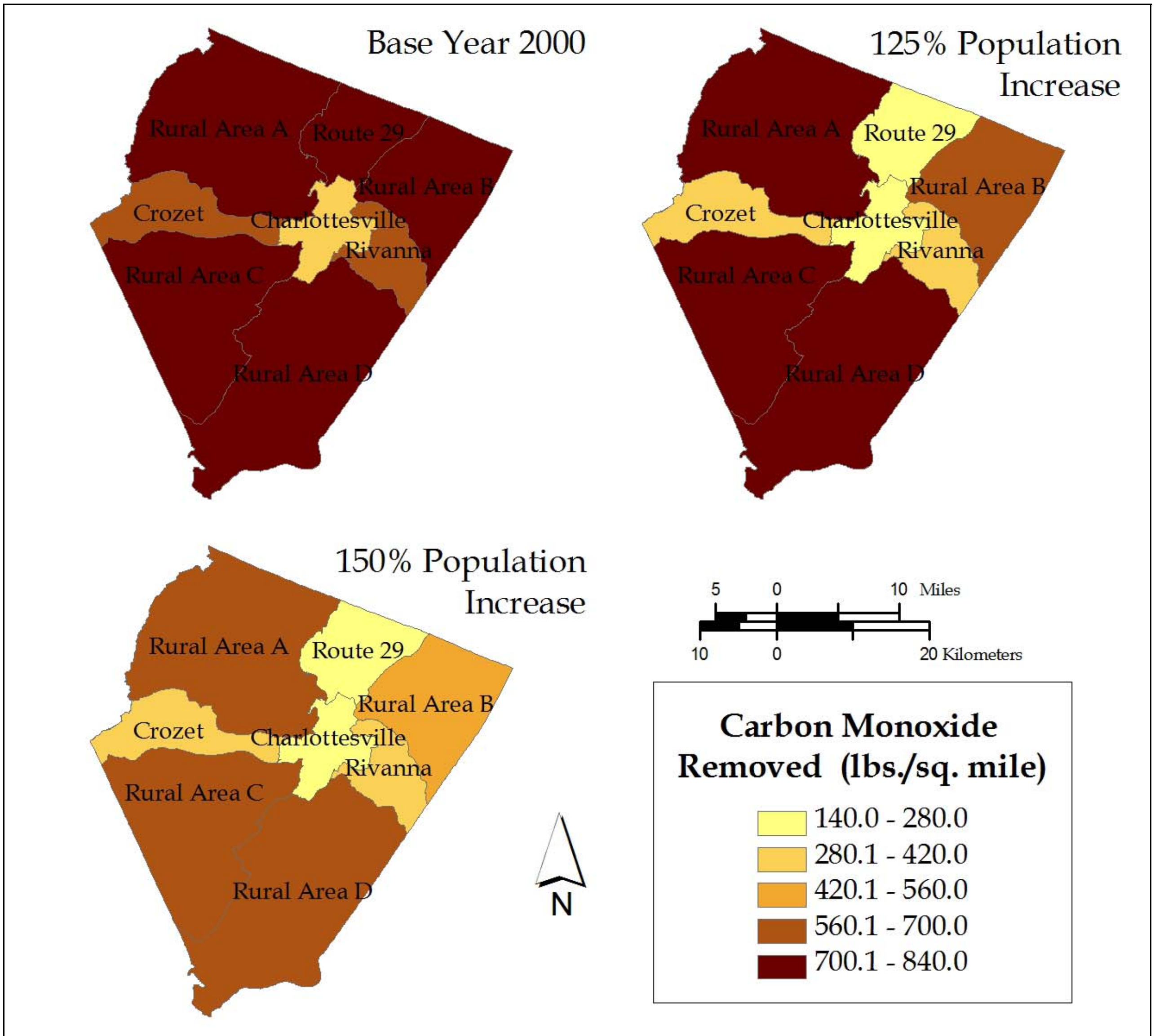

Figure 15. The decreasing rate of carbon monoxide removal by the tree canopy becomes widespread between the 125% and 150% population increase scenarios (pop. 279,642 and 310,715 respectively).

4.2.4 Ozone

At ground level, ozone (O_3) is usually created through the chemical reaction that occurs when nitrogen oxides (NO_x) and volatile organic compounds (VOCs) are exposed to sunlight. Ozone is therefore a principal component of smog, which is produced when sunlight and warm temperatures are combined with high levels of air pollutants (like NO_x and VOCs) from vehicle exhaust and other sources of emissions from fossil fuel combustion. Ozone poses a hazard to human health due to its negative effects on the respiratory system. Exposure to ozone can result difficulty breathing, particularly for those with respiratory illnesses, inflammation of the lungs, and permanent lung damage with repeated exposures. Ozone also has a negative effect on vegetation, causing damage to leaves and therefore decreasing plants' ability to produce and store food (EPA 2009).

The removal of ozone by the tree canopy decreases steadily over the population growth scenarios (Figure 16). The four developing sub-study areas make up approximately one-sixth of the total ozone removal service in 2000. The drop in service from the tree canopy following the 50% scenario coincides with the exhaustion of developable land in the Charlottesville sub-study area. It is also at this point that the ozone removal rate declines more rapidly in the remaining sub-study areas, falling to a plateau of lowered removal rates after the 125% growth scenario, when all of the developing sub-study areas have reached build-out. At the 150% population increase scenario total ozone removal is estimated to be reduced by 25%.

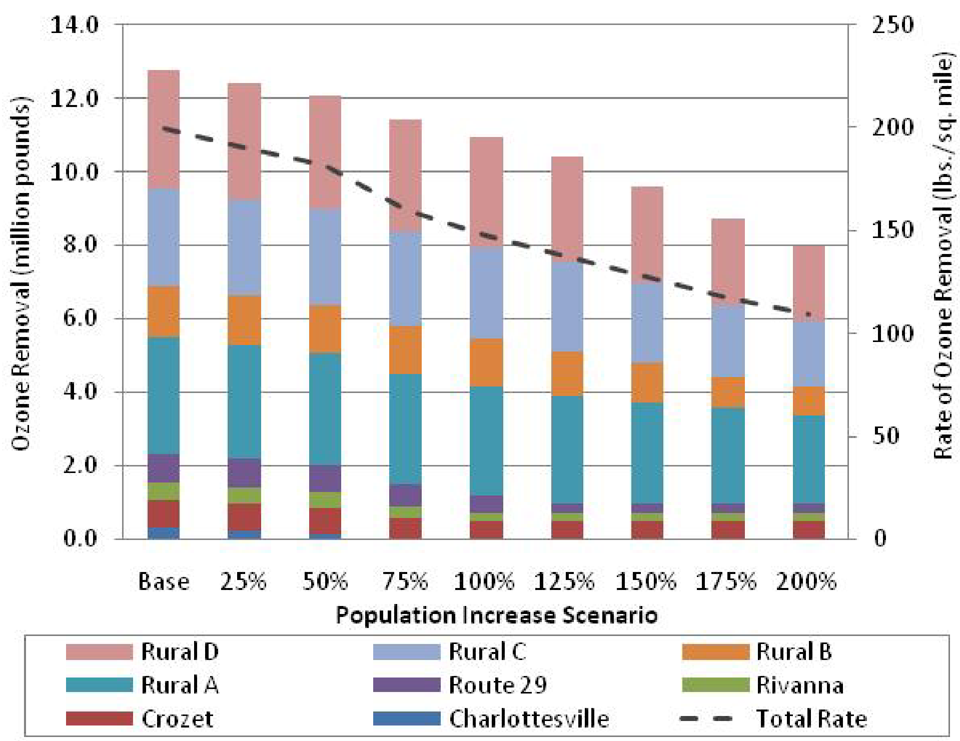

Figure 16. Annual ozone removal totals divided by sub-study area compared to the removal rate for the entire study area.

4.2.5 Nitrogen dioxide

Nitrogen dioxide (NO_2) is one of the nitrogen oxides (NO_x) mentioned above. In addition to being one of the primary contributors to the formation of smog, it also has negative human health effects, particularly on the respiratory system (EPA 2009).

The removal of nitrogen dioxide from the atmosphere decreases in a pattern similar to that of carbon monoxide and ozone. The decrease in this ecosystem service is incrementally greater with each population increase. Total nitrogen dioxide removal for the entire study area in the 125% scenario was 82.4% of 2000 levels; it is then estimated to fall to 76.0% in the 150% scenario. The spatial trend mirrors the pattern found in the carbon monoxide removal ecosystem service (Figure 17).

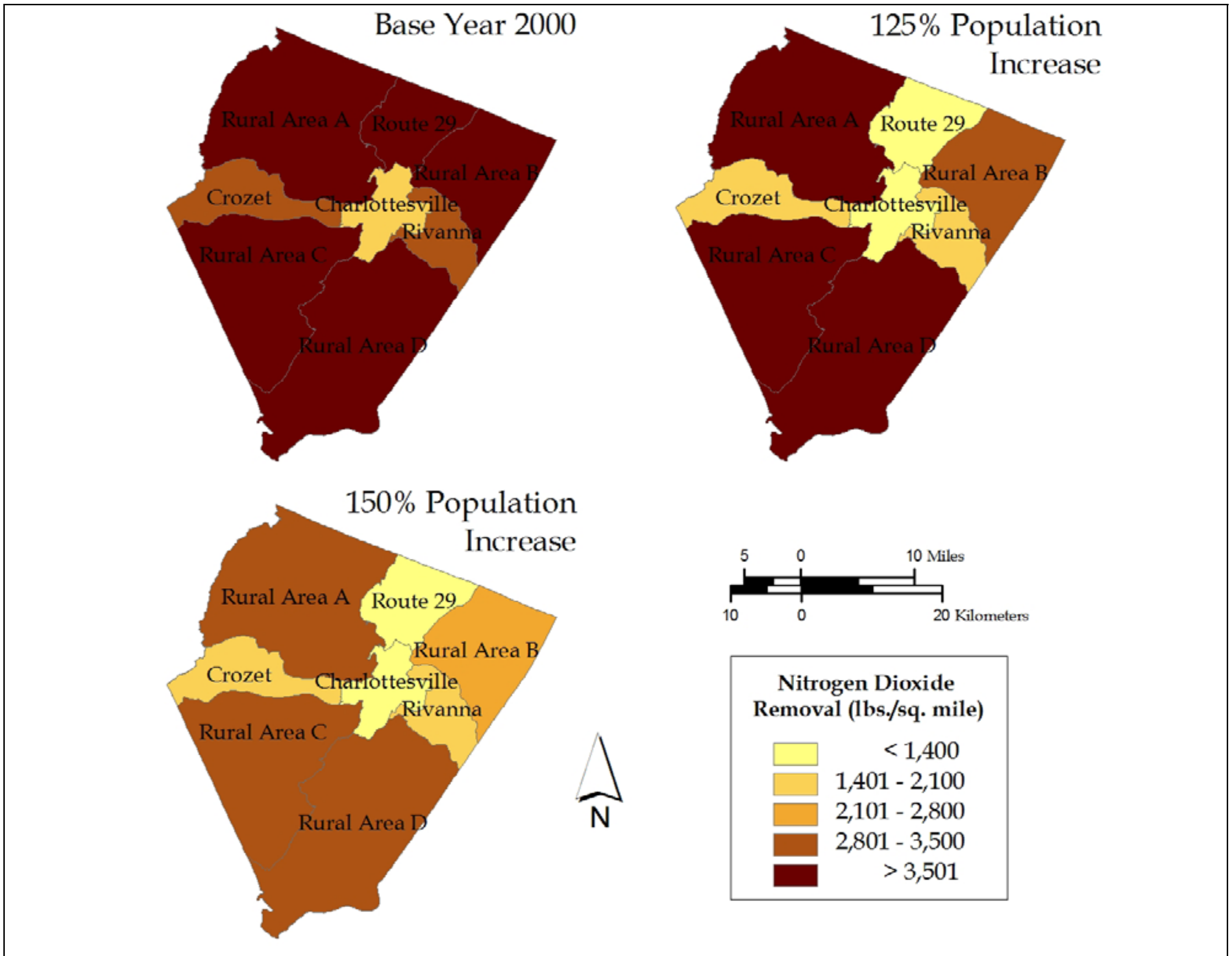

Figure 17. The rate of nitrogen dioxide removal (pounds/mile^2) by the tree canopy begins a widespread decrease across Albemarle County between the 125 and 150% population increase scenarios (pop. 279,642 and 310,715 respectively).

4.2.6 Sulfur dioxide

Sulfur dioxide (SO_2) belongs to a general class of sulfur oxide gases (SO_x) and is emitted into the atmosphere when fuels containing sulfur, such as coal and oil, are burned. In the air, sulfur dioxide can cause respiratory problems in humans. Because SO_2 dissolves readily in water, it has strong detrimental effects on water resources through the formation of acid rain or the acidification of surface water and soil through direct atmospheric deposition (EPA 2009).

Similar to the other atmospheric ecosystem services studied in this report, overall SO_2 removal rates decline steadily over the population growth scenarios, although differences among sub-study areas can be noted (Figure 18). After the 125% scenario, the developing sub-study areas have reached build-out so their removal rates stabilize at a low level. After the 125% scenario the lost service is widespread throughout the study area, with rural area B showing the greatest decrease (and lowest removal rate) among the sub-study areas.

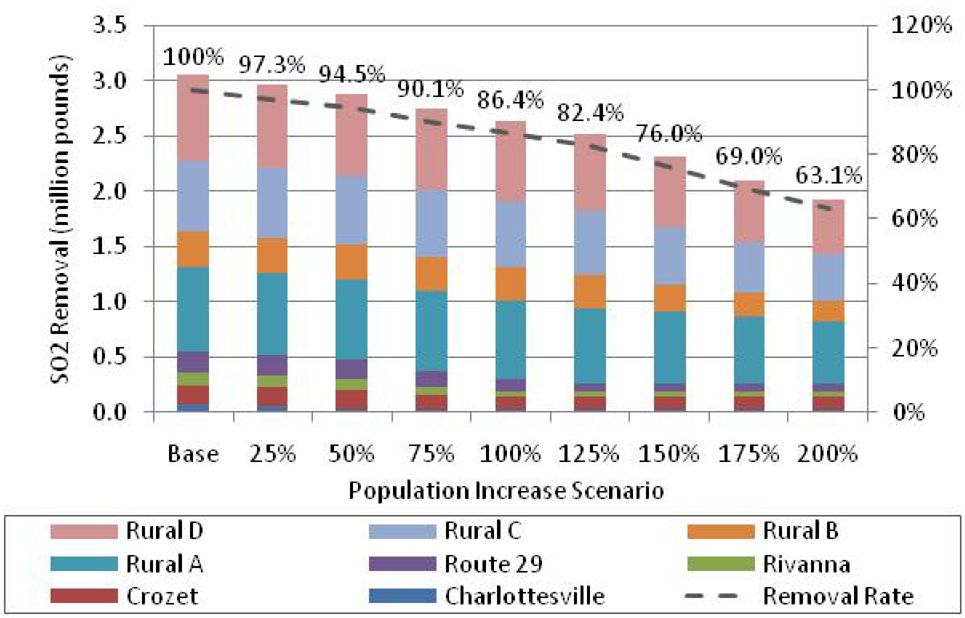

Figure 18. The removal of sulfur dioxide by the tree canopy by sub-study area. The total removal capacity trend is illustrated by the dashed line.

4.2.7 Particulate matter (PM10)

Particulate matter (PM) is a complex mixture of small particles and liquid droplets made up of elements that include acids, organic chemicals, soil and dust particles, and metals. Sources of particle pollution include dusty roadways and industries and forest fires, and they also can be formed when emissions from fossil fuel combustion chemically react in the air (i.e. as with smog formation) (EPA 2009). CITYgreen analyzes the absorption of particulates that are smaller than 10 micrometers in diameter (PM10). Particles in this size range are particularly harmful to human health, causing damage to the lungs and heart. Particulate pollution can also produce atmospheric haze and contributes to the acidification of water resources, among other environmental impacts (EPA 2009).

The rate of particulate matter removal exhibits slightly different spatial patterns in base year 2000 (Figure 19) as compared to other air pollution-related ecosystem services. The northeast corner of the study area begins with a low removal rate, likely due to the lower forest cover (and greater areas of pasture and/or development) in these sub-study areas (Route 29, Rivanna and rural area B). Rural area A has the highest removal rate until the 125% scenario, when the developing sub-study areas have reached build-out, and the trend of decreasing PM10 removal accelerates after this scenario. Overall, decreases in PM10 removal compared to year 2000 levels drop below 80% after the 125% scenario.

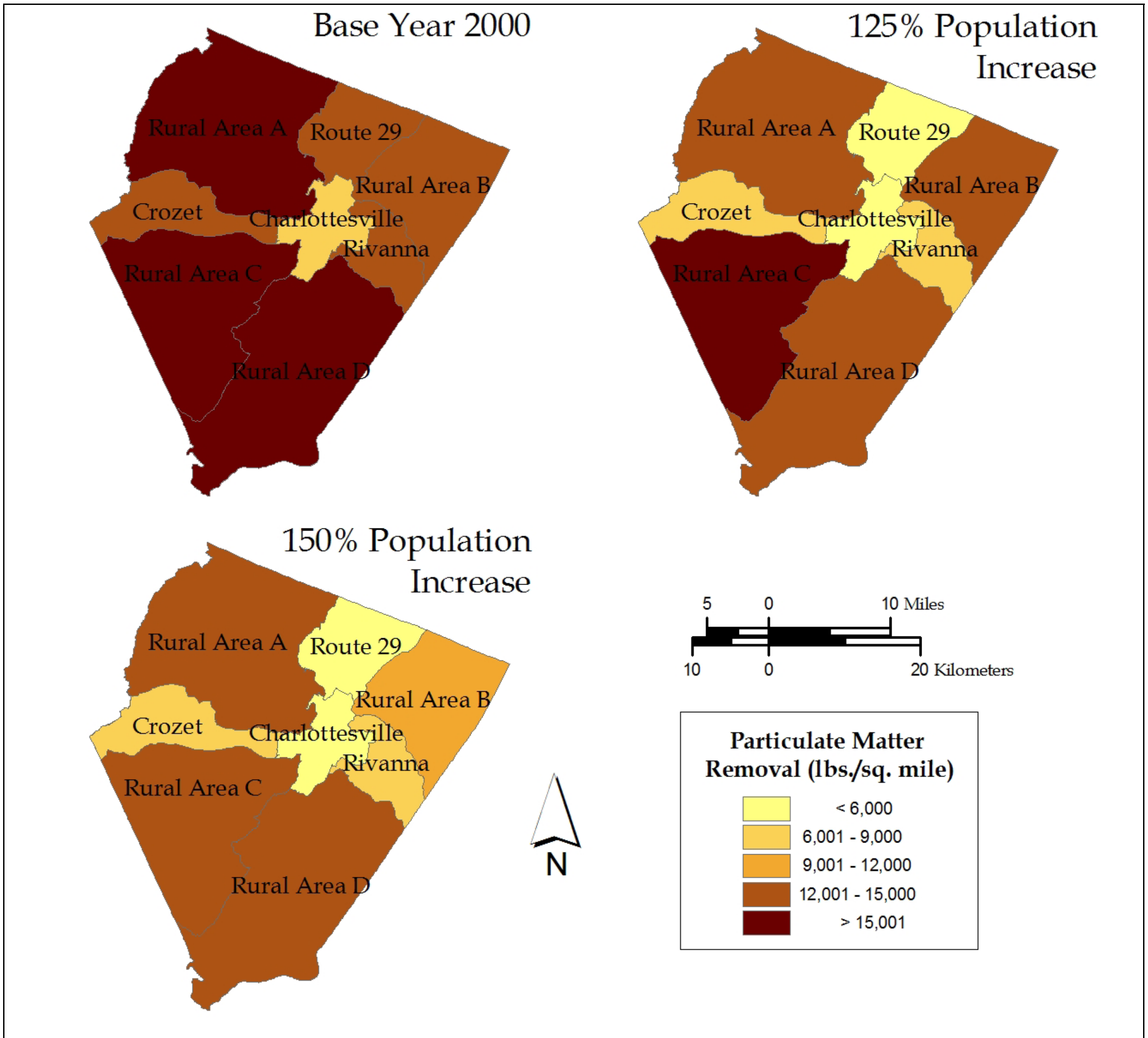

Figure 19. The removal rate (pounds/square mile) of particulate matter (PM10) by sub-study area for the Albemarle County-Charlottesville Area.

4.3 Impacts on water-related ecosystem services

The Virginia Department of Environmental Quality (DEQ) reports that of the rivers in the study area assessed for contaminants in 2008, most exceeded VA Water Quality Boards standards for at least one reason (VA DEQ 2008). Similar results were found in 2006 (EPA 2007). This illustrates that the current health of the river systems is already being degraded with about 10% of the study area developed in 2000. As expected, those areas experiencing the most development due to an increased population are projected to have the greatest increase in stream pollutants and stormwater runoff.

4.3.1 Stormwater runoff

As an area is developed, the increase in impervious surfaces and the loss of natural and semi-natural land cover prevents water from filtering through the soil or being take up by vegetation. Instead, rainfall runs directly off the land surface into streams and water bodies, resulting in an increased risk of flooding, "flashy" streams (where the water levels increase and decrease rapidly), greater stream bank erosion, and increased levels of pollutants entering streams (Jantz and Goetz 2007). The risk of increased stormwater runoff due to the development of open spaces is one of the few ecosystem services that are explicitly recognized and already regulated in the Albemarle County Code with the Water Protection Ordinance (Chapter 17).

Increases in stormwater runoff volume are observed in the study area as the population and level of development increases (Figure 20). The millions of cubic feet of water shown in Figure 20 are in addition to the runoff that already occurs and represent a volume of water that would require additional stormwater detention facilities. This analysis found rapid degradation of the study area's ability to mitigate stormwater runoff at two points: beginning with the 50% population scenario and then after the 125% scenario (dashed line in Figure 20).

We note, however, that because stormwater retention is an extremely localized ecosystem service it is difficult to draw conclusions for the entire study area; decreased runoff in one area will be off-set by an increase in another region. Crozet, for example, shows a net stormwater runoff of 352, 772 ft^3 at build-out. But Crozet- East (the eastern division of the Crozet sub-study area, Figure 5) is estimated to produce 1,015,556 ft^3 of runoff after a just a 25% population increase. In this case, the stormwater retention capabilities of the central and western divisions of Crozet appear to offset the effects of the runoff generated in Crozet-East.

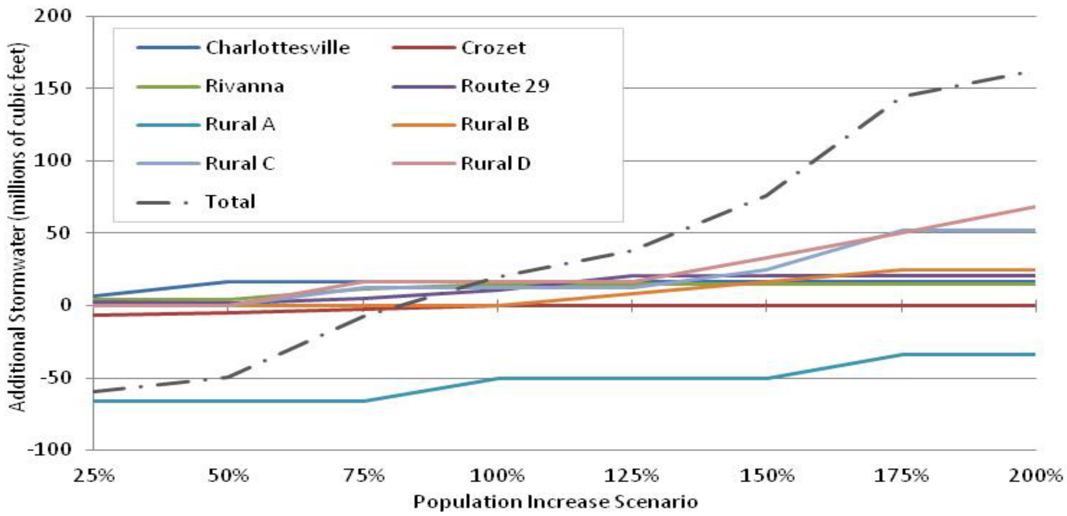

Figure 20. Stormwater produced from new development by sub-study area on an annual basis.

Another interesting result that is observed in Figure 20 is the negative stormwater runoff values for rural area A and Crozet. This indicates that stormwater runoff actually *decreased* as development occurred in these sub-study areas. These results can be explained by the soil type in these areas, the type of development projected to occur, and by the assumptions that the model makes regarding stormwater management techniques. For example, eighty-eight percent of the development in rural A consists of single-family homes on one-acre lots. When this type of development is located on soils with relatively low infiltration rates (e.g. hydrologic group C), it is estimated to produce the same quantity of runoff as a pasture (American Forests 2004). Indeed, the soils along the western border of Albemarle County, particularly within rural area A and Crozet, have a low infiltration rate. The hydrologic model used by CITYgreen, TR-55, assumes that greater stormwater management will accompany new development than is expected of a pasture, resulting in a net decrease in runoff. This assumption is not unrealistic, since Albemarle County's Water Protection Ordinance requires stormwater management at sites of new development, while stormwater management requirements for agricultural land are minimal.

Stormwater management in the developing areas is a concern even given low levels of population growth. Modest population growth in Charlottesville and Rivanna is estimated to result in over 2 million cubic feet (nearly 15 million gallons) of stormwater runoff annually for each sub-study area (Figure 21). The Route 29 sub-study area experienced an increasingly rapid increase in stormwater runoff after a 15% population increase (pop. 14,327 for the Rivanna sub-study area). Again, negative stormwater runoff values in Figure 21 indicate initial decreases in runoff with new development, given the infiltration rate of the soils and the assumed stormwater management controls that would be put in place with new development.

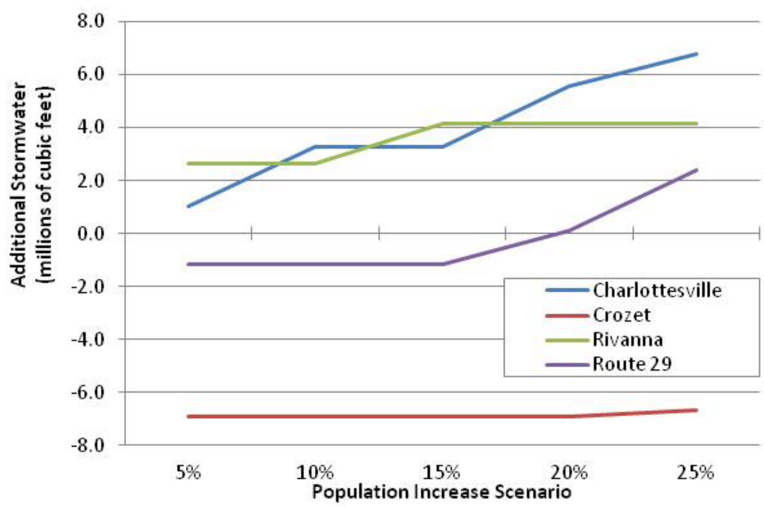

Figure 21. Additional stormwater runoff predictions for the developing sub-study areas. This graph illustrates the volumes of runoff that could be produced by even modest population growth.

4.3.2 Nitrogen loading

Nitrogen (N) is an essential plant nutrient. Too much nitrogen in an ecosystem, however, has negative impacts, especially on water resources. When a water body accumulates too many nutrients (a condition referred to as eutrophication), algae populations explode, causing an algae bloom on the surface of the water, preventing sunlight from reaching sub-surface habitats. Furthermore, as the algae die, the process of decomposition consumes the oxygen needed by other aquatic life. Sources of nitrogen include chemical fertilizers applied directly to the land for crops and lawns, animal manure, treated and untreated wastewater, septic systems, and emissions from fossil fuel combustion (Mueller and Helsel 1996). Forests, vegetated riparian zones and wetlands serve to absorb excess nutrients before they enter surface water or groundwater.

As noted in Section 3.4.2, results for nitrogen and phosphorous are presented for sub-watersheds instead of sub-study areas, and baseline conditions are derived from the SPARROW model. Current nitrogen-loading values correspond to current levels of development, and high loading values are particularly evident in the Charlottesville area (base year 2000, Figure 22), likely due to the wastewater treatment plant and high levels of urbanization in this sub-watershed. This sub-watershed drains the southern portion of the Charlottesville area before the Rivanna River travels to the east. With population growth, the developing sub-study areas again show the greatest impacts, although by the 150% scenario nitrogen loading in the sub-watersheds of the rural areas has increased.

The average increase in nitrogen loading at the 125% scenario was 9.7% for the sub-watersheds used in this analysis (excluding the sub-watershed of the southern portion of Charlottesville which was treated as an outlier due to its much higher loading values). At the 125% population increase scenario, percent increases in nitrogen loading are prominent in all four of the developing sub-study areas (Figure 23). Percent increases in the rural areas are less dramatic, especially in rural area A, where much of the forested land is protected and where stormwater management is assumed to effectively mitigate the effects of development.

Given that these estimates only represent locally generated nitrogen, there may be a significantly greater accumulation of nitrogen in the downstream reaches of southern Albemarle County. This could occur as early as the 75% scenario where mean nitrogen loading rates jump to 6.22% from base year 2000 levels, up from just 3.77% following the 50% scenario.

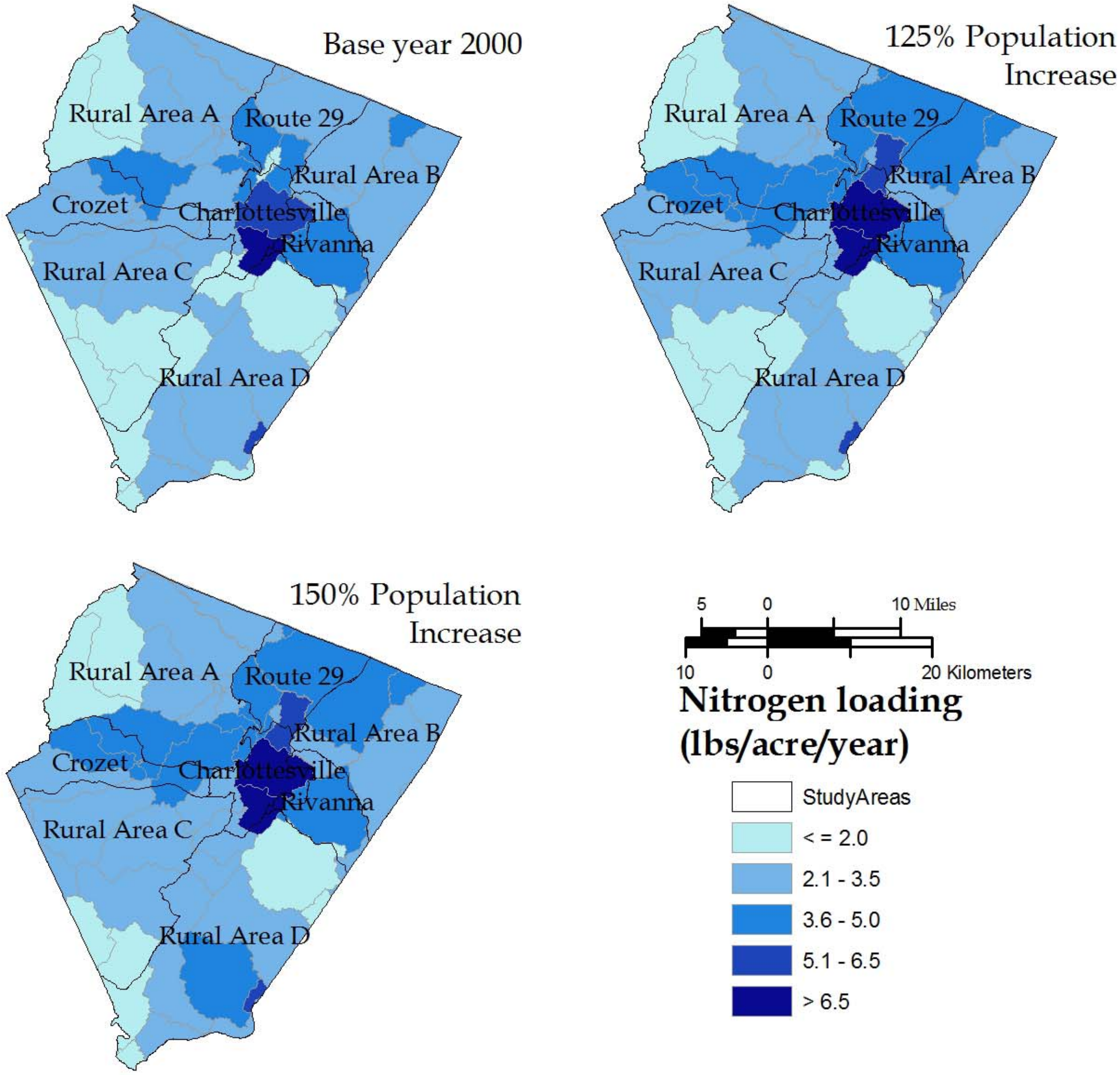

Figure 22. Nitrogen loading levels based on SPARROW estimates for loading rates for the year 2000 (pounds/acre/year).

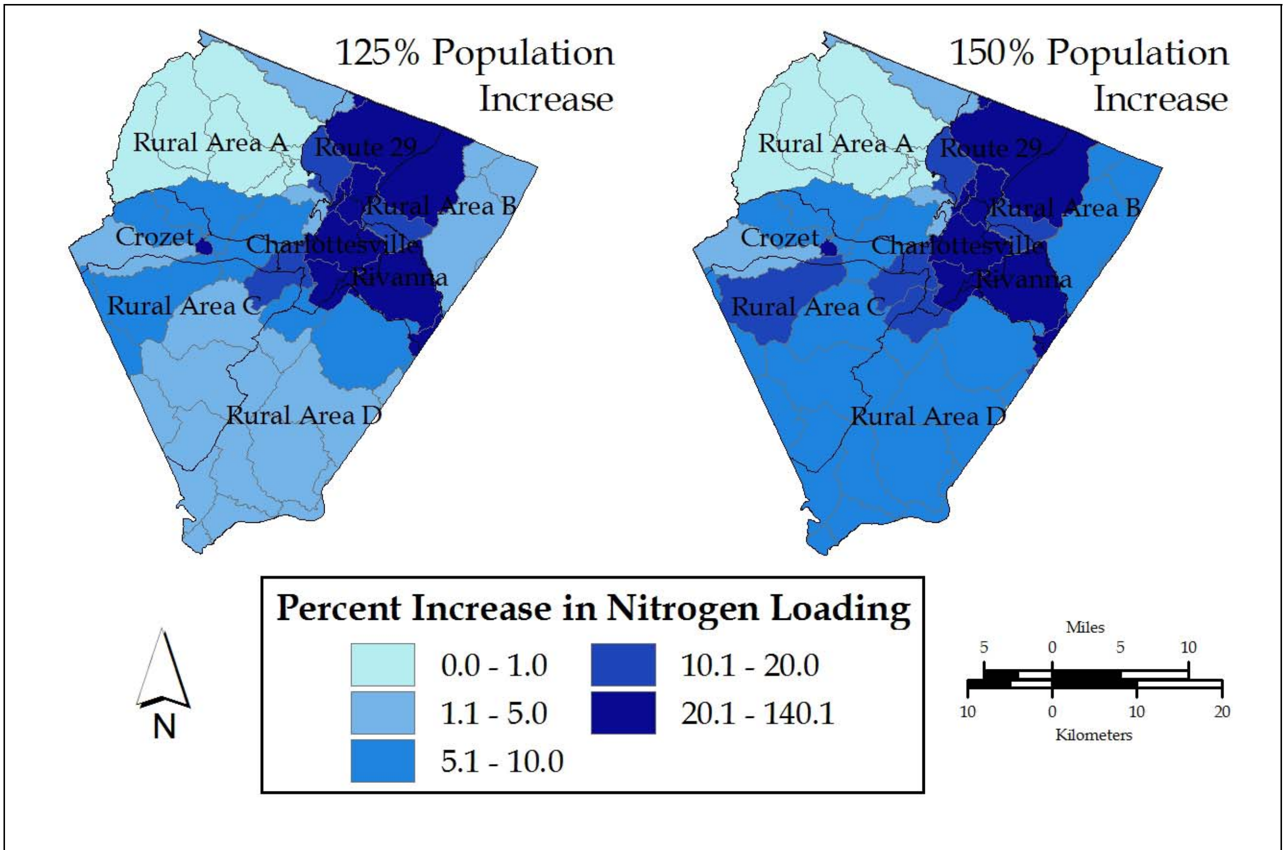

Figure 23. The percent increase in nitrogen loading in sub-watersheds. The 125% population increase represents when the developing sub-study areas reach build-out and thus the rural areas are significantly impacted: the proverbial tipping point for this study area.

4.3.3 Phosphorous loading

Like nitrogen, phosphorous (P) is an essential plant nutrient and, more so than nitrogen, often serves as the limiting factor in plant growth. This means that excess phosphorous is often the trigger for algae blooms in water bodies. Sources of phosphorous are similar to those of nitrogen, although urban and suburban areas play a larger role in producing excess phosphorous than farmlands (on a per acre basis) due to the widespread use of lawn fertilizers (Mueller and Helsel 1996).

Patterns in phosphorous loadings as a result of population increase are unique, since phosphorous is the only pollutant in this analysis that impacted such a large proportion of the study area before the 125% population increase scenario. Increased phosphorous loading becomes widespread across the southern and eastern sub-watersheds at the 75% population increase (Figure 24). The Rivanna and rural area D sub-study areas are estimated to experience the greatest increases in phosphorous loading compared to base year 2000 (Figure 25). At the 125% threshold identified with the other contaminants, the entire eastern half of the county has phosphorous increases greater than 50%. These observed patterns are likely due to the fact that developed land is assumed to have higher rates of phosphorous loading than the pastures and forests it is replacing. In contrast, rates of nitrogen loading are similar for some developed land uses and pasture.

Similar to estimates of nitrogen loading, the distribution of increased loading rates at the downstream reaches of the watershed may indicate an earlier threshold for this ecosystem service. Without evidence for in-stream losses of phosphorous (or nitrogen), no conclusions can be made here regarding the accumulation of increasing contaminants at the most downstream reaches of the Rivanna River watershed in Albemarle County.

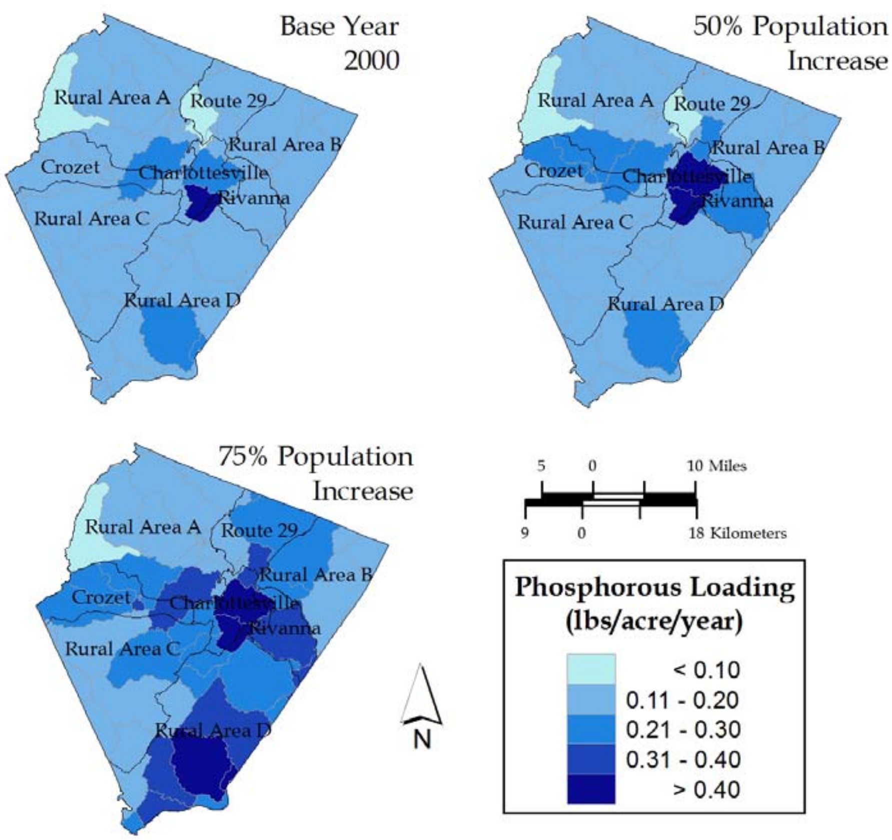

Figure 24. Phosphorous loading rates (pounds/acre/year) based on the SPARROW model estimates for Base Year 2000 (USGS 2004).

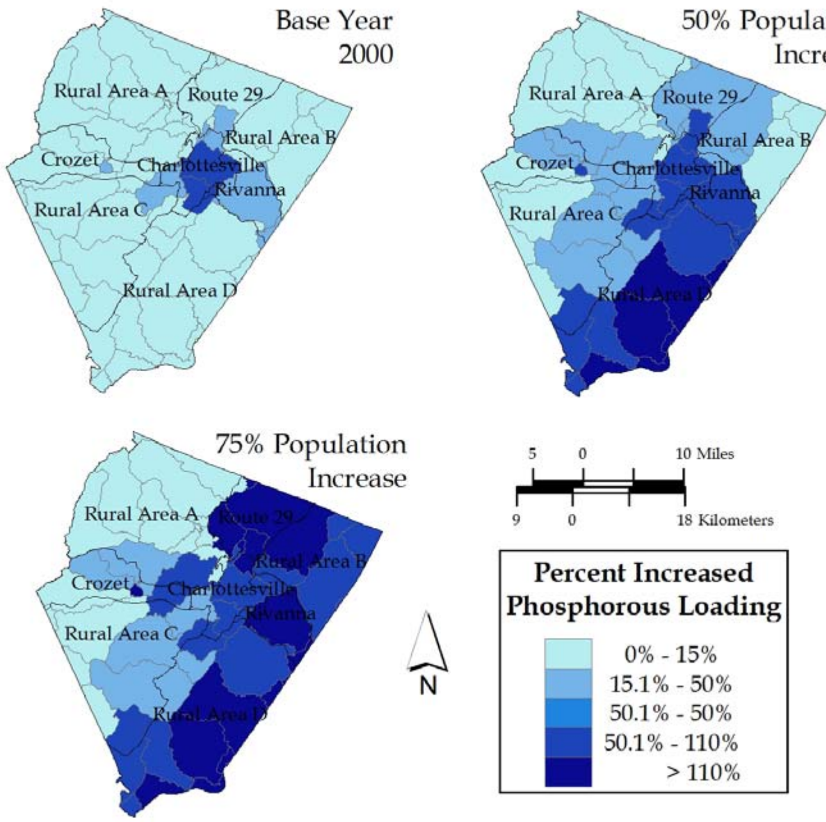

Figure 25. The relative increase in phosphorous loading levels in local streams based on SPARROW (USGS 2004) estimates for Base Year 2000.

4.3.4 Biological oxygen demand

Water bodies both produce and consume oxygen. Oxygen is produced through atmospheric exchange and by aquatic plants. The respiration of aquatic organisms, the process of decomposition, and other chemical and biological processes consume oxygen. Biological oxygen demand (BOD) is the total amount of oxygen consumed by these processes (EPA 2007). In eutrophic water bodies, BOD often increases due to the decomposition of algae. In these cases, oxygen dissolved in the water is used by the microorganisms that are breaking down the dead algae, making it unavailable to other forms of aquatic life. In some cases, levels of dissolved oxygen can drop so low that no aquatic life can survive, producing what are known as “dead zones” in the water body—a phenomenon that is well documented for the Chesapeake Bay (Jantz and Goetz 2007).

In the Albemarle County-Charlottesville area, the greatest increases in biological oxygen demand were in Route 29 and rural areas C and D (Figure 26), which correspond to the areas that are also expected to experience higher nitrogen and phosphorous loadings. The 125% scenario is estimated to have the greatest BOD increase in the developing sub-study areas. The rural sub-study areas, except for rural area A, are estimated to experience rapid increases in BOD: a 20% increase in rural area B; a 27% increase in rural area D; and rural area C's BOD increase doubles after each scenario following the 125% scenario. Because we do not have baseline data for current BOD in streams, these results must be interpreted with caution. For example, even though the most dramatic percent increases in BOD are observed in some of the rural areas, the baseline levels for BOD might be quite low.

Another interesting finding is that rural area A did not exhibit an increase in BOD under any of the scenarios. Rural area A experienced minimal increases in nitrogen and phosphorous loading and an overall decrease in runoff due to the effects of stormwater management. Since nutrient pollution and increased stormwater runoff would be the drivers for increases in BOD, the fact that the ecosystem services that mitigate N and P levels remain intact in rural area A is underscored by these results for BOD.

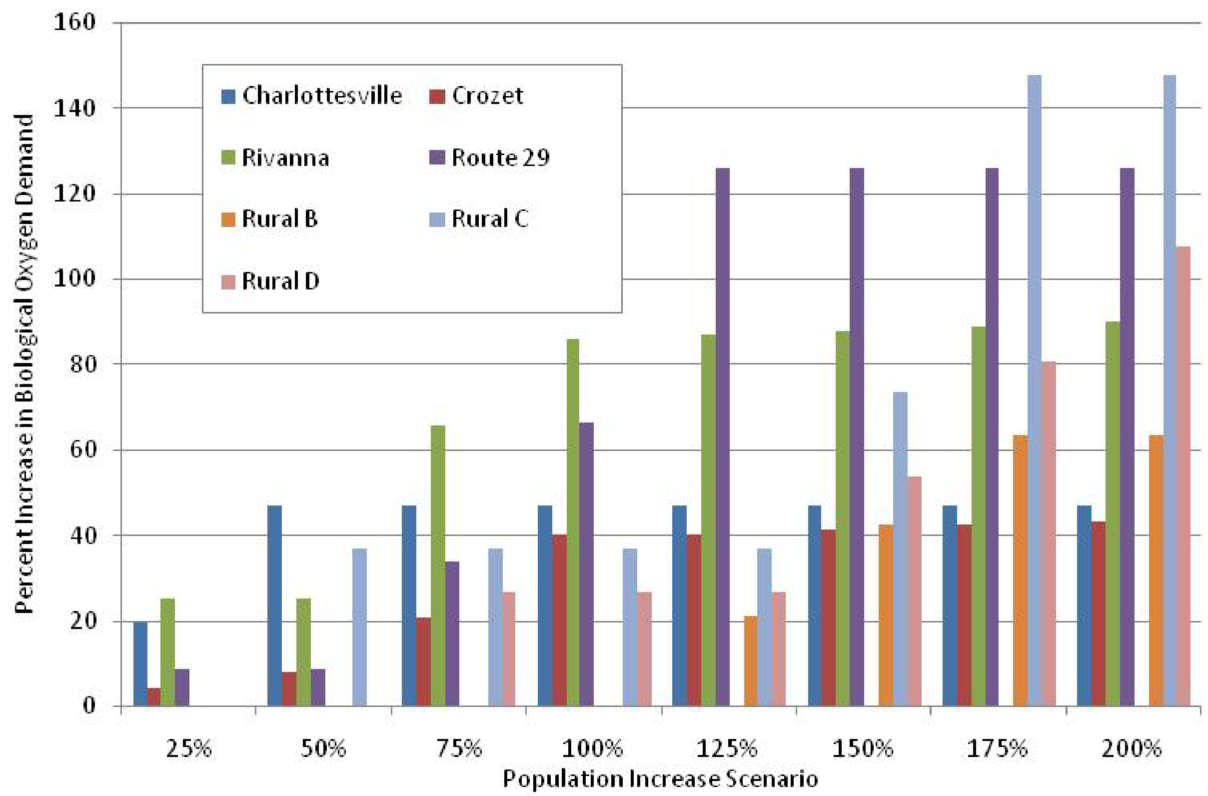

Figure 26. Increases of biological oxygen demand (BOD) for each sub-study area in the study. Note that Rural Area A was not estimated to have an increase in BOD under these scenarios.

4.3.5 Impacts on the biotic health of streams

As noted in section 3.4.3, increases in impervious surface that often accompany population growth have documented and predictable negative impacts on the biotic health of streams. The Charlottesville sub-study area is already beyond the 10% impervious surface area (ISA) threshold—the threshold at which biotic health tends to decline (Figure 27). All of the developing sub-study areas surpass the 10% threshold with a 100% population increase. Route 29 was the last developing sub-study area to reach build-out and it had the greatest relative increase in ISA of the developing sub-study areas. None of the rural areas passed the 10% threshold in this analysis; rural area C had the greatest ISA of the rural areas during the 200% scenario (8.0% ISA).

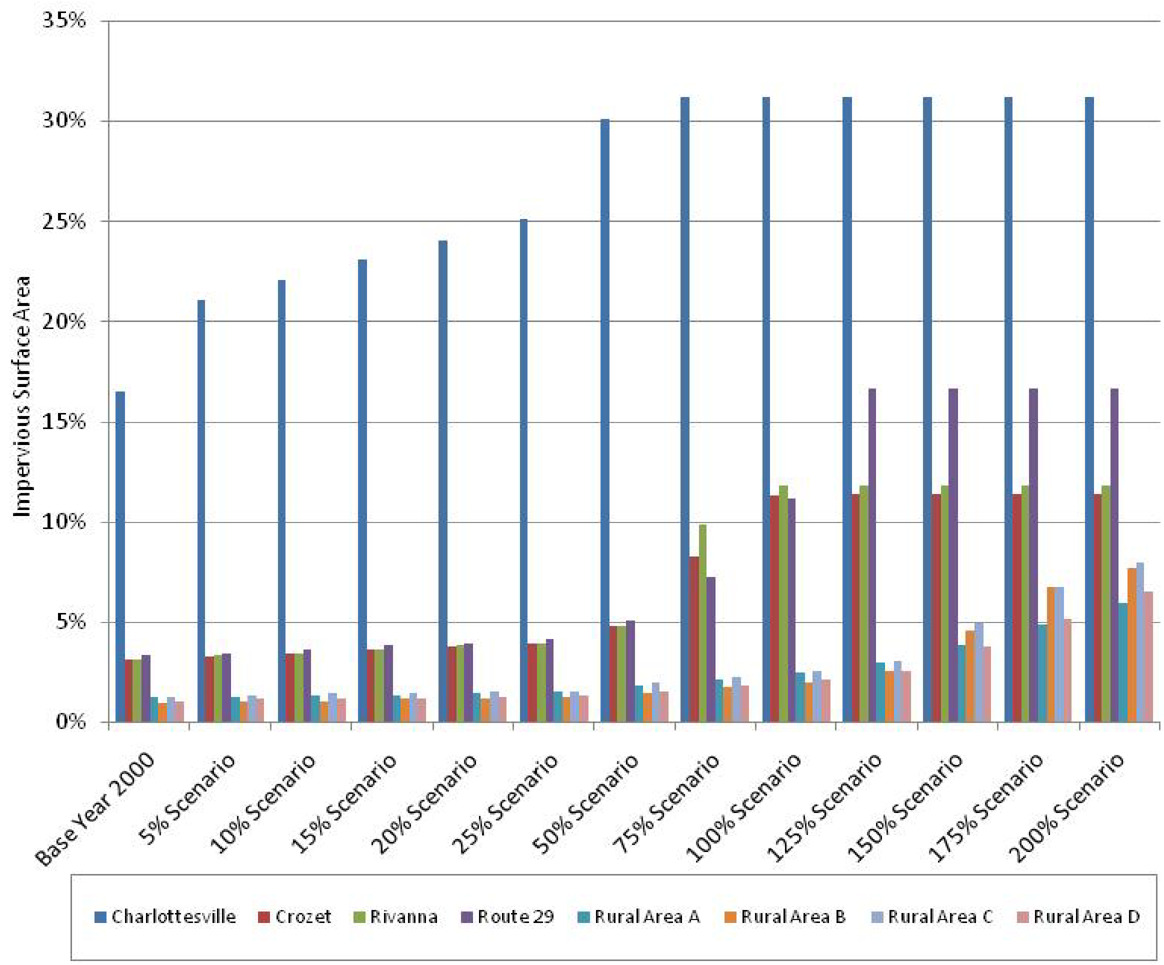

Figure 27. Estimated impervious surface area for the sub-study areas. Significant degradation at the 10% threshold has been observed in other locations in the Chesapeake Bay watershed (Goetz and Fiske 2008).

5.0 Discussion of projected growth scenarios

The results presented above can now be discussed and interpreted at a broader level. As discussed in section 3.3, growth scenarios were designed to increase population incrementally across the whole study area, and then population was allocated to the eight sub-study areas. However, due to some areas reaching build-out, the growth rates within the remaining sub-study areas were often higher than that for the study area as a whole. This process resulted in non-linear trends of land use change (Figure 10), and non-linear (but consistent) trends in how ecosystem services were impacted. Specifically, based on consistent trends observed in how ecosystem services respond to different levels of population growth, the population growth scenarios can be partitioned into four groups based on the observed patterns:

1. The 5 – 20% scenarios represent the impacts of moderate population growth in the study area;
2. The 25 – 75% scenarios represent targeted growth in the developing sub-study areas (Charlottesville area, Crozet, Rivanna and Route 29) and reflect the impacts of the Charlottesville sub-study area reaching build-out;
3. The 100 – 125% scenarios represent the remainder of targeted development in Crozet, Rivanna and Route 29 at which point these sub-study areas reached build-out; and
4. The 150 -200% scenarios represent a shift towards increased development of the rural areas.

5.1 5 – 20% Scenarios

The 5 – 20% population increase scenarios represent an opportunity to estimate what could happen given modest population growth—growth levels that could occur in the near future. A key finding here is that Charlottesville seems to have already passed a critical threshold and exhibits rapid declines even with small population increases. After a 5% population increase the Charlottesville sub-study area produces an additional 1,025,707 ft^3 of stormwater runoff and loses 6% of its current carbon storage and sequestration capacity.

In terms of broad trends in air-related ecosystem services, the capacity of the tree canopy to filter air pollutants decreases by less than one percent between each of these four scenarios: 0.61%, 0.47%, 0.51%, and 0.60% respectively (Table A4). After the 5% scenario there is a trend of increasingly greater losses in the air-filtration capacity of the tree canopy.

For water-related services, rates of increase in nitrogen begin to the east of Charlottesville, largely in the Rivanna sub-study area, but remain confined to the developing sub-study areas (Figure 28). Phosphorous loading estimates follow a similar pattern over these scenarios (Figure 29), except there is a greater increase in the Route 29 sub-study area at the 20% scenario. Increases in BOD are less than one percent across the study area.

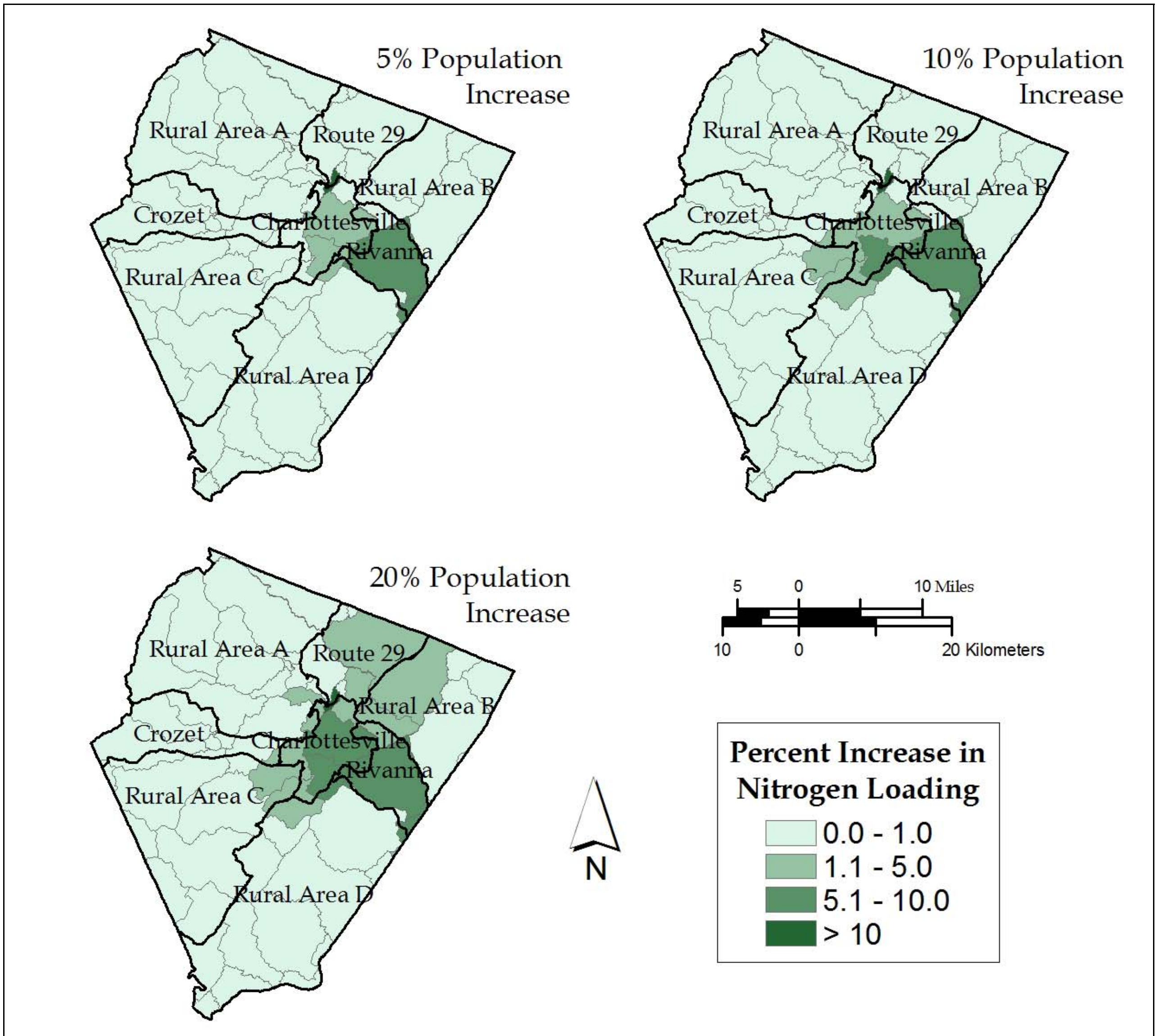

Figure 28. The rate of increase in nitrogen loading during the 5%, 10% and 20% population increase scenarios compared to Base Year 2000.

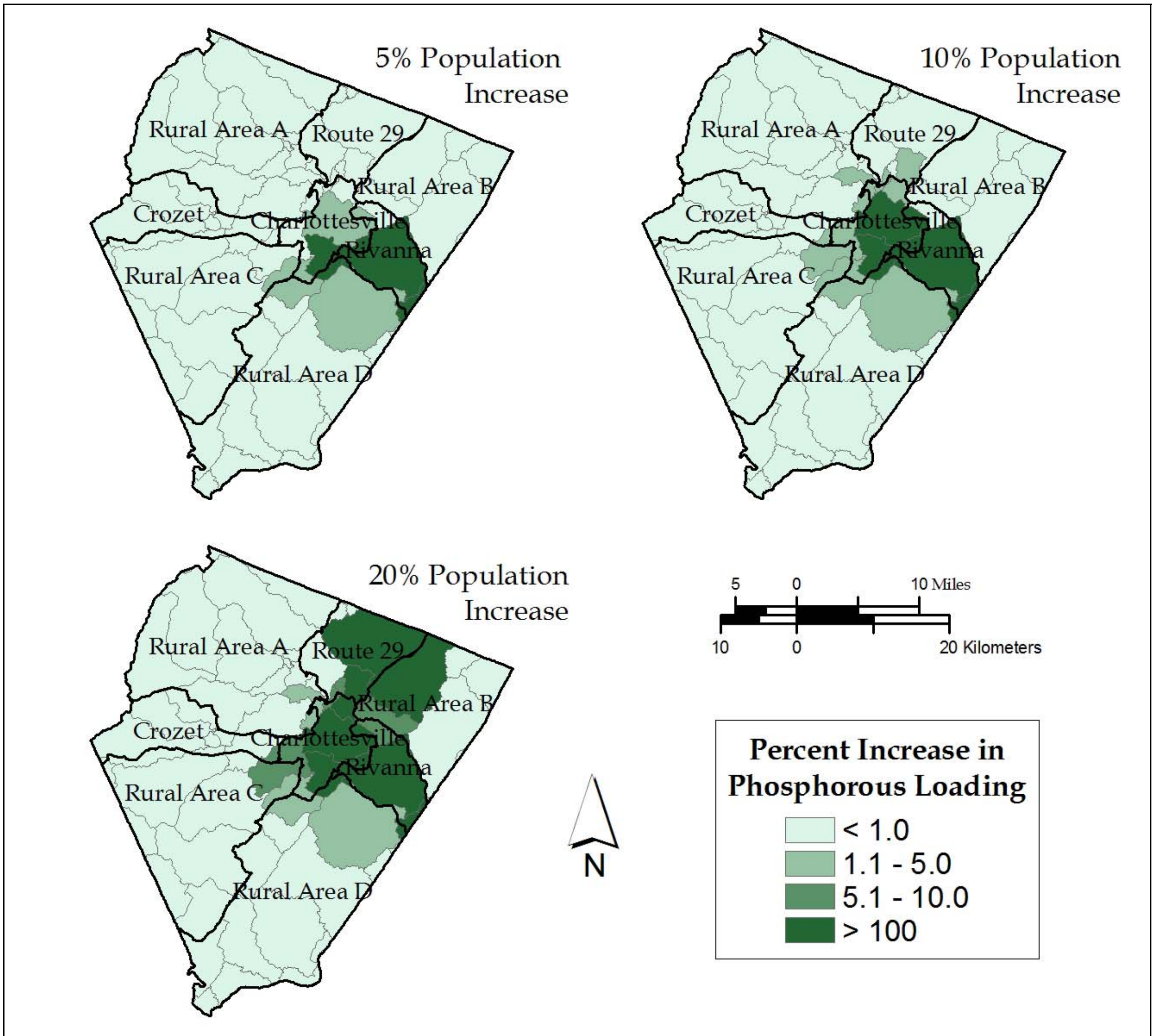

Figure 29. The rate of increase in phosphorous loading during the 5%, 10% and 20% population increase scenarios compared to Base Year 2000.

5.2 25 - 75% Scenarios

This set of scenarios is defined by targeted development in the Charlottesville area, Crozet, Rivanna, and Route 29, with the Charlottesville area reaching build-out between the 50 and 75% scenarios and sending overflow population to the other developing sub-study areas. The loss of the Charlottesville area as a location for development is felt across the entire study area. After the Charlottesville area reaches build-out (with a 55% increase in population), stream contaminant loading increases by more than 100% between the 50% and 75% scenarios. The tremendous increase in phosphorous loading (Figure 24) begins between these two scenarios with a leap from 7.1% to 41.8% increased loading rates. The overall capacity to remove airborne pollutants in the developing sub-study areas is dramatically impacted at this population level, although tree canopies in the rural areas are not significantly impacted by this population level.

5.3 100 and 125% Scenarios

All four of the developing sub-study areas reach build-out by the 125% population scenario (total pop. 279,642), and developed land is projected to increase from 10% in 2000 to 27%. A key finding for this set of scenarios is that until the population increases by 125%, the degradation of ecosystem services is contained *within the developing areas*. After this scenario, degradation becomes far more widespread, impacting all of the rural areas. The dramatic increase in phosphorous loading in streams that occurred at the 125% scenario exemplifies that pattern (Figure 25).

At the level of the entire study area, the continued functioning of the rural areas masks the degradation occurring in the developing regions. Once the rural areas begin to experience population growth pressure, however, ecosystem services rapidly decline across the study area. Trends in carbon storage (Figure 12) and carbon sequestration (Figure 14) lend support to these statements. Over the study area as a whole, rates of carbon storage and carbon sequestration seem to fall gradually, but there are dramatic losses that occur in the developing sub-study areas while the rural sub-study areas are able to maintain relatively high rates until the 125% scenario.

The Route 29 sub-study area stands out as the area that experiences the most severe declines in ecosystem services, losing 56% of its open space by the 125% scenario. Of the areas targeted for development, the Route 29 sub-study area has the most land available for development and a moderate land consumption ratio. This explains why it is able to accommodate the greatest population overflows from the Charlottesville area, Crozet, and Rivanna and why the model projects its loss of ecosystem services to be the most dramatic.

5.4 150 - 200% Scenarios

In the final three scenarios, only rural areas B and C reach build-out between the 175 and 200% scenarios. Degradation of ecosystem services is less intense than in the preceding scenarios since the downward trends in the growth areas have stabilized due to build-out. An interesting finding here is that rural area A experiences the least degradation of ecosystem services for all of the population growth scenarios. Aside from the Charlottesville area, rural area A begins with the lowest amount of developable land (30.2% for Charlottesville and 31.8% for rural area A, see Table 3). The difference between these two sub-study areas is that Charlottesville had already built on much of its available land by 2000, while rural area A's limited amount of developable land was due to the protections put in place on its forests and farms. In fact, much of the forest land in rural area A is protected from development, a key reason why ecosystem impacts in this rural area are minimized.

6.0 Conclusions

Objective 4: Identify limits to growth

Steps:

1) Observe trends in ecosystem services for each population growth scenario. When an ecosystem service begins to decline rapidly, assume an unsustainable trend towards collapse.
2) Discuss and analyze trends for each sub-study area and for the study area as a whole. Draw conclusions about a sustainable population size.

As noted in the introduction, the ultimate goal of the OSPS Project is to help estimate a sustainable population size, recognizing that there are limits to growth even at a community level. This component of the OSPS Project has focused on how ecosystem services respond to different levels of population growth. Given the above analysis and discussion, conclusions can now be drawn regarding the ability of the ecosystems in the Albemarle County-Charlottesville community's to cope with population growth.

This study shows that, given current land consumption patterns, there are two population thresholds of importance. First, after a 50% increase in population (total population of 186,429), ecosystem services in the developing sub-areas of Crozet, Route 29 and Rivanna begin to decline rapidly when Charlottesville runs out of developable land. The loss of services in the Route 29 area is exceptionally dramatic. Second, after a 125% increase in population (total population of 279,642), ecosystem services in the rural areas begin to experience decline when the developing sub-study areas reach build-out.

These results suggest two population thresholds for the study area, assuming that the current planning strategy of directing growth into the developing areas and preserving the rural areas remains intact. If the community wishes to maintain ecosystem services across the study area, a population of roughly 200,000 or less should be maintained, with that growth being focused in the growth areas. If it is acceptable to sacrifice services in the developing areas, a population up to roughly 300,000 could be accommodated. Beyond this level, the study area loses its capacity to accommodate population in the developing areas and ecosystem services in the rural areas begin to be compromised.

It is clear from these findings that the community needs to balance the needs of the entire area with local ecosystem health. As is already articulated in the current comprehensive plan for Albemarle County, funneling growth into the most densely populated areas is necessary to protect overall ecosystem services (Department of Community Development 2007b). The findings of this study suggest that, in the short term, a development strategy that encourages growth and efficient use of land in the developing sub-study areas while preserving the rural areas has the best chance for offsetting the impacts of population growth.

It is important to note, however, that maintaining this growth management strategy under unabated population growth will result in two outcomes. First, ecosystem services in the developing sub-areas will become extremely degraded. Second, growth will inevitably begin to negatively impact the rural areas, compromising the community's ability to uphold the long term planning goals for the rural areas, as noted in the rural areas vision statement:

> "Albemarle County envisions its Rural Areas as multifaceted places that will, *over centuries*, provide and protect the key elements that give the area its character. This vision is … a positive design to be achieved, maintained, and improved *over the very long term*, with the intention that the Rural Areas *remain rural*. " (Department of Community Development 2007c, p. 9, emphasis added)

Given these findings, it seems that the best strategy to meet current and long term planning goals, and to maintain ecosystem services over the long term for this community, would be to couple the implementation of the comprehensive planning strategies with the identification and maintenance of a sustainable human population. This study, taken together with others in the OSPS Project, will help to determine that.

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Appendix I. Dataset selection

The VA Department of Forestry (VA DoF) dataset was deemed inappropriate for this study because of the lack of sufficient detail in the land use classification scheme. ASAP's Global Footprint Network (GFN) project, a related project that also relies heavily on land cover data, made the same conclusion. The VA DoF dataset was originally completed in order to inventory forest lands and the land use classifications are not flexible enough for our study. There is no distinction between low and high density development, nor does this dataset discern between row crops and pastures. The VA DoF dataset was the most recently mapped aerial dataset (2005). However, we require an accurate link between land use and population. The National Land Cover Dataset (NLCD) and the Regional Earth Science Applications Center (RESAC) datasets both represent circa 2000/2001 land use, and are thus better linked to the U.S. Census 2000 data. We examined these two data sets more closely to determine which would be most appropriate for this project.

NLCD vs. RESAC

The NLCD and RESAC land cover data sets were both derived from Landsat satellite imagery, but used different mapping techniques and thus differ in many ways. For this project, these data sets needed to be evaluated to determine their strengths and weaknesses relative to our goals. This evaluation was undertaken in consultation with the GFN research group with the intention to keep the land cover data set consistent between the two projects. After evaluating both data sets, we and the GFN group both decided to use the NLCD. The following sections illustrate the differences between the NLCD and the RESAC data set, and highlight the strengths of the NLCD for this project.

Water/Wetlands

The RESAC data underreported the water coverage by more than 50%, 8.96 km^2, in the entire study area compared to the NLCD data. Spatially this was most apparent where the RESAC data set failed to identify river/stream features. This can be seen, for example, downstream of the dammed reservoir on the South Fork Rivanna River.

The NLCD identified more water area, while the RESAC dataset classified a large amount of wetlands in the study area, 34.90 km^2 in RESAC versus 1.49 km^2 in the NLCD. Most of this discrepancy was found in the evergreen wetland class (Table A2). This was confirmed where the RESAC dataset frequently classified stands of upland forests as evergreen wetland and the NLCD classified the stands as evergreen forest.

Despite this difference, RESAC still classified more evergreen forest as well (see the *Forests* section below).

Because RESAC has a smaller area classified as water, this would translate into higher pollutant levels in CITYgreen calculations since the software does not assign any nutrient loading or air filtering to the water class. CITYgreen does not have a wetlands classification so all these regions would be classified as either 'trees' or 'shrub' as recommended by American Forests. These and other decisions regarding the conversion of NLCD classes to CITYgreen land use classes are discussed further below.

Developed areas

Both the NLCD and RESAC database have a variety of different categories of developed land, six and nine classes respectively. The stormwater runoff production from a downtown block is dramatically different than a quarter-acre lot with one house, so making distinctions between different intensities of developed land is important. Regardless of the selected land cover map, the land cover categories must be made consistent with the categories of land use required in CITYgreen. How the NLCD and RESAC datasets distinguish land use in mixed-use landscapes is crucial to accurately understand and project development patterns.

In this project, we refer to land being "developed" when it has been constructed to serve the local population, excluding agricultural land. Generally this included all housing, commercial and industrial properties and the transportation network. For the purposes of comparing these datasets, developed areas were those that were classified in one of the six "Developed" classes or "Impervious-Paved" class in the NLCD (Table A2, lines *b.* – *e.* and *k.*) and any of the three "Urban" classes, the "Transportation" class or any of the four "Urban/Residential" classes from the RESAC dataset (Table A2, lines *c.* – *l.*).

The NLCD classed 33% (64.22 km^2) more developed land in the entire study area than the RESAC dataset. The main are of discrepancy was determined to be the way the road network was represented in each dataset. The RESAC dataset has a class for transportation that clearly identifies the major highway, although fails to identify many of the non-major roads in the county. Conversely, the NLCD does not have a transportation land class; rather, roads are identified effectively by the "Developed, Open Spaces" land class. This class is characterized by maintained lawns and less than 20% impervious coverage (NLCD 2001). This more accurately portrays what is occurring on the ground than the RESAC classification because highway corridors typically include extensive grassed medians and borders. Examples of this are throughout the study area, but are very well illustrated by a highway cloverleaf in an otherwise forested region. The "Developed, Open Spaces" class does not identify small, local streets within residential developments.

The "Developed, Open Spaces" class is an excellent example of how the NLCD best fits the CITYgreen model compared to RESAC. The runoff curve numbers utilized by CITYgreen were developed for both agricultural and partially developed land covers. The strength of the system is that it accounts for all types of land cover based on the amount of areal coverage. In the example of the "Developed, Open Spaces" land class, the NLCD (2001) documentation tells us that those areas are comprised of less than 20% impervious cover. Where this classification is representing a road the RESAC dataset classifies the pixel as "Transportation." Given the 30x30 meter pixel size, RESAC is over-representing impervious cover compared to the NLCD.

Overall, the increased number of classes in the RESAC dataset does not provide any greater accuracy, particularly in residential neighborhoods, nor are they of great use given that they need to be lumped into less specific CITYgreen classes. In the greater Charlottesville metropolitan area the NLCD represents a greater "high-intensity" area while otherwise representing a smaller urban core. The RESAC dataset fails to locate wooded stands in this urbanized area such as those found north of the 5th Street Exit off I-64. Failure to identify stands of trees within a developed area limits the application of the CITYgreen software. Another example of an accuracy issue with the RESAC data occurs at the intersection of Rio Road East and Seminole Trail (the neighborhood accessed by Northfield Road): the neighborhood shape is wholly incorrect.

Crop/Pasture/Grasslands

The NLCD includes nearly twice as much pasture than the RESAC dataset: 420.42 km^2 and 212.41 km^2, respectively. The different contaminant loading capacities (and the composition of those contaminants) between manicured lawns, pasture and row crops will produce substantially different results; thus an accurate definition of grasses and grains in the study area is needed.

The RESAC dataset has 127.14 km^2 classified as croplands and the NLCD has only 12.17 km^2. The 2002 U.S. Census of Agriculture indicates that approximately one-third of the area of Albemarle County is devoted to farms (USDA 2004). Agricultural production statistics show that most agricultural production in Albemarle County is based on the grazing of livestock on pastures or hay production. In addition, many residents keep horses on pastures. These data indicate that there is less land devoted to row crops in favor of pasture, as reported by the NLCD.

Golf courses, one of the "grassland" land uses in the area, are much easier to identify visually and so a few were observed with both datasets. The NLCD usually identifies golf courses as pasture except for the Keswick Club (701 Club Dr. 22947), which is classified as "Developed, Open Space" (this golf course might have more paved cart paths than others or it may reflect nearby residential roads). The RESAC dataset is a mix of pasture and crop, despite having a classification for this type of development (Urban/Residential Recreational Grass). Overall, we cannot discern a pattern in the differences between land classifications by RESAC (i.e. the fields at the northern edge of Crozet between Crozet Avenue/School Road and Parkview Drive). These issues, like identifying wetlands, reflect questions of accuracy and consistency that the RESAC dataset cannot answer.

Forests

The RESAC dataset classified 130.52 km^2 more forested land than the NLCD dataset (Table A2, lines *m. – o.*). RESAC displays more continuous forested land, particularly because the NLCD dataset identifies many of the roads that fragment the forests. In areas where RESAC classifies large patches of uninterrupted forests, the NLCD identifies smaller stands of forest that are fragmented by roads or development. This ability of the NLCD to identify single family houses in otherwise forested land is important for our purposes because it is a common type of development in Albemarle County. Neither dataset regularly identifies utility line cuts through forested land.

	CITYgreen	NLCD		RESAC		Difference
	Class	Class	Area (km²)	Class	Area (km²)	(km²)
a.	Water	Water	15.17	Water	6.21	8.96
b.	Urban-residential- 1.0 acre	Developed, Open Spaces	140.05		-	140.05
c.	Urban- residential	Developed, Low Intensity	41.26	Low Development	6.55	34.71
d.	Urban	Developed, Medium Intensity	11.00	Medium Development	5.54	5.46
e.	Impervious-Buildings	Developed, High Intensity	4.26	High Development	5.04	(0.78)
f.	Impervious-Paved		-	Transportation	28.15	(28.15)
g.	Urban-residential		-	Urban/Residential Deciduous Tree	60.74	(60.74)
h.	Urban-residential		-	Urban/Residential Evergreen Tree	9.99	(9.99)
i.	Urban-residential		-	Urban/Residential Mixed Tree	3.13	(3.13)
j.	Urban-residential		-	Urban/Residential Recreational Grass	13.33	(13.33)
k.	Urban: Bare	Bare Land	0.73		-	0.73
l.	Urban--Industrial		-	Extractive	0.60	(0.60)
m.	Trees: Forest Adequate Soil	Deciduous Forest	933.97	Deciduous	1,133.16	(199.19)
n.	Trees: Forest Adequate Soil	Evergreen Forest	197.26	Evergreen	245.34	(48.08)
o.	Trees: Forest	Mixed Forest	129.40	Mixed	12.65	116.75
p.	Open Space - Grass/Scattered Trees	Grassland	0.004	'Natural' Grassland	0.117	(0.113)
q.	Pasture/Range	Pasture/Hay	420.42	Pasture	212.41	208.01
r.	Cropland: Row Crops	Cultivated Land	12.17	Croplands	127.14	(114.97)
s.	Trees	Woody Wetlands	1.43	Deciduous Wooded Wetlands	2.95	(1.52)
t.	Trees		-	Evergreen Wooded Wetlands	28.41	(28.41)
u.	Shrub	Emergent: Herbaceous Wetland	0.06	Emergent (sedge-herb) wetland	2.68	(2.62)
v.	Shrub		-	Mixed Wetland	0.86	(0.86)
w.	Totals		1,907.18		1,905.00	2.18

Table A1. A comparison of areas by land class between the NLCD and RESAC datasets. The associated class in CITYgreen is also listed for reference.

Appendix II. Converting land use classifications

In order to run the CITYgreen analysis the NLCD land use data had to be converted into land cover categories compatible with CITYgreen (Table A1). CITYgreen's land use categories relate to a unique combination of curve numbers and pollutant loading regressions (American Forests 2004). Some re-classification decisions were simple, for example open water is open water, while other decisions required observation of how the classes were defined by the NLCD and how they should be bext represented in CITYgreen.

For example, the NLCD separates different forest types by dominant species (coniferous vs. deciduous), while CITYgreen classifies forests based on the status of the understory of the canopy (i.e. paved, mowed lawn or forest litter). All deciduous and evergreen forested areas were classed as mature forests ("Trees: Forest litter understory: Adequate soil coverage") and mixed forests slightly less mature (Table A1). Both of these land classes produce the least runoff and filter the most pollutants. Similarly, "Cultivated land" is classified as "Croplands: Rowcrops" to generalize the agricultural practices on all farmers' non-pasture fields.

The NLCD's "Developed, Open Spaces" land class is an important determination because it identifies the highway network and accounts for 7.33% of the entire study area (Table A1). CITYgreen has an "Impervious Surfaces: Paved" classification, however this would be an inappropriate conversion because it would imply that 100% of the represented area is an impervious paved surface. The "Urban: Residential: 1.0 acre'" classification was chosen because it has grass cover, typical of medians and of buffers along highways, while including sufficient imperviousness to account for transportation-related pollutant loading. Two types of wetland were classified by the NLCD and represent less than 0.01% of the study area; they were classified based on the recommendations from American Forests personnel (Table A2, Appendix II).

NLCD Classification	NLCD Code	CITYgreen Classification	Area km²	Percentage of Total
Water	11	Water	15.17	0.80
Developed, Open Spaces	21	Urban: Residential: 1.0 acre	140.05	7.33
Developed, Low Intensity	22	Urban: Residential	41.26	2.16
Developed, Medium Intensity	23	Urban	11.0	0.58
Developed, High Intensity	24	Impervious Surfaces: Buildings	4.26	0.22
Bare Land	31	Urban: Bare	0.73	0.04
Deciduous Forest	41	Trees: Forest: Adequate	933.91	48.97
Evergreen Forest	42	Trees: Forest: Adequate	197.26	10.34
Mixed Forest	43	Trees: Forest	129.4	6.78
Shrub/Scrub	52	Shrub	0.00	0.00
Grassland	71	Open Space - Grass/Scattered Trees: >75%	0.004	<0.001
Pasture/Hay	81	Pasture/Range	420.42	22.04
Cultivated Land	82	Cropland: Row Crops	12.17	0.64
Woody Wetlands	90	Trees	1.43	0.07
Emergent: Herbaceous Wetland	95	Shrub	0.06	<0.001
Totals			1907.18	100.0

Table A2. NLCD land classifications that occur in the study area including both Albemarle County and the City of Charlottesville, Virginia and the respective CITYgreen classification used in the land use analysis of ecosystem services.

Appendix III. Lands excluded from development

Lands deemed to meet at least one of the following criteria by Albemarle County or the City of Charlottesville were included in the 'Excluded Dataset', which represents lands that are unavailable for development. For the purposes of this analysis we assume that these areas remain unchanged and that the local governments do not grant variances to restricted land uses.

- **Critical slopes**- land that has a greater than 25% grade.
- **Ragged Mountain Natural Area**- site of one drinking water reservoir.
- **Shenandoah National Park**
- **Water Protection Ordinance buffer**- the larger of either the 100-year floodplain or 100 feet from the streambank and a 200-foot buffer around water supply reservoirs' 100-year floodplain.
- **Conservation Easements**- those parcels that are under easements from a government and non-governmental organization.
- **Agriculture/Forest Districts**- participating parcels are restricted from more intense development because of their agricultural or forestal use. We acknowledge that the future status of these lands is in question: they could remain as they are, they could be converted into permanently protected lands through the adoption of conservation easements, or they could become developed. In this study we assume that land within agriculture and forest districts will remain undeveloped. While the inclusion of this land may alter the capacity of the study area to accommodate new population, it ultimately results in a more conservative estimate of impacts on ecosystem services.

The "Scenic Streams Overlay" from the Albemarle County on-line GIS was not included in the 'Excluded Dataset' since it is entirely included in the "Water Protection Ordinance" buffer and was thus redundant. The "Entrance Corridor Overlay" was not included because these lands can be developed, and in some cases are already developed (i.e. the parcel that includes the quarry along I-64 is in this overlay).

All of the lands listed above were available as geographic datasets, or layers, and were individually projected into the NAD83 VA State Plane projection. Then, the layers were merged to create a single map of excluded lands. Before being incorporated into further analyses, this layer had to be conferred into a raster, or gird, format. That is, instead of the land boundaries being represented by lines, excluded lands were represented by groups of cells, or pixels. A 30x30 meter cell size was chosen to match the resolution of the NLCD. This procedure meant that the smallest of land units (less than ¼ acre) could be missed and others over-represented, particularly with critical slope areas. However, areas of critical slope that were lost due to this data transformation were minimal. This raster map was then reclassified into a binary classification: excluded or not excluded. Finally, each study area was clipped to the extent of the NLCD for the respective study areas. For the entire county, 52.4% (247,157 acres) falls under exclusion for at least one reason.

Upon determining where development cannot occur, we calculated where development could occur and the current footprints of urban land. "Developable areas" are defined as all land currently under agricultural or forested land use that is not excluded nor already developed. In 2001 40.3% of Albemarle County qualified as "developable' (Table 1).

Appendix IV. CITYgreen settings

In order to evaluate the ecosystem system services in a given area, CITYgreen provides default data for the models' equations so that it will be ready "out of the box." These "Preferences" are spatially registered so the software can identify suitable data for the study location. In this analysis used the default hydrologic soil types (frequently `B' in Albemarle County). Likewise, we did not alter any of the curve numbers and their associated pollutant loading coefficients as established by the Soil Conservation Service in their development of TR-55.

The 2-year, 24-hour storm event is used for all analyses by CITYgreen. This is an appropriate storm event and is not an alterable configuration in the software. However, the depth of rainfall for this part of Virginia during such a storm event was changed to reflect current climatic conditions. According to the National Weather Service (2008) the 2-year, 24-hour event for most of the study area was 3.40 inches and for the northwest quarter of Albemarle County, 3.39 inches. The polygons that CITYgreen uses to establish precipitation depths were up-dated to use these data for our analyses. The rainfall type will be Type II[3] as confirmed by the National Weather Service (2008).

CITYgreen has a database of 55 cities for air quality references and uses them to identify the nearest representative city. When the software initially calculated the nearest city, Rural Area B used Washington DC for air quality, and Roanoke was associated with the remaining sub-study areas. The prevailing westerly winds that dominate circulation in the area were assumed to have a greater influence than the linear distance between the sub-study area and Washington DC, so we designated Roanoke as the representative air quality city for the entire study area. Default carbon storage and sequestration values were accepted for this analysis to maintain uniformity across the study area.

A digital elevation model (DEM) with a pixel size of 30x30 meters was used to determine slope across the study area. The 30x30meter pixel size was chosen to match the resolution of the National Land Cover Dataset. Where CITYgreen is unable to calculate a slope from the DEM, a slope of two degrees was used.

[3] The rainfall type refers to an idealized 24-hour rainfall pattern. The Type II rainfall distribution is applicable to much of the continental United States, and describes a pattern where most of the rainfall within a 24 hour period accumulates between the hours of 11am and 3pm.

Appendix V. Population data and CITYgreen results

		Population Increase Scenario						
Sub-Study Area	**Year 2000 (Baseline)**	**50% Scenario**	**75% Scenario**	**100% Scenario**	**125% Scenario**	**150% Scenario**	**175% Scenario**	**200% Scenario**
Charlottesville Area	72,297	108,445	111,882	111,882	111,882	111,882	111,882	111,882
Crozet	7,101	10,652	17,306	25,106	25,357	25,357	25,357	25,357
Rivanna	3,960	5,941	11,449	14,205	14,205	14,205	14,205	14,205
Route 29	12,458	18,687	26,681	40,439	60,310	60,310	60,310	60,310
Rural A	12,146	18,219	21,256	24,292	28,287	37,312	46,947	57,493
Rural B	3,471	5,207	6,074	6,942	8,768	15,625	23,090	26,141
Rural C	5,968	8,952	10,444	11,936	14,386	21,867	29,957	35,763
Rural D	6,884	10,326	12,047	13,768	16,447	24,157	32,479	41,707
Total	124,285	186,429	217,139	248,570	279,642	310,715	344,224	372,858

Table A3. Population figures showing the incremental population increase across the entire study area. When a sub-study area reached build-out the excess population was re-allocated to other sub-study areas.

	Population Increase Scenario					
Sub-Study Area	**Year 2000**	**5% Scenario**	**10% Scenario**	**15% Scenario**	**20% Scenario**	**25% Scenario**
Charlottesville Area	72,297	75,912	79,527	83,142	86,756	90,371
Crozet	7,101	7,456	7,811	8,166	8,521	8,877
Rivanna	3,960	4,158	4,356	4,554	4,752	4,950
Route 29	12,458	13,081	13,704	14,327	14,950	15,573
Rural A	12,146	12,753	13,361	13,968	14,575	15,138
Rural B	3,471	3,645	3,818	3,992	4,165	4,339
Rural C	5,968	6,266	6,565	6,863	7,162	7,460
Rural D	6,884	7,228	7,572	7,917	8,261	8,605
Total	124,285	130,499	136,714	142,928	149,142	155,358

Table A4. Population figures showing the incremental population increase across the entire study area.

	Base Year 2000	50% Scenario	75% Scenario	100% Scenario	125% Scenario	150% Scenario	175% Scenario	200% Scenario
BOD	-	11.41	22.23	26.36	32.90	48.82	71.74	**78.25**
Nitrogen	-	2.61	4.93	6.11	7.60	10.16	13.66	**14.79**
Phosphorous	-	7.12	41.75	49.91	63.67	123.27	204.46	**233.08**
Suspended Solids	-	10.63	20.81	24.99	30.99	45.66	66.68	**72.73**
Stormwater Runoff (cu. ft.)	-	(14,647,921)	(7,653,212)	(3,342,223)	(1,765,932)	5,628,134	19,629,943	**23,959,314**
Carbon Monoxide	556,508	526,037	501,436	480,666	458,580	422,677	384,068	**351,215**
Ozone	12,799,,658	12,098,838	11,427,416	10,949,703	10,441,731	9,615,924	8,727,929	**7,972,290**
Nitrogen Dioxide	2,782,534	2,630,183	2,507,183	2,403,334	2,292,905	2,113,382	1,920,339	**1,756,071**
Particulate matter	11,130,137	10,824,695	10,520,728	10,028,736	9,613,333	9,171,618	8,453,524	**7,681,354**
Sulfur Dioxide	3,060,788	2,892,700	2,757,903	2,643,667	2,522,194	2,324,719	21,123,73	**1,931,676**
Carbon stored (tons)	13,432,272	12,696,815	12,103,058	11,601,737	11,068,659	10,202,036	9,270,152	**8,477,168**
Carbon Sequestered annually	104,574	98,848	94,225	90,322	86,172	79,425	72,170	**65,997**

Table A5. Results from the ecosystem services analysis with CITYgreen (population increase scenarios 50% - 200%.

	Base Year 2000	5% Scenario	10% Scenario	15% Scenario	20% Scenario	25% Scenario
BOD	-	0.67	1.14	1.60	2.49	**2.94**
Nitrogen	-	0.28	0.49	0.62	0.90	**1.03**
Phosphorous	-	0.87	1.46	2.25	3.80	**4.76**
Suspended Solids	-	0.66	1.12	1.55	2.41	**2.84**
Stormwater Runoff (cu. ft.)	-	(15,751,308)	(15,601,797)	(15,533,564)	(15,347,198)	**(15,124,610)**
Carbon Monoxide	556,508	544,337	550,547	547,758	544,502	**541,232**
Ozone	12,799,658	12,727,497	12,662,557	12,598,441	12,523,551	**12,448,398**
Nitrogen Dioxide	2,782,534	2,766,846	2,752,730	2,738,793	2,722,509	**2,706,174**
Particulate matter	11,130,137	11,067,388	11,067,388	11,010,918	10,955,167	**10,890,046**
Sulfur Dioxide	3,060,788	3,043,531	3,028,001	3,012,671	2,994,761	**2,976,791**
Carbon stored (tons)	13,432,272	13,356,545	13,288,393	13,221,112	13,142,530	**13,063,650**
Carbon Sequestered annually	104,574	103,985	103,454	102,930	102,319	**101,703**

Table A6. Results from the ecosystem services analysis with CITYgreen (population increase scenarios 5% - 25%.