Estimating Impacts of Population Growth on Ecosystem Services for the Upper Delaware Scenic and Recreational River

By Eric Atkins

For Geoenvironmental Research Requirement for Shippensburg University

Introduction

Ecosystem services refer to many processes where the natural environment produces a good or resource that benefits mankind. Many of these resources are often taken for granted such as clean water, production of timber, habitat for fisheries, and pollination of native and agricultural plants (Ecological Society of America 2000). As forests and fields are converted into development the ability of the natural environment to perform ecosystem services are often hampered or in some cases completely halted (Jantz and Manuel 2009). For example, removal of shade producing trees along a cold water stream can limit or eliminate that streams ability to sustain a successful trout fishery by allowing sunlight to warm the waters of that stream to temperatures above the threshold required for trout production (Barton and Taylor 1985).

In 2007, the Upper Delaware River was named one of the most endangered rivers in America by the American Rivers Organization. One of the major threats to the river at the time was a proposed power line that would have stretched the length of the river, some 73 miles (Richey 2006). The reasoning behind the power line was to provide more energy for a growing population throughout the region. Impacts from building the power line would create fragmentation of habitat and reduce habitat for wildlife like the American bald eagle, which uses the Delaware River corridor as a primary nesting ground (Raabe 2009).

The purpose of this research is to examine impacts that forecasted urban land cover change may have on ecosystem services within the fourteen municipalities that border The Upper Delaware Scenic and Recreational River (UPDE). This examination was achieved by using CITYgreen, a software package for ArcGIS that was designed to calculate economic and biologic value of ecosystem services of trees. By using ArcGIS a spatial approach in analyzing existing land cover across the region can be taken. Three growth scenarios were used for forecasting throughout each municipality. These were trend, growth, and conservation scenarios. The trend scenario is an extension of the historical growth that has occurred throughout the region. The growth scenario assumes growth above the trend where no area is excluded from being developed where as the conservation places restrictions on growth thereby limiting areas of growth. The conservation trend assumes growth will be below the historical trend (Jantz *et al.* 2009).

Study Area

The Upper Delaware Scenic and Recreational River, administered by the National Park Service, consists of some 73 miles of the 360 total miles of the Delaware River. UPDE stretches from Hancock, NY to Sparrowbush, NY along the border of New York State and Pennsylvania. Although considered a National Park Unit, most of the property is privately owned. Federal land consists of only about 30 acres of the 55,575 total acres that make up the unit.

For this study 14 local municipalities from counties in New York and Pennsylvania were chosen. Municipalities are listed in table 1 and depicted in figure 1 below. Table 2 lists acreage size of each municipality.

Table 1: Municipalities included in the study. Each contains some area of land that touches the Upper Delaware Scenic and Recreational River.

Pennsylvania		**New York**	
Municipality	**County**	**Municipality**	**County**
Berlin	Wayne	Cochecton	Delaware
Buckingham	Wayne	Delaware	Sullivan
Damascus	Wayne	Fremont	Sullivan
Manchester	Wayne	Hancock	Sullivan
Lackawaxen	Pike	Highland	Sullivan
Shohola	Pike	Lumberland	Sullivan
Westfall	Pike	Tusten	Sullivan

Table 2: Acreage size of each municipality found within DEWA.

Pennsylvania		**New York**	
Municipality	**Acres**	**Municipality**	**Acres**
Berlin	25,237	Cochecton	23,906
Buckingham	29,053	Delaware	22,587
Damascus	51,549	Fremont	32,758
Manchester	28,750	Hancock	103,488
Lackawaxen	51,831	Highland	33,052
Shohola	29,339	Lumberland	31,742
Westfall	19,825	Tusten	31,213

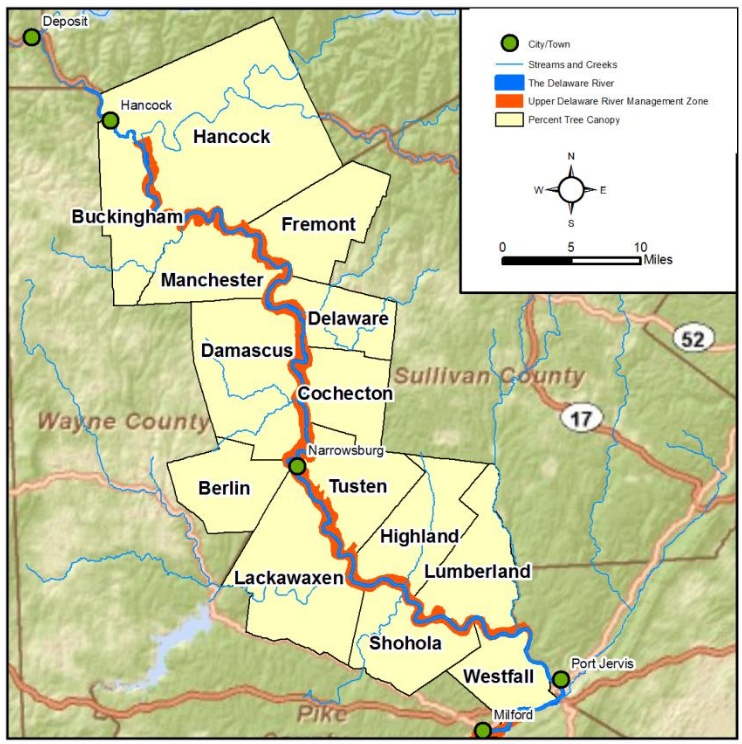

Figure 1: Municipalities selected for this project. Seven from the Pennsylvania side of the river and seven from the New York side of the river. The management boundary for the Upper Delaware Scenic and Recreational River can be seen in orange.

These municipalities (figure 1) were chosen because each contains land adjacent to the boundary of DEWA. Due to the lack of federal ownership of land within this Park Service Unit, these fourteen municipalities share responsibility for maintaining and improving high standards of quality for the river. The region in which the Delaware River resides has seen an increase in development in recent years as more people are making this area home while discovering the beauty of the river itself. Development along the river plus a recent rush to explore the Marcellus Shale has increased concern for the ecosystem and thus its services of the region. UPDE management and the Park Service each have a responsibility to work with local, county and state leaders to ensure the river is protected while at the same time not preventing each municipality rights for growth and economic gain.

This region also serves another important purpose and that is to protect drinking water thru watershed protection. Protecting watersheds provides for high standards of water quality. Watershed protection efforts generally focus on the man-made and animal contaminant sources, and are tailored to the type of source (point or nonpoint) and the way the pollutants are moved, like storm water runoff. New York City's water supply watersheds contains some 9 million consumers residents along with all plant and animal species found within the region. Thru planning, water quality can be protected and improved while still serving multiple priorities. The essence of watershed management is to remove or prevent contaminants from reaching the natural flow-path of water and trees provide this service free of charge.

New York City's Department of Environmental Protection has developed a comprehensive watershed protection program which focuses on both protective and corrective programs. These programs ensure that the Catskill/Delaware reservoir system is filtered naturally and sustains extraordinary high quality.

Literature Review

Human's society receives many goods and services from the environment. So many in fact, that most are taken for granted. These services include food, fuel, and medicine just to name a few. These goods not only are beneficial to human survival but also to the world's economy as a whole. Daily *et al* (1997) points out that concern isn't given to most of these services until they fail to benefit humans or keep humans safe. According the authors, research has shown deforestation has revealed the critical role forested landscapes serve in regulating water. Specifically in mitigating flood and drought conditions, controlling the erosive forces of wind and rain, and preventing silt to enter waterways.

Daily *et al* (1997) also brings to light a few certainties regarding ecosystem services. These are:

- Ecosystem services are essential to society.
- Ecosystem services operate on such a grand scale and in such intricate and little-explored ways that most could not be replaced by technology.

- Human activities (fragmentation, deforestation) are already impairing the flow of ecosystem services on a large scale.
- If current trends continue, humanity will dramatically alter virtually all of Earth's remaining natural ecosystems within a few decades

Daily *et al* (1997) concludes by saying that our economy depends does depend upon ecosystem services being performed "for free" and that these services are estimated to be worth many trillions of dollars. Economic development that destroys habitats and impairs services may lead to high costs to humanity over the long term exceeding the short-term economic benefits of the development. These costs are hidden from traditional economic accounting, but she states they are nonetheless real. Traditionally a short-term focus in land-use decisions is often set in motion even though these decisions may have great costs future generations will have to pay. A need for policies that achieve a balance between sustaining ecosystem services and pursuing the worthy short-term goals of economic development is needed.

Placing a value on ecosystem services has long been a challenge to naturalists and economists alike. These ecosystem are really priceless because they are critical to the functioning of the Earth's life-support system. However, Costanza *et al.* (1997) calculated the dollar value of 17 ecosystem services for 16 biomes, based on published studies and a few original calculations and the natural capital stocks that produce them. The authors were able to calculate their value based on considerations of what the service contributes to human welfare, both directly and indirectly, and were able to create a representation of the total economic value of the planet. The authors were able to estimate the current economic value of these 17 ecosystem services. For the entire biosphere, the dollar value was estimated to be in the range of 16-54 trillion dollars per year, with an average of 33 trillion dollars per year. The authors do stress that this is just an estimate and may in fact be a minimum vaule. To put this into prospective at the time of this article the global gross national product for the United States was around 18 trillion dollars per year.

In an article by Brauman *et al* (2007) also co-authored by Daily, the authors discuss hydrologic ecosystem services. These range from the supply of water for household use to the mitigation of flood damages. Hydrologic services benefits to people are affected by what happens within the terrestrial ecosystem. The authors suggest it is useful to organize hydrologic services into five broad categories, each of which can be impacted. These are; improvement of removable water supply, improvement of stream water supply, water damage mitigation, provision of water related cultural services, and water-associated supporting services. Water quality is directly impacted by the terrestrial ecosystem as water moves through a landscape. By affecting each category, ecosystem processes improve or degrade the supply of hydrologic services.

Natural resources of protected areas are coming under threat due to the expansion of human population into what was once considered wilderness. Protected areas often are not big enough by themselves to support a wide variety of species oftentimes needing the surrounding lands to ensure animals have proper space for nesting, foraging, and ensuring proper gene flow among species among all plants and animals.

In an article by Radeloff *et al.* (2009), the authors studied housing trends around protected areas within the United States from 1940 until present, then used this information to forecast growth trends to the year 2030. It was found that even though wilderness areas have the highest level of protection, the surrounding area was dramatically changing. In 2000, it was found that some 20.5 million housing units were within 50km of a designated wilderness area compared to only 4.4 million in 1940. The number of housing units within 1km grew from 9,400 in 1940 to 54,000 in 2000. Housing units within 50km of a National Park grew from 1.5 million (1940) to 6.6 million (2000) with 85,000 of these being within 1km. National Parks in the East experienced the highest increase in housing units compared to other areas. Housing growth around National Forests within 50km went from 9 million (1940) housing units to 34.8 million (2000) with 484,000 housing units being located within 1km in 1940 to 1.8 million in 2000.

It is projected that for wilderness areas, 10 million additional housing units within 50 km will appear by 2030 (45% growth 2000–2030); for national parks, 3 million new units (45% growth); and for national forests, 16 million new units (46% growth). This growth, if trends continue, will apply even more stress to natural resources and will require active proper management to ensure survival.

As landscapes become urbanized the resulting habitat loss can fragment the landscape. This is a leading cause of species diversity loss. Fischer and Lindenmayer (2007) conducted a literature review to determine the relationship between several threatening processes associated with landscape modification and the biological traits of species that increases extinction proneness. It was found that 5 key processes exist that can drive species to extinction. These listed in the table 1 below along with an explanation.

Table 3: Processes that can drive species to extinction and possible results of that process

Process	Result
Habitat Loss and Degradation	- Specialized species are more likely to lose their habitats as a result of landscape change - Disturbance-tolerant species are more likely to find suitable habitat in modified landscapes - Species that can live in the matrix experience no habitat loss as a result of landscape modification
Habitat Isolation	- Species that can move through the matrix are less likely to suffer the negative consequences of habitat isolation - Strong dispersers may be more likely to maintain viable metapopulations
Disrupted Species interaction	- Species that can switch prey or mutualists are more likely to withstand landscape change - Species that are strong competitors are less likely to be outcompeted by species whose habitat expands as a result of landscape change
Disrupted Biology	- Species with a complex biology (e.g. social or breeding systems) are more likely to have their biological processes disrupted as a result of landscape change than species with simpler biological systems
Stochastic Events	- High density populations contain many individuals even in a small area, and hence are more resilient to stochastic threats

Data and Methods

To begin this analysis, data was collected and edited for each individual municipality. Separate base maps were created that contained information regarding land cover, soils, and elevation within each municipality boundary. Fourteen maps were created in all. An impervious surface dataset (Jantz et al. 2009) was used to update the 2001 NLCD dataset to 2005 producing a more up-to-date representation of development throughout the study area. The NLCD was reclassified using ArcGIS into a CITYgreen user format. Table 4 lists NLCD 2001 land use classes and each associated CITYgreen reclassification.

Table 4: NLCD 2001 land use classes and code and associated CITYgreen classification. It should be noted that no CITYgreen classification currently exists for wetland, so in this analysis all wetland were considered shrub.

NLCD 2001 Classifications	NLCD Code	CITYgreen Classifications
Water	11	Water
Developed, Open Space	21	Urban: Residential: 1.0 Acre
Developed, Low Intensity	22	Urban: Residential
Developed, Medium Intensity	23	Urban
Developed, High Intensity	24	Impervious Surfaces: Buildings
Bare Land	31	Urban Bare
Shoreline	32	
Deciduous Forest	41	Trees: Forest Litter Understory
Evergreen Forest	42	
Mixed Forest	43	Trees
Shrub/Scrub	52	Shrub
Grassland	71	Open Space –Grass/Scattered Trees: Grass Cover > 75%
Pasture/Hay	81	Pasture/Range (Continuous forage for Grazing)
Cultivated Land	82	Cropland: Row Crops
Woody Wetlands	90	Shrub
Emergent: Herbaceous Wetland	95	

Each of the fourteen municipality base map were run separately through CITYgreen producing a current estimation of the ecosystem benefits of trees. This data was treated as a baseline for forecasting the future impacts that each municipalities urban growth may have on the ecosystem benefits of trees.

A second dataset consisting of three growth sceneries were used to model future urban growth for each municipality. The first scenario being a trend forecast that followed historical urban growth trends and extended these trends into the year 2030. The second being a growth forecast, which allowed for a higher rate of growth above that of the historical growth trend. The third being a conservation forecast which limited growth below that of the historical growth trend by placing increased emphasis on the conservation of land.

Forecasted urban land use change from each of the three sceneries for each municipality was used to assess impacts of future growth on ecosystem services (Jantz et al. 2009). These future forecast maps were used to calculate potential growth of the urban land use class and potential loss of all other land cover types. These forecast maps generated the probability that each individual pixel will become urbanized. A way to equally estimate land cover change for each municipality was created for all municipalities. An example of this can be seen in the table 5 below:

Table 5: The information is just one small section of data taken from Delaware Municipality for the conservation forecast. The Type = 1 represents all Cropland: Row Crops. One pixel represents 27.9 meters squared or an area of 778.4 square meters. Probabilities of development range from 0 to 100 percent in increments of 4. Pixel percentage was calculated by muntiplying pixels by percent chance of change. The sum of this calculation, in this case 378.2 was dividied by total number of pixels (2684) producing a forecasted change of 14.1 percent, meaning 14.1 percent of 2684 pixels of all Cropland: Row Crops are forecasted to become urbanized in 2030.

I.D.	Land Use Type	Pixels	Percent Chance of Change	Pixel * Percentage
4	1	1771	0	0.00
30	1	13	28	3.64
35	1	16	20	3.20
36	1	308	100	308.00
41	1	93	8	7.44
44	1	342	4	13.68
54	1	17	24	4.08
62	1	23	16	3.68
74	1	37	12	4.44
80	1	7	32	2.24
133	1	9	44	3.96
140	1	13	36	4.68
144	1	10	48	4.80
149	1	5	40	2.00
150	1	3	60	1.80
151	1	2	84	1.68
152	1	7	52	3.64
153	1	3	56	1.68
156	1	2	64	1.28
158	1	1	76	0.76
165	1	1	80	0.80
167	1	1	72	0.72
		Sum = 2684		Sum= 378.20
				378.2/2684 = 14.1

This table provides a unique I.D. for each calculation run. Land use type is also represented by a unique I.D. (in this case number 1 represents a land use type of cropland: row crops). The count is the number of pixels that were counted for each calculation. The percentage column is the likelihood that the representing number of pixels will be converted into development. In this table we see that 1771 pixels have a zero percent change of converting to development, while 308 have a one hundred percent change of being converted into development. The last column represents total number of pixels multiplied by the percent change of change. Every number in the final column was added together to represent the total number of pixels that are forecasted to be converted into development. In this case 378.2 pixels of 2684 total pixels (14.1 percent) of cropland: row crops are forecasted to be converted into development.

To calculate percentage change in land use for each of the three scenarios the total number of pixels of all non-urban land use classes (except water where pixel count remained the same from 2005 to 2030) were added to the current total of the urban land use pixels. Because five urban land use classes were created, a distribution percentage chart was calculated for each municipality that evenly distributed the forecasted urban pixels into the five existing urban pixel classes. Even distribution of future urban pixels was assumed for this project. Table 6 below is an example of this distribution.

Table 6: Example of how all pixels that were forecasted to change into urban were distributed evenly into each urban land use class.

Urban 2005	**Percent Urban 2005**	**Total Pixels Converted to Urban in 2030**	**Pixel Distribution for Urban**	**Total Urban Pixel Count for 2030**
83	0.01010	1787	18	101
206	0.02506		45	251
18	0.00219		4	22
921	0.11203		200	1,121
6,993	0.85063		1,520	8,513
Sum = 8,221	Sum = 1.000	Sum = 1787	Sum = 1,787	Sum = 10,008

To offset the addition of forecasted urban pixels to the already existing urban pixels, the forecasted number of non-urban development pixels was subtracted from the total number of pixels for each non-urban land use class. This was done to offset a mismatch that existed between the impervious surface data used and the NLCD land cover dataset. An example can be seen in the table 7 below.

Table 7: Non-urban land use re-distribution. Forecasted pixel count was subtracted from current pixel count.

Land Use Class	Current Pixels in Each Land Use Class	Forecasted Pixels being converted into development	Remaining pixels (Current Minus Forecasted)
Cropland: Row Crops	2763	308	2455
Open Space – Grass/Scattered Trees: Grass Cover > 75%	57	2	55
Pasture/Range (Continuous forage for Grazing)	31170	555	30615
shrub	11	0	11
Trees	731	9	722
Trees: Forest Litter Understory	72301	913	71388
	Sum = 107033	Sum = 1787	Sum = 105246

Once each pixel count for each land use class was adjusted, the new pixel count was divided by the sum of all pixels producing an adjusted percentage, which was then used to alter each municipality scenario in CITYgreen. An example of this can be seen in the table 8 below.

Table 8: CITYgreen percentage redistribution for each land use type. This is a conservation scenario for Delaware Municipality. Each land use pixel count was divided by the sum of total pixels.

Land Use Type	2005 Pixel Count	Percent	2030 forecasted Pixel Count	Percent
Cropland: Row Crops	2763	2.36	2454	2.09
Impervious Surface: Buildings/Structures	83	0.07	101	0.09
Open Space – Grass/Scattered trees: Grass cover > 75%	57	0.05	55	0.05
Pasture/Range(Continuous forage for grazing)	31170	26.58	30615	26.10
Shrub	11	0.01	11	0.01
Trees	731	0.62	722	0.62
Trees: Forest Litter Understory	72301	61.65	71388	60.87
Urban	206	0.18	250.7783	0.21
Urban: Bare	18	0.02	21.91266	0.02
Urban: Residential	921	0.79	1121.198	0.96
Urban: Residential: 1 Acre	6993	5.96	8513.069	7.26
Water	2028	1.73	2028	1.73
	Sum = 117282	Sum = 100	Sum = 117282	Sum = 100

This process was done for each land use class, for each of the three forecasts, in each of the fourteen municipalities. In total, forty-two CITYgreen analyses were completed.

Results

Baseline and Forecasted Land Cover Change.

To examine the results base line information must first be established. The following information is for the 2005 base map of each municipality. New York State municipalities possesses 278,746 acres of land while Pennsylvania's municipalities possesses 235,584 acres.

A. Baseline Tree Canopy

When mapping tree canopy cover (Figure 2) for each municipality it was found that the low was 62.3 percent, found in Delaware municipality, and the high was 92.2 percent, found in Highland municipality. Municipalities on the New York side had the four highest percentages of tree canopies with these being the only ones to have at least 90.0 percent coverage. It is interesting to note the three lowest tree canopy percentages are found in the middle of the study area. Municipalities on the New York side of the study area were found to have 241,198 acres of tree canopy cover (86.5 percent of the New York side of the study area landscape) compared to the

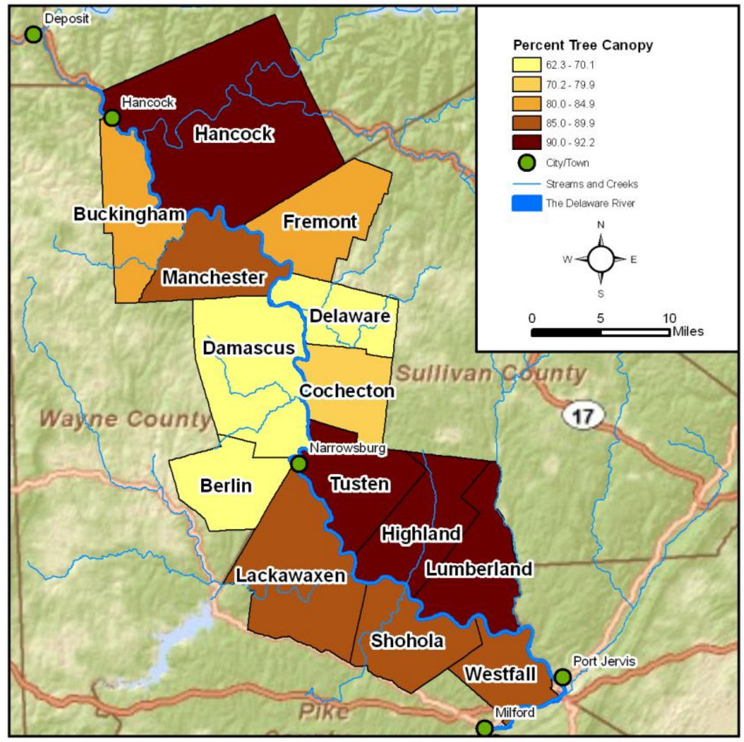

Figure 2: Percent tree canopy coverage for each municipality in the study area.

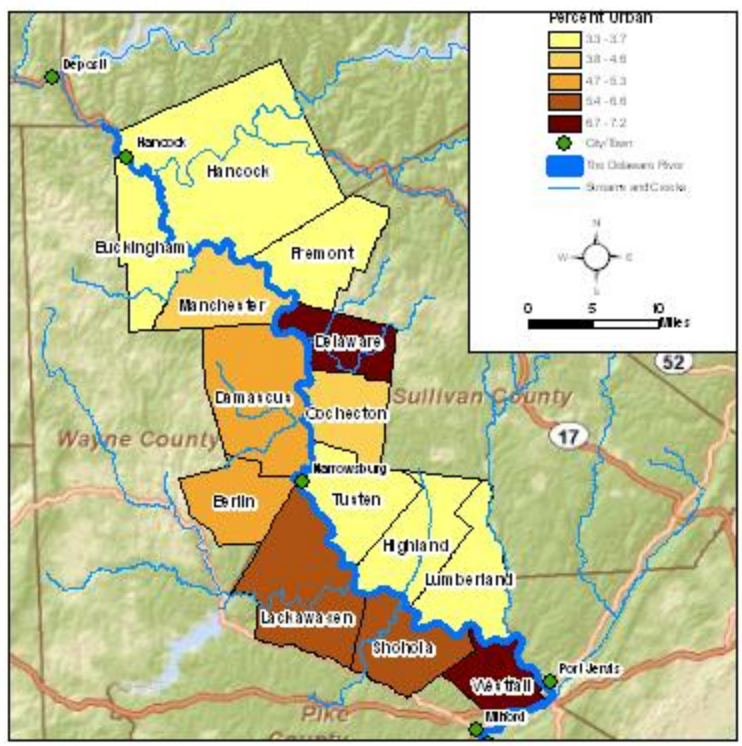

Figure 3: Percent urban for each municipality in the study area.

municipalities on the Pennsylvania side of the study area with 192,695 (81.8 percent of the Pennsylvania side of the study area landscape).

B. Baseline Urban

When mapping percent urban (Figure 3) it was found that the lowest urban percent was 3.3 (Tusten Municipality) with a high being 7.2 (Westfall Municipality). The municipalities in the State of New York were found to have 10,930 total acres of urban (3.9 percent of the New York side of the study area landscape) among the seven municipalities while Pennsylvania's study area municipalities had 13,106 (5.6 percent of the Pennsylvania side of the study area landscape).

C. Baseline Agriculture

When mapping percent agriculture (Figure 4) for each of the municipalities it was found that the low was 0.4 percent (Highland Municipality) and the high was 29.0 percent (Delaware Municipality). The municipalities with the largest percentage of agriculture also contains the smallest percentage of forest cover. The municipalities in the State of New York study area were found to have 18,748 total acres of agriculture landscape (8.0 percent of the New York side of the study area landscape) while Pennsylvania study area municipalities had 22,792 acres (9.7 percent of the Pennsylvania side of the study area landscape). Table 9 below charts results for percent forest, urban and agriculture for the parts of New York State and Pennsylvania found within the study area.

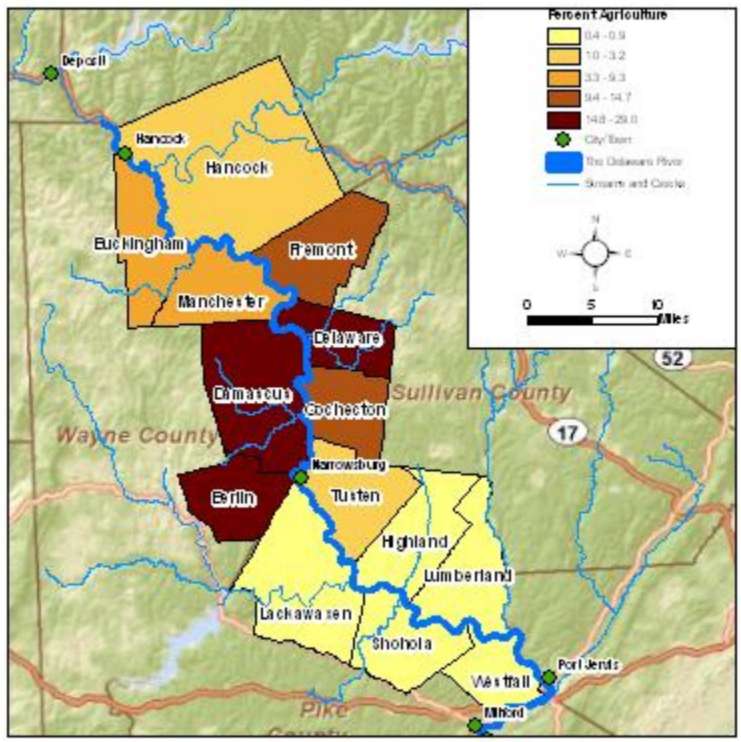

Figure 4: Percent Agriculture landscape throughout each municipality in the study area

Table 9: Study area wide percentages for trees, urban, Agriculture, and other for each state.

State	Acres	Trees	Urban	Agriculture	Other	Total
New York	278,746	86.5	3.9	8.0	1.6	100
Pennsylvania	235,584	81.8	5.6	9.4	3.2	100
Averages	514,330	84.3	4.7	8.6	2.4	100

D. Forecast Tree Canopy Scenario Comparison

As each of the three 2030 scenarios is compared to the 2005 base line data (Figure 5) it can be seen that each of the fourteen municipalities displays a decrease in the total percent of tree canopy. The amount of decline depends on the scenario, however even the conservation scenario displays a slight decrease in tree canopy by the year 2030. The growth scenario displays the largest rate of decline from the 2005 data. Rates of change by municipality can be seen in Figure 6.

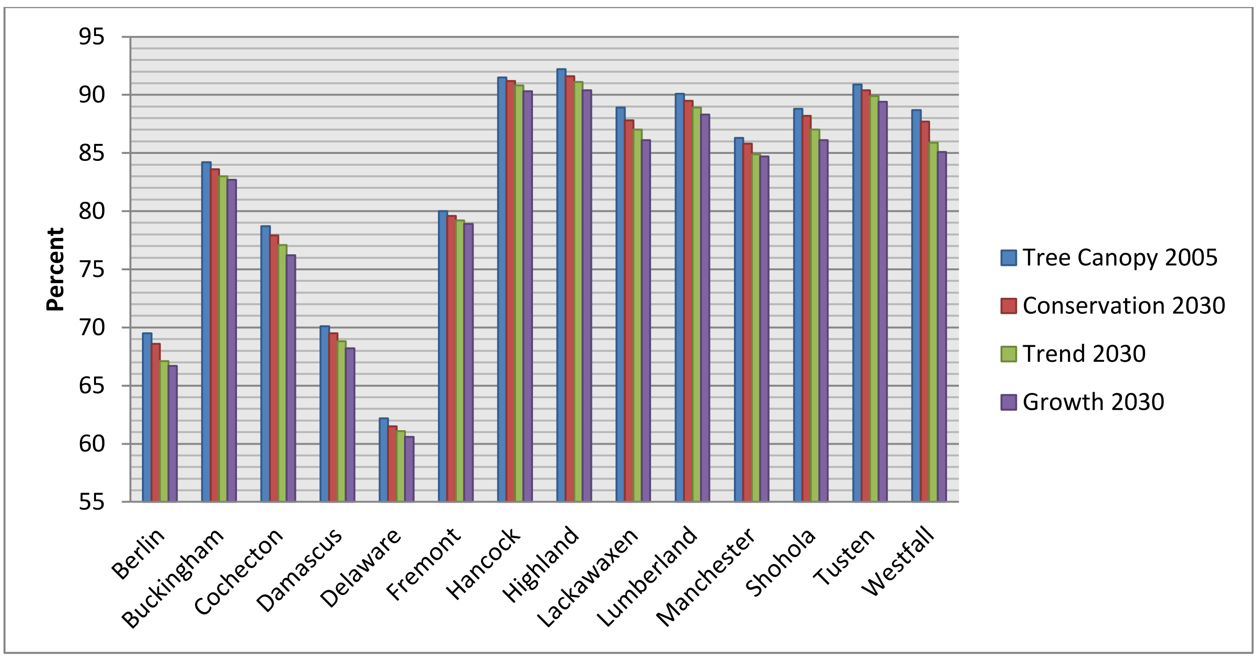

Figure 5: Tree canopy scenario comparisons. The highest percentage is found in the base line 2005 data while the lowest percentage is found in the 2030 growth scenario.

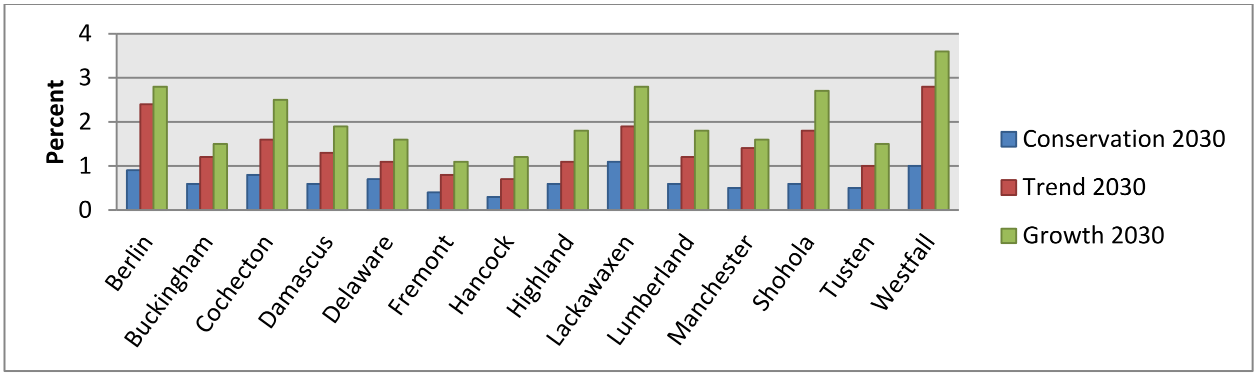

Figure 6: Percent rates of change for each municipality. Lackawaxen contained the largest amount of change for the conservation scenario while Westfall contained the largest change for the trend and growth scenarios.

E. Forecast Urban Scenario Comparison

As each 2030 scenario is compared to the 2005 base line data (Figure 7) it can be seen that each of the fourteen municipalities displays an increase in the percent of urban landscape. When looking at growth in 2030 (purple) three municipalities display a forecasted growth to over 10.0 percent of the total landscape. Berlin Township displays the largest percent of forecasted growth between 2005 and each of the three scenarios. Westfall contains the largest urban percent for 2005 while also having the largest forecasted growth area for the trend and growth scenarios. Delaware has the largest urban percent area for the conservation scenario. Rates of change by municipality can be seen in Figure 8.

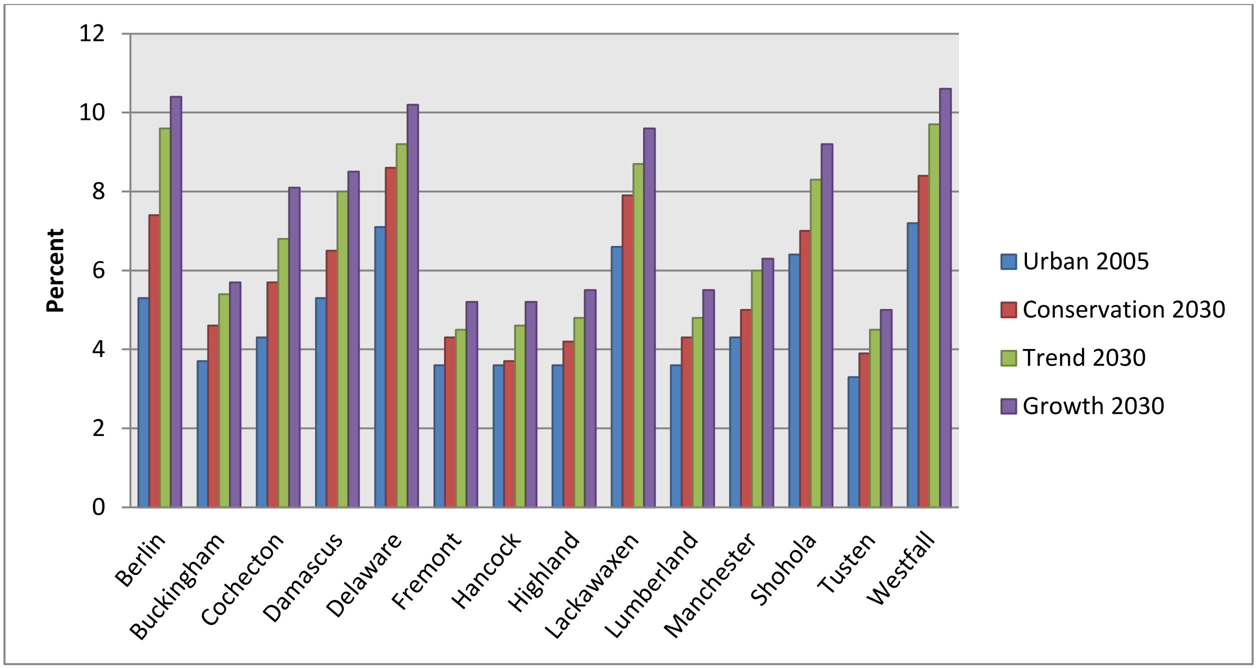

Figure 7: Urban scenario comparisons. The highest percentage is found in the base line 2005 data while the lowest percentage is found in the 2030 growth scenario.

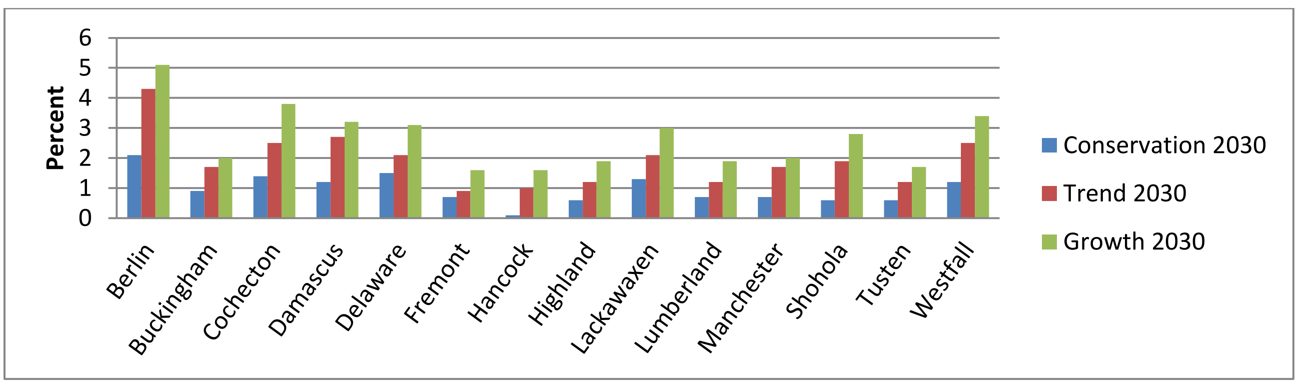

Figure 8: Percent rates of change for each municipality. Berlin contained the largest amount of change for each of three forecasted scenarios.

F. Forecast Agriculture Scenario Comparison

As each 2030 scenario is compared to the 2005 base line data (Figure 9) it can be seen that each of the fourteen municipalities displays a decrease in the percent of agriculture land. This land use type in terms of percentage of total landscape was the most variable of any studied. The range was 0.4 percent (Highland and Westfall) to 29 percent (Delaware) of total land in agriculture. Berlin Township displayed the largest decreases when comparing 2005 data to each of the three scenarios. Rates of change by municipality can be seen in Figure 10.

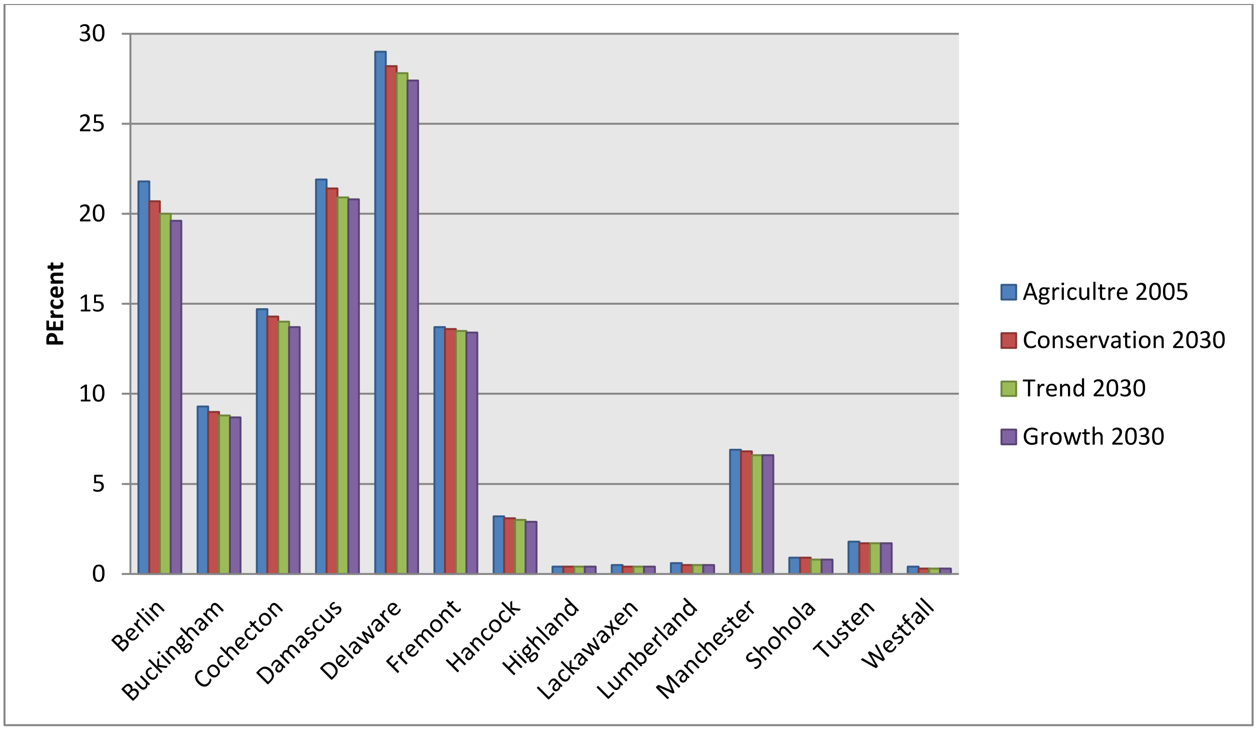

Figure 9: Agriculture scenario comparisons. The highest percentage is found in the base line 2005 data while the lowest percentage is found in the 2030 growth scenario.

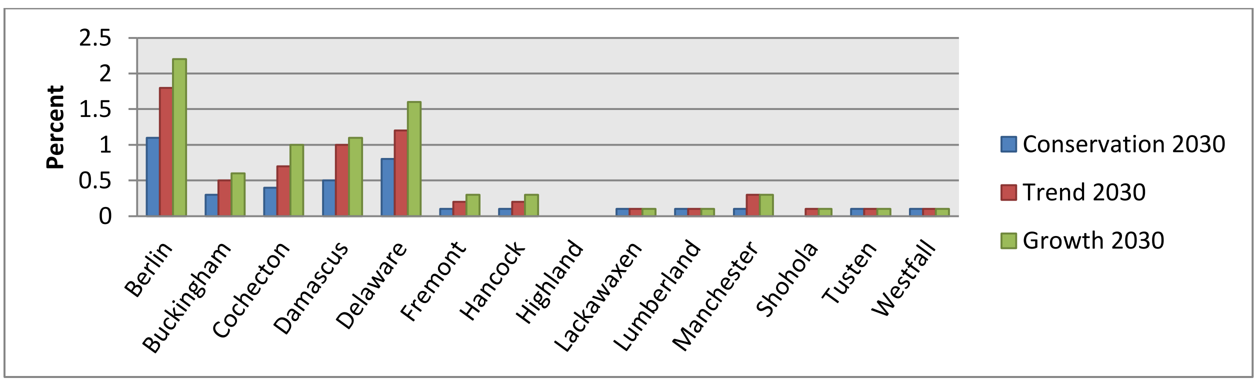

Figure 10: Percent rates of change for each municipality. Berlin contained the largest amount of change for each of three forecasted scenarios

Ecosystem Services and Forecast Models

CITYgreen also not only measures changes in the landscape area but it also measures the ecosystem benefits of trees. The following results are based on the forecasted changes in landscape still focusing on each of the three, conservation, trend, and a growth scenarios for each municipality.

A. Air Pollution Removal

CITYgreen calculates pollution pounds removed while assigning an associated dollar value if one were to pay for removal of air pollution. Compounds CITYgreen focuses on are carbon monoxide, ozone, nitrogen dioxide, particulate matter, and sulfur dioxide. Table 10 below illustrates total pounds removed per year and total costs in dollars for each municipality for 2005 baseline and each of the three scenarios. These costs are those borne by society such as rising health care costs and reduced tourism revenue. The actual external costs used in CITYgreen for all air pollutants is set by each states Public Service Commission.

Table 10: Pounds removed per year and associated savings for each municipality's baseline, conservation, trend, and growth scenarios. Savings is the estimated costs such as increasing health care costs that are associated with the reduction in trees. A decline in both can be seen from 2005 to each scenario.

Municipality	Lbs/Yr Removed	Savings in Dollars	Municipality	Lbs/Yr Removed	Savings in Dollars
Berlin – 2005	1,954,114	4,713,970	**Highland**	3,394,336	8,188,261
Conservation – 2030	1,928,817	4,652,946	Conservation – 2030	3,374,265	8,139,843
Trend – 2030	1,888,323	4,555,261	Trend – 2030	3,353,272	8,089,201
Growth - 2030	1,876,512	4,526,769	Growth - 2030	3,328,228	8,028,788
Buckingham - 2005	2,724,311	6,571,988	**Lackawaxen**	5,135,837	12,389,339
Conservation – 2030	2,706,367	6,528,651	Conservation – 2030	5,069,915	12,230,313
Trend – 2030	2,684,679	6,476,335	Trend – 2030	5,023,715	12,118,862
Growth - 2030	2,676,587	6,456,814	Growth - 2030	4,967,697	11,983,729
Cochecton	2,096,664	5,057,848	**Lumberland**	3,184,255	7,681,477
Conservation – 2030	2,073,632	5,002,286	Conservation – 2030	3,163,410	7,631,191
Trend – 2030	2,052,056	4,950,238	Trend – 2030	3,144,311	7,585,117
Growth - 2030	2,028,616	4,893,694	Growth - 2030	3,121,321	7,529,658
Damascus	4,026,595	9,713,478	**Manchester**	2,763,772	6,667,133
Conservation – 2030	3,991,340	9,628,433	Conservation – 2030	2,746,938	6,626,524
Trend – 2030	3,938,498	9,500,959	Trend – 2030	2,719,712	6,560,846
Growth - 2030	3,919,543	9,455,235	Growth - 2030	2,710,744	6,539,211
Delaware	1,567,171	3,780,535	**Shohola**	2,905,035	7,007,905
Conservation – 2030	1,547,530	3,733,154	Conservation – 2030	2,883,211	6,955,259
Trend – 2030	1,536,960	3,707,655	Trend – 2030	2,843,325	6,859,041
Growth - 2030	1,524,125	3,676,693	Growth - 2030	2,813,248	6,786,484
Fremont	2,918,554	7,040,517	**Tusten**	3,161,681	7,627,020
Conservation – 2030	2,904,523	7,006,670	Conservation – 2030	3,142,724	7,581,290
Trend – 2030	2,893,572	6,980,253	Trend – 2030	3,127,421	7,544,373
Growth - 2030	2,878,606	6,944,150	Growth - 2030	3,110,726	7,504,100
Hancock	6,246,651	15,919,234	**Westfall**	1,954,543	4,715,005
Conservation – 2030	6,220,067	15,851,488	Conservation – 2030	1,932,038	4,660,714
Trend – 2030	6,196,858	15,792,341	Trend – 2030	1,894,561	4,570,308
Growth - 2030	6,163,410	15,707,099	Growth - 2030	1,875,382	4,524,041

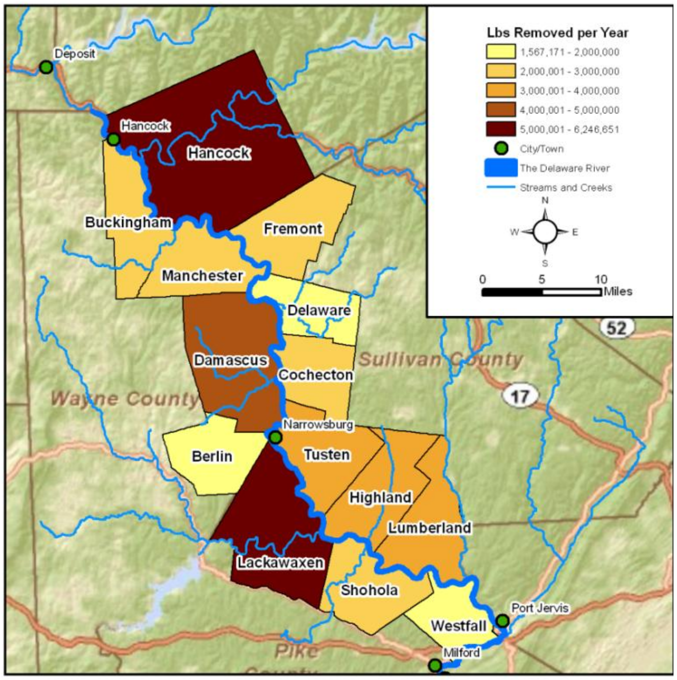

Figure 11: Pounds of pollution removes per year throughout each municipality within the study area.

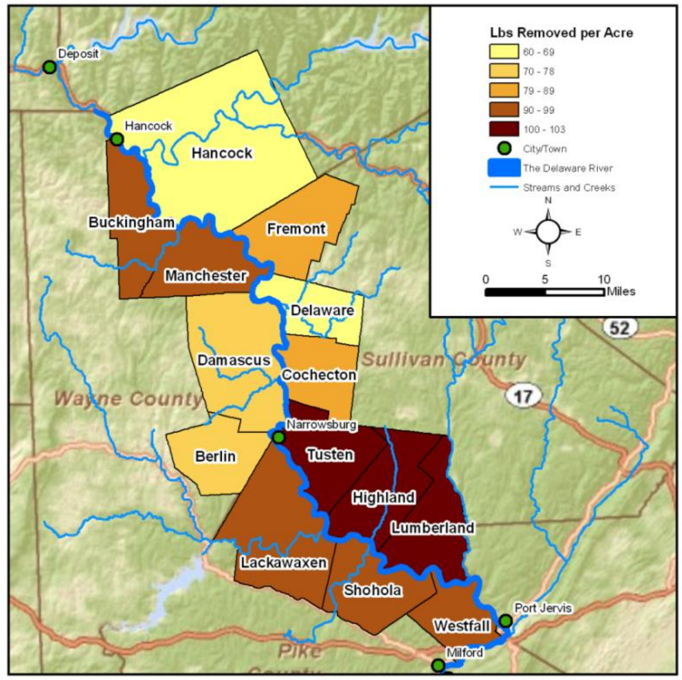

Figure 12: Pounds of pollution removes per year per acre throughout each municipality within the study area.

Figures 11 and 12 represent the combined pounds of all pollutants removed per year and combined pounds of pollution removed per year per acre. It is interesting to note that Hancock municipality was at the top of the list as far as pounds removed per year. This can be attributed in part to the municipality containing 91.5 percent forest cover, but also in part because of the municipalities sheer size in relation to each of the other municipalities studied. Hancock is twice the size of the next largest municipality.

When mapping out pounds of pollution removed per year per acre a different prospective can be gained. This change in displaying information reveals that Hancock municipality is the lowest calculated at pounds removed per acre. When comparing the two maps it can also be seen that Tusten, Highland, and Lumberland are removing the most pollution per acre even though these three municipalities are in the middle range for total pounds removed per year.

G. Carbon Sequestration

When mapping the amount of carbon being stored (Figure 13) and sequestered (Figure 14) it is again found that Hancock Municipality plays an important role in each. Hancock stores the most carbon, again because of its sheer size in comparison to the other municipalities however this time; unlike with pounds removed per acre Hancock also stores the most tonnage per acre, along with Trusten and Highland Municipalities. Delaware, Damascus, and Berlin Municipalities are at the bottom as far as carbon stored per acre because of the lack of tree canopy cover each municipality contains.

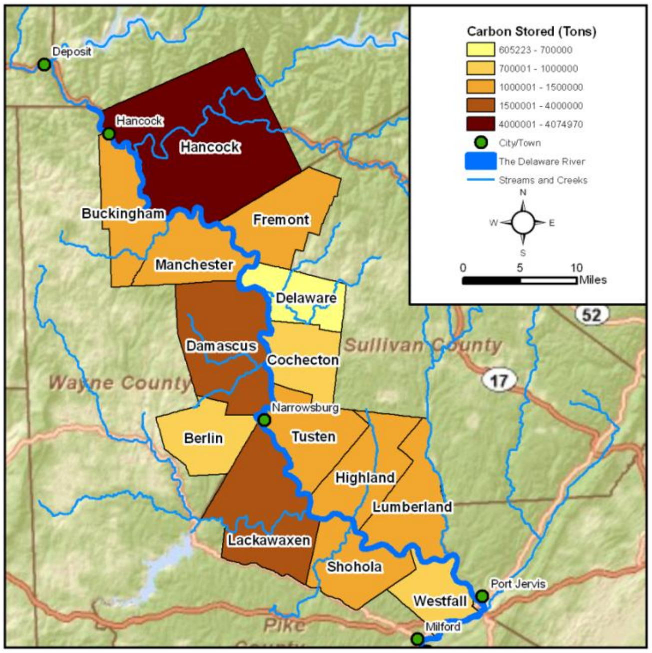

Figure 13: Tons of carbon stored per year throughout each municipality within the study area.

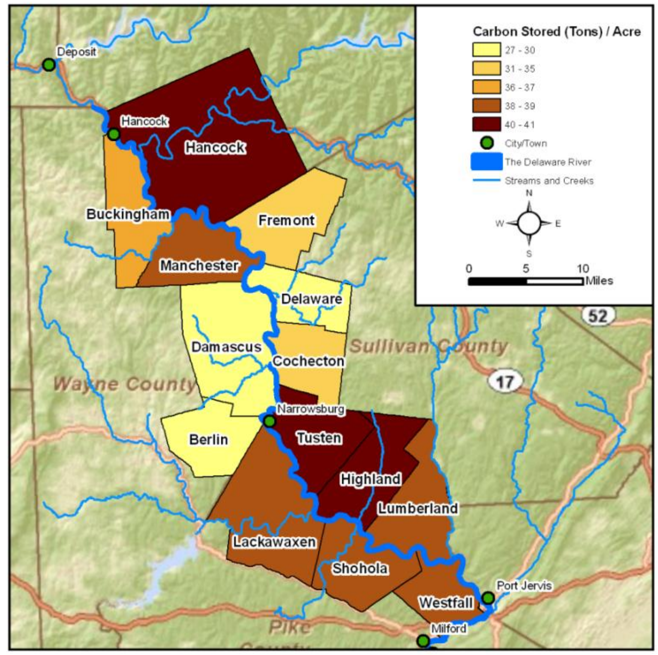

Figure 14: Tons of carbon stored per year per acre throughout each municipality within the study area.

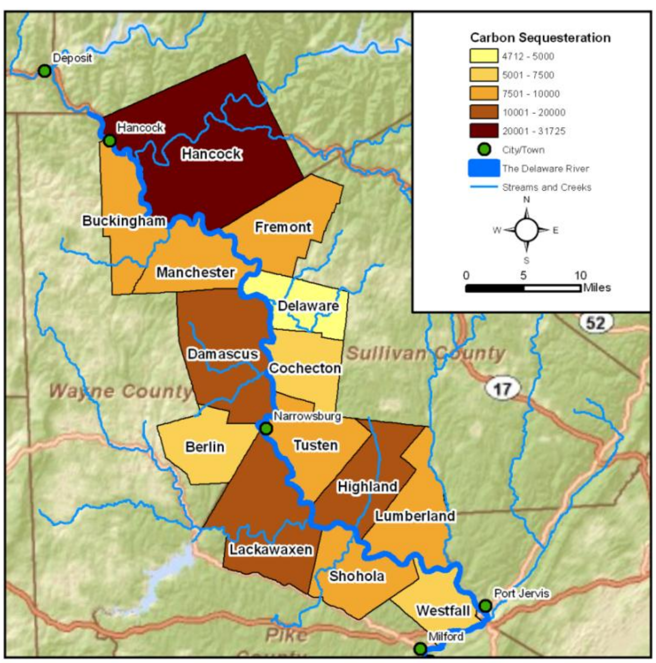

Figure 15: Tons of carbon sequestered per year throughout each municipality within the study area.

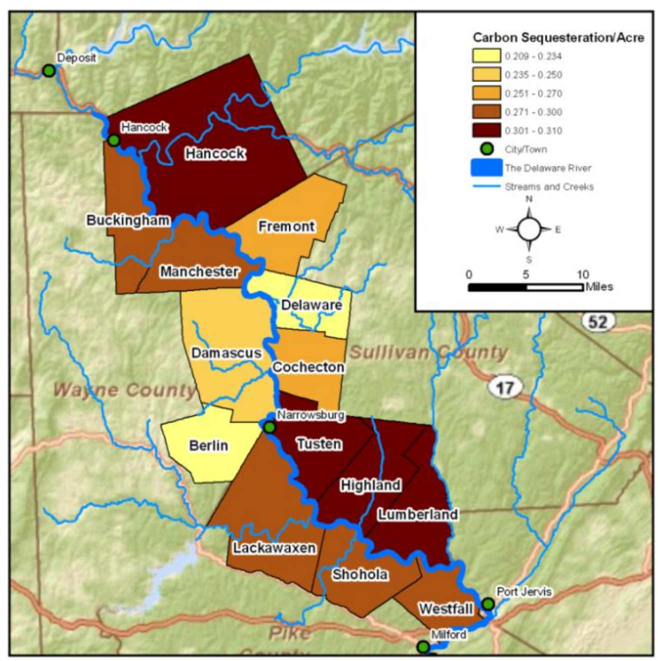

Figure 16: Tons of carbon sequestered per year per acre throughout each municipality within the study area

Carbon sequestration, when mapped in both tons stored per year (Figure 15) and tons stored per year per acre (Figure 16), reveals that again Hancock Municipality is playing an important role in each. However once more we also see that Tusten, Highland, and Lumberland are also sequestering just has much carbon per acre as Hancock Municipality. Again it is found that Delaware, Damascus, and Berlin Municipalities are near the bottom because of the lack of tree canopy cover each municipality contains.

H. Storm Water (Curve Numbers)

CITYgreen uses the TR-55 model developed by the Natural Resource Conservation Service which is very effective in evaluating the effects of land cover change in regards to storm water runoff. Curve numbers are associated with runoff intensity. The range of curve numbers is from 30 to 100. Curve numbers closer to 100 have a higher potential for more runoff than numbers closer to 30. Table 11 displays curve numbers for each municipality in the study area.

Table 11: Curve numbers for each municipality within the study area.

Pennsylvania		**New York**	
Municipality	**Curve Number**	**Municipality**	**Curve Number**
Berlin	64	Cochecton	63
Buckingham	62	Delaware	64
Damascus	63	Fremont	62
Manchester	62	Hancock	61
Lackawaxen	62	Highland	62
Shohola	62	Lumberland	63
Westfall	62	Tusten	62

Discussion

The New York municipalities as a whole currently have a greater amount of tree cover, less urban land, and less land in agriculture, all of which leads to a greater ability to produce ecosystem service benefits. Possessing more trees will result in higher removal rates of air borne pollutants and higher storage and sequestration rates for carbon. Currently Hancock, Tusten, Highland, and Lumberland have the highest levels of ecosystem services. Delaware, Berlin, and Damascus, because of the high percentage of land dedicated to agriculture and urban land, are removing and storing less carbon and show the greatest alterations on the hydrologic cycle. While these landscapes are certainly providing valuable services in terms of providing agricultural products and living spaces, since they are also located in the middle of the 73 mile stretch of the Upper Delaware River they may be the most critical areas to target in terms of ensuring proper management of the remaining forest land.

When forecasting urban development it is evident that Berlin Municipality exhibits the highest growth rate percentage of any municipality. Berlin also has the largest decline in agriculture land while having the second greatest rate of forecasted forest loss by percentage. Lackawaxen is forecasted to have the largest percentage of decline in forest land in the 2030 conservation scenario while Westfall has the largest percentage of decline for the trend and growth scenarios. These results would suggest that these municipalities should be at the top of the list when considering any type of urban expansion. These forecasts are based on historical trends, so these counties have previously displayed an upward trend in urban development.

Air pollution removal and carbon storage and sequestration should become a point of concern when thinking into the future. No matter what scenario was studied the data suggest that each of the fourteen municipalities will exhibit a decline in the ability to filter pollution and remove and store carbon. Storm water runoff, measured by the curve number exhibited no change in any of the municipalities suggesting that the decline in trees for all forecasted models is not enough to affect stormwater water runoff. Also conversion from agriculture land to low density runoff development, which is forecasted to happen, does not produce a change in run-off.

When comparing forecasted models for New York State and Pennsylvania it can be found that the largest forecasted decline of forest is found in Pennsylvania while also exhibiting the largest increase in urban land use. New York State exhibits the largest decline in all agriculture land. The forecasted decline in forest along with an increase in urban development indicates that the Pennsylvania municipalities are of more concern to DEWA when thinking about the year 2030 than New York State.

Historical trends point to a continued reduction in forest land and agriculture land throughout the fourteen municipality region. Using forecasted models further supports this evidence.

Conclusion

The Upper Delaware Scenic and Recreational Rivers management team is and should continue putting its best foot forward protecting and keeping the river as pristine as possible. This has and will involve being active in each of the communities, keeping up with private landowner use decisions, and establishing and modifying management plans for the river itself. Several threats are happening within the river corridor that could potentially lead to temporary or even permanent damage to not only the Park Service unit, but to several millions of people's drinking water. These threats include urban growth, especially along the river itself, power line insanitation, and natural gas exploration.

Keeping the River protected will not be an easy task but having and gaining knowledge will supply DEWA management with means to make informed decisions. Further research from this point include studying the affects of reduction of trees long term throughout the region, studying the impacts of natural gas exploration and its potential impacts to wildlife, forests, soil, and drinking water, and continued use of CITYgreen on different scales surrounding the river. Possible scales could include just looking only at the 55,575 acres that make-up DEWA, a one-mile buffer surrounding DEWA boundary, and a regional approach looking at trends throughout the entire watershed or more. With information comes knowledge, and with better knowledge, better choices can be made ensure generations to come can visit and enjoys DEWA like all generations before have been able to do.

References

American Forests, 2004. CITYgreen for ESRI's ArcGIS: Calculating the value of nature (user's manual). Washington DC: American Forests.

Barton, D. and W. Taylor. 1985. Dimensions of Riparian Buffer Strips Required to Maintain Trout Habitat in Southern Ontario Streams. North American Journal of Fisheries Management Vol. 5.

Brauman KA, Daily GC, Duarte TK, Mooney HA. 2007. The Nature and Value of Ecosystem Services: An Overview Highlighting Hydrologic Services. Annual Review of Environment and Resources 32:6.1-6.32.

Costanza R, D'arge R, De Groot R, Farber S. 1997. The value of the world's ecosystem services and natrual capital. Nature 387:253-60.

Daily GC, Alexander S, Ehrlich PR, Goulder L. 1997. Ecosystem services benefits supplied to human societies by natural ecosystems. Ecological Society of America 2:1-18.

Ecological Society of America. 2000. Ecosystem Services. http://www.esa.org. (accessed April 22, 2010).

Fisher, J., & Lindenmayer, D. B. 2007. Landscape modification and habitat fragmentation: A synthesis. *Global Ecology and Biogeography*, *16*, 265-280.

Jantz, Claire, and James J. Manuel. 2009. Estimating impacts of population growth on ecosystem services for the community of Albemarle County and Charlottesville, VA. 1: 1-85.

Jantz, C.A., M. Mrozinski and E. Coar. Forecasting Land Use Change in Pike and Wayne Counties, Pennsylvania. April 2009. 45 p.

Raabe, Peter. 2009. America's most endagered rivers of 2007: Upper Delaware River, New York. American Rivers. http://railroadearth.com/ (accessed April 22, 2010).

Radeloff, V. C., Stewart, S. I., Hawbaker, T. J., & Urs, G. 2009. Housing growth in and near United States protected areas limits their conservation value. *PNAS*, *107*(2), 940-945.

Richey, Charles S. 2006. Unpatriotic threat To American eagle habitat. Article Dashboard. http://www.articledashboard.com (accessed April 23, 2010).

Data Sources

American Forests' CITYgreen software
(http://www.americanforests.org/productsandpubs/citygreen/)

National Land Cover Dataset (NLCD) from 2001 (http://landcover.usgs.gov/)

Elevation data from the United States Geologic Survey (USGS)
(http://ned.usgs.gov/)

Soils data from Soil Survey Geographic Database (SSURGO)
(http://soils.usda.gov/survey/geography/ssurgo/)