HIGHLANDS REGIONAL STUDY

Connecticut and Pennsylvania Updates

Forest & Agriculture Resources Analysis
Growth and Impact Analysis

REPORT

To the USDA Forest Service, Northeastern Area State & Private Forestry

August 31, 2008

Prepared by:

YALE SCHOOL OF FORESTRY & ENVIRONMENTAL STUDIES
Global Institute of Sustainable Forestry

SUNY COLLEGE OF ENVIRONMENTAL SCIENCE AND FORESTRY

REGIONAL PLAN ASSOCIATION

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CHAPTER 1 INTRODUCTION

The purpose of this study is to provide a scientific understanding of the dynamics and trends of land use change, demographics, and development in the Connecticut and Pennsylvania Highlands, and of how these changes are affecting the forest and agricultural resources of the region. The results are intended to be used to develop conservation priorities and strategies that will protect the natural resources that have the highest ecological and social value and are most at risk from development pressure.

Although the Connecticut and Pennsylvania Study was modeled after, and complements, the New York–New Jersey Highlands Regional Study Technical Report (USDA Forest Service 2003), data sources and methods differed somewhat. Our intent was to apply available data, current knowledge, proven techniques, and local values to the study, yet produce a resulting analysis that is consistent with that of the New York-New Jersey study. We analyzed trends in population, land use, land use planning, and development, and used rigorous modeling techniques to project how those trends might continue into the future if growth and development stay on the same trajectory with the same forces in play. In particular, we looked at the impacts of past and future development on forests, farmlands, and the riparian areas that protect streams and wetlands.

The Highlands region, which stretches from northwestern Connecticut to the rolling hills of Pennsylvania between Philadelphia and Harrisburg, is an area of farms and forests just inside the highly-developed coastlines of Connecticut, New York, and New Jersey (Figure 1-1). The region is under tremendous pressure from development sprawling out of New York City, Philadelphia, and even the Washington, DC metropolitan area.

The Connecticut Highlands encompasses 677,000 acres in northwestern Connecticut, including the mostly rural Litchfield Hills, and parts of the Housatonic and Farmington River Valleys (figure 1-2). With everything from very small towns of 600 people to the city of Danbury with over 70,000 people, the dynamics are variable across the landscape. Its eastern and southern borders are becoming more and more suburban as farmland is converted to housing developments. The northwest corner has had relatively low growth, in comparison. Two-thirds of the landscape is forested, 18% is developed, and only 6% is in active agriculture. There is a strong footprint of conservation on the land – 24% of the region is currently protected open space.

In Pennsylvania, the 1,382,700 acre Highlands includes parts of 10 counties stretching from Northhampton and Bucks in the northeast to York and Lancaster in the southwest (figure 1-3). The 173 municipalities range in size from tiny villages of 200 people to the cities of Bethlehem, Reading, and Allentown, with upwards of 100,000 people. One-third of the land is in urban/developed use. Development has been strongest in the center of the Highlands in Berks, Lancaster and Montgomery Counties. Nevertheless, much of the region is still a pastoral landscape, with about one-third of the land in agricultural fields. Sixteen percent of the area is protected from development, either through public ownership or agricultural conservation easements. Agricultural conservation is a priority in most counties, strongly supported by state funding. Forests, about a third of the area, are mostly on the higher ridges.

People living and working in the communities of the Highlands are struggling to balance conservation and economic viability while maintaining their rural character and sense of place. It is our hope that the information we have provided through this analysis will help them in their efforts to plan for the future of their communities.

The report is organized in sections according to the major analyses that were conducted: socio-demographic trends; forest resources; agricultural resources; municipal zoning; land use change; models of future land use change; and impacts of growth and development on the natural resources of the region. Each section includes major findings, methods, and results. We have tried to balance the need for this to be an integrated report for both Connecticut and Pennsylvania with the natural tendency for communities to want information for only their state. In all cases, results are presented state by state in separate subsections. Introductory and methods sections were integrated wherever possible for ease of reading and to avoid repetition.

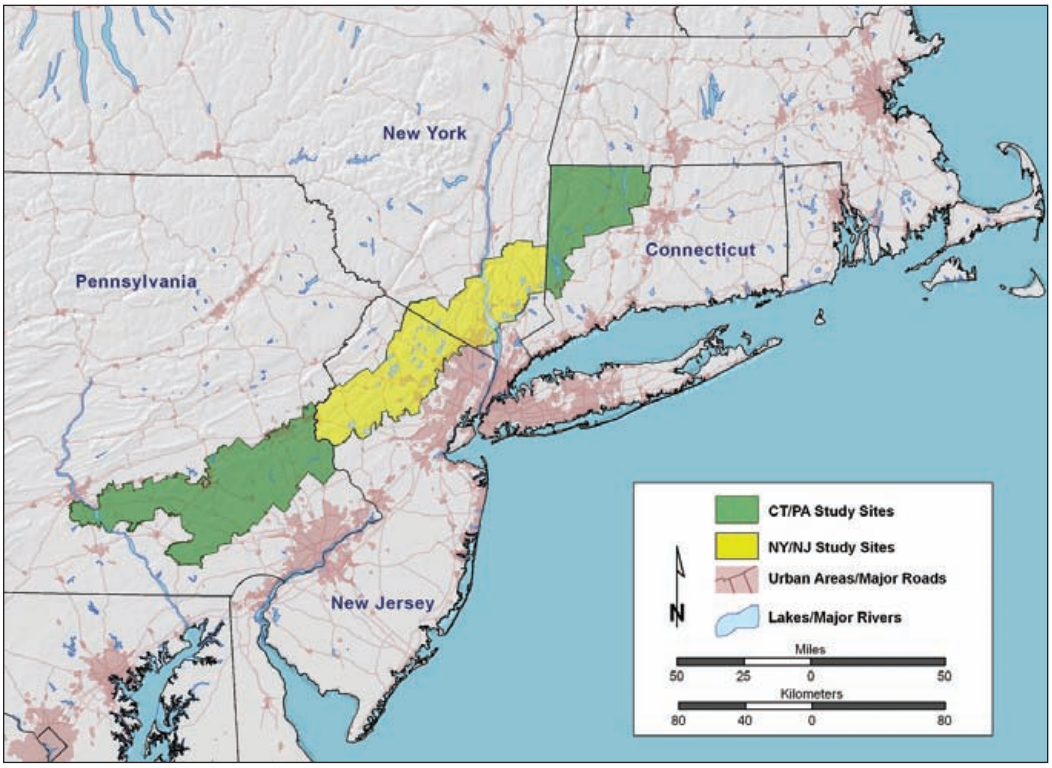


Figure 1-1. *Highlands region.*

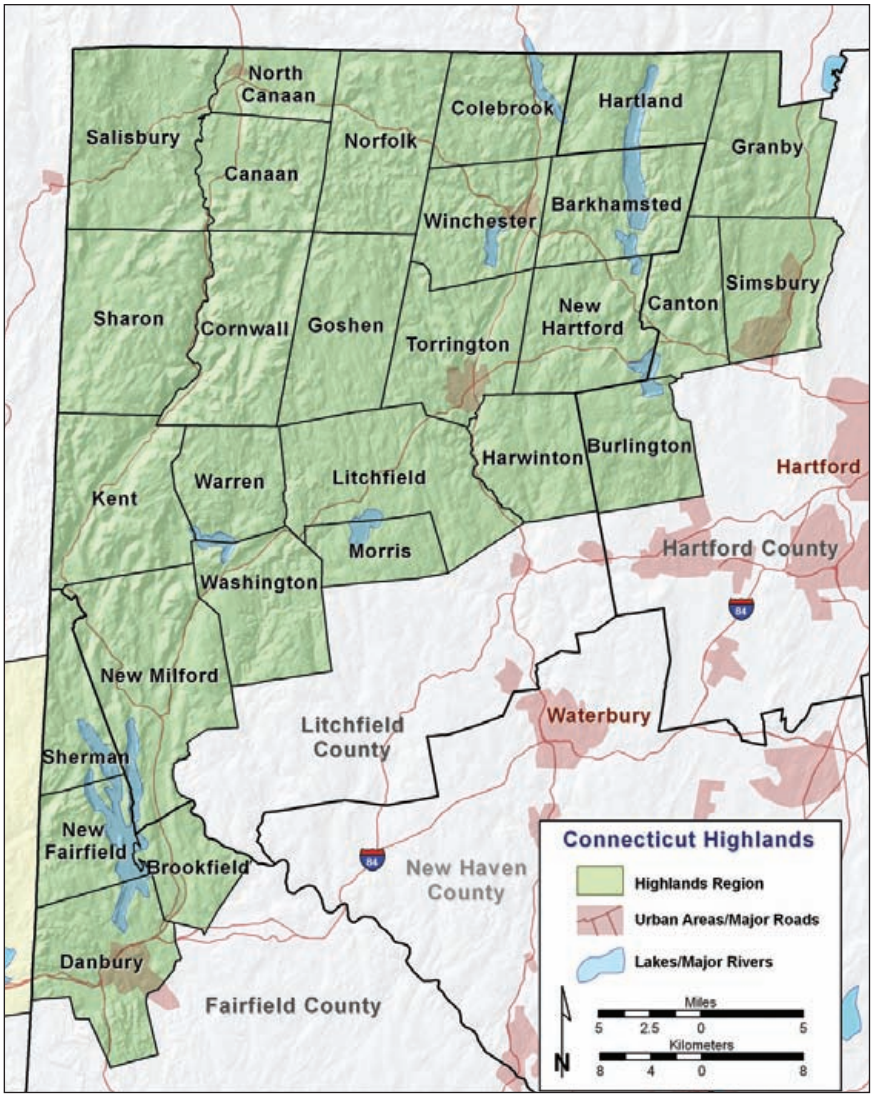


Figure 1-2. *The Connecticut Highlands region.*

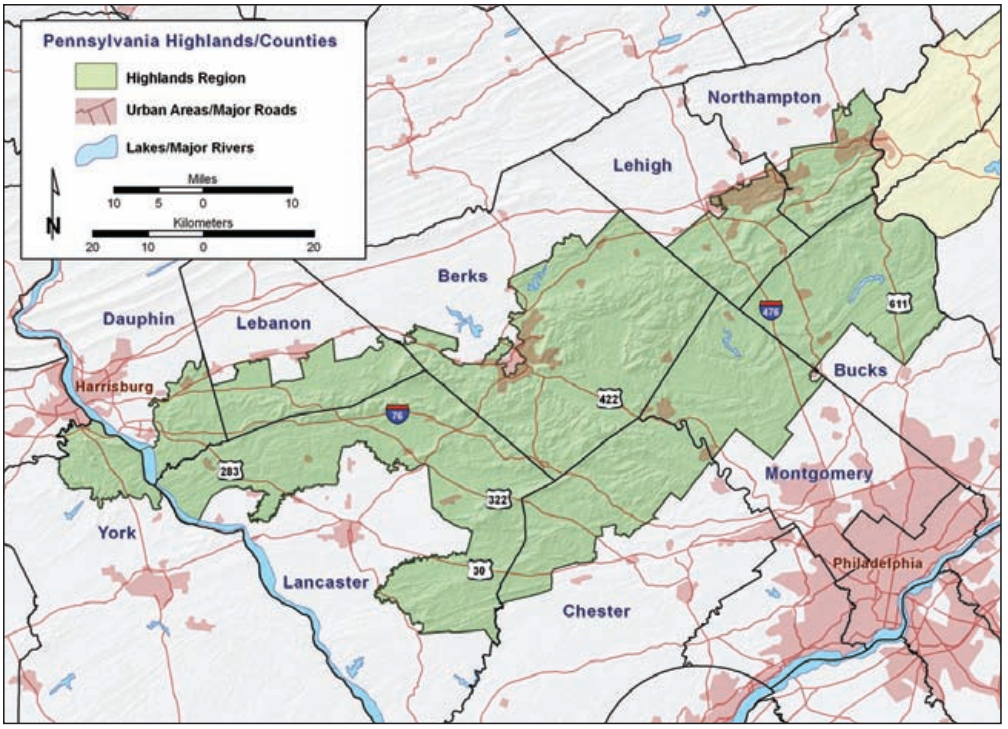


Figure 1-3. *The Pennsylvania Highlands region.*

CHAPTER 2 CONSERVED LAND

Knowing which lands are protected from development is critical to the process by which we model future growth. Protected areas should be excluded from land that has the potential to be developed so that our model does not end up "choosing" locations and patterns of future development that coincide with protected lands, and therefore producing an unrealistic outcome. Knowing where these lands are located also allows us to test whether or not proximity to conservation lands attracts development, which is thought to be the case by many in both the conservation and development sectors. Therefore, producing an accurate "protected lands layer" was an important early step in the analytical process. Having a protected lands layer also allows researchers, lawmakers and the public to see the extent to which land has already been protected in the Pennsylvania and Connecticut Highlands, and help them prioritize further conservation measures.

Land is considered protected when a conservation easement restricting development on the land is held in trust by a conservation organization or public agency, or when the land is owned outright by a public agency or private conservation organization.

Connecticut

There is no state-wide, comprehensive, up-to-date source for spatial information on lands that are protected from development. The Connecticut Department of Environmental Protection has a partial database but it is not up-to-date. With 169 land trusts active in the state, and no centralized network to keep track of conservation easements, records are scattered among towns and small non-profit organizations. The protected lands GIS data layer used in this study was compiled from numerous sources, and is the most complete information possible from existing spatial data. The Greenprint Project of the Housatonic Valley Association and the Trust for Public Land provided a comprehensive GIS database of all protected lands in Litchfield County, which was a tremendous boon to our study. Other data were obtained from the Connecticut Department of Environmental Protection and the Metropolitan District Commission.

In the Connecticut Highlands, at least 160,660 acres (24%) are in conservation ownership (Figure 2-1). This includes public lands, private lands permanently protected from development by conservation easements, and water company-owned lands. Although the 17,640 acres of water company-owned lands are not permanently protected from development, they were considered to be in "conservation ownership" for purposes of this study. Fifty-eight percent is in private ownership, the largest being Great Mountain Forest.

Most of the protected lands in Connecticut are considered *high* or *highest* conservation value according to the Phase 1 Connecticut-Pennsylvania Highlands Study Conservation Value Assessment (Figure 2-4). And almost two-thirds of the *highest* value land is currently conserved (Figure 2-3).

Pennsylvania

In Pennsylvania, as in Connecticut, there is no state-wide, comprehensive, up-to-date source for spatial information on lands that are protected from development. Counties maintain information on farmland preservation easements, and most are in spatial format. We were able to obtain current farmland easement data from all counties except Bucks.[1] Additional data were obtained from the Conservation Fund, Natural Lands Trust, the Heritage Conservancy, Berks County Conservancy, and the Pennsylvania Game Commission.

1 Bucks County data is from 1999.

There are at least 223,200 acres (16%) in conservation ownership (Figure 2-2). This includes public lands as well as private lands, mostly farmland, permanently protected from development by conservation easements. Sixty-eight percent is in public ownership, the rest consists of over 3,000 parcels of mostly small farmlands.

Almost half of the protected lands in Pennsylvania are considered *highest* conservation value according to the Phase 1 Connecticut-Pennsylvania Highlands Study Conservation Value Assessment (Figure 2-4). However, only 37% of the *highest* value land is currently conserved (Figure 2-3).

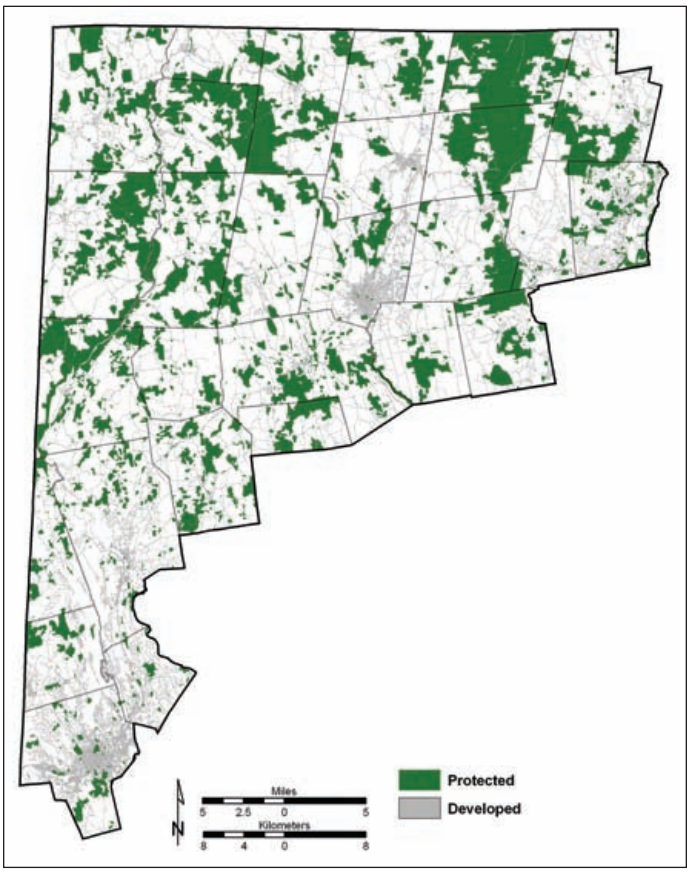


Figure 2-1. *Connecticut Highlands: Protected lands.*

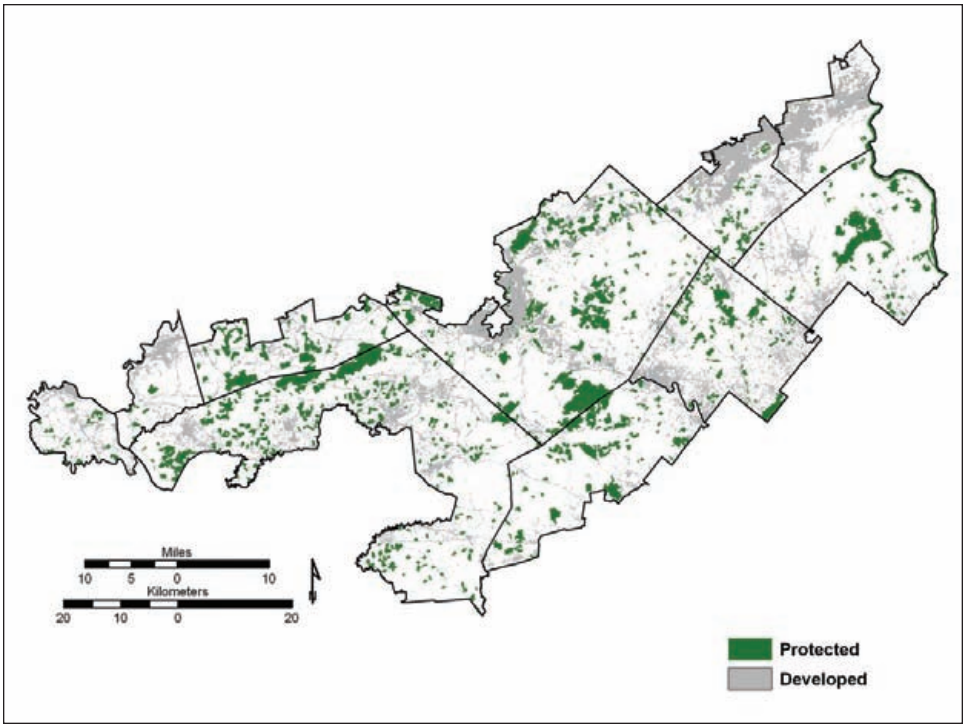
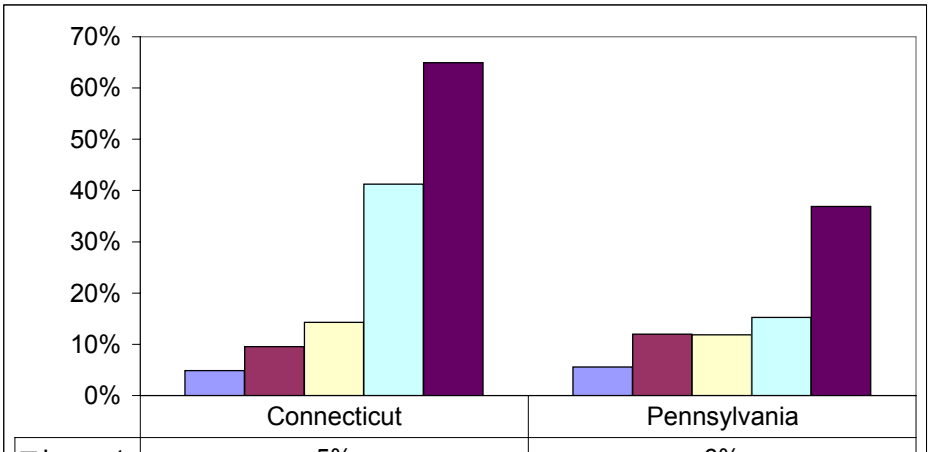
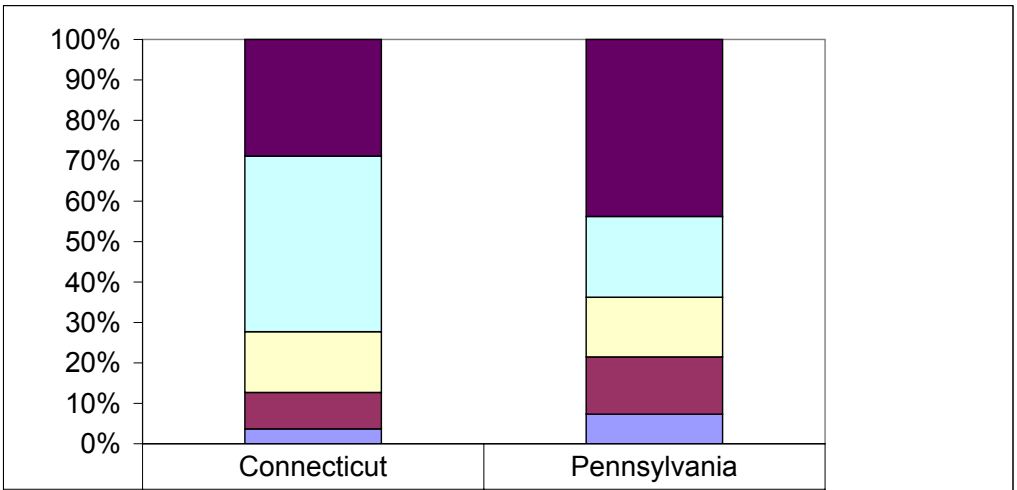


Figure 2-2. *Pennsylvania Highlands: Protected lands.*



	Connecticut	Pennsylvania
Lowest	5%	6%
Low	10%	12%
Medium	14%	12%
High	41%	15%
Highest	65%	37%

Figure 2-3. *Percent of land in each Conservation Value Assessment (CVA) category that is protected from development. CVA data are from Phase 1 of Connecticut-Pennsylvania Highlands study.*



	Connecticut	Pennsylvania
Highest	29%	44%
High	43%	20%
Medium	15%	15%
Low	9%	14%
Lowest	4%	7%

Figure 2-4. *Percent of total protected land in each Conservation Value Assessment (CVA) category. CVA data are from Phase 1 of the Connecticut-Pennsylvania Highlands study.*

CHAPTER 3 SOCIO-DEMOGRAPHIC CHARACTERISTICS AND TRENDS

Key Findings

Connecticut

- In the 2000 census, the Connecticut Highlands had a population of 285,730, representing just 8.4 percent of the state.
- Population and housing in the Highlands region is growing much faster than the state as a whole.
- Population density increased from 192 to 270 people per square mile between 1970 and 2000.
- The population over 65 years of age is growing much faster than the population of young people under 30 years of age.
- From 1970 to 1990, housing grew much faster than population, with fewer people living in each house by 1990; this has been stable since 1990 at approximately 2.4 people per household.

Pennsylvania

- In the 2000 census, the Pennsylvania Highlands had a population of 1,216,725, representing just 10 percent of the state.
- Population and housing in the Highlands region is growing much faster than the state as a whole.
- Population density increased from 423 to 563 people per square mile between 1970 and 2000.
- The population of 30-40 year-olds and those over 65 is growing much faster than the population of young people under 30 years of age.
- From 1970 to 1990, housing grew much faster than population, with fewer people living in each house by 1990; this has been stable since 1990 at approximately 2.5 people per household.

Introduction

We analyzed trends in population, housing, income, and employment for municipalities in the Connecticut and Pennsylvania Highlands region. US Census data from 1970, 1980, 1990, and 2000 were obtained in spatial format at the municipality level from GeoLytics, Inc. Municipalities were merged when necessary so that data from the four census years could be compared.

In both Connecticut and Pennsylvania, the population in the Highlands region grew at a much higher rate than the population of the state as a whole. From 1970 to 2000 the population in the Connecticut Highlands increased 40.4%, compared to 12.3% for the entire state. In Pennsylvania, the Highlands region experienced a 33.1% increase in population, while the state's population increased only 4.1% (Table 3-1).

Connecticut Population

Connecticut's Highlands includes 28 municipalities (towns and cities) in Fairfield, Hartford, and Litchfield counties, which range in size from 18 to 64 square miles. Population in these municipalites ranged from 1,081 to 74,848 in the year 2000. The region saw an increase of 82,000 people over a 30-year period. Population density increased from 192 to 270 people per square mile. Although population has increased in every census period since 1970, this growth was slowing down as of 2000. In the 1990s the rate of population increase was only half of what it was in the 1970s.

Table 3-1. *Highlands population growth compared to state-wide trends 1970-2000.*

	1970	1980	% change 70 - 80	1990	% change 80 - 90	2000	% change 90 - 00	% change 70 - 00
Connecticut								
Highlands	203,473	238,560	17.20%	264,131	10.70%	285,730	8.20%	40.40%
CT state	3,032,217	3,107,576	2.50%	3,287,116	5.80%	3,405,565	3.60%	12.30%
Pennsylvania								
Highlands	914,179	990,974	8.40%	1,095,067	10.50%	1,216,725	11.10%	33.10%
PA state	11,793,909	11,863,895	0.60%	11,881,643	0.10%	12,281,054	3.40%	4.10%

Most municipalities experienced population growth between 1970 and 2000. Sherman stood out, at 184% increase. Burlington, New Fairfield, and Goshen all experienced more than 90% growth. Winchester and Norfolk were the only municipalities that decreased in population between 1970 and 2000 (Figures 3-1 and 3-2). Municipalities with between 10,000 and 17,000 people experienced the most growth between 1970 and 2000. However, Danbury, the only city with over 70,000 people also increased in population, by nearly 50%, during that period (Figure 3-3). Growth rate doesn't tell the whole story, however, particularly for small rural towns. For example, Warren saw an increase of 395 people, which was one of the lowest population increases in the region in terms of sheer numbers. But those 395 people represented an almost 50% increase in the town's population. Such a magnitude of change can have an enormous impact on a small town.

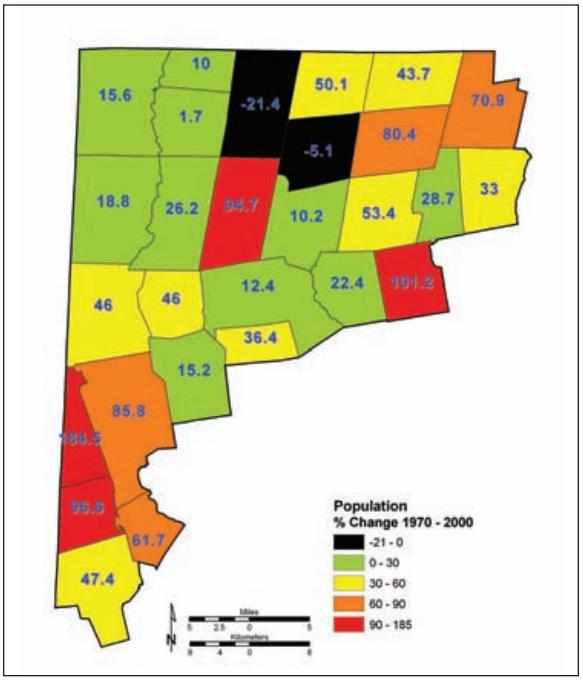


Figure3-1. *Connecticut Highlands: Population growth as % change in population, 1970-2000.*

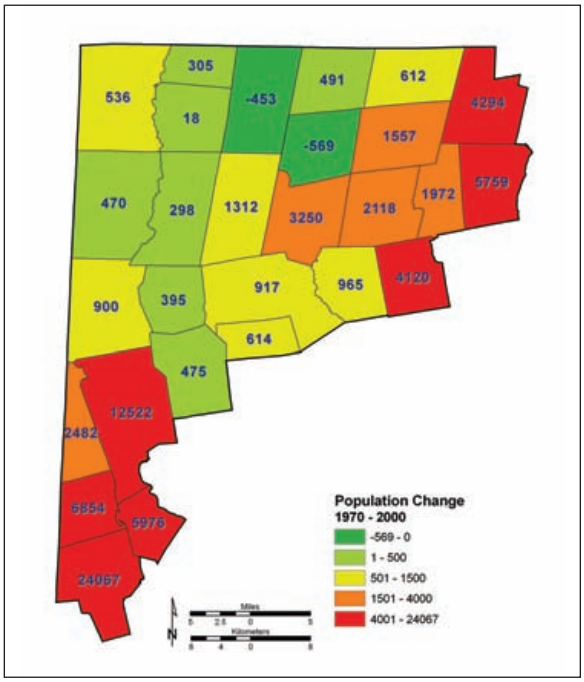


Figure 3-2. *Connecticut Highlands: Population growth in number of people, 1970-2000.*

Overall, the population of the Connecticut Highlands is getting older. Despite an increase of over 82,000 people in the region, there was a decrease in the number of children and a very small increase in young adults. In 1970, the percentage of people under 30 was over 50%; in 2000 it was 36% (Figure 3-4).

Per capita income and education were lowest in Danbury, North Canaan, Winchester and Torrington. While these four lowest-income municipalities also had the fewest people who have attended at least some college, education and income were not well correlated in the other municipalities.

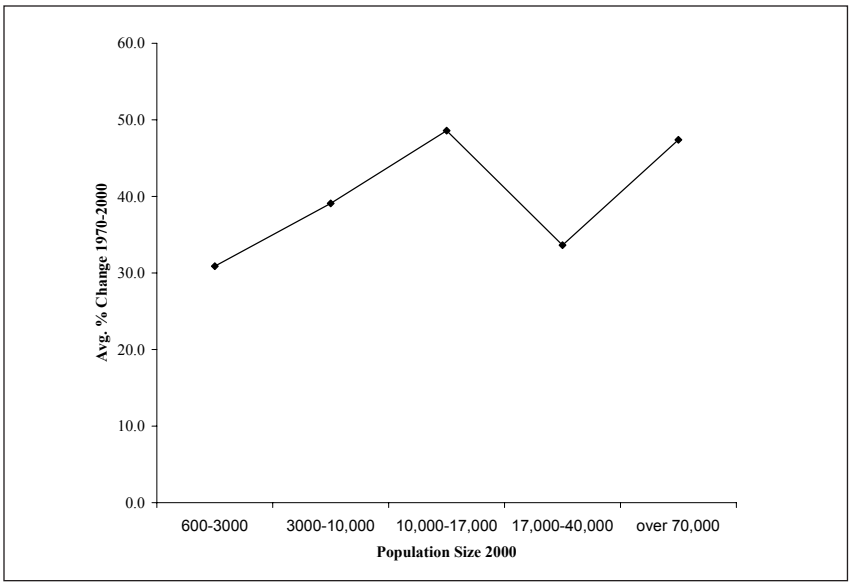


Figure 3-3. *Connecticut Highlands: Population change in municipalities by size category, 1970-2000.*

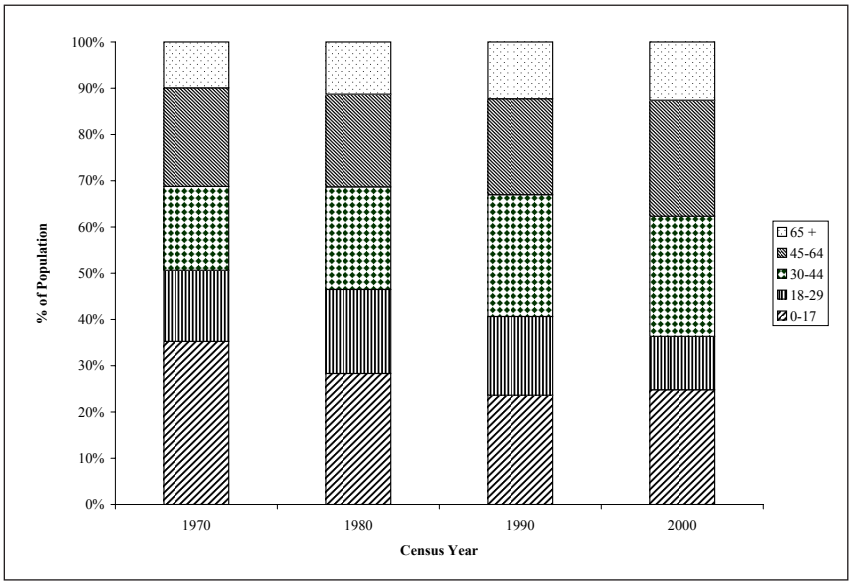


Figure 3-4. *Connecticut Highlands: Population by age class in 1970, 1980, 1990, and 2000.*

Connecticut Housing

By 2000, there were 46,500 more housing units in the Connecticut Highlands than there were in 1970. Housing growth in the Highlands increased faster than housing growth in the state as a whole in every decade from 1970 to 2000. Total housing units increased 65.8% in the Connecticut Highlands compared to 41.3% in the whole state (Table 3-2). Housing grew faster than population between 1970 and 2000; on average fewer people were living in each house in 2000 compared to 1970 (Figures 3-5 and 3-6). However, housing growth slowed considerably in the 1990s.

Pennsylvania Population

Pennsylvania's Highlands region includes 173 municipalities (townships, boroughs and cities) ranging in size from one-tenth of a square mile to almost 50 square miles, with a population size ranging from 243 to over 100,000.

The region has seen a steady increase in population over the past 30 years, with an additional 302,500 people. Population density increased from 423 to 563 people per square mile. The rate of growth increased in each decade from 8.4% in the 1970s to 11.1% in the 1990s.

Table 3-2. *Housing growth compared to Connecticut state-wide trends.*

	1970	1980	% change 70 - 80	1990	% change 80 - 90	2000	% change 90 - 00	% change 70 - 00
Highlands	70,701	88,345	25.00%	109,026	23.40%	117,211	7.50%	65.80%
CT State	981,158	1,158,884	18.10%	1,320,850	14.00%	1,385,975	4.90%	41.30%

Table SOC-2. Connecticut Highlands: Housing growth compared to Connecticut state-wide trends

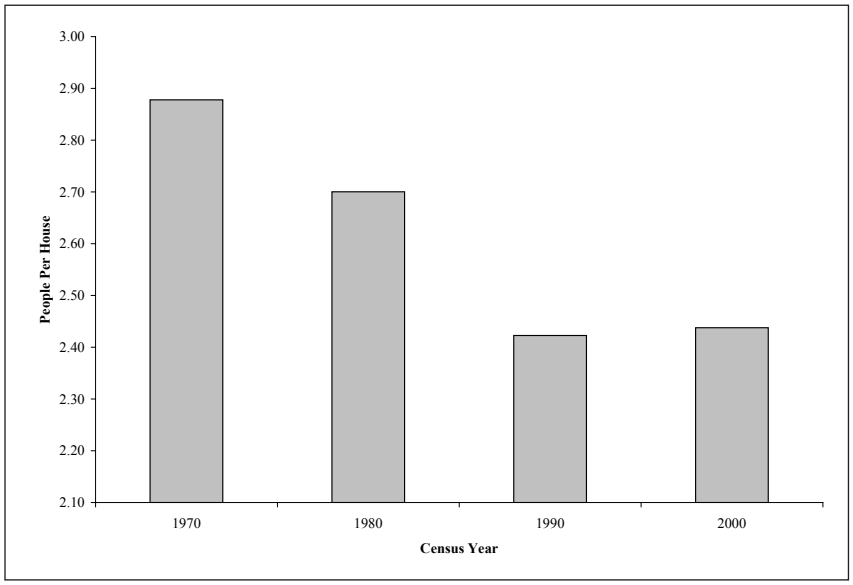


Figure 3-5. *Connecticut Highlands: Average number of people per house in 1970, 1980, 1990, and 2000.*

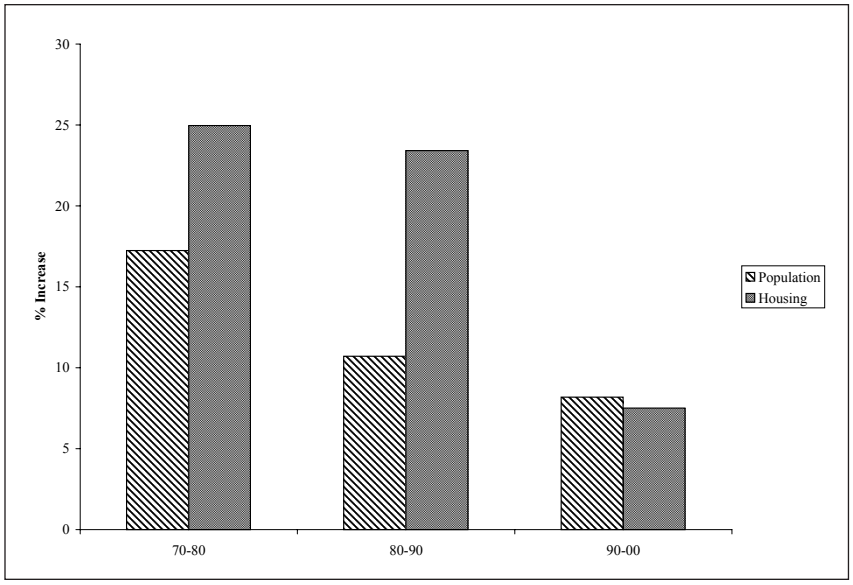


Figure 3-6. *Connecticut Highlands: Comparisn of housing and population growth.*

Most municipalities experienced population growth between 1970 and 2000. Upper Uwchlan was the leader, with a 611% increase, or 5,887 more people in a municipality that had a population just under 1,000 in 1970. Allentown, Bethlehem, Easton, Reading, and Ontelaunee were among those municipalities that decreased in population in that time period (Figures 3-7 and 3-8).

A pattern emerged when comparing the largest municipalities (over 70,000 people), the smallest municipalities (under 600 people) and four categories in between. The smallest and the largest municipalities experienced an overall drop in population while the four middle size classes all gained in population (Figure 3-9).

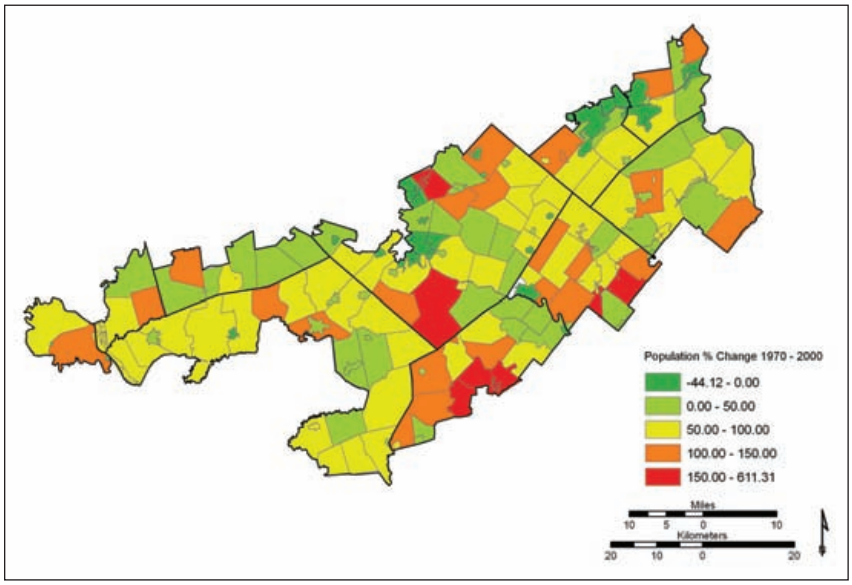


Figure 3-7. *Pennsylvania Highlands: Population growth by municipality as % change in population, 1970-2000.*

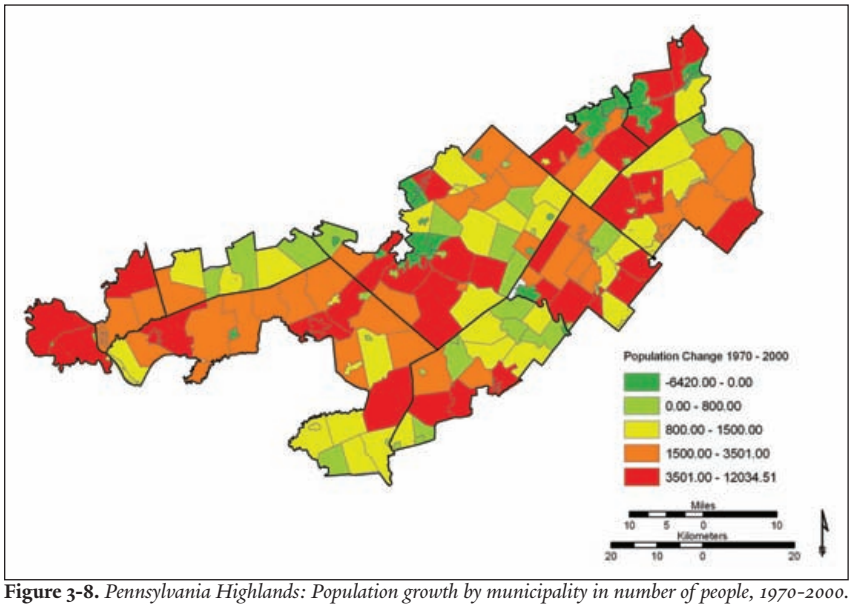


Figure 3-8. *Pennsylvania Highlands: Population growth by municipality in number of people, 1970-2000.*

Municipalities that shrank in population from 1970 to 2000 included the three largest in the Highlands region: Bethlehem, Allentown, and Reading. However, they did not experience a continual loss of population over the 30 year period. All three lost population during the 1970s, but Bethlehem and Allentown gained slightly during the 1980s and Allentown and Reading gained slightly during the 1990s (Figure 3-10).

In these three municipalities, a very high percentage of people were living in poverty in 2000 compared to the rest of the Highlands region (Figure 3-11). Looking closely at Figures 3-7 and 3-8

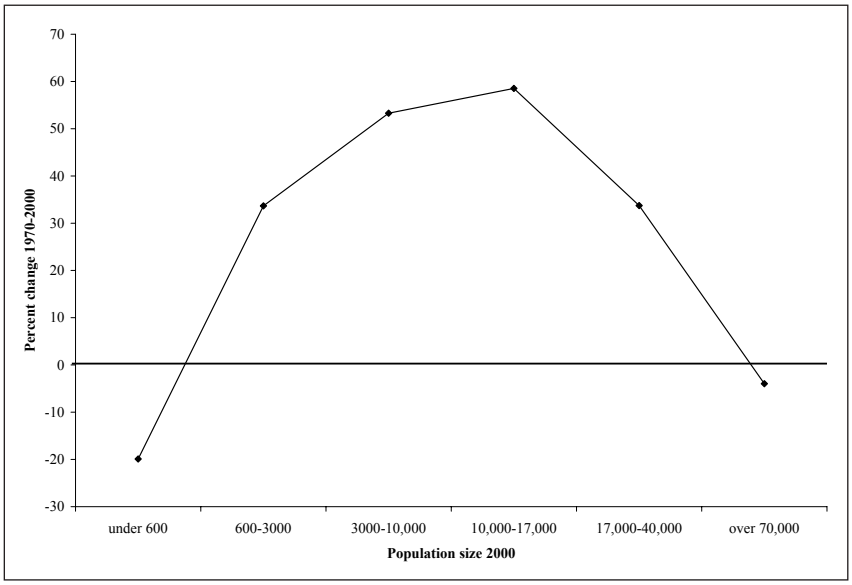


Figure 3-9. *Pennsylvania Highlands: Population change by size of municipality, 1970-2000.*

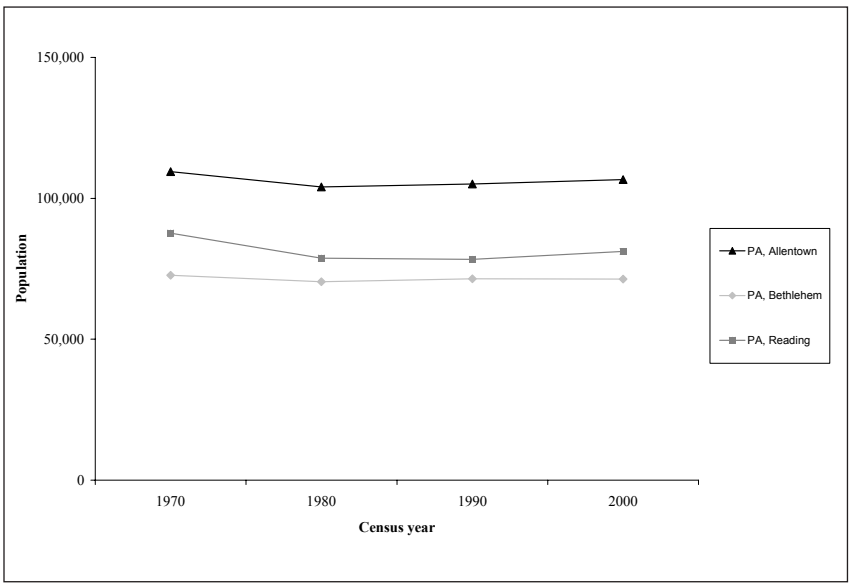


Figure 3-10. *Pennsylvania Highlands: Population trends in large municipalities, 1970-2000.*

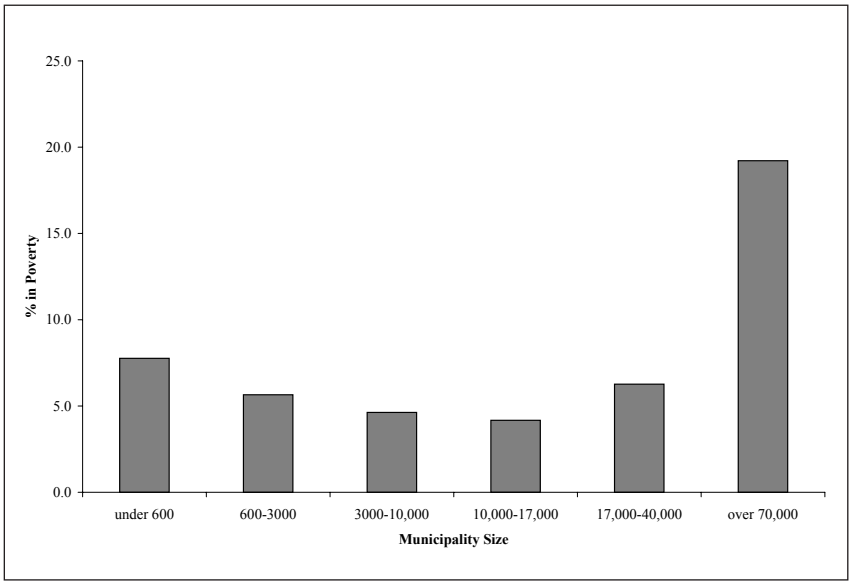


Figure 3-11. *Pennsylvania Highlands: Percent of population in poverty by municipality sie in 2000.*

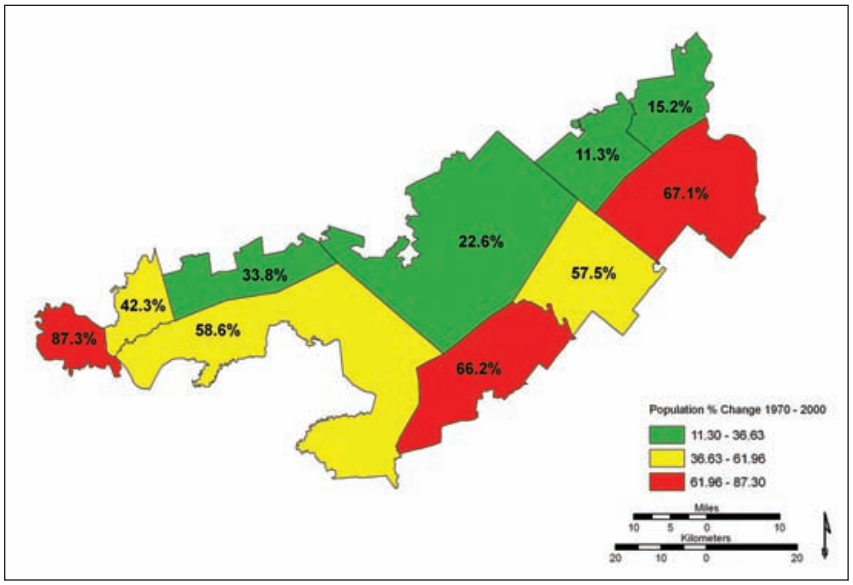


Figure 3-12. *Pennsylvania Highlands: Percent change in population between 1970 and 2000, by county.*

reveals a ring effect around the biggest cities. While Bethlehem, Allentown and Reading lost population, they are surrounded by municipalities that significantly increased in population.

One reason that the Bethlehem area declined in population between 1970 and 2000 is the loss of its industrial base. Bethlehem Steel was a major employer in the Bethlehem area for many decades, peaking in World War II. The company started its decline toward bankruptcy in the late 1970s and through the 1980s when it began experiencing annual losses. Today, the Lehigh Valley Industrial Park, Inc. (LVIP) is bringing industrial development into the region, employing 20,000 people at 400 companies in Lehigh and Northampton counties (LVIP 2007).

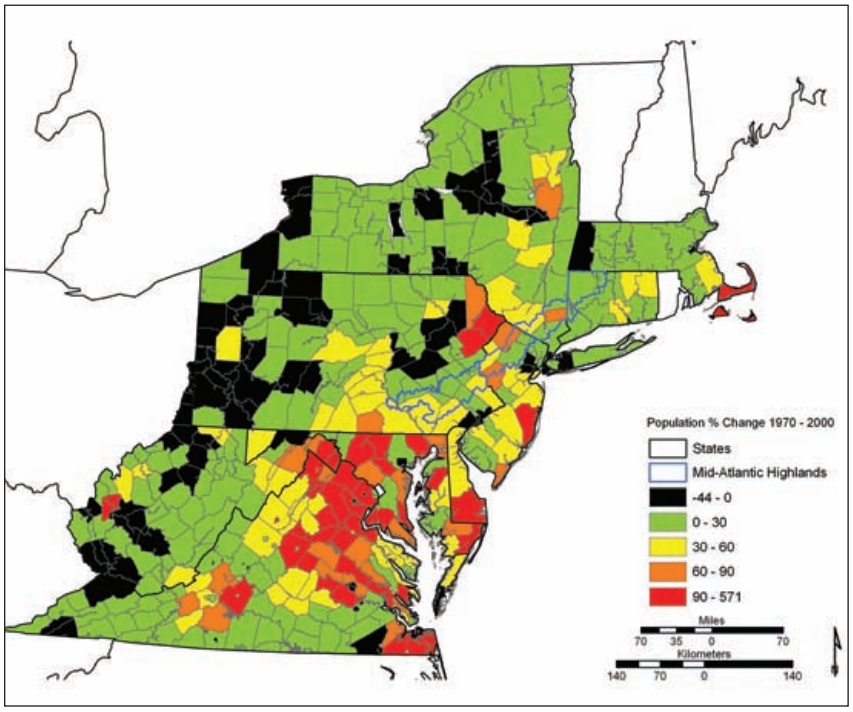


Figure 3-13. *Population growth for counties on the U.S. eastern seaboard from Chesapeake Bay to Cape Cod. Note: Data are for entire counties as compared to Figure 3-12 which is for only that portion of each county that is in the Highlands. Highlands portions of most counties are growing faster than the whole county.*

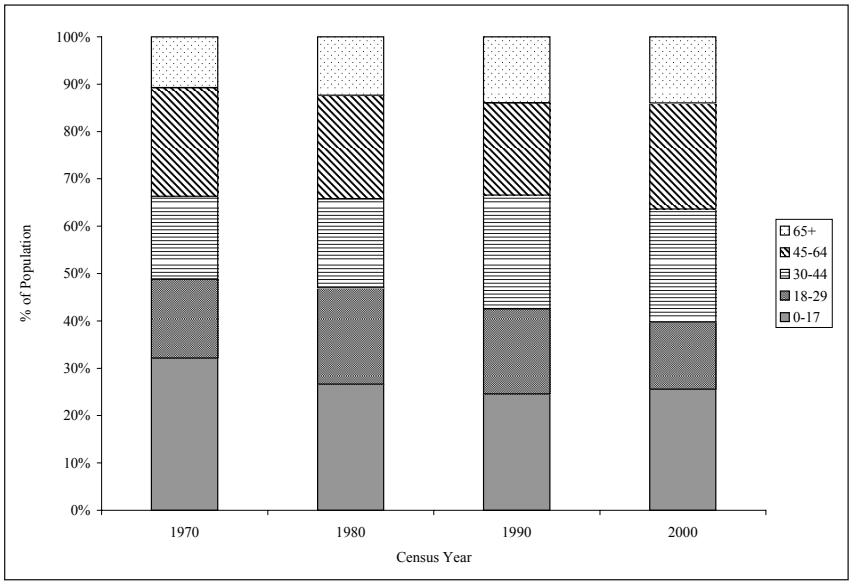


Figure 3-14. *Pennsylvania Highlands: Populaton by age class in 1970, 1980, 1990, and 2000.*

Table 3-3. *Pennsylvania Highlands: Housing unit growth compared to Pennsylvania state-wide trends.*

	1970	1980	% change 70 - 80	1990	% change 80 - 90	2000	% change 90 - 00	% change 70 - 00
Highlands	300,613	367,978	22.40%	424,103	15.30%	481,225	13.50%	60.10%
PA State	3,924,757	4,596,431	17.10%	4,938,140	7.40%	5,249,750	6.30%	33.80%

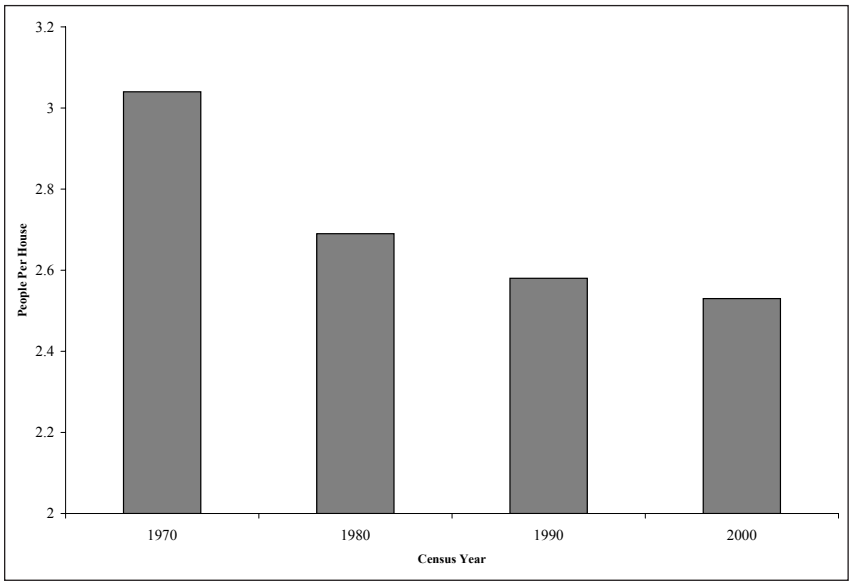


Figure 3-15. *Pennsylvania Highlands: Average number of people per house in 1970, 1980, 1990, and 2000.*

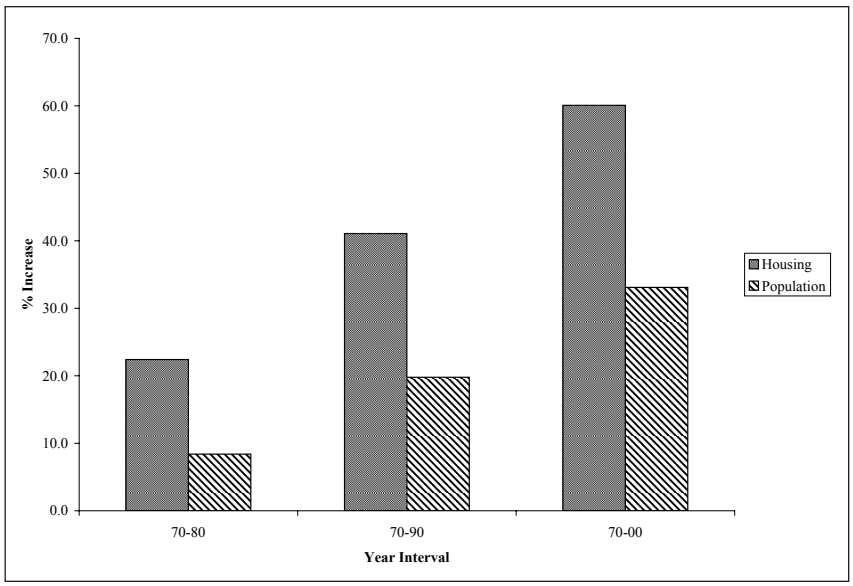


Figure 3-16. *Pennsylvania Highlands: Comparison of housing and populaton growth.*

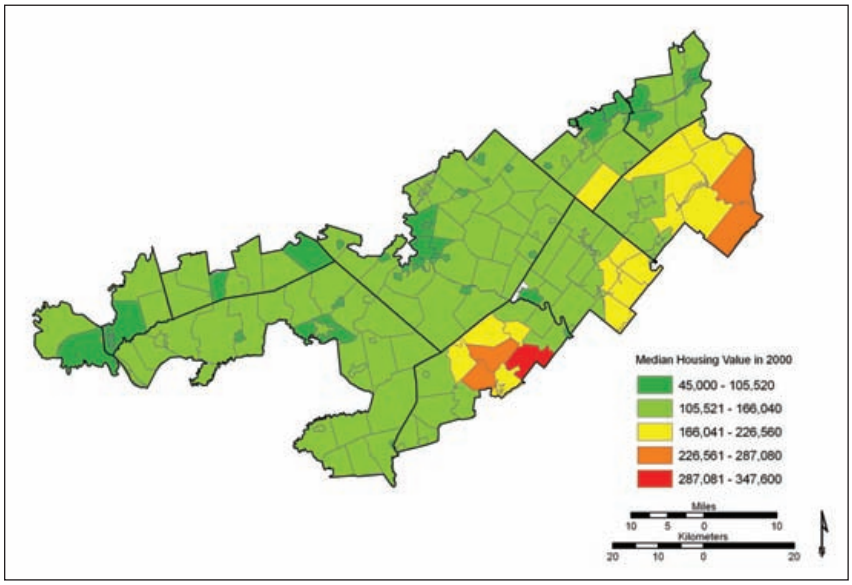


Figure 3-17. *Pennsylvania Highlands: Median housing value in 2000, by municipality.*

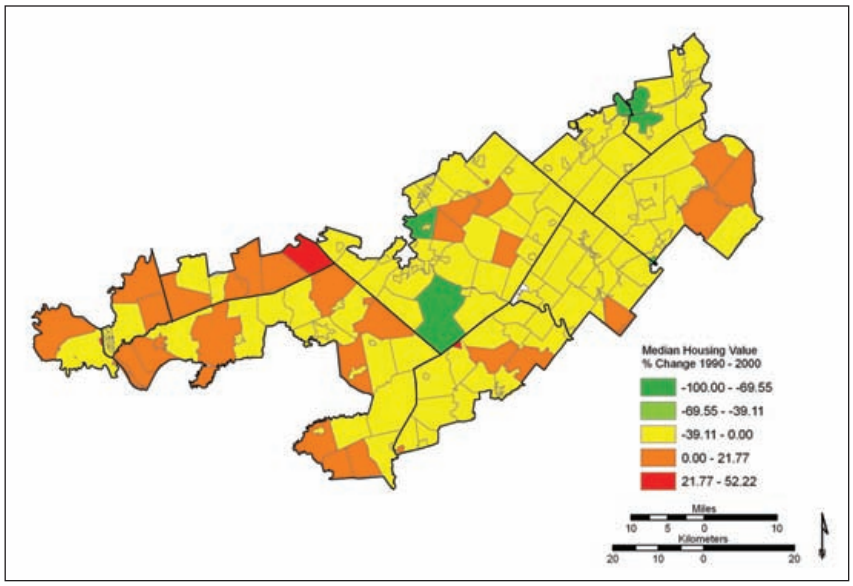


Figure 3-18. *Pennsylvania Highlands: Percent change in median housing value by municipality, 1990-2000.*

While all the counties in the Pennsylvania Highlands gained in population between 1970 and 2000, Lehigh and Northampton gained the least, and the portion of York County that falls within the Highlands border gained the most (Figure 3-12). A map of eastern seaboard counties from Virginia to New York shows that the counties of the Pennsylvania Highlands are exhibiting low to average growth compared to surrounding areas. The Pennsylvania Highlands are surrounded on three sides by very high population growth, sprawling out from New York, Philadelphia, and the Washington, DC metropolis (Figure 3-13).

The population of the Pennsylvania Highlands is aging. The proportion of the population under 30 has gone down, and the fastest-growing age categories are 30-44 and over 65 (Figure 3-14).

Education and income correlated fairly closely in the Pennsylvania Highlands in 2000. The eastern and south-eastern parts of the Highlands tended to have a higher per capita income and a higher proportion of people who had received at least some college education.

Pennsylvania Housing

With an additional 180,600 new housing units, housing in the Pennsylvania Highlands has increased at a much higher rate than housing in the state of Pennsylvania as a whole. From 1970 to 2000, housing increased 60.1% in the Highlands and only 33.8% in Pennsylvania (Table 3-3). The increase in housing was greater than the increase in population; fewer people are living in each house, on average. In 1970, the average number of people per house was over 3, while in 2000 the average number was closer to 2.5 (Figure 3-15).

There is a striking pattern in median house value across the Pennsylvania Highlands. Median house value increases the closer a municipality is located to Philadelphia or New York City. Median house value was highest in West Vincent, a suburb of Philadelphia, at $347,600. The other municipalities with median house value greater than $200,000 were Tinicum, East Nantmeal, Wallace, Plumstead, Durham, Upper Uwchlan, Bedminster, Nockamixon, and Haycock. Reading had the lowest median house value, at $45,000 (Figure 3-17).

Housing values are generally declining. Only 35 out of 173 municipalities experienced an increase in median housing value between 1990 and 2000. The western end of the Highlands, where median house values are generally lower, showed a greater increase in housing value than did the eastern end. Bedminster, Nockamixon, and Tinicum are the three municipalities at the eastern end of the Pennsylvania Highlands that showed an increase in median housing value (Figure 3-18).

CHAPTER 4 FOREST RESOURCES CHARACTERISTICS AND TRENDS

Key Findings

Connecticut

- Forests, which cover 67% of the region, are mostly oak-hickory and mixed hardwoods; red maple is the dominant species.
- There is a fairly even mix of age classes, except for a low percentage of young stands (less than 40 years).
- Stand structure is fairly homogeneous, with 76 percent comprised mostly of sawtimber size trees, generally larger than 11 inches in diameter.
- There has been a net loss of 10,808 acres of forest between 1985 and 2002.
- In the State of Connecticut, 77 percent of the forestland is owned privately, 50 percent by families; twenty-five percent of family forest owners are over age 65. These landowner demographics are likely similar for the Highlands region.
- Forests of the Connecticut Highlands are more fragmented than they were in 1985; although core forest (patches greater than 18.6 acres) is still dominant at 43 percent of the area, there were 24,300 fewer acres of core forest in 2002 than in 1985.
- A comparison of forest fragmentation and the Forest Inventory Analysis (FIA) plot data for the Highlands region showed that fragmentation has a significant impact on stand composition and structure.
- There are currently no major forest insect or disease outbreaks.

Pennsylvania

- Thirty-two percent of the region is forest consisting mostly of oak species and red maple; forest cover remained stable between 1992 and 2001.
- Stand structure is fairly homogeneous, comprised mostly of sawtimber size trees, generally larger than 11 inches in diameter. There is a fairly even distribution of age classes.
- In the Commonwealth of Pennsylvania, 71% of the forestland is owned privately, 54% by families; 30% of family forest owners are over age 65. These landowner demographics are likely similar for the Highlands region.
- The Pennsylvania Highlands forests are highly fragmented; only 23 percent is core forest (patches greater than 18.6 acres).
- A comparison of forest fragmentation and the Forest Inventory Analysis (FIA) plot data for the Highlands Region showed that fragmentation has an impact on stand composition and structure.
- There are currently no major forest insect or disease outbreaks; gypsy moth outbreaks are cyclical, but biological controls have so far prevented a recurrence of the massive defoliation events of the 1980s.
- Forests in Pennsylvania are vulnerable to major mortality caused by the Emerald Ash Borer which has been found in Maryland and western Pennsylvania.

Introduction

The goals of this study were to analyze forest composition, structure and health, and report on long-term trends wherever possible.

In 2002 there were approximately 457,200 forested acres in the Connecticut Highlands, with an additional 20,200 acres of forested wetlands. There were approximately 444,700 forested acres in Pennsylvania in 2001. While the Pennsylvania Highlands region is larger, the Connecticut region is more heavily forested (67% compared to 32%). This is because there is much more prime agricultural land in Pennsylvania.

Data Sources

Forest composition was determined primarily using data obtained from the Forest Inventory and Analysis (FIA) program of the USDA Forest Service (USDA Forest Service 2007). FIA datasets were downloaded and analyzed using Microsoft Access.

Completed inventories from 1985, 1998 and a subset of data collected between 2003 and 2005 were analyzed for Connecticut. In addition, summarized forest inventory data from the Mohawk, Enders, Tunxis, People's and American Legion State Forests, and inventory data from lands managed by the Metropolitan District Commission (MDC) were used. Published results from long-term data collected by the Connecticut Agriculture Experiment Station (CAES) were also analyzed to better understand long-term trends.

For Pennsylvania, the completed FIA inventories from 1989 and 2005 were used. In addition, the analysis looked at forest inventory data from 24,530 acres of state game lands.

Forest health issues in Connecticut were identified by analyzing data from the CAES forest health monitoring plots, established in 1994. Forest health issues in Pennsylvania were identified by analyzing data from the Bureau of Forestry aerial sketch maps of defoliation from 1964-2006 and group surveys from 2001-2006. In addition, the USDA Forest Service 2002 National Risk Maps for Insects and Diseases are shown and discussed.

Forest fragmentation was assessed based on work done by the UCONN Center for Land use Education And Research (CLEAR) for Connecticut, and on a similar forest fragmentation map for Pennsylvania prepared for this study.

Forest ownership patterns were determined by analyzing the 2006 results from the USDA Forest Service, Forest Inventory and Analysis National Woodland Owner Survey. These were aggregated for counties within the Highlands Region by the Forest Service (Butler 2008a).

FIA Data

The Forest Inventory and Analysis (FIA) program of the USDA Forest Service collects data on an annual basis from the nation's forests. Once a full cycle has been completed, FIA data include one plot for each 6,000 acres across the state. For this study, FIA data points falling within the Highlands boundary, plus those within a five mile buffer around the Highlands boundary, were used. The buffer was included to increase the number of sample points in the analyses but did not extend beyond state boundaries to ensure consistency of data. Area based estimates were adjusted to correspond to the known actual acres of forest land from the land cover maps. The data were analyzed to determine current forest cover types, species composition, and size and age classes.

The most recent inventory cycle for Connecticut contains data collected in 2003, 2004 and 2005, and represents 3/7ths of total plots that will be measured during this inventory cycle (Table

4-1). A subset of the data was compared to FIA datasets from 1985 and 1998 to determine changes that have occurred over the last two decades.

Table 4-1. *Connecticut Highlands: Number of FIA plots by inventory cycle.*

	Inventory Cycle Year		
	1985	1998	2005
# Plots	141	134	68

The most recent inventory cycle for Pennsylvania contains data collected in 2000, 2001, 2002, 2003, and 2004[2] (Table 4-2). A subset of the data was compared to FIA data from 1989 to determine changes that have occurred over the last two decades.

Table 4-2. *Pennsylvania Highlands: Number of FIA plots by inventory cycle.*

	Inventory Cycle Year	
	1989	**2005**
# Plots	448	398

Analysis of FIA Data by Fragmentation Class

The FIA plot data were analyzed with respect to how "fragmented" the forest was at each plot location. This was done by overlaying the FIA plot data onto a forest fragmentation map. We used the University of Connecticut's Center for Land use Education And Research (CLEAR) fragmentation analysis for the state of Connecticut (CLEAR 2002) whereby all forested land was classified into one of 5 types: *core*, *perforated*, *edge*, *transitional* and *patch* (see Appendix 1 for definitions). Each FIA plot was classified into one of the 5 fragmentation types based on the level of fragmentation within an 18.6 acre window (9 x 9 pixels on the land use map), with the plot center at the center of the window. The plot was classified as core forest only if the entire window was forest. A similar fragmentation map was prepared for Pennsylvania as part of this study.

In order to protect confidentiality, the Forest Service does not provide real plot locations, and the publicly available coordinates have been fuzzed up to a mile and possibly switched with other plots within the same county. Therefore, we provided the fragmentation maps to the Forest Service, who provided us with the fragmentation value of the real plot location. Our fragmentation analysis focuses on *core* and *edge* forest as being the most distinct fragmentation categories for comparison of plot data.

Forest Resources in the Connecticut Highlands

There are several major forest tracts in the Connecticut Highlands, making it an important state and regional resource. Great Mountain Forest, at 6,400 acres, is the largest private, family-owned forest in the state. Other large tracts are the 3,800 acres of forest belonging to the White Memorial Foundation, the 4,300 acre Mount Riga property and the Metropolitan District Commission's

2 The dataset downloaded from the FIA NIMS database is titled "2005" but in reality contains data collected through December 2004.

14,740 acres of forest. The Connecticut Department of Environmental Protection manages over 40,000 acres of land in the Highlands, including state parks, wildlife management areas, and state forests. The vast majority of the forested land in the region, however, is comprised of small, privately owned parcels.

Of the approximately 677,000 acres in the Connecticut Highlands, 457,200 are forested. The forests contain a mixture of deciduous and coniferous species. The major species are red maple (*Acer rubrum*), northern red oak (*Quercus rubra*), eastern hemlock (*Tsuga canadensis*), and sweet birch (*Betula lenta*). A major wave of reforestation occurred following agricultural abandonment and the end of charcoal production for the iron industry in the early 20th century; most of these forests are now between 60 and 100 years old. On actively managed lands, the forests are gradually being harvested and regenerated, resulting in a greater diversity of age and size classes. However, it is estimated that 43% of the land is owned by families, most of whom are not managing their land using what would be considered good silvicultural practice.

There is no "virgin forest" in the region. The last old growth forest in the state, located in Colebrook, was cleared in 1912 (Nichols 1913). Old-growth stands had a much larger component of hemlock, American beech (*Fagus grandifolia)*, yellow birch (*Betula alleghaniensis)*, red maple and sugar maple (*Acer saccharum)*. Current timber management has favored red oak, while Ward (2005) found that long-term unmanaged plots are increasingly being dominated by late seral species like hemlock and beech.

According to the land use change analysis, 13,270 acres of forest were lost to other land uses between 1985 and 2002, while about 2,500 acres of land previously in other land use categories are now in forest. This "conversion" to *forest* came primarily from land previously designated as *water* or *wetland* and may be an artifact of the classification process or to changes in water levels from year to year.

Of the 13,270 forested acres lost, 61% were converted to *developed* and associated land use, 27% to *other grasses & agriculture* or *turf & grass*, and 12% to *water/wetlands*. It is reasonable to assume that the majority of this loss can be attributed to development since grasses associated with development (turf, lawn, athletic field, etc.) are easily confused with agricultural fields in land use/land cover classifications. Forest loss has slowed since 1990, with more than half of the loss between 1985 and 2002 occurring prior to 1990.

Current Forest Composition

The following results are based on FIA data collected in 2003, 2004, and 2005 on 68 plots throughout the Highlands. These data cannot reasonably be extrapolated to reflect with any degree of certainty the composition of all forests of the Highlands. However, they are the only region-wide inventory data in existence.

Forests with FIA plots are primarily composed of various oak/hickory stand types, with smaller northern hardwood components (Figure 4-1). Only a small percentage is composed of young stands, with the majority made up of even-aged stands between 61 and 100 years (Figure 4-2). Twenty percent of stands are over 100 years old. Most (76%) of the plots are comprised of large sawtimber trees (greater than 11 inches dbh) (Figure 4-3).

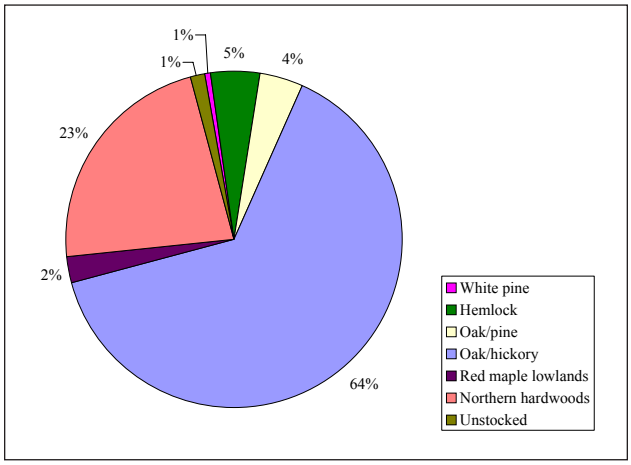


Figure 4-1. *Connectictiut Highlands: Composition of forest types within FIA plots.*

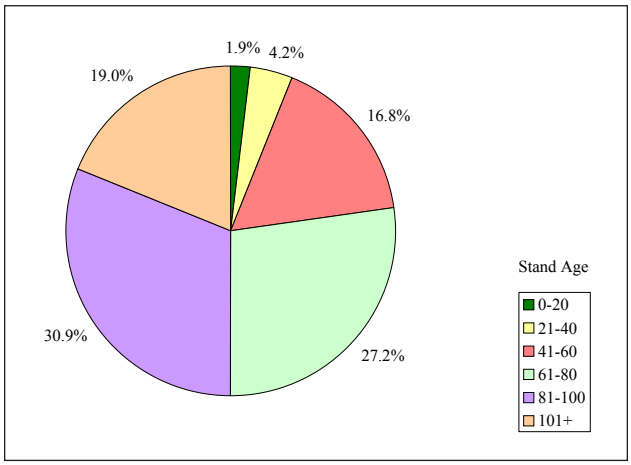


Figure 4-2. *Connectictiut Highlands: Stand age in FIA plots.*

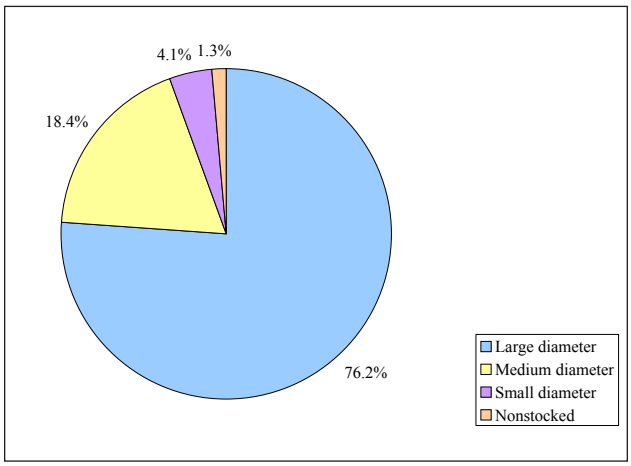


Figure 4-3. *Connectictiut Highlands: Stand size in FIA plots.*

Trends Over Time

FIA data from the 1985, 1998 and 2005 inventory cycles were compared to detect any trends in forest composition and structure over time (Figures 4-4 and 4-5). Because the 2005 inventory cycle is not yet complete, however, these comparisons should be interpreted with caution. The analyses of changes in density and basal area over time were done on a per acre basis to normalize results. Over time and in the absence of management or other disturbance, vigorous young-to-mature natural forest stands decrease in density and increase in basal area as the dominant trees grow and less competitive and suppressed trees die. Basically, as the forest ages, there are fewer trees but those trees are increasingly larger in diameter. The FIA data show that average density (trees/acre) has increased in both the overstory and understory, and average basal area per acre has increased as well (Figure 4-6). The unexpected increase in density could result from the development of a shade tolerant understory that is able to persist even with strong competition from overstory trees.

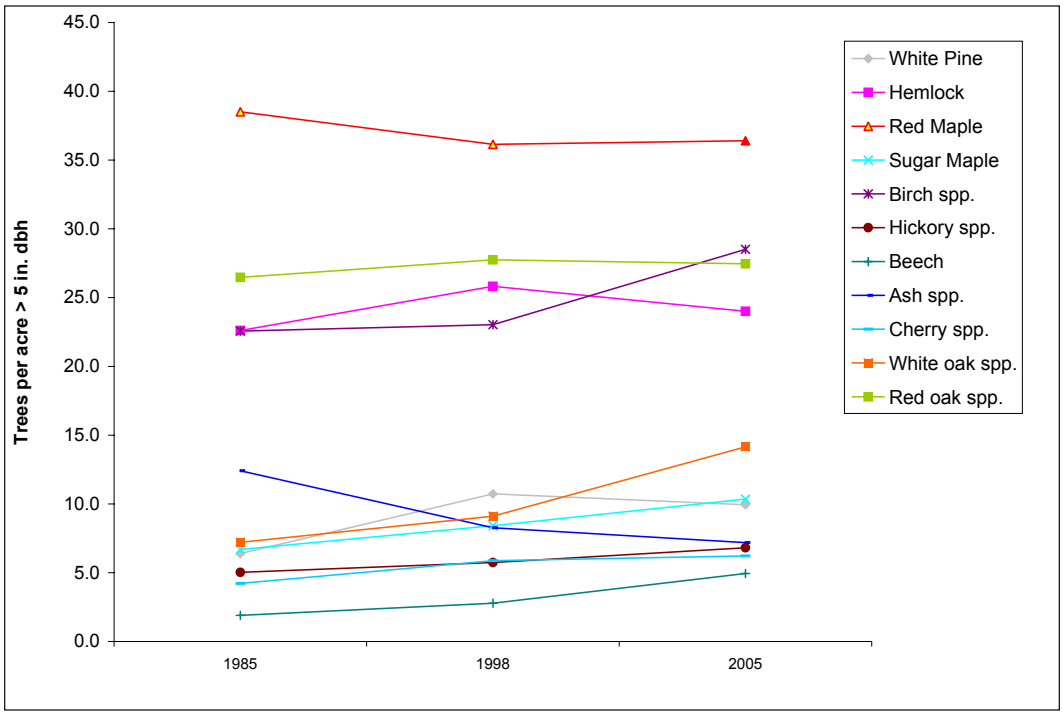


Figure 4-4. *Connectictiut Highlands: Number of trees >5 inches dbh by species in FIA plots, 1985-2005.*

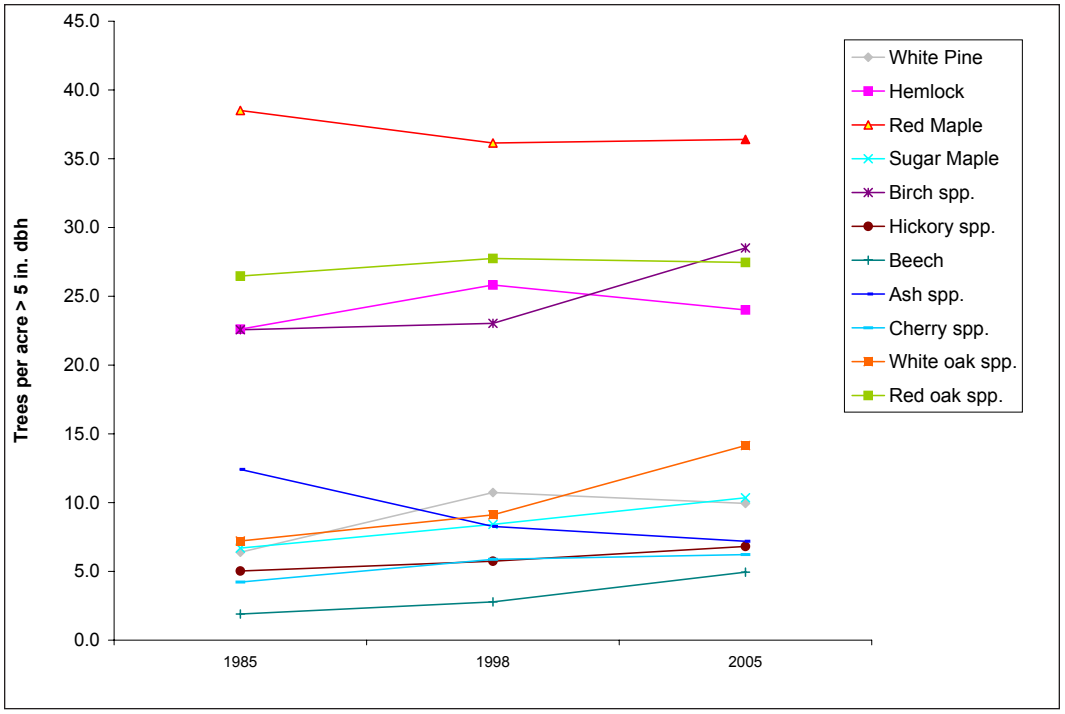


Figure 4-5. *Connectictiut Highlands: Number of trees 1-5 inches dbh by species in FIa plots.*

Red maple, a moderately shade tolerant species, is by far the most prevalent tree in both the overstory and understory. However, both the density and basal area of red maple has decreased since 1985. The change in basal area was not statistically significant, so it is uncertain if the trend is real (Figure 4-7).

Sweet birch, a moderately shade tolerant, early successional species, which does well on a wide range of sites, is increasing in both density and basal area, although increases in density are much more significant for trees between 1 and 5 inches dbh. The density of eastern hemlock, a very shade tolerant species, is decreasing in the overstory and increasing in the understory. Hemlock basal area increased between 1985 and 1998, and decreased from 1998 and 2005. The basal areas of both red oak and sugar maple have increased over the past 20 years.

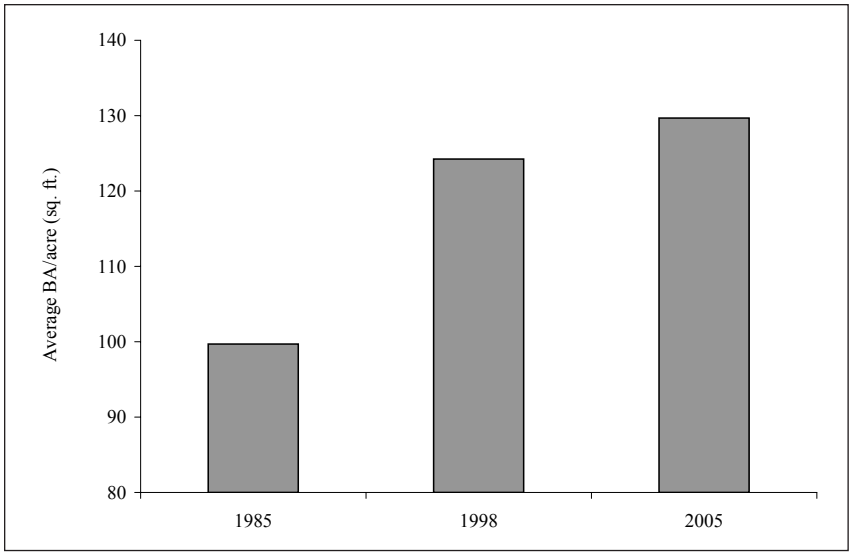


Figure 4-6. *Connectictiut Highlands: Average basal area per acre in FIA plots, 1985, 1998, 2005.*

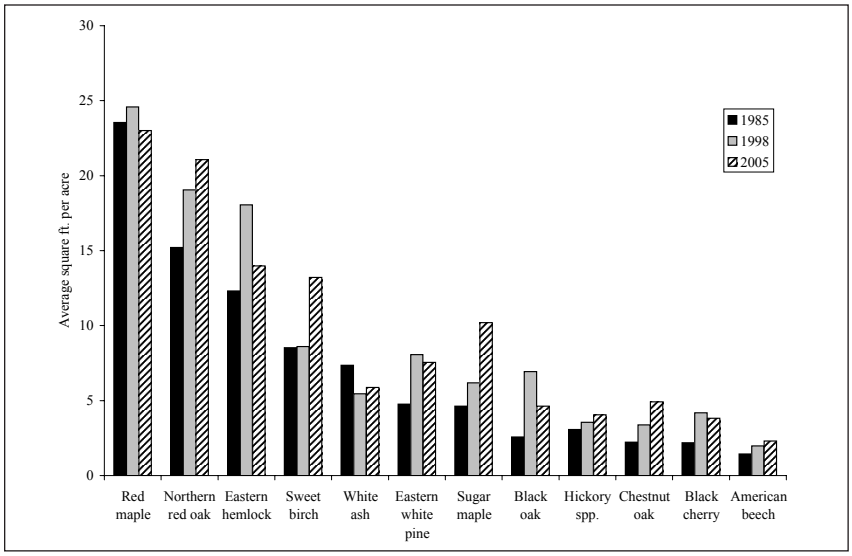


Figure 4-7. *Connectictiut Highlands: Basal area by species in FIA plots, 1985, 1998, 2005.*

Forest Fragmentation – Extent and Effects[3]

The CLEAR fragmentation analysis shows that forests of the Connecticut Highlands are becoming more fragmented. The perimeter:area ratio has increased, meaning that forest patches have a greater amount of edge per unit area; thus forest patches are becoming more fragmented and, therefore, more complex in shape with less interior area. Since 1985, there has been a decrease in both core and edge forest, most notably a loss of 24,300 acres of core forest. (Table 4-3). Losses in

3 For more information about methods and results for fragmentation indices, refer to Chapter 9, *Impacts of Land Use/Land Cover Change on the Resources of the Highlands*.

these two types over time can be caused by conversion to a non-forest cover type (*e.g.,* total deforestation for development) or conversion to one of the remaining three fragmentation-types. Patch, transition, and perforated fragmentation-types all increased during that same period, although not to the extent of the loss of core forest. Therefore, the total loss of 13,200 acres of forest has come mostly at the expense of interior, or core, forest, either by direct loss of large forest patches, or by losses of small areas which reduce the size of core patches.

Table 4-3. *Connecticut Highlands: Acres and percent composition by forest fragmentatin type for 1985 and 2002.*

	1985		2002		Change 1985-2002
Forest Type	**%**	**Acres**	**%**	**Acres**	
Core	47	221,319	43	197,015	(24,304)
Patch	2	11,557	3	12,561	1,003
Transition	6	28,627	7	30,643	2,016
Edge	25	118,300	25	115,132	(3,168)
Perforated	20	94,522	23	106,891	12,369

Results of the comparison of FIA plot data to forest fragmentation class show that red oak, red maple and eastern hemlock dominate the overstory[4] in core forest, while red maple, sweet birch and white pine (*Pinus strobus*) are more characteristic of edge forest overstories (Figure 4-8). Yellow birch and beech are virtually absent in edge forest (Figure 4-9). Because of sample size, it was more difficult to assess differences between core and edge forests for less common tree species, such as sugar maple. Core forest understories tend to be dominated by red maple (Figure 4-10). Other characteristic understory species included hemlock, black and yellow birch, and white pine. We suspect that hemlock saplings may have been mis-classified as white pine because white pine does not grow well under closed canopies. In the edge forest understory, red maple was even more prevalent; yellow birch and hemlock were generally absent (Figure 4-11). The data show that species of non-native and exotic invasive tree species are absent, even in the edge forests.

Unfragmented forests tend to have larger, older trees (Table 4-5). Plots classified as core forest had a higher basal area than the edge forest (an average of 118.5 ft^2/acre, compared to an average of 95.9 ft^2/acre) and a higher average stand age (85.1 years compared to 62.7 years).

4 Overstory trees are those trees with a diameter-at-breast-height (dbh) of greater or equal to 5 inches. Understory trees are those trees with a dbh between 1 and 5 inches.

Table 4-4. *Connecticut Highlands: FIA plot data summary by fragmentation type for those plots in the Highlands for which tree data were collected.*

Fragmentation Type	# Plots	%	Trees >5 in. dbh			Trees 1-5 in. dbh		
			# Species	# Trees	Average # Trees per Plot	# Species	# Trees	Average # Trees per Plot
Core Forest	19	40%	24	611	32	17	76	4
Perforated Forest	9	19%	18	177	20	11	38	4
Edge Forest	14	30%	26	367	26	14	49	4
Transition Forest	4	9%	8	33	8	1	3	1
Patch Forest	1	2%	0	0	0	0	0	0

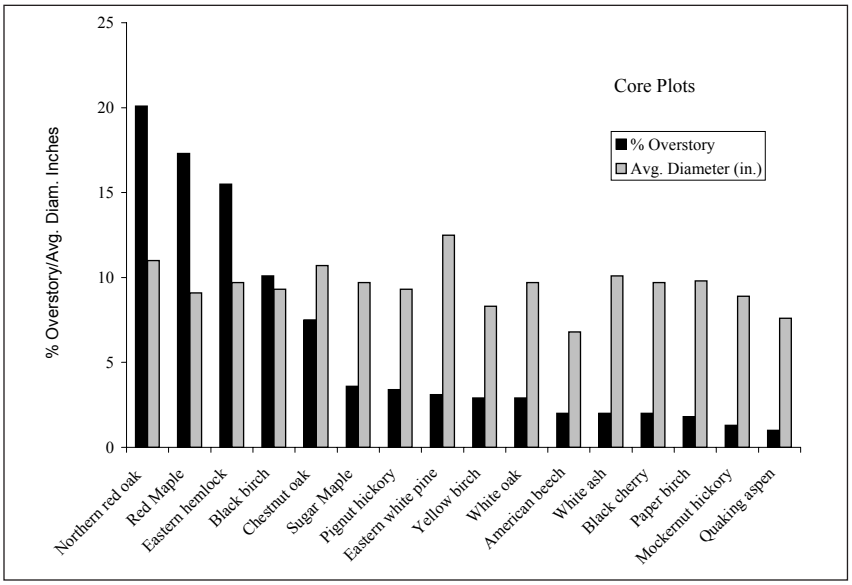


Figure 4-8. *Connectictiut Highlands: Average diameter and percent of total for overstory trees in 19 core forest plots.*

Table 4-5. *Connecticut Highlands: Basal area (ft^2/acre) amd stand age (years) by forest fragmentation value of FIA plots in core and edge forest.*

	Average Basal Area	Average Stand Age
Core	118.5	85.1
Edge	95.9	62.7

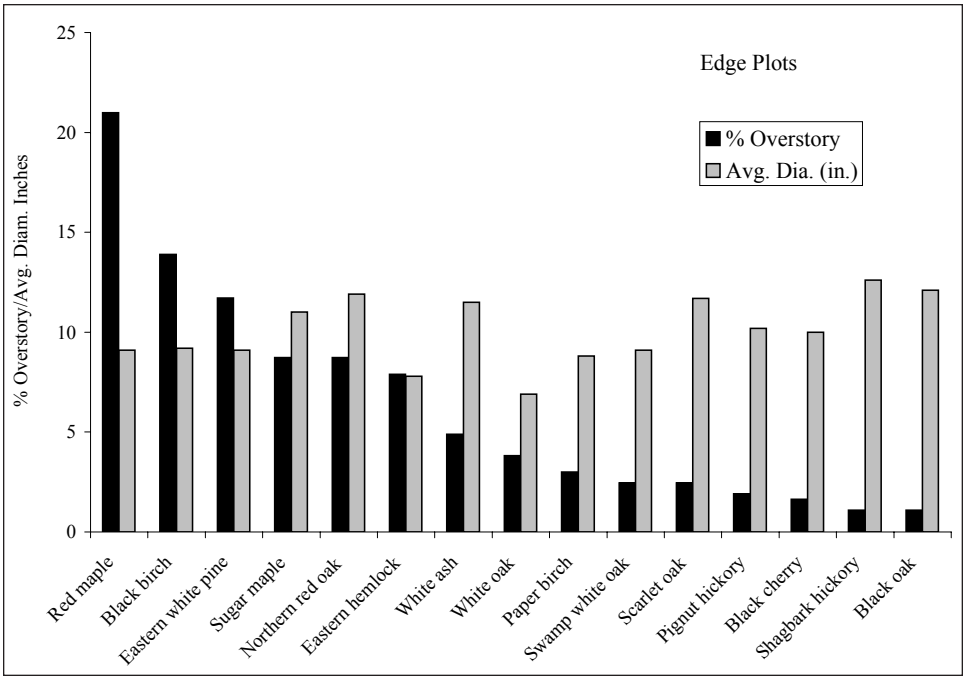


Figure 4-9. *Connectictiut Highlands: Average diameter and percent of total for overstory trees in 14 edge forest plots.*

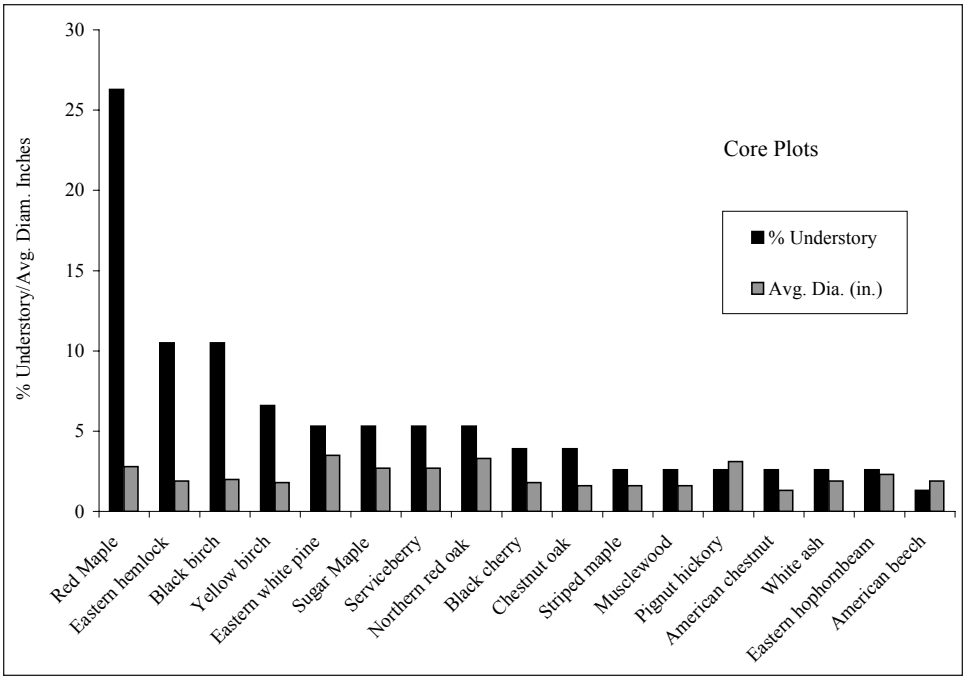


Figure 4-10. *Connectictiut Highlands: Average diameter and percent of total for understory trees (between 1 and 5 inches dbh) in 19 core forest plots.*

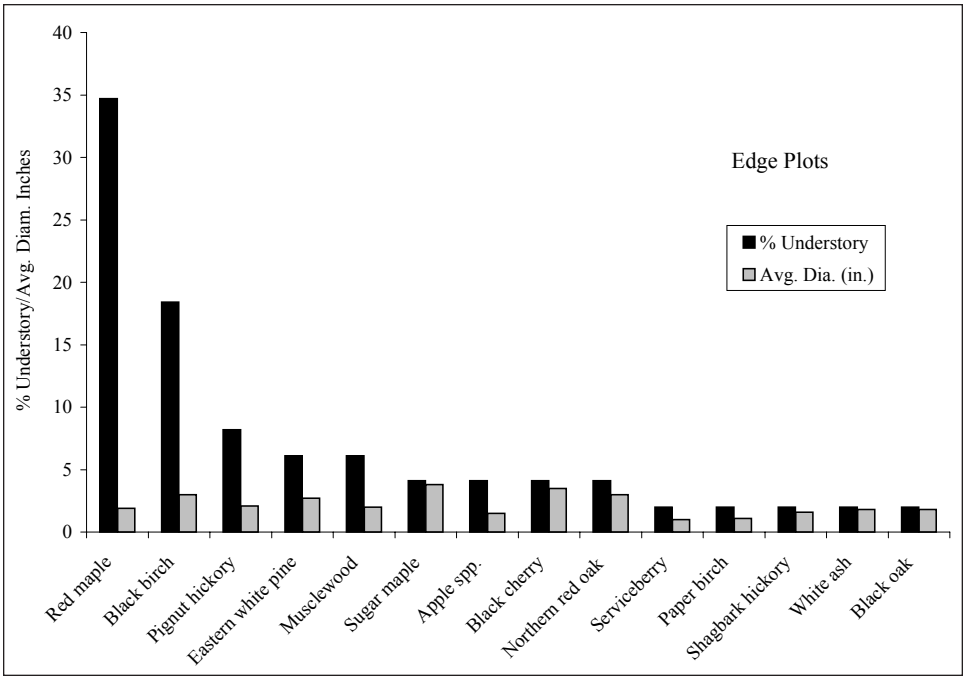


Figure 4-11. *Connectictiut Highlands: Average diameter and percent of total for understory trees (between 1 and 5 inches dbh) in 14 edge forest plots.*

State Forest Inventory Data

The Connecticut Department of Environmental Protection, Division of Forestry, manages 15 state forests in the Highlands region.

Forest inventory data from recent management plans were analyzed for the 13,429 acres on the Mohawk, Enders, Tunxis, People's and American Legion State Forests.[5] All inventory data for these forests were gathered within the last decade. Inventories were generally conducted only on areas of the forest managed for timber and may not represent conditions on other portions of the state forests. Specifically, portions of the forest set aside to protect older and larger trees would not be included in inventory data; therefore inventory data may underestimate the presence of older and larger trees.

Tables 4-6 and 4-7 show the relative importance of forest cover type and stand size in the state forests of the Highlands. On inventoried acres, 69% is comprised of sawtimber-sized trees (>11 inches dbh). Very little of the forest is currently in either the seedling/sapling (< 5 inches dbh) or poletimber (5-11 inches dbh) stages; however, because these acres are actively managed and regenerated, the amount of younger stands will almost certainly increase over the next decade. Most of the managed acreage on state forests are under even-aged management (including some two-aged stands); only 13% are currently classified as uneven-aged.

The majority of the inventoried land (60%) is covered with some type of hardwood forest. Twenty percent is classified as oak-hickory, 6% as northern hardwoods (maple-beech-birch), and

5 This represents 13,249 acres out of the total of 41,640 acres of state forest land. Recent inventory data on the rest of the state forests was either not available, or not in a format that was amenable to compilation and analysis.

the remaining 34% is comprised of other mixed hardwood types (Table 4-6). There is no clear differentiation in the data among various hardwood forest types. Some of the stands designated as mixed hardwoods may actually be oak-hickory or northern hardwoods. Under current management scenarios, the proportion of hardwood stands is likely to increase over time, as 98.4% of the regenerating stands and 98.5% of the poletimber stands are classified as hardwood stands. Following harvest, mature conifer plantations are being converted to other stand types, primarily hardwoods or hardwood conifer mixtures. Most of the red pine plantations that were planted decades ago on state forests have already been harvested.

Table 4-6. *Connecticut Highlands: Data for Mohawk, Enders, Nepaug, Tunxis, People's and American Legion State Forests (in acres)*

Forest Type	Sapling (< 5" dbh)	Poletimber (5-11" dbh)	Pole-Sawtimber mix	Sawtimber (>16" dbh)	All-Aged	Sawtimber-Sapling mix	Total	%
Mixed Hardwood	310	468	839	2,288	575	159	4,480	34%
Oak-Hickory	146	0	181	2,227	60	0	2,614	20%
Northern Hardwoods	25	40	10	610	163	0	848	6%
Softwood/ Hardwood	5	2	286	1,773	487	427	2,553	19%
Mixed Softwood	3	0	0	654	81	10	738	6%
Pine	0	5	0	480	103	0	588	4%
Hemlock	0	0	47	1,025	259	0	1,331	10%
Plantation	0	1.8	6	90	0	17	97	1%
Total Acres	489	517	1,369	9,147	1,728	613	13,249	100%
%	4%	4%	10%	69%	13%	5%	100%	

Table 4-7. *Connecticut Highlands: Summary data for Mohawk, Enders, Nepaug, Tunxis, People's and American Legion State Forests (in acres).*

Forest Type	Seedling/Sapling (<5" dbh)	Poletimber (5-11" dbh)	Pole-Sawtimber mix	Sawtimber (>16" dbh)	All-Aged	Sawtimber-Sapling mix	Total	%
Total Hardwoods	481	508	1,030	5,125	798	159	7,942	60%
Total Softwood/Hardwood	5	2	286	1,773	487	427	2,553	19%
Total Softwoods	3	7	53	2,249	443	27	2,754	21%
Total Acres	489	517	1,369	9,147	1,728	613	13,249	100%
%	4%	4%	10%	69%	13%	5%	100%	

Metropolitan District Commission

The Metropolitan District Commission (MDC) is a non-profit municipal corporation chartered by the state to provide regional water services. The MDC owns and manages 18,785 acres in the Highlands. Another 1,849 acres in Massachusetts were included in the analyses because they fell within the 5-mile buffer and data between states were consistent enough to analyze together. Of the total acres managed by the MDC, 14,740 are forested.

Stands dominated by trees greater than 11 inches dbh comprise 95% of the stands MDC manages, with 66% consisting of trees greater than 16 inches dbh (Table 4-8). Twenty eight percent of the stands are classified as oak-hickory, 26% as other hardwoods, and 31% as mixed hardwood/softwood stands (Table 4-9).

Table 4-8. *Connecticut Highlands: Distribution of forested acres by size class on Metropolitan District Commission land.*

Description	Size Class	Acres	%
Seedling	< 1" dbh	16	0.1%
Sapling	1" - 5" dbh	209	1.4%
Poletimber	5" - 11" dbh	571	3.9%
Small Sawtimber	11" - 16" dbh	4,248	28.8%
Large Sawtimber	> 16" dbh	9,703	65.8%
Total		14,746	100.0%

Table 4-9. *Connecticut Highlands: Distribution of forested acres by forest type on Metropolitan District Commission land.*

Forest Type	Acres	%
Mixed/Other Hardwoods	3,795	26%
Oak-Hickory	4,145	28%
Northern Hardwoods	187	1%
Softwood-Hardwoods	4,604	31%
Mixed Softwoods	303	2%
Pine	1,191	8%
Hemlock	416	3%
Plantation	99	1%
Total	14,740	100%

Table 4-10. *Connecticut Highlands: Distribution of forested acres by crown closure class on Metropolitan District Commission land.*

Crown Closure Class	Acres	%
86%-100%	1,984	13%
61%-85%	8,460	57%
31%-60%	3,347	23%
0-30%	956	6%
Total	14,746	100%

Long-term Trends in Forest Development

The Connecticut Agricultural Experiment Station (CAES) maintains sample plots on several sites in the Highlands. The so-called New-Series plots were established in 1959-1960 to expand the geographic area covered by CAES's long-term research plots. Ward (2005) used data from these plots to look at forest development patterns from 1959 through 2000. Two plots are in the Highlands, one in Catlin Woods, part of the White Memorial Foundation in Litchfield, and one in Great Mountain Forest in Norfolk. Trees on the Catlin Woods plot are about 210 years old, and include eastern white pine, hemlock and transition hardwood stands. Trees on the plot at Great Mountain are younger, having initiated between 1880 and 1910, and there is a greater proportion of hardwood species compared to the plot in Catlin Woods.

There has been no active management of the stands since these plots were established (Ward and Cudsworth personal communication). A small amount of harvesting mistakenly occurred in Catlin woods in the late 1970s, but was halted before many trees were removed. Ward's analysis indicates that these unmanaged forests are increasingly dominated by late-seral species, such as hemlock and beech. Between 1959 and 1990, there was a large increase in the total density of conifer species, although in the last decade the number of conifers per acre showed a small decrease. The same pattern was seen to a lesser degree for beech, while maples and birches slowly declined in density over the entire period. While never present in great numbers, oak constitutes about 25% of the basal area. Oak species have not been found in the subcanopy since 1960, indicating that the oak is likely to decline over time as overstory trees die and are replaced by different species. Stand density increased steadily over the period studied, with very little mortality. The increases in stand density are driven by increases in the density of understory hemlock and beech. Ninety percent of the subcanopy is comprised of these two species. There has also been an increase of striped maple and elderberry in the understory. The basal areas of conifers and beech in the overstory have also increased.

Comparison of All Data Sources

A comparison of forest inventory data among FIA, State Forests, and the MDC shows some significant differences. The FIA plots are distributed over the entire Highlands landscape and are designed to provide coarse landscape-scale information. Because the sampling scheme is designed to have one plot for approximately every 6,000 acres (USDA Forest Service 2007), this information is difficult to scale down to stand level or up to fine scale landscape information. State Forest and MDC inventories are much more detailed, measuring every stand that is being actively managed, but probably missing unmanaged stands whose composition and structure would likely be very different from stands managed for timber production (Table 4-11).

FIA data, extrapolated from 68 plots to the entire Highlands area, suggest a much larger hardwood component (89%) than the other two inventories (60% and 55%) (Table 4-12). Furthermore, the FIA hardwood component is categorized as primarily oak-hickory or northern hardwoods. State Forest and MDC inventories show a much larger "mixed hardwood" component, but some of the stands classified as mixed woods in the State Forest inventories are so designated because older inventories on these lands included only a single category for hardwood stands. Past management practices on State and MDC lands included planting and regenerating large areas to conifer plantations. Only about 14% of the forests of the highlands are managed professionally on an ongoing basis. It appears that only a few of the FIA plots are on these managed lands; most are

on the vast majority of small parcel privately-owned land. What we might take from this is that most of the forest of the highlands is more like the FIA plots than the managed lands, with a large component of oak-hickory across most of the landscape, and northern hardwoods in the higher elevations of the northwest.

The three data sources all show that forests in the Highlands are dominated by trees over 11 inches dbh (Table 4-13). While the FIA data include only one category for trees over 11 inches dbh, the MDC differentiates further, breaking out trees between 11-16 inches dbh and over 16 inches dbh. MDC data show that roughly two-thirds of the trees over 11 inches are in the larger, greater than 16 inch category. The state forest data include more mixed categories, which were not used by the other inventories. Eighteen percent of state forest stands are either uneven-aged, or a mix between saplings and larger trees, mostly as a result of shelterwood harvests.

Table 4-11. *Connecticut Highlands: Comparison of forest types from all data sources.*

Forest Type	FIA	STATE	MDC
Mixed/Other Hardwoods	2%	34%	26%
Oak-Hickory	64%	20%	28%
Northern Hardwoods	23%	6%	1%
Softwood-Hardwoods	4%	19%	31%
Mixed Softwoods		6%	2%
Pine	1%	4%	8%
Hemlock	5%	10%	3%
Plantation		1%	1%

Table 4-12. *Connecticut Highlands: Summary of forest type be data source. Note: FIA numbers are extrapolated to the entire Highlands area based on the data from 68 plots within the Highlands.*

	FIA		STATE		MDC	
Forest Type	Acres	%	Acres	%	Acres	%
All Hardwoods	425,518	89%	7,942	60%	8,127	55%
Softwood/Hardwood	20,166	4%	2,553	19%	4,604	31%
All Softwoods	25,546	5%	2,754	21%	2,009	14%

Table 4-13. *Connecticut Highlands: Comparison of distribution of size classes across all data sources.*

	Percent Total		
Size Class (dbh)	FIA	STATE	MDC
<5 inches	4%	4%	2%
5 - 11 inches	18%	4%	4%
11 - 16 inches		10%	29%
> 11 inches	76%		
>16 inches		69%	66%
Two or All-aged		18%	

NOTE: FIA does not differentiate between small and large sawtimber. State forest mixed pole/sawtimber stands were included in the 11-16 inch category.

Forest Health

The Connecticut Agricultural Experiment Station has 14 forest health plots in the Highlands region. These plots, which are part of the FIA Forest Health monitoring system, have been measured annually since 1994. Observations are made on the general condition of the plot, and measurements are taken of damage on tagged trees, and attributed to specific forest insects and diseases where possible (Table 4-14). The analysis included a count of all observations made, both on tagged trees and non-tagged trees, in order to provide a broad picture of forest health. Records from 1994, the year when the plots were set up, contain detailed description of forest health in the area around each plot. For example, mention is made of chestnut blight in the understory of 6 of the 14 plots. However, in subsequent years, this level of detail is not included, which makes it difficult to make consistent comparisons across the years.

Of the 14 plots, most are described as being in good health (Table 4-15). Most observed damage is not attributed to obvious insect or disease outbreaks. One plot has been seriously impacted by beech bark disease, and two are suffering from continuous elongate hemlock scale infestation. Although hemlock wooly adelgid is not widespread yet, it does exist in the area, and the hemlocks are stressed by a variety of other pests, including elongate hemlock scale, hemlock looper and green hemlock needle miner, making them more susceptible to the adelgid. Beech bark disease appears to be stabilizing, where the majority of beech stands have some level of infestation with the beech scale, but heavy cankering and mortality have already occurred.

Ward's (2005) analysis of the New Series plots found that the eastern Connecticut tracts had more severe and frequent episodes of defoliation from gypsy moth than the Highlands tracts. Nevertheless, the tracts in the Highlands suffered from gypsy moth outbreaks in 1972, 1981, and 1989. However, since 1989, the gypsy moth has been controlled by the gypsy moth fungus (*Entomophaga maimiaga*). All tracts suffered from beech bark disease and chestnut blight, but less than plots in the central part of the state. Furthermore, while 18% of trees (from both eastern Connecticut and western Connecticut tracts) are infected with beech bark disease, there has not been an increase in beech mortality over the last 40 years. Hemlock woolly adelgid and elongate hemlock scale have been observed in the Highlands tracts, but have not caused much damage to this point.

The USDA Forest Service recently updated the 2002 National Risk Map for Insects and Diseases (Krist *et al.,* 2007). The revision depicts where tree mortality from insect and disease outbreaks is likely to exceed 25% over the next 15 years at locations throughout the United States. The information in this map is designed for use by managers at the national level to prioritize areas in need for strategic plans to protect forest health.

The 2006 National Risk Map was created using mathematical risk models applied to a variety of compiled geo-spatial data layers (Figures 4-12 to 4-17). Such data layers include distributions of tree species derived from FIA data that have been statistically modeled to one kilometer spatial resolution. Other data in the model include soil, climate and pest distributions as variables influencing where future tree mortality is most likely to occur. The maps shown here depict potential forest loss from gypsy moth, hemlock wooly adelgid, Asian longhorned beetle, ash decline and oak decline, based on the combined factors of host tree abundance, soil drainage, temperature zones, and anticipated defoliation.

It is important to note that ash and oak decline are not biotic agents like the other three, but involve a slow, progressive deterioration in health and vigor. Decline diseases involve decreased growth and dieback in older trees. The causes are often complex and may involve both abiotic and biotic factors. Oak decline is not currently a problem in Connecticut. It is mainly a concern in the

Table 4-14. *Connecticut Highlands: Forest insects, pests, and disease complexes.*

Common Name	Scientific Name	Exotic/Native
Chestnut Blight	*Cryphonectria parasitica*	exotic
Gypsy Moth	*Lymantria dispa*	exotic
WP Blister Rust	*Cronartium ribicola*	exotic
Elongate Hemlock Scale	*Fiorinia externa*	exotic
Hemlock Wooly Adelgid	*Adelges tsugae,*	exotic
Oak skeletonizer	*Bucculatrix ainsliella*	native
Forest Tent Caterpillar	*Malacosoma disstria*	native
Eastern Tent Caterpillar	*Malacosoma americanum*	native
Green Hemlock Needle Miner	*Epinotia tsugana*	native
Hemlock looper	*Lambdina fiscellaria*	native
Asian longhorned beetle	*Anoplophora glabripennis*	exotic

Table 4-15. *Connecticut Highlands: Connecticut Agriculture Experiment Station forest health plots. Data represents the number of plots where forest insects and diseases were observed by year.*

	Year												
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Ash Decline	2	3	2	1	1								
Beech Bark Disease	3	2	2	1	1	1	1	1			1	1	1
Chestnut Blight	6	1	1										
Gypsy Moth	2			1		1			1				
WP Blister Rust	1	1	1	1	1	1							
Elongate Hemlock Scale	1	1	1	1	1	1	2	2		2	2	2	2
Hemlock Wooly Adelgid						2	1		1	1			
Oak skeletonizer											2	1	
Storm Damage			1	3					1	3			
Forest Tent Caterpillar	2												
Eastern Tent Caterpillar	1												
Green Hemlock Needle Miner		1	1	1								1	
Hemlock looper		1	1										

Ozarks. Nonetheless, with changing climate and the possibility of increasing drought, this analysis shows that it could be a significant factor in the future. The risk of mortality from ash decline is widespread, but there are no areas at risk of over 15% mortality. The Asian longhorned beetle (*Anoplophora glabripennis)* has recently been discovered in east-central Massachusetts, near the Connecticut border (University of Massachusetts 2008). It is estimated that the insect has been in the vicinity for about five years. Although this occurrence is not near the Highlands, it is a cautionary tale for all of Connecticut's forests. Although the risk of mortality from Asian longhorned beetle is considered low (Figure 4-14), not much is known about how it will behave in natural forests of the northeast (Hobson *et al.,* 2003).

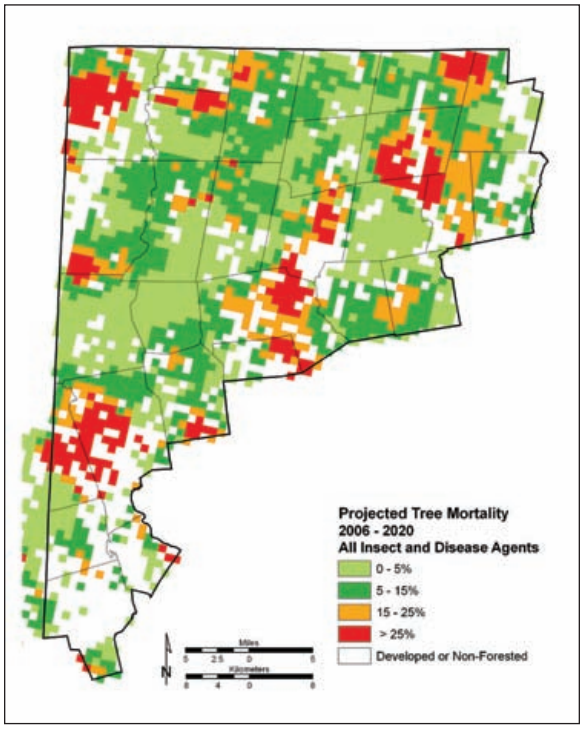


Figure 4-12. *Connecticut Highlands: Projected tree mortality from all damaging insects and diseases from 2006-2020.*

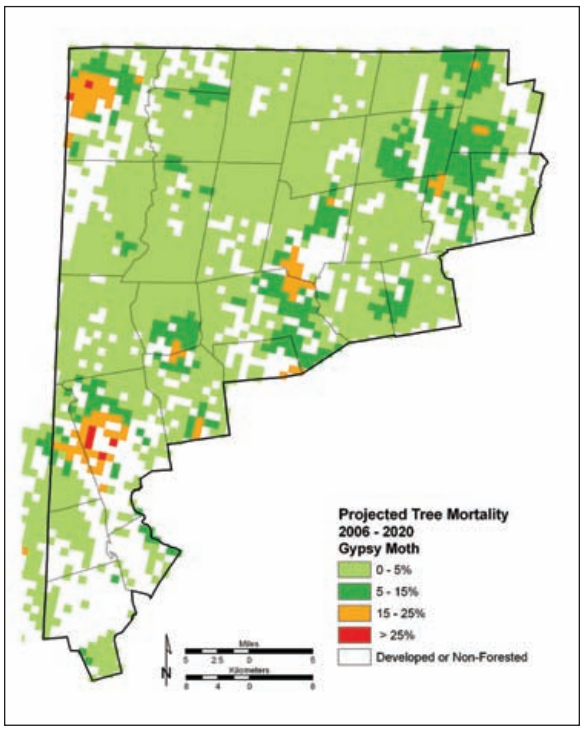


Figure 4-13. *Connecticut Highlands: Projected tree mortality from gypsy moth defoliation from 2006-2020.*

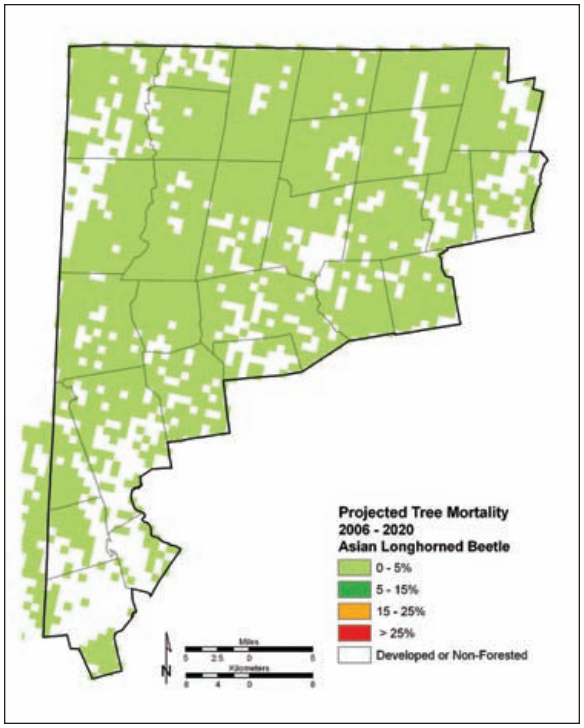


Figure 4-14. *Connecticut Highlands: Projected tree mortality from Asian longhorned beetle* (Anoplophora glabripennis) *from 2006-2020.*

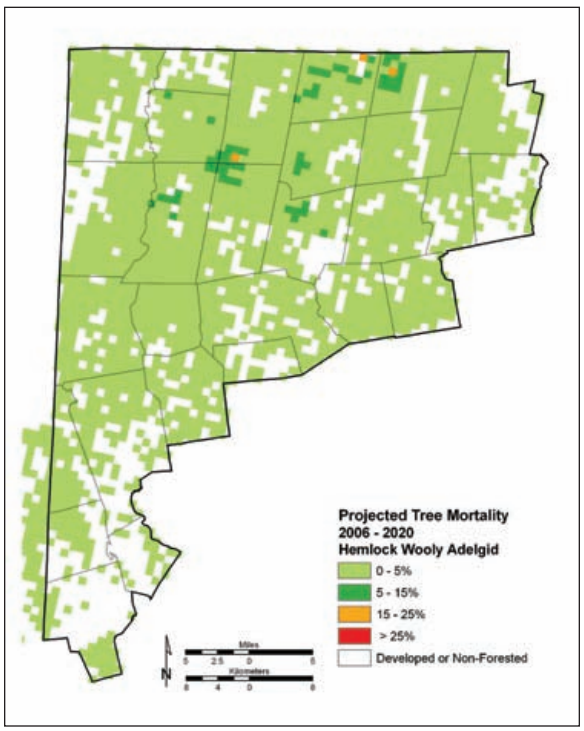


Figure 4-15. *Connecticut Highlands: Projected tree mortality from hemlock wooly adelgid* (Adelges tsugae) *from 2006-2020.*

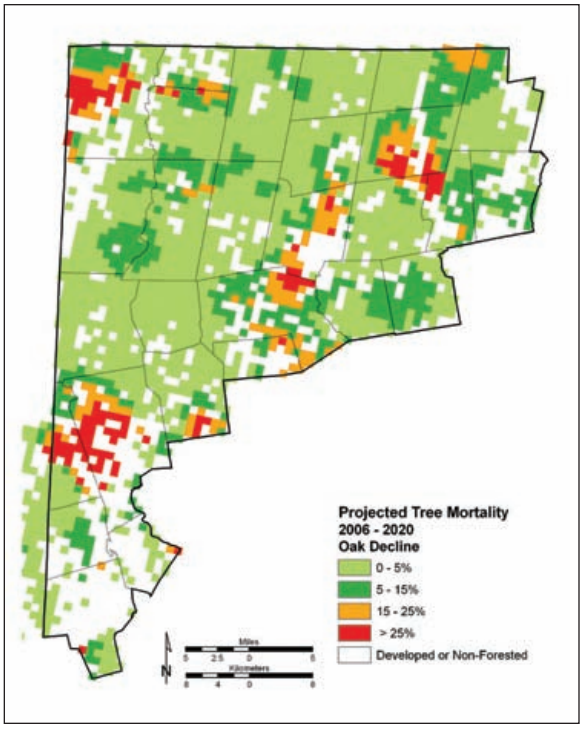


Figure 4-16. *Connecticut Highlands: Projected tree mortality from oak decline from 2006-2020.*

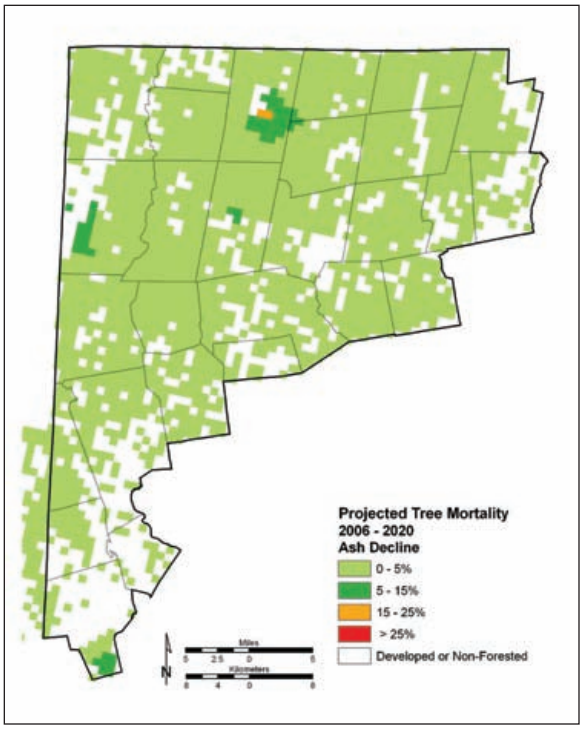


Figure 4-17. *Connecticut Highlands: Projected tree mortality from ash decline from 2006-2020.*

Preliminary Results of National Woodland Owner Survey

The USDA Forest Service conducts a national census of all private woodland owners in order to characterize the size of land holdings, ownership and management objectives, and the demographics of the ownerships. Prior national surveys were done in 1978 and 1994. Since 2001, surveys are being conducted on an annual basis. The goal is to reach 50,000 owners of woodlands where FIA plots are established. Twenty percent of these ownerships are contacted each year with complete samples being finished in 5 to 10 years, depending on the state. Survey results are extrapolated to make area and population estimates for the entire state. A detailed description of the methodology is contained in Butler et al 2005.

The survey is designed to receive at least 250 responses per state in order to be statistically rigorous at the state level. Because of the small sample size within the Highlands study boundary, responses were analyzed from all lands within the three counties that contain the Highlands (Litchfield, Fairfield and Hartford).[6] This area contains a significant amount of land outside of the Highlands itself. Nonetheless, between 2002 and 2006, there were only 22 responses from the larger area, and sample error remains a concern. Given the low number of responses, the following are rough estimates only. (Butler 2008a)

Table 4-16. *Connecticut Highlands: Forest insects, pests, and disease complexes.*

All ownerships	Public				Private		
	Total *a*	Federal *a*	State *a*	Local *a*	Total *a*	Family	Business *b*
			Thousands of acres				
815	173	0	94	78	642	353	289

a Source: *Forest Resources of the United States, 2002* (Smith et al. 2004).
b Includes corporations, non-family partnerships, tribal lands, non-governmental organizations, clubs, and other non-family groups.
Note: Data may not add to totals because of rounding.

Preliminary results indicate that there is a balance of public land, large private lands, and family-owned forests in the Connecticut Highlands (Table 4-16). Families own the most forest, followed by private businesses (which include NGOs, clubs and any non-family business), then local government and state government. This breakdown in ownership class is similar to that of the state as a whole. Of all family-owned forest land, about one-third of the area is in 1-20 acre plots, one-third 20-100 acre plots, and one-third in larger holdings over 100 acres. However, over 90% of landowners have plots of 20 acres or smaller.

Privacy and the enjoyment of beauty and scenery dominated the reasons cited for owning forest land, followed by family legacy. Almost none of the landowners have a management plan, and only 20% have received advice about managing their land. Although only 14% of the respondents cited firewood, biofuels, or timber production as a reason for owning land, 40% have harvested trees for various reasons. Sixty-four percent of the landowners who harvested received professional advice, which is much higher than the national average. Very few indicate an intention to sell their land, and only 12% are over 65, which may indicate stability in land ownership for the next few years.

6 This methodology is consistent with how the ownership data were analyzed for the NY-NJ Highlands Study.

Forests of the Pennsylvania Highlands

Introduction

There are 444,726 acres of forest in the Pennsylvania Highlands. The analysis of land use change showed that forest cover remained stable between 1992 and 2001, with 32% of the area in forest. The region has several important forest blocks. The Hopewell Big Woods is a 73,000 acre region in Chester and Burks counties. Within the Hopewell Big Woods, 14,800 acres are protected from development by conservation easements, or public ownership, such as state parks and game lands, including the Hopewell Furnace National Historic Site and French Creek State Park. There is also the 27,500-acre Oley Hills region, which is 75% forested. Other important forested areas include the Unami hills in northeastern Montgomery and northwestern Bucks counties, and Furnace Hills, which contains approximately 100 square miles of contiguous forest in Berks and Chester counties (Appalachian Mountain Club 2006).

There are 24,530 acres of state game lands in the Pennsylvania Highlands. Most State Game Land forests were cut over repeatedly in the early 20th century and subsequently acquired by the state during the 1920s through 1950s. Currently, state managed lands have a balanced distribution of age and size class, and are under even-aged management.

FIA Data

According to the FIA data, 61% of forested acres are covered by oak-hickory forests and 27% by northern hardwood forests (Figure 4-18). Tulip poplar (*Liriodendron tulipifera)* has the largest basal area for an individual species over the study area, but when combined, oak species are the largest component of the forest (Figure 4-24). The main oak species are black oak, (*Quercus velutina*) northern red oak (*Quercus rubra*) and chestnut oak (*Quercus prinus)*. Other important species in terms of basal area are red maple (*Acer rubrum*) and white ash (*Fraxinus Americana*). Red maple has the highest density of any overstory species, followed by white ash and tulip poplar (Figure 4-21). Black cherry (*Prunus serotina*) has the highest understory density, followed by red maple and white ash (Figure 4-22).

There is a fairly good mix of age classes, although half of the stands are 40 - 80 years old, and 63.5% of the stands are made up of large diameter timber (Figures 4-19 and 4-20).

Comparison of 2005 to 1989 data shows that the basal area per acre of oak, tulip poplar, maple and ash are declining, while that of birch, cherry and black walnut (*Juglans nigra)* are increasing (Figure 4-24). Overall, average basal area has declined sharply, from 122 square feet per acre to 87 square feet per acre. The density of all oak species and red maple is declining, while the density of sweet birch (*Betula lenta*), cherry, sassafras (*Sassafras albidum)*, black walnut and sugar maple (*Acer saccharum*) is increasing.

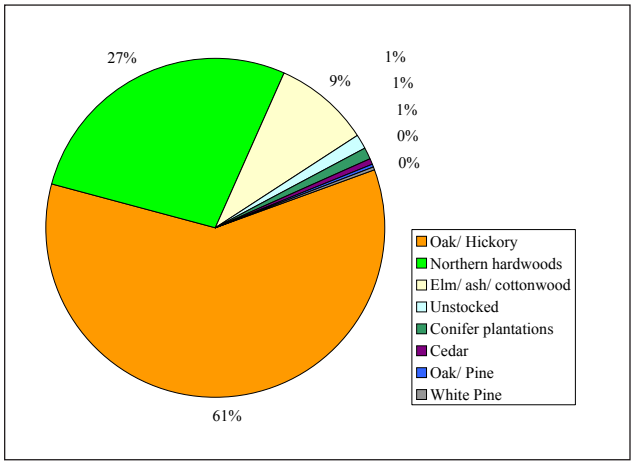


Figure 4-18. *Pennsylvania Highlands: Composition of forest types within FIA plots.*

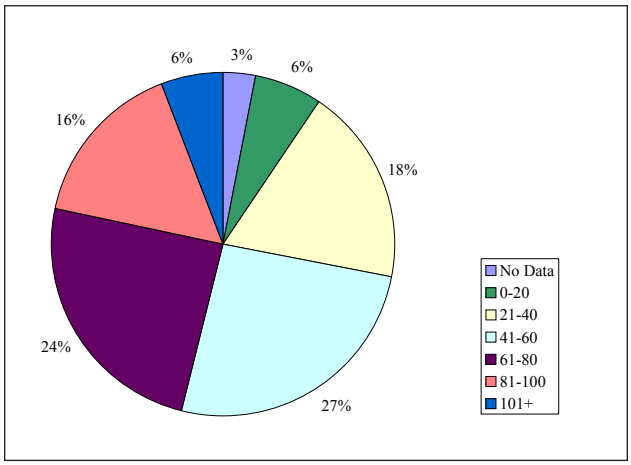


Figure 4-19. *Pennsylvania Highlands: Stand age in FIA plots.*

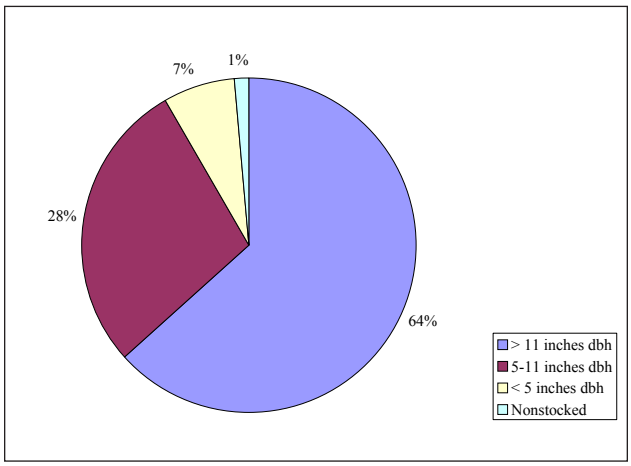


Figure 4-20. *Pennsylvania Highlands: Stand size in FIA plots.*

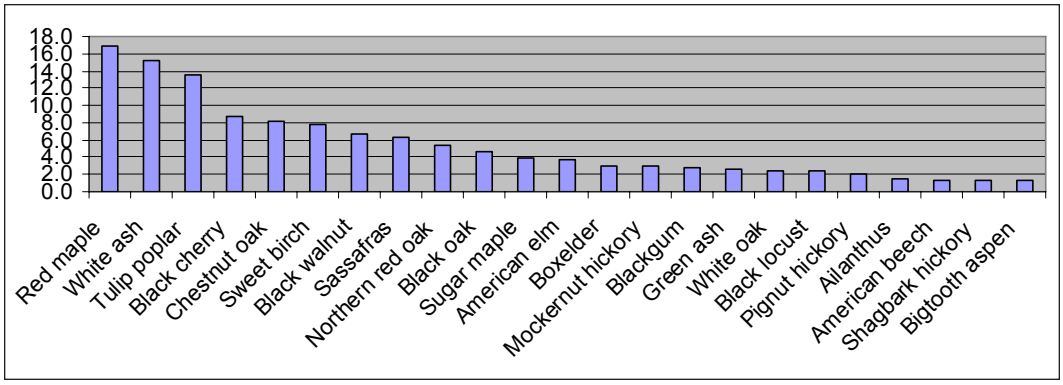


Figure 4-21. *Pennsylvania Highlands: Average trees per acre in 2005 FIA plots, trees > 5 inches dbh.*

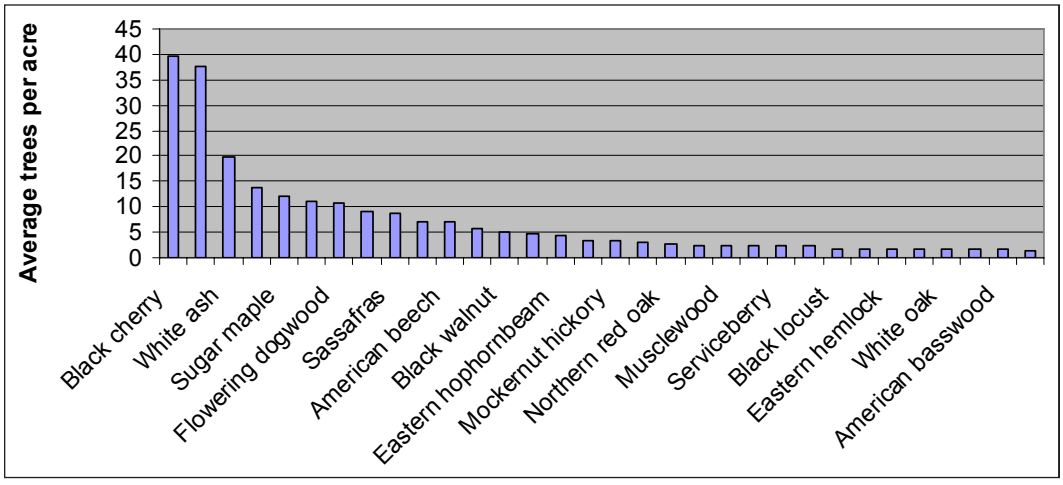


Figure 4-22. *Pennsylvania Highlands: Average trees per acre in 2005 FIA plots, trees 1-5 inches dbh.*

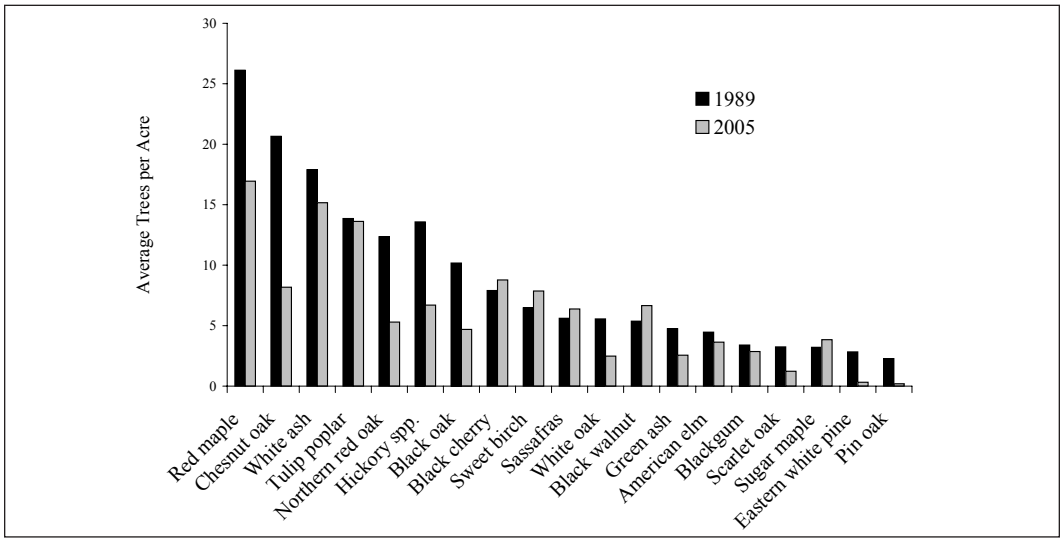


Figure 4-23. *Pennsylvania Highlands: Average trees per acre greater than one inch dbh, by species, in FIA plots 1989 and 2005.*

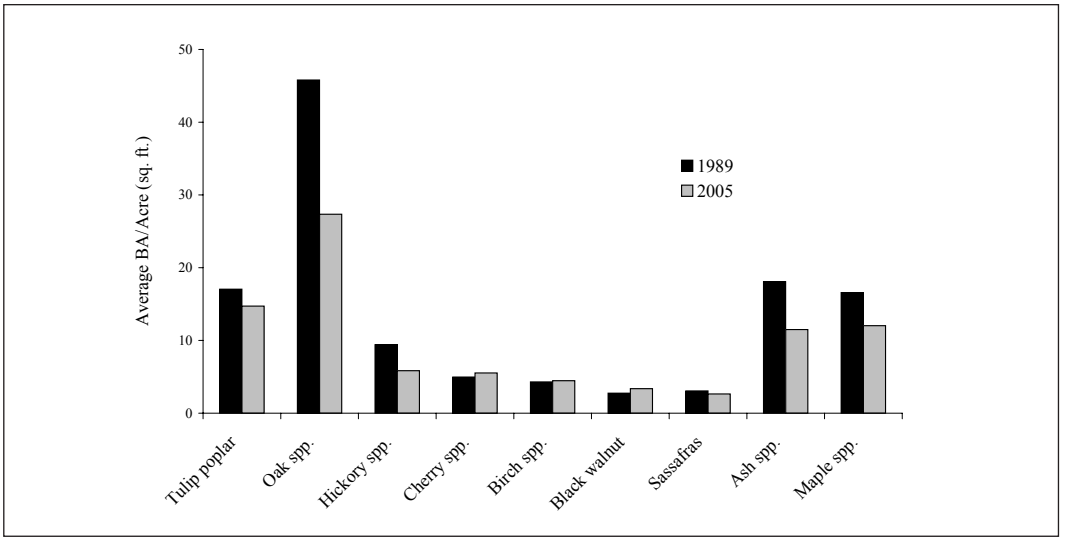


Figure 4-24. *Pennsylvania Highlands: Average basal area by species in FIA plots in 1989 and 2005.*

Forest Fragmentation – Extent and Effects[7]

Pennsylvania Highlands forests are highly fragmented. According to our analysis of the 2001 land cover, only 23% of the forest is core, meaning unfragmented within an 18.6 acre window of analysis (Table 4-17). The rest is fragmented into either small patches, edges, or perforated with other land uses. The transition category can be a combination of any of the other fragmentation classes.

When looking at where the FIA plots fell on the fragmentation map of 2001, only 8 out of 49 plots were classified as core forest. Seventeen were edge and the rest either patch, transition, or perforated, all indicators of a highly fragmented resource (Table 4-17). This can have a significant impact on the Highlands forests, since fragmentation can affect forest structure and composition.

There were many more species in the edge forest than in the core forest. However, there were only half as many core forest plots in the sample as there were edge forest plots, which could affect the data. Fragmentation also appears to affect stand structure. Plots classified as core forest had a higher basal area than the edge forest (an average of 104.3 ft^2/acre, compared to an average of 84.6 ft^2/acre) and a higher average stand age (72.1 years compared to 57.7 years) (Table 4-18).

7 For more information about methods and results for fragmentation indices, refer to Chapter 9, *Impacts of Land Use/Land Cover Change on the Resources of the Highlands*.

Table 4-17. *Pennsylvania Highlands: FIA plot data summary by fragmentation type for those plots in the Highlands for which tree data were collected.*

Fragmentation Type	# Plots	%	Trees >5 in. dbh			Trees 1-5 in. dbh		
			# Species	# Trees	Average # Trees per Plot	# Species	# Trees	Average # Trees per Plot
Core Forest	8	23%	21	176	22	8	196	25
Perforated Forest	12	18%	26	311	26	16	350	29
Edge Forest	17	35%	44	317	19	19	368	22
Transition Forest	10	14%	27	174	17	8	203	20
Patch Forest	2	9%	12	34	17	3	38	19

Table 4-18. *Pennsylvania Highlands: Basa area and stand age in FIA plots by forest fragmentation type.*

Description	Average Basal Area	Average Stand Age
Core	104.3	72.1
Transition	75.1	40.7
Edge	84.6	57.7
Perforated	95.5	66.3

When comparing the overstory[8] forest composition of the core forest and edge forest, we find that red maple has the highest density in both, but chestnut oak and tulip poplar occur more frequently in the core forest, while white ash and sweet birch have a higher occurrence in the edge forest (Figures 4-25 and 4-27). The only conifer to appear in the core forest plots was eastern red cedar (*Juniperus virginiana*). The edge forest plots contain the exotics Norway spruce (*Picea abies*); Douglas-fir (*Pseudotsuga menziesii*), and Fraser fir (*Abies fraseri*), which must have been planted; and the invasive *Ailanthus altissima*.

Red maple is the most commonly occurring understory tree in the core forest plots, followed by black gum (*Nyssa sylvatica*); there is no black cherry (Figure 4-26). The edge understory is dominated by black cherry, followed by red maple, dogwood (*Cornus florida*) and white ash (Figure 4-28).

8 Overstory trees are those trees with a diameter-at-breast-height (dbh) of greater or equal to 5 inches. Understory trees are those trees with a dbh between 1 and 5 inches.

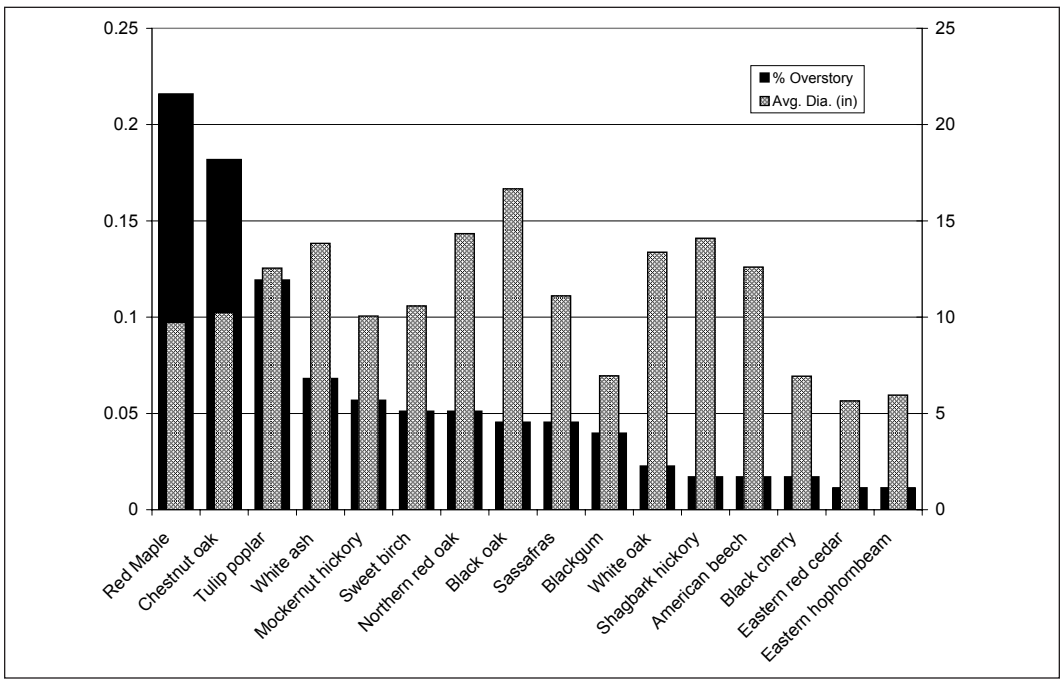


Figure 4-25. *Pennsylvania Highlands: Percent total and average diameter of overstory trees in eight core forest FIA plots. Includes only species that were greater than 1% of the total.*

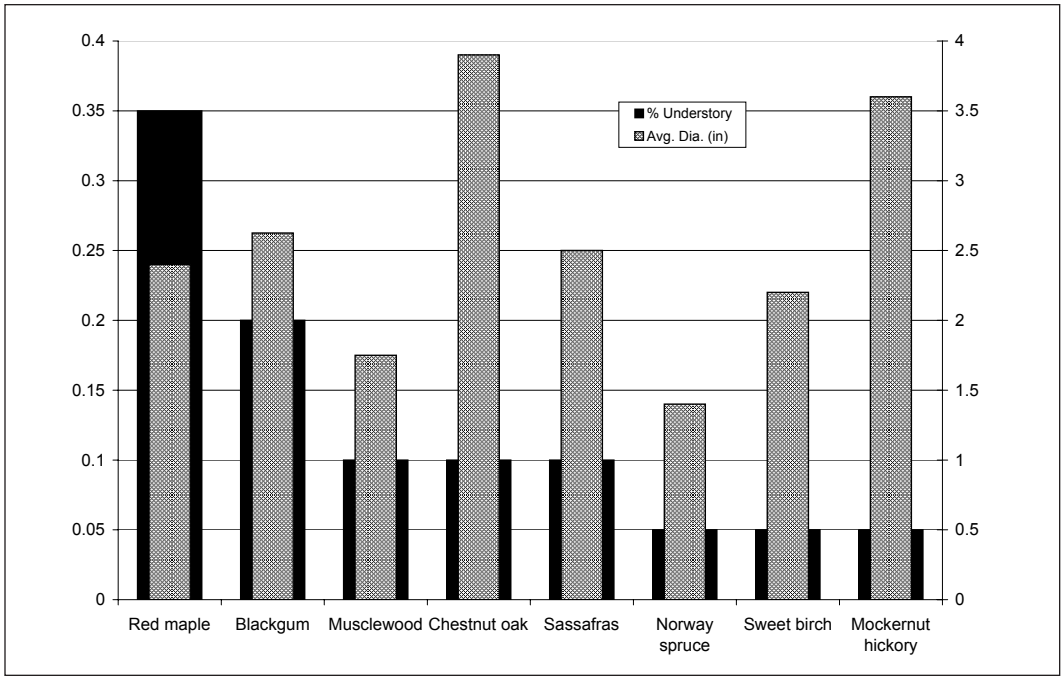


Figure 4-26. *Pennsylvania Highlands: Percent total and average diameter of understory trees in eight core forest FIA plots. Includes only species that were greater than 1% of the total.*

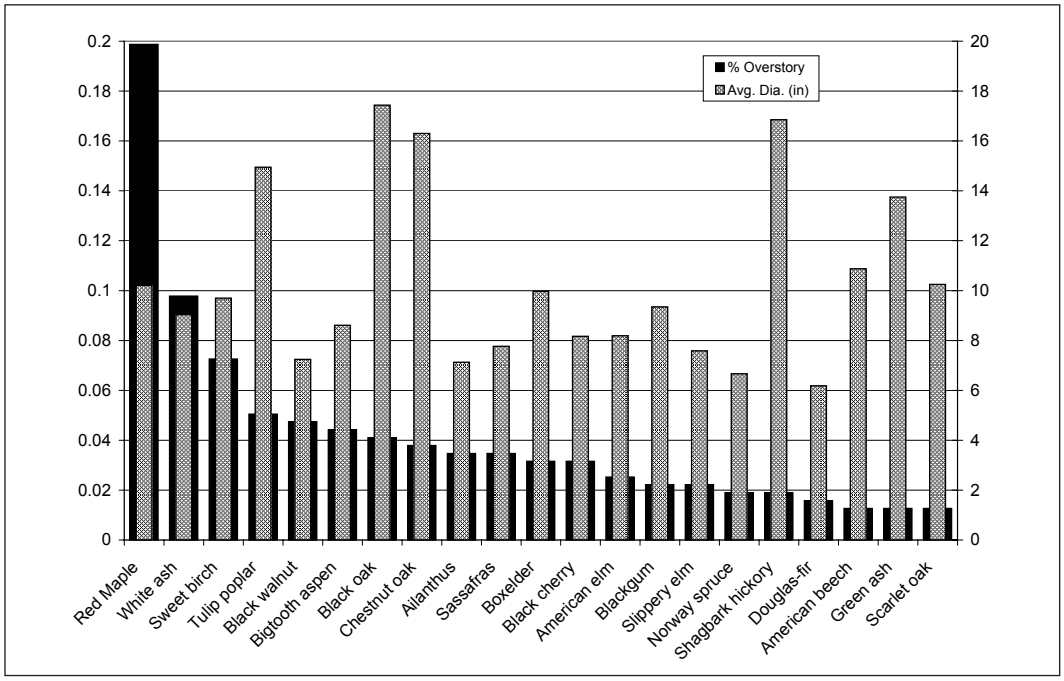


Figure 4-27. *Pennsylvania Highlands: Percent total and average diameter of overstory trees in 14 edge forest FIA plots. Includes only species that were greater than 1% total.*

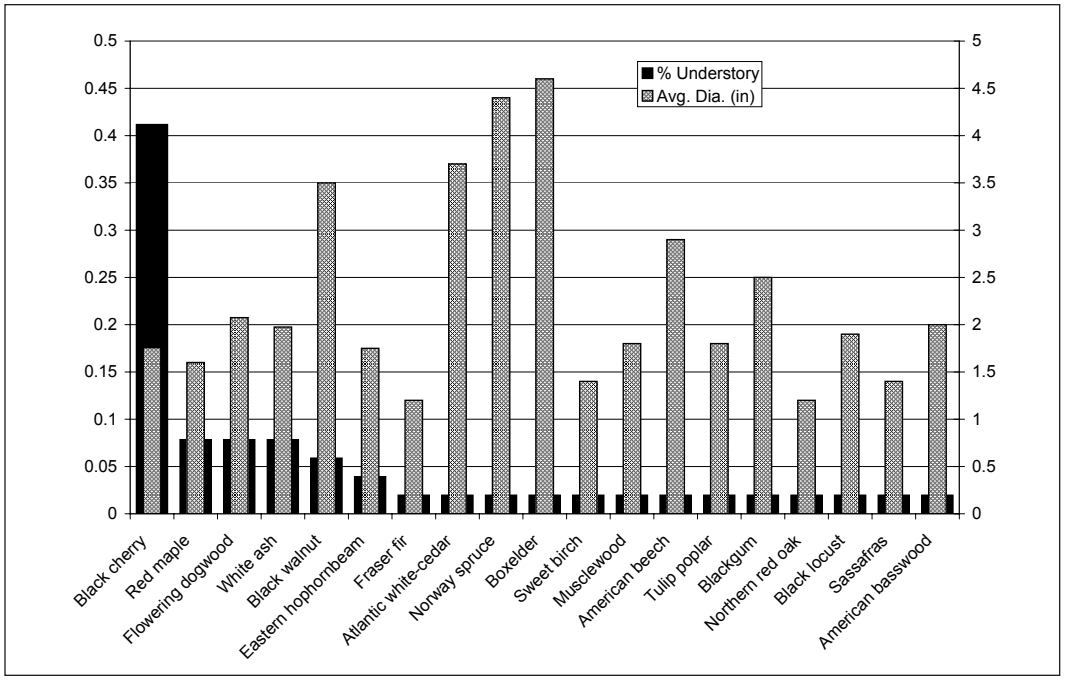


Figure 4-28. *Pennsylvania Highlands: Percent total and average diameter of understory trees in 14 edge forest FIA plots. Includes only species that were greater than 1% of the total.*

State Game Lands

There are 24,530 acres of state game lands in the Pennsylvania Highlands. Of these, 20,867 acres are forested. The majority of the forest (55.6%) is made up of mixed oak stands, and there is also a large component of various northern hardwood mixes (36.8%) (Table 4-19). The forest is dominated by small sawtimber stands (52% in the 11-17 inch dbh size class). Only 6% of the stands are made up of trees greater than 17 inches dbh, and only 6% of stands are made up of trees less than 5 inches dbh.

Table 4-19. *Pennsylvania Highlands: Total forested acres by forest type and size class in state game lands within the Highlands.*

	Acres in Each Size Class							
Forest Type	**1 (>17")**	**2 (11-17")**	**3 (5-11")**	**4 (<5")**	**Mixed 2,3**	**Mixed 2,4**	**Total**	**% Grand Total**
Mixed Oak	302	5323	3319	920	990	756	11610	55.6%
Northern Hardwood Mixtures	864	4917	965	368	237	330	7681	36.8%
Birch	0	29	97	11	28	80	245	1.2%
Oak-Hard Pine	0	0	20	0	0	0	20	0.1%
Black Locust	0	7	39	0	0	0	46	0.2%
Red Maple	0	30	120	0	0	0	150	0.7%
Hardwood Swamp	0	565	465	32	0	0	1062	5.1%
Plantations	0	0	34	19	0	0	53	0.3%
Total	1166	10871	5059	1350	1255	1166	20867	100%
% Grand Total	6%	52%	24%	6%	6%	6%	100%	

Forest Health

Gypsy moth (*Lymantria dispar)* has been the most serious pest affecting forests in the Pennsylvania Highlands. Aerial sketch maps of defoliation from 1964 through 2006[9] show that the gypsy moth has defoliated approximately 813,016 acres throughout that period (Table 4-20). Many acres were defoliated several times. Yearly damage ranged from only 26 acres in 2004 to 186,739 acres in 1981 (Figure 4-29). Variations in yearly totals are dominated by gypsy moth cycles. The largest outbreaks occurred in 1971-1978, 1981, and 1990. Recent drop-offs in damage from gypsy moth infestations may be due to control from biological insecticide, *Bacillus thuringiensis*, variety kurstaki (Btk) (Hall, pers. comm.).

The next most important pests, in terms of total damage, have been oak leafroller (*Archips semiferanus*), oak leaftier (*Croesia semipurpurana)* and fall cankerworm (*Alsophila pometaria*), which unlike gypsy moths, are native. Oak leafroller defoliated large areas in the early 1970s, but there have been no major outbreaks since then. Oak leaftier caused a major outbreak in 1972, but there has been no major damage recently. In 1978 more than 100,000 acres were defoliated in the states of Connecticut, Massachusetts, New Jersey, New York, Pennsylvania, and West Virginia (Snowden 1990). Oak leafroller targets both red and white oak species, and is more severe on ridge tops, while oak leafroller targets mainly red oak species. Fall cankerworm favors elms, but also attacks oaks, hickories, maples and cherries.

Since 1990, gypsy moth has remained the most important source of damage, although outbreaks are smaller than in the 1970s and 80s. Fall cankerworm is also a top culprit, and the exotic hemlock woolly adelgid (*Adelges tsugae*) has emerged as a major concern. Only 2,619 total acres have been defoliated by the adelgid so far, but all of this damage has occurred since 1993.

9 Aerial sketch maps and ground survey data provided by the Pennsylvania Bureau of Forestry.

Table 4-20. *Pennsylvania Highlands: Total acres of defoliation by agent, 1964-2006.*

Agent	Exotic/Native	Total Acres
Gypsy moth	exotic	813,016
Oak leafroller	native	71,527
Oak leaftier	native	49,531
Fall cankerworm	native	34,851
Linden looper	native	10,714
Maple leaf atrophy	n/a	9,865
Native insect complex	native	9,967
Locust leafminer	native	5,211
Cicada	native	5,104
Hemlock wooly adelgid	exotic	2,619
Flagging	n/a	2,138
Unidentified	n/a	1,494
Palmerworm	probably native	823
Pine needleminer	native	785
Fall webworm	native	751
Pine spittlebug	native	313
Geometrid moths	most native	232
Larch sawfly	exotic	162
Wind-tornado	n/a	152
Eastern tent caterpillar	native	105
Cherry scallop shell moth	native	86
Frost	n/a	60
Storm damage	n/a	58
Oak leaf miner	native	42
Periodical cicada	native	26
Total		1,009,767

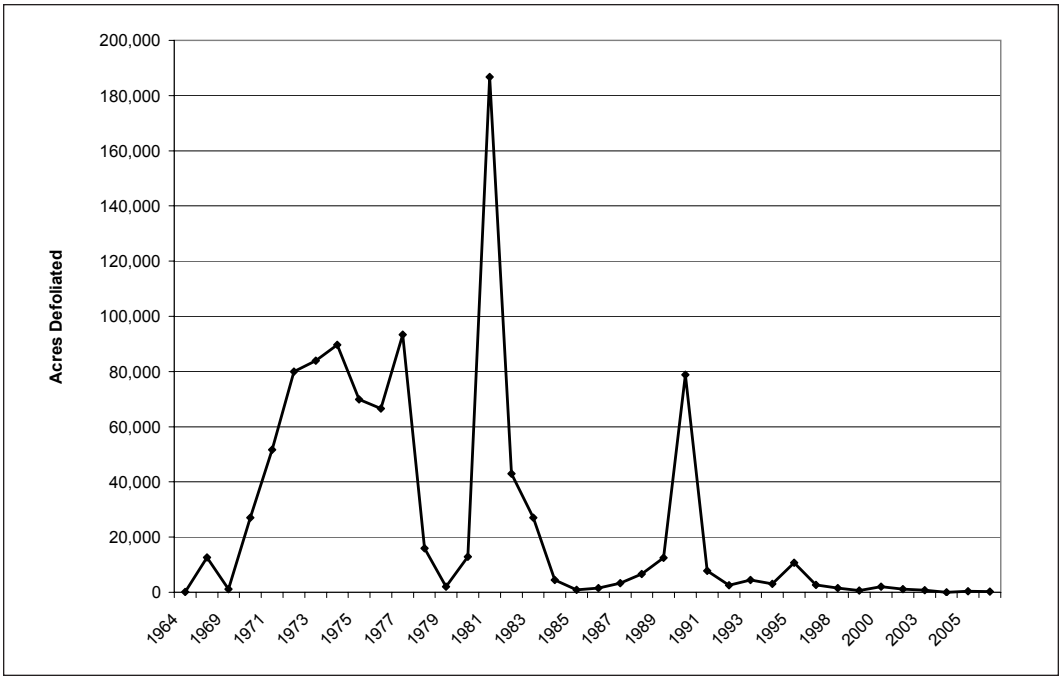


Figure 4-29. *Pennsylvania Highlands: Total acres of defolliation by year, for all agents, 1964-2006.*

Table 4-21. *Pennsylvania Highlands: Total observed instances by agent and severity, 2001-2006.*

Agent	Total Count	Severe	Heavy	Moderate	Light
Fabrella Needle Blight	16	0	0	14	2
Hemlock Wooly Adelgid	8	1	3	1	3
Elongate Hemlock Scale	4	1	2	1	0
Fall Cankerworm	2	1	0	0	1
Cankerworm with other Geometrid Defoliators	5	4	0	0	1
Anthracnose	4	0	0	3	1
Gypsy Moth	2	0	0	0	2
Bark Beetles	2	0	1	0	1

The Bureau of Forestry also collects ground survey information on forest health. Ground survey information is available for the Highlands region from 1994-2006, although data from the 1990s are sparse. Estimates of acreage are also very rough, and were not available for any reports from 2004. There was a large outbreak of fabrella needle blight on hemlocks in 2004 in Schuylkil County, and in Carbon County, just bordering the Highlands. Fabrella was first observed in Pennsylvania in 1974. It is now present in 35 counties and throughout the Highlands Region. Damage is generally not significant, but can lead to twig and branch dieback when coupled with other stressors such as drought or hemlock woolly adelgid (Pennsylvania DEC). Two other pests that attack hemlocks, the adelgid and the elongate hemlock scale (*Fiorinia externa)*, were also among the most commonly observed by ground surveys. In accord with the aerial survey observations, fall cankerworm (*Alsophilia pometaria)*, either alone or in a complex with other geometrid defoliators, was also a cause of severe defoliation. There was a large outbreak in Berks County in 2005.

Forests in Pennsylvania are vulnerable to major mortality caused by the emerald ash borer *(Agrilus planipennis),* which is now spreading in Illinois, Michigan, Ohio, and southwestern Ontario. It has been found in several locations in Maryland and on June 21, 2007, emerald ash borer was detected for the first time in western Pennsylvania in Cranberry Township, Butler County. Five counties are under federal quarantine as of November, 2008. Ash species represent 11 percent of the basal area in the Pennsylvania Highlands. (USDAFS 2008)

Deer

Heavy deer populations have had a negative impact on the forests of Pennsylvania. Deer browse has in some instances severely limited regeneration of important species, such as oak. A 2006 report by the Bureau of Forestry (Benner 2006) describes the impacts of browsing across the state forests. While there are no state forests within the Highlands, districts 18 and 19, which contain Northampton, Lebanon and Dauphin counties, are 2 of the 6 districts with the most severe browsing problems. Deer have reportedly been a problem on the state game lands. However, the State Game Commission instituted an aggressive deer management program starting in 2000 that has been able to successfully regenerate oak by fencing in seedlings. (Henry 2007)

Invasive Species

Invasive species are becoming a forest health problem. The species of concern identified by the State Game Commission are royal pawlonia (*Paulownia tomentosa)*, tree of heaven (*Ailanthus altissima),* and multiflora rose (*Rosa multiflora*). Other problematic species are mile-a-minute weed (*Polygonum perfoliatum*), Japanese stilt grass (*Microstegium vimineum)*, bush honeysuckle (*Diervilla lonicera*), privet (*Ligustrum ovalifolium)* and Russian olive (*Elaeagnus angustifolia)*. (Henry 2007)

While still only a small proportion of basal area and density, the invasive trees Norway maple (*Acer platanoides*) and tree of heaven were found in FIA plots in the Highlands.

Forest Health Projections

The USDA Forest Service recently updated the 2002 National Risk Map for Insects and Diseases (Krist et al, 2007). The revision depicts where tree mortality from insect and disease outbreaks is likely to exceed 25% over the next 15 years at locations throughout the United States. The information in this map is designed for use by managers at the national level to prioritize areas in need for strategic plans to protect forest health.

The 2006 National Risk Map was created using mathematical risk models applied to a variety of compiled geo-spatial data layers (Figures 4-30 through 4-35). Such data layers include distributions of tree species derived from FIA data that have been statistically modeled to one kilometer spatial resolution. Other data in the model include soil, climate and pest distributions as variables influencing where future tree mortality is most likely to occur. The maps shown here depict potential forest loss from gypsy moth, hemlock wooly adelgid, Asian longhorned beetle, ash decline and oak decline, based on the combined factors of host tree abundance, soil drainage, temperature zones, and anticipated defoliation.

It is important to note that ash and oak decline are not biotic agents like the other three, but involve a slow, progressive deterioration in health and vigor. Decline diseases involve decreased growth and dieback in older trees. The causes are often complex and may involve both abiotic and biotic factors. Oak decline is not currently a problem in Pennsylvania. It is mainly a concern in the Ozarks. Nonetheless, with changing climate and the possibility of increasing drought, this analysis shows that it could be a factor in the future.

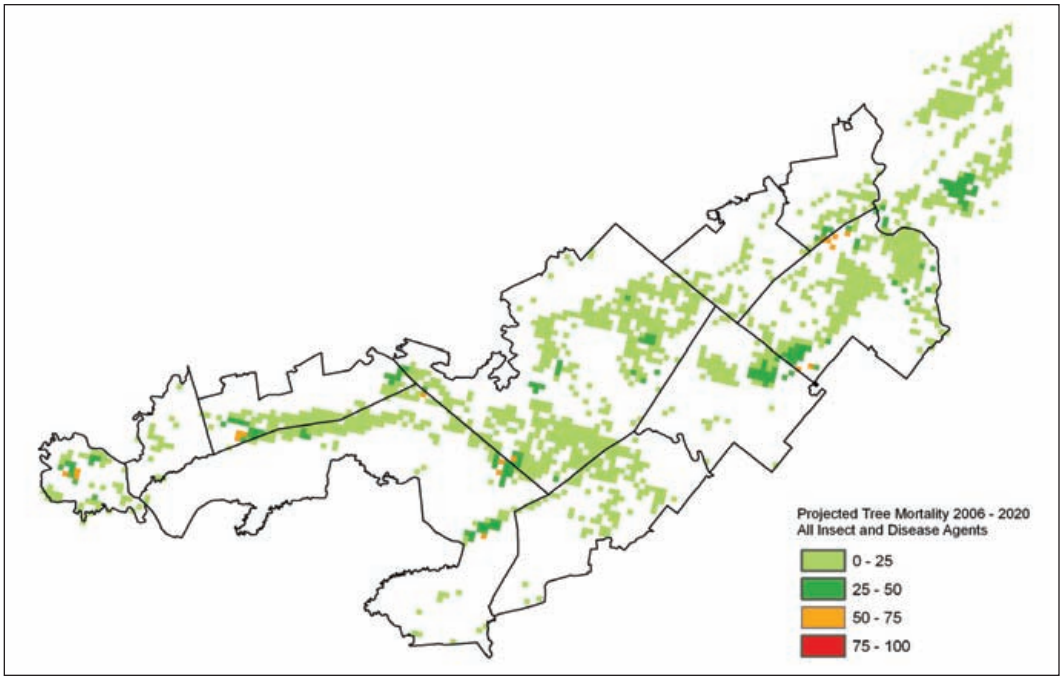


Figure 4-30. *Pennsylvania Highlands: Projected tree mortality from all insect and disease agents from 2006-2020.*

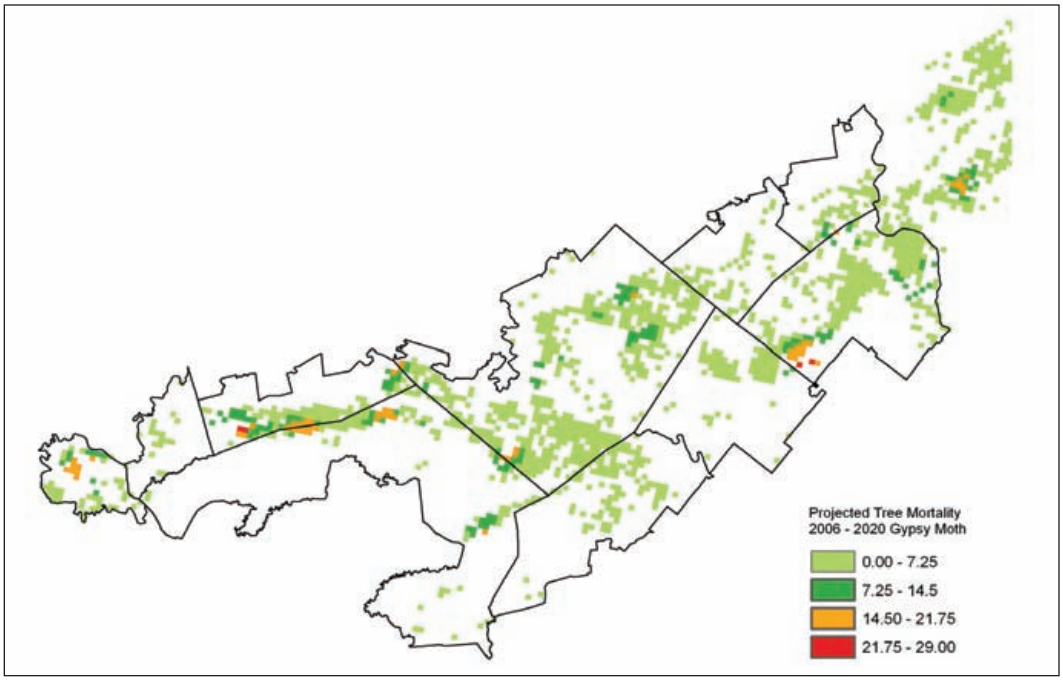


Figure 4-31. *Pennsylvania Highlands: Projected tree mortality from gypsy moth* (Lymantria dispar) *defoliation from 2006-2020.*

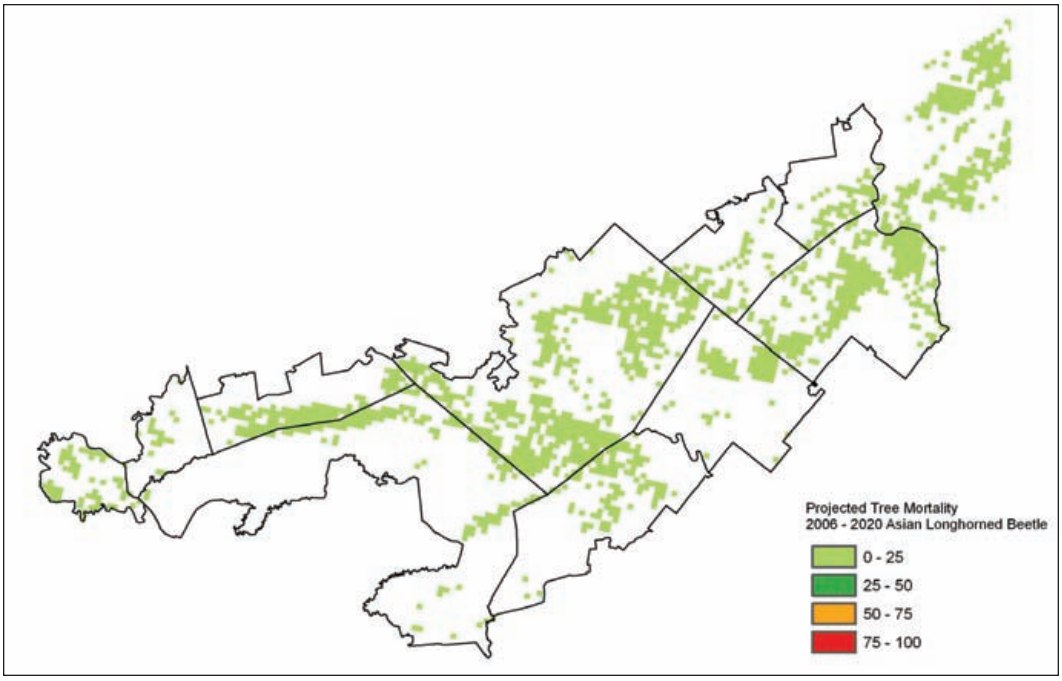


Figure 4-32. *Pennsylvania Highlands: Projected tree mortality from Asian longhorn beetle from 2006-2020.*

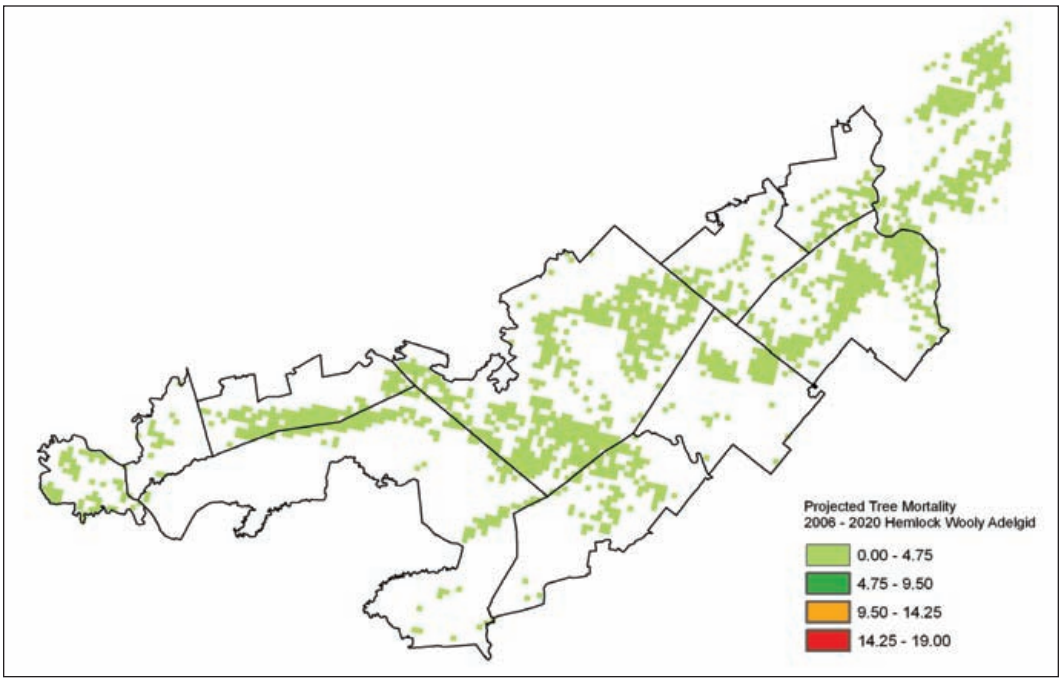


Figure 4-33. *Pennsylvania Highlands: Projected tree mortality from hemlock wooly adelgid from 2006-2020.*

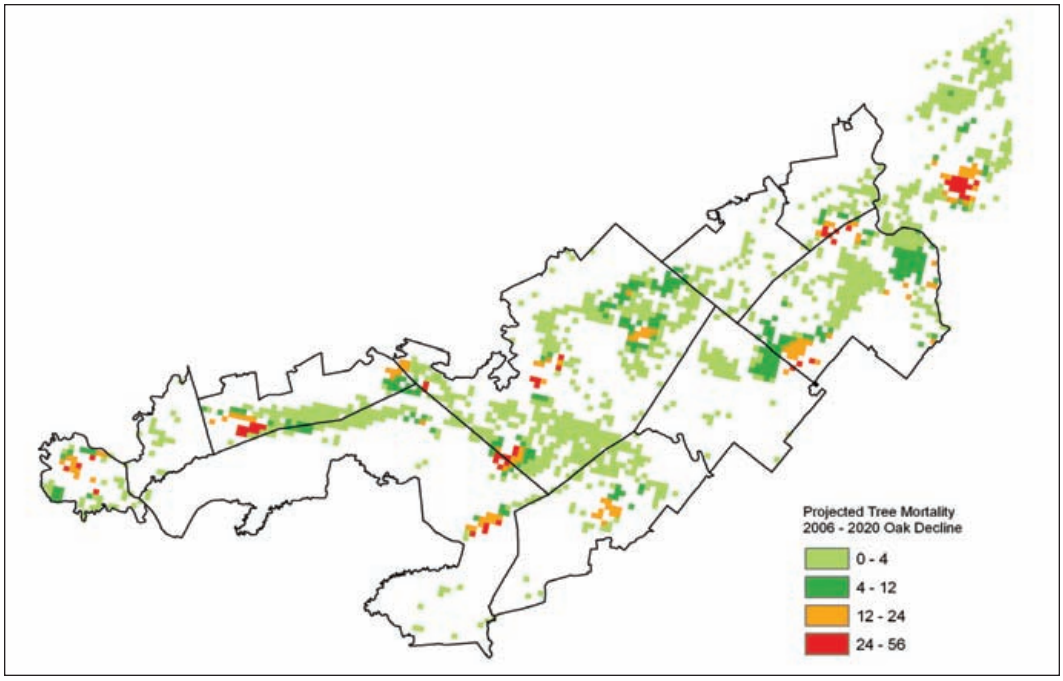


Figure 4-34. *Pennsylvania Highlands: Projected tree mortality from oak decline from 2006-2020.*

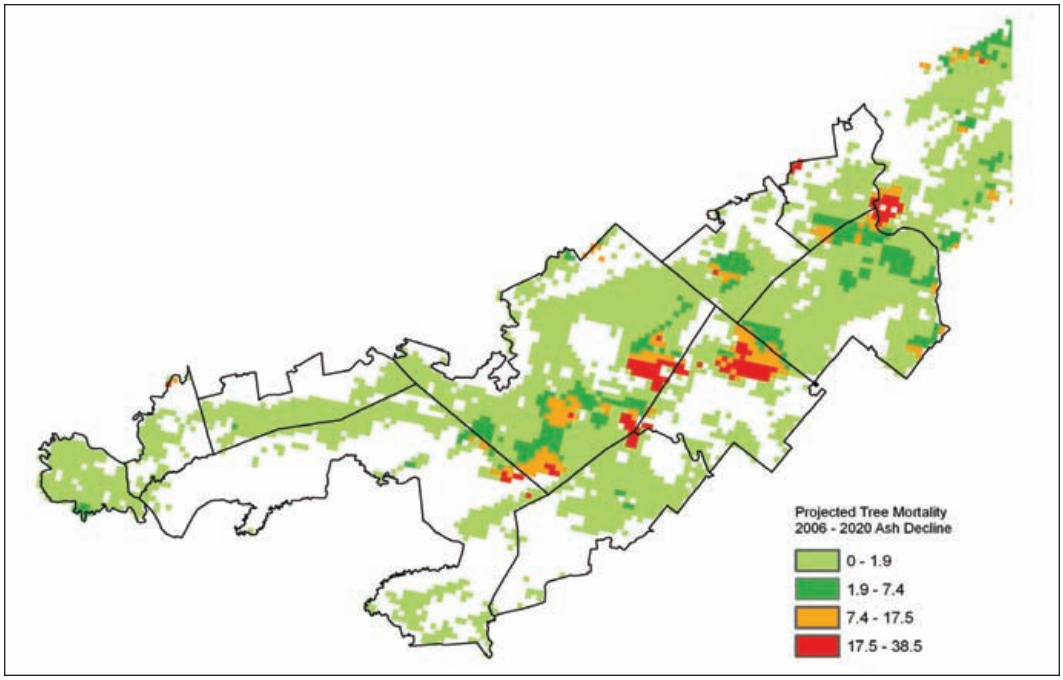


Figure 4-35. *Pennsylvania Highlands: Projected tree mortality from ash decline from 2006-2020.*

Preliminary Results of the National Woodlands Survey

The USDA Forest Service conducts a national census of all private forest and woodland owners in order to characterize the size of land holdings, ownership and management objectives, and the demographics of the ownerships. Prior national surveys were done in 1978 and 1994. Since 2001, surveys are being conducted on an annual basis. The goal is to reach 50,000 owners of woodlands where FIA plots are established. Twenty percent of these ownerships are contacted each year with complete samples being finished in 5 to 10 years, depending on the state. Survey results are extrapolated to make area and population estimates for the entire state. A detailed description of the methodology is contained in Butler 2008b.

The survey is designed to receive at least 250 responses per state in order to be statistically rigorous at the state level. Because of the small sample size within the Highlands study boundary, responses were analyzed from all lands within the 10 counties that contain the Highlands (Berks, Bucks, Chester, Dauphin, Lancaster, Lebanon, Lehigh, Montgomery, Northampton, and York).[10] This area contains a significant amount of land outside of the Highlands itself. Nonetheless, between 2002 and 2006, there were only 24 responses from the larger area, and sample error remains a concern. Given the low number of responses, the following are rough estimates only. (Butler 2008a)

Results indicate that most of the forestland in the Pennsylvania Highlands is privately owned, the vast majority by families (Table 4-22). Of all family-owned forest land, about 80% of the area is in 1-20 acre plots, indicating a very fragmented ownership.

Table 4-22. *Pennsylvania Highlands: Forest land area in counties of the Pennsylvania Highlands by ownership type, 2006 National Woodland Owner Survey.*

All ownerships	Public				Private		
	Total [a]	Federal [a]	State [a]	Local [a]	Total [a]	Family	Business [b]
			Thousands of acres				
981	241	21	162	58	740	638	102

a Source: *Forest Resources of the United States, 2002* (Smith et al. 2004).
b Includes corporations, non-family partnerships, tribal lands, non-governmental organizations, clubs, and other non-family groups.
Note: Data may not add to totals because of rounding.

Privacy, enjoyment of beauty and scenery, home, protection of nature, and family legacy dominated the reasons cited for owning forest land. Only 27% indicated that the woodland was part of a farm. None of the respondents have a management plan, and only 5% have received advice about managing their land. This is extremely low compared to national numbers.

Although only 14% of the respondents cited firewood, biofuels, or timber production as a reason for owning land, 57% have harvested trees, the biggest reason being to clear land. Forty percent of the landowners who harvested received professional advice, which is higher than the national average. None indicated an intention to sell or sub-divide their land, and only 19% are over 65, which may indicate stability in land ownership for the next few years.

10 This methodology is consistent with how the ownership data was analyzed for the NY-NJ Highlands Study.

CHAPTER 5 AGRICULTURAL RESOURCES CHARACTERISTICS AND TRENDS

Key Findings

Connecticut

- Only six percent of the land in the Connecticut Highlands is in active agriculture. The region lost 13,500 acres of farmland between 1995 and 2002, mostly to development.
- The USDA Census of Agriculture indicates that from 1997 to 2002, cropland, pasture, and range in the Connecticut Highlands decreased by 16.7 percent.
- The trend is towards smaller farms.
- Eighteen percent of active agricultural land (7,800 acres) is protected from development with a conservation easement.
- The farmer population is aging and few young people are going into farming; fewer than half consider farming to be their primary occupation.

Pennsylvania

- At 35 percent of the landscape, agriculture is still an important activity and central to the culture and identity of eastern Pennsylvania.
- Most of the recent development in the Pennsylvania Highlands has occurred on agricultural land; we estimate that between 22,600 and 52,600 acres of farmland were lost between 1997 and 2001, most likely closer to the high end of that range.
- Agricultural land use is on the decline in all Highlands counties except Lebanon.
- Between 1997 and 2002, the numbers of farms, on-farm populations, farm jobs and medium sized farms (50-999 acres) all declined around the major cities of the Highlands region as well as along the state highways connecting them.
- Farms greater than 1,000 acres in size have disappeared; The number of smaller farms is on the rise; and from 1997 to 2002, there was a 48 percent increase in farms of 50 acres or less.
- About 16 percent of farmland is preserved from development with an agricultural conservation easement.

Introduction

Agricultural activities and resources in the Highlands of Connecticut and Pennsylvania are key components of the region's rural character, as well as residents' lifestyles and identities. Juxtaposed on the landscape of the region with forests, water and other resources, agricultural lands contribute to local economies, visual aesthetics and natural habitats. Farming activities and other agricultural pursuits are integral to the character of communities, the ebb and flow of daily life and the nature of commerce in the region. Land ownership patterns have evolved from a time when the agrarian society was dominant and almost all of the region was in farmland.

The purpose of this analysis was to examine agricultural resource data for the Connecticut and Pennsylvania Highlands in order to identify trends in agricultural land use, agricultural activity, and conversion of agricultural lands to other uses. The primary data source was the United States Department of Agriculture Census of Agriculture of 1997 and 2002. Trends prior to 1997 are difficult to discern because of changes in methodology and definitions.

Because agriculture has such a strong influence on community character and personal lifestyles in the region, it is of interest to examine not only agricultural resource trends statistically and geospatially, but also people's perceptions of those trends. Do people think that there is more change taking place in agriculture than there really is? Is agriculture as a profession or business disappearing from the landscape faster than people think? In order to provide a social and cultural context to this analysis, a series of interviews were conducted with agricultural and conservation professionals to elicit their impressions of changes in the region. The information gleaned from these interviews provides a context for discussion of the data analysis. The interviews were conducted following a "Key Informant" process, in which each interview leads to one or more additional interviews. A sample of the questionnaire used during the interview process can be found in Appendix 5.

For Connecticut, we have also analyzed changes in active agricultural land by means of digitizing farmland from aerial photos and comparing this "ground-truth" to remotely sensed data and to the agricultural census data. This type of resource-intensive analysis was not possible for Pennsylvania.

Connecticut Agricultural Resources

Methods and Data Sources

There are four sources of information about agricultural lands in somewhat comparable time periods: the Agricultural Census (1997 and 2002) (USDA 2002); the CLEAR satellite derived land use data (LULC) (1995 and 2002); the digitized map of active agricultural lands (farmland map) (2004); and the Highlands Conservation Values Assessment map (CVA) (2006). Although these are not exactly comparable, as they were developed for different purposes, we can use them to draw some tentative conclusions about what is happening to agricultural lands in the region over the past 5-10 years.

Agricultural Statistics

USDA Census of Agriculture data, as reported by the National Agricultural Statistics Service in 1997 and 2002, were used to compare agricultural activities, farm numbers, acreages and other metrics such as farm size, ownership and other pertinent information. These data are presented on a county by county basis. The Connecticut Highlands Region encompasses most communities in Litchfield County plus selected communities from Hartford and Fairfield Counties, but there is no single county which is entirely contained within the Highlands boundary. Thus, the census data have been apportioned according to the area of each county that is within the Highlands boundary in order to estimate trends across the region. In some cases, Litchfield County has been considered to be representative for the region (Table 5-1).

Table 5-1. *Connecticut Highlands: Proportion of counties within the Highlands region.*

County	County Acres	Acres in Highlands	% of Highlands	% of County in Highlands
Litchfield	604,772	499,544	73.7%	82.6%
Hartford	480,491	105,688	15.6%	22.0%
Fairfield	412,634	72,205	10.7%	17.5%
Total		677,437	100%	

Geographic Data

Spatial data for the analysis of agricultural resources were derived or developed from two sources.

1. LULC: Satellite data from the University of Connecticut's Land Use/Land Cover series developed by the Center for Land use Education And Research (CLEAR). Land cover map data classified into 11 land use/land cover categories are available for the years 1985, 1990, 1995 and 2001. Within this data set the category best associated with agricultural uses of land is *other grasses & agriculture*. However, the inclusion of *other grasses* makes it difficult to discern how much is *agriculture* and how much is development-associated grasses. Land cover data from 1995 and 2001 provide a spatial backdrop for discussion of the Census of Agriculture data for 1997 and 2002.

2. Farmland map: Digitized map of active agricultural lands. High-resolution digital aerial photography from a flight conducted in 2004 by the State of Connecticut was used to create a vector data layer by on-screen digitizing all land in the Highlands Region actively being used for agricultural purposes (Figure 5-1). The imagery is sufficiently detailed to determine the difference between agricultural uses and other areas that might be mistaken for agricultural use, such as athletic fields, cemeteries and large lawns. No distinction was made between differing types of agricultural use such as pasture vs. row crops vs. hayfield; it is simply a representation of land that is being used for some agricultural purpose. Table 5-2 provides a summary of how active agricultural lands are distributed throughout the region on a town by town basis.

High priority agricultural land previously identified and mapped in the Agricultural Assessment portion of Conservation Values Assessment conducted in Phase I of this project was also used in some comparisons.

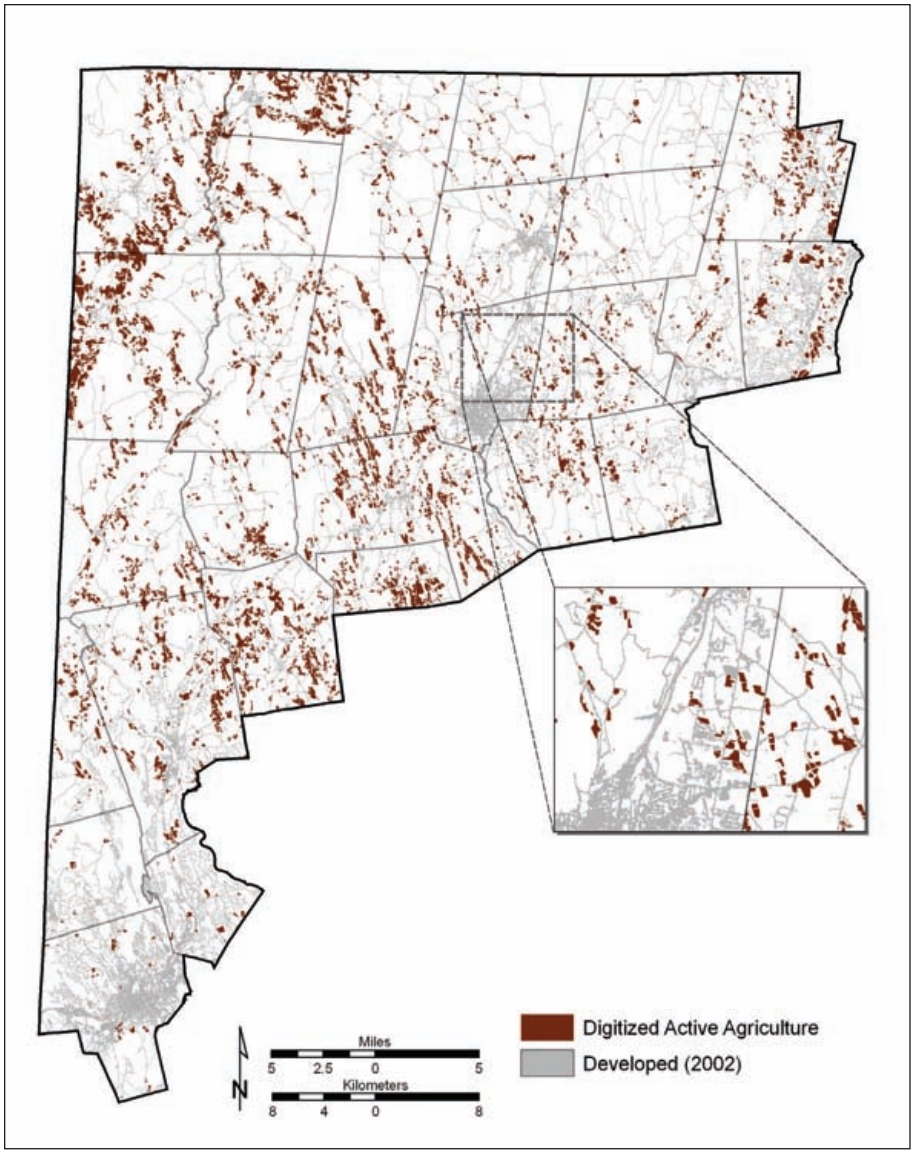


Figure 5-1. *Connecticut Highlands: Digitized map of 2004 active agricultural lands (farmland map).*

Table 5-2. *Connecticut Highlands: Agricultural acreage by town in 2004 from aerial photo interpretation.*

Town	Town Acres	Agriculture Acres	% of Town in Agriculture
Barkhamsted	24,775	315	1.3%
Brookfield	13,037	200	1.5%
Burlington	19,499	523	2.7%
Canaan	21,212	1,300	6.1%
Canton	16,014	493	3.1%
Colebrook	21,047	460	2.2%
Cornwall	29,717	1,550	5.2%
Danbury	28,118	267	1.0%
Goshen	28,934	2,565	8.9%
Granby	26,299	2,011	7.6%
Hartland	21,935	177	0.8%
Harwinton	19,907	1,125	5.6%
Kent	31,808	2,021	6.4%
Litchfield	36,436	3,736	10.3%
Morris	11,963	1,567	13.1%
New Fairfield	16,103	109	0.7%
New Hartford	24,363	1,367	5.6%
New Milford	40,882	2,747	6.7%
Norfolk	29,663	912	3.1%
North Canaan	12,495	2,278	18.2%
Salisbury	38,514	4,291	11.1%
Sharon	38,209	4,713	12.3%
Sherman	14,971	809	5.4%
Simsbury	21,970	1,576	7.2%
Torrington	25,793	999	3.9%
Warren	17,597	981	5.6%
Washington	24,728	3,354	13.6%
Winchester	21,675	583	2.7%
Total	677,666	43,027	

Social/Cultural Data

In order to provide a social and cultural context to this analysis a series of interviews were conducted with 43 individuals who are associated with agriculture in the region. These included 17 farmers (40%), 7 agricultural agency personnel (16%), 4 educators (9%), and 15 agricultural association members and the like (35%).

Data Differences and Commonalities

The impetus for planning this portion of the project was, in part, the idea that different sources of information such as those described above could be used together to address questions about trends in agricultural resources and activities in the Highlands region, put simply as follows: What changes are taking place with respect to agriculture? Where are those changes occurring? and, Are people with interests in agriculture aware of the nature of the changes?

The assumption that data from the different sources would be mutually supportive is one that came into question early in the process. Resolving apparent differences in the information from various sources of data, while also recognizing commonalities, was the first step in a search for trends that can be reported with some degree of confidence.

Several generalizations can be made. First, the census data are useful for qualitatively and temporally describing changes and trends in the agricultural use of land at the regional scale. The census does not, however, provide information on where these changes are taking place, below the county level. Due to the lumping of *other grasses*, most of which are associated with development,

with *agriculture* in the LULC data, it is very difficult to discern true changes in agricultural lands over time. The farmland map provides a more precise check for whether land cover changes shown in the LULC are agriculturally related. It is a reliable source for knowing where agriculture is still active on the landscape, but this map, derived for only one point in time (2004), cannot tell us anything about changes over time. We have thus used all three data sources to present a picture of what is most likely happening to agricultural lands in the Highlands region.

In order to compare census data with the LULC data and the farmland map, county census data were apportioned to the Highlands based on the percentage of each county that lies within the Highlands (Table 5-3).

Table 5-3. *Connecticut Highlands: Census of agriculture statistics for 1997 and 2002 by county. County data were apportioned to the Highlands based on the percentage of each county that lies within the Highlands. "Other" includes farm buildings, ponds, roads and wasteland.*

		# Farms	Cropland	Pasture/Range	Cropland/Pasture/Range	Woodland	Other	Total Farm
			Acres					
Litchfield County	1997	916	49,557	8,062	57,619	34,612	8,939	101,170
	2002	789	41,646	6,290	47,936	35,725	9,908	93,569
Portion in Highlands Region	1997	757	40,934	6,659	47,593	28,590	7,384	83,566
	2002	652	34,400	5,195	39,594	29,509	8,184	77,288
Hartford County	1997	803	36,648	1,965	38,613	14,128	6,361	59,102
	2002	724	30,748	2,625	31,013	11,929	4,890	50,192
Portion in Highlands Region	1997	177	8,063	432	8,495	3,108	1,399	13,002
	2002	159	6,765	578	7,342	2,624	1,096	11,042
Fairfield County	1997	345	7,676	1,007	8,683	4,198	1,969	14,850
	2002	287	5,294	876	6,107	4,994	1,664	12,828
Portion in Highlands Region	1997	60	1,343	176	1,520	735	345	2,599
	2002	50	926	153	1,080	874	291	2,245
Totals for Highlands Region	1997	994	50,340	7,268	57,608	32,432	9,128	99,168
	2002	861	42,091	5,925	48,016	33,007	9,571	90,575

Table 5-4. *Connecticut Highlands: Summary Census of Agriculture statistics for 1997 and 2002.*

	1997		2002		Change (1997 to 2001)	
	Acres	% of Total	Acres	% of Total	Acres	% from 1997
Cropland Acreage	50,340	50.8%	42,091	46.5%	-8,249	-16.4%
Pasture/Range Acreage	7,268	7.3%	5,925	6.5%	-1,343	-18.5%
Cropland/Pasture/Range Acreage	57,608	58.1%	48,016	53.0%	-9,592	-16.7%
Woodland Acreage	32,432	32.7%	33,007	36.4%	575	1.8%
Other Acreage	9,128	9.2%	9,571	10.6%	443	4.9%
Total Farm Acreage	99,168	100.0%	90,575	100.0%	-8,593	-8.7%

			Change (1997 to 2001)	
	1997	2002	Number	% from 1997
Number of Farms	994	861	-133	-13.4%

Results

Trends in Agricultural Land Use

Comparisons of the census data for the Highlands Region are shown in Table 5-4 for 1997 and 2002. Agricultural land (all categories, including woodlands that are part of farm properties) decreased from 1997 to 2002 on the order of 8.7%. There were 133 fewer farms and a loss of 9,592 acres of active farmland.

Losses of farms and farmland between 1997 and 2002 were recorded in all farm-size categories (Figure 5-2). The number of small farms (1 to 49 acres) decreased from an estimated 559 in 1997 to 510 in 2002, an average 1.75% annual decrease. Medium sized farms (50 to 999 acres) decreased from approximately 425 to 345, an average 3.76% annual rate of loss and numbers of large farms (1000 acres or more) dropped from about 10 to 6.

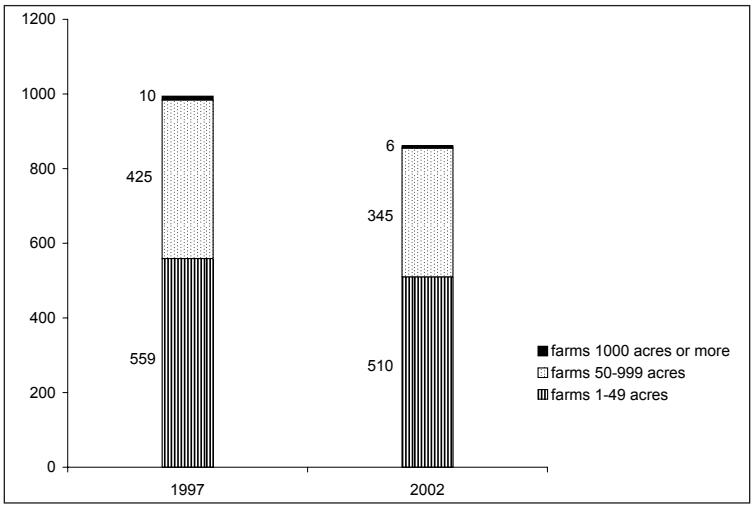


Figure 5-2. *Connecticut Highlands: Number of small, medium, and large farms (by acres) in 1997 and 2002 according to the USDA Census or Agriculture.*

For the region as a whole, the average size of farms decreased on the order of 6.3% between 1997 and 2002, although in Litchfield county there was a gain in average farm size. This may be due to consolidation of farms. Consolidation would also explain why, although overall farm numbers decreased by 14% between 1997 and 2002, total farm acreage loss for the same period was only 8.7%. However, this could also be explained by a disproportionate loss of small farms.

There were also changes in farmland use. Losses were recorded for cropland, pastureland, and range land. Woodland on farms increased, particularly woodland that is also used for grazing, as did other uses of farm property such as for buildings, roads, ponds, etc.

During the construction of the farmland map, it was observed that some agricultural land has recently been lost to other uses, particularly to residential construction. It cannot be determined from available geographic data how much of the almost 10,000 acres of farmland loss as reported by the census is due to residential development. However, it can be inferred from the LULC data and the analysis of active farm land that more than half of the acres changing from *other grasses & agriculture* to some other use, went to *developed*. And we can estimate, by comparing the farmland map to the LULC data, that the region gained about 13,300 acres of development-associated grasses between 1995 and 2002 (Table 5-6).

Data from the farmland map can also be compared to census categories of cropland, pasture and rangeland. For example, the total acreage in 2002 for agricultural use (cropland + pasture + range) in the Highlands is 48,016 acres, or 7% of the region. There are 43,516 acres on the 2004 farmland map, or 6.42% of the region. The differences between the two sets of figures could be because of the two year time difference (reflecting an actual loss of 5,000 acres of farmland). Or it could be because of the way we allocated the county agricultural statistics to the portion of the county that lies in the Highlands. In fact, the distribution of farmland may not be spread evenly throughout the county.

If we trust that the census data and the farmland map are a good approximation of how much land was in agriculture in 2002 and 2004, then we can use this to estimate how much of the LULC category of *other grasses & agriculture* is actually grasses associated with development, such as athletic fields, cemeteries, large lawns, and recreational sites.

For 2002, the LULC data indicate that approximately 12% of the Highlands region (81,168 acres) was *other grasses and agriculture*. If we consider that the 2002 census is a "ground truthing" for agricultural land use, then approximately 59% of the satellite-derived *other grasses & agriculture,* are actually active crop/pastureland. The rest, 33,186 acres are in a *developed* land use. Using all three data sources, a rough estimate is that development associate grasses increased by about 13,300 acres between 1995 and 2002, which is a 66% increase (Table 5-6). Farmland decreased by a similar amount, representing a 22% loss.

When comparing the spatial agreement between the 2004 farmland map and the 2002 LULC data (Figure 5-3), for the entire Highlands region, the differences are dramatic. The farmland map contains approximately 43,516 acres of land used for agriculture and the LULC map contains just over 81,168 acres of land in the *other grasses and agriculture* class, but there are just 35,698 acres where both layers coincide. Only 44% of the LULC *other grasses and agriculture* class matches the farmland map, which is to be expected as this map includes more than active agricultural fields. On the other hand, only 82% of the farmland map matches the LULC map, which is somewhat lower than expected given that both maps are intended to include all agricultural lands (Figure 5-3). The farmland map is considered to be the most precise with respect to actual agricultural use. This shows that caution must be taken when using remote sensing data at a pixel by pixel scale.

Table 5-5. *Connecticut Highlands: Estimates of agricultural land from three sources: LULC classified satellite imagery, includes other grasses and agriculture (UCONN, CLEAR); Census of Agricultural survey, includes cropland, pasture, and range (USDA); and active agricultural land hand-digitized from aerial photographs (UCONN).*

Satellite Derived LULC (CLEAR data)					
1995		2002		Change 1995-2002	
Acres	% of Area	Acres	% of Area	Acres	% from 1995
81,345	12.0%	81,202	12.0%	-143	-0.2%

Census of Agriculture (USDA)					
1997		2002		Change 1995-2002	
Acres	% of Area	Acres	% of Area	Acres	% from 1995
57,608	8.4%	48,016	7.1%	-9,592	-16.7%

Digitized from Aerial Photos (UCONN)	
2004	
Acres	% of Area
43,516	6.4%

Table 5-6. *Connecticut Highlands: Agriculture vs. development-associated grasses. Farmland acres derived from USDA census of agriculture (1997 and 2002) and digitized active agriculture layer (2004). 1995 farmland acres estimated from the rate of change between 1997 and 2004; farmland prior to 1995 assumed to be relatively constant.*

	Acres						
	1985	1990	1995	1997	2002	2004	95-02
Other Grass & Ag (CLEAR LULC)	79,313	80,107	81,345		81,202		-143
Farmland	61,500	61,500	61,500	57,608	48,016	43,516	-13,484
Other grasses (Extrapolated)	17,813	18,607	19,845		33,186		13,341

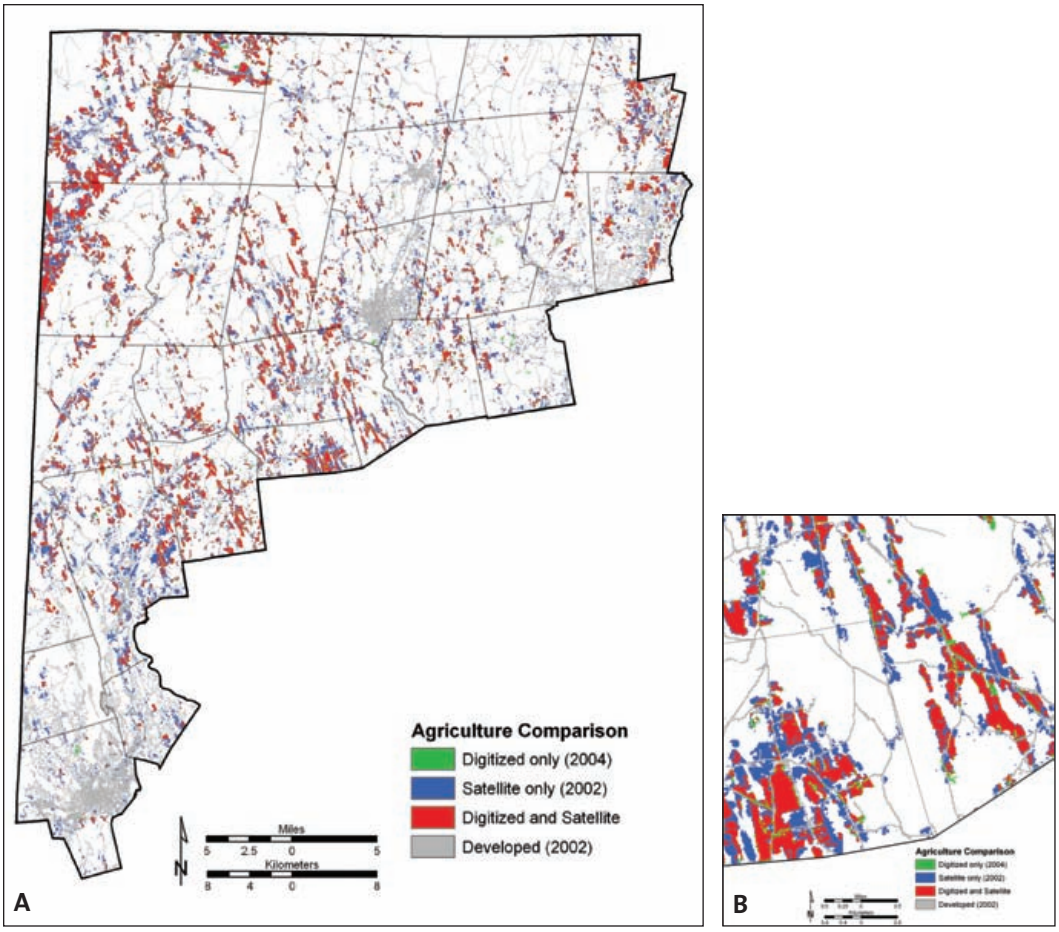


Figure 5-3. *Connecticut Highlands: A) Overlay of agriculture land cover derived by hand-digitization of orthophotos from year 2004 (green) and classification of satellite imagery from 2002 (blue). Areas of overlap are shown in red. B) Larger view of A for a section of the map.*

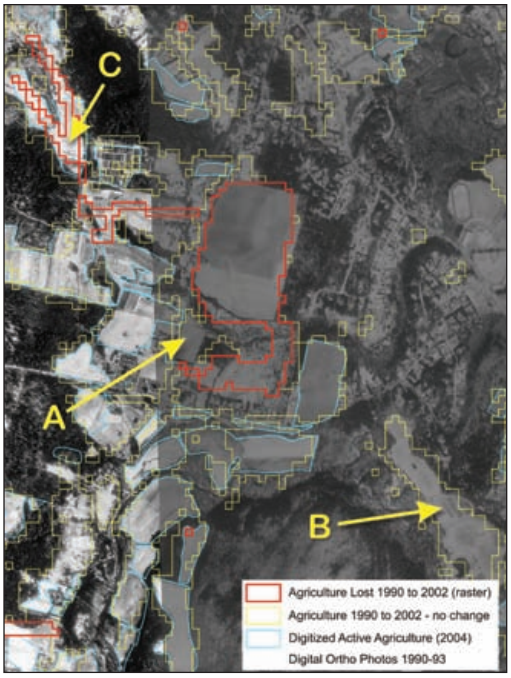


Figure 5-4. *Connecticut Highlands: 1990 digital orthophoto comparing land cover designation of satellite imagery classification and digitized agricultural lands map.*

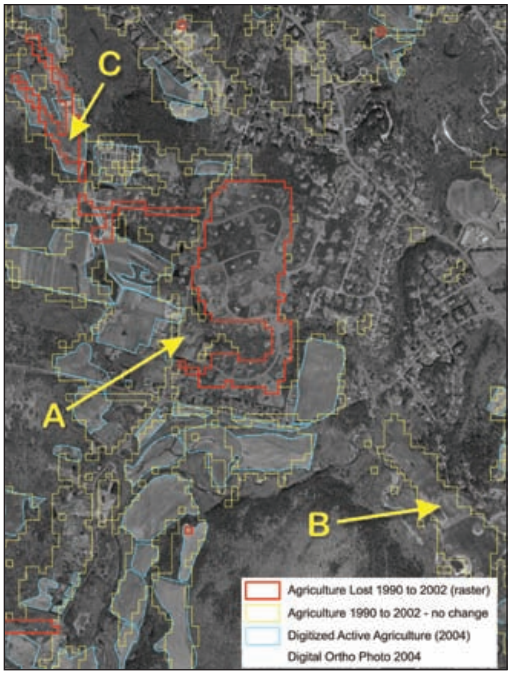


Figure 5-5. *Connecticut Highlands: 2004 digital orthophoto comparing land cover designation of satellite imagery classification and digitized agricultural lands map.*

A close inspection of Figures 5-4 and 5-5 illustrate some of the problems with using remote sensing data at a pixel by pixel scale. Figure 5-4 shows the 1990 digital orthophoto with an overlay of (1) LULC areas classified as *other grasses & agriculture* (outlined in yellow) and (2) the farmland map (outlined in green). The same was done using the 2004 digital orthophoto (Figure 5-5). In this manner, locations in the LULC data where changes occurred between 1990 and 2002 were compared against the farmland layer. Outlined in red are areas indicated as changed to *developed* between 1990 and 2002. Location A is correctly classified as farmland in 1990, and also correctly classified as developed in 2002. Location B is an area of athletic fields mis-classified as *other grasses & agriculture* instead of *turf & grass* in both 1990 and 2002. Location C, in the upper left corner of the image, was correctly classified as agriculture as of 1990, however, according to the LULC classification, this area was developed in 2002 when in fact, it was still in agriculture in 2004 according to the digital orthophoto.

Table 5-7. *Connecticut Highlands: Comparison of active agricultural land with lands designated as high agricultural conservation value (value of 4 or 5 out of 5)*

	Acres	% Not in Overlap
Active Agriculture	43,402	53.0%
High Conservation Value	40,111	49.2%
Overlap (Active Agriculture and High Conservation Value)	20,393	–

Comparing high priority agricultural areas from the Conservation Values Assessment (CVA) map to the farmlands map brings out some interesting points (Figure 5-6 and Table 5-7). More than half of the acreage under active agriculture does not coincide with high value/priority agri-

cultural lands as designated in the Conservation Values Assessment. And almost half of the acres designated as high value/priority for agriculture are not presently in agricultural use. The inclusion of prime agricultural soils as a component in the conservation values assessment is probably the main reason for the difference. Many areas rated as prime agricultural soils are forest-covered, or developed.

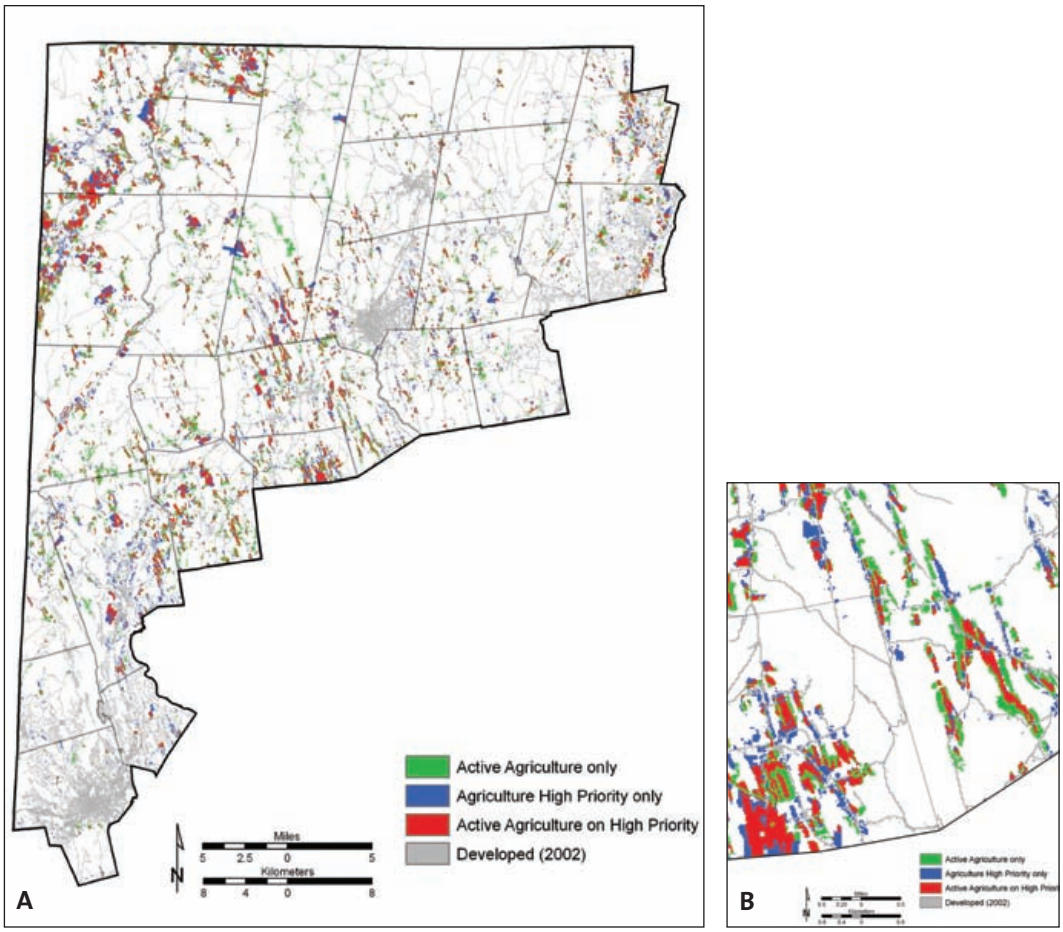


Figure 5-6. *Connecticut Highlands: A) Comparison of agriculture land cover derived by handd-digitization of orthophotos from year 2004 and high agricultural conservaton value (value of 4 or 5 out of 5). B) Larger view of a section of the map in A.*

Trends in Agricultural Production

Among agricultural producers fewer than half consider farming to be their primary occupation (42% in 1997 and 47% in 2002) and the number of full time farmers decreased during the same period. The high percentage of part-time farmers is reflected in value-of-sales figures. More than half of the farms in the region had less than $5000 annual sales, 80% had less than $25,000 and only 12.7% of farms had $50,000 or more in annual sales. Nevertheless the average market value of production for the region in 2002 increased approximately 29% from 1997 to 2002. Much of this increase was driven by Hartford and Fairfield counties. Market value of products grown in Fairfield County nearly doubled in value between 1997 and 2002 (Table 5-8).

Table 5-8. *Connecticut Highlands: Farm statistics from the Census of Agricultural Summary for 1997 and 2002 by county. County data were apportioned to the Highlands based on the percentage of each county that lies within the Highlands.*

	# of farms 2002	% change from 1997	Acres in farms 2002	% change from 1997	Ave farm acres 2002	% change from 1997	Ave market value of production 2002	% change from 1997	Total market value of production 2002	% change from 1997
Litchfield County*	789	-14%	93,569	-7.5%	119	8%	$38,141	18%	$30,093,000	1.2%
Portion in Highlands Region (82.6%)	83%	652	-14%	77,288	18%				$24,856,810	1.2%
Hartford County*	724	-10%	50,192	-15%	69	-6.7%	$175,119	23%	$126,786,000	11%
Portion in Highlands Region (22.0%)	159	-10%	11,042	-15%					$27,892,920	11%
Fairfield County*	287	-17%	12,828	-14%	45	4.7%	$105,478	97%	$30,272,000	64%
Portion in Highlands Region (17.5%)	50	-17%	2,245	-14%					$5,296,600	64%
Totals for Highlands Region	861	-14%	90,575	-8.7%	103.3	-6.3%	$66,695	29%	$58,047,330	9.6%

*Values are for the entire county indicated.

Farmers and Farmland Protection

Nearly 25% of the agricultural producers in the region are over 65 years of age, a proportion that has remained constant from 1997 through 2002. The numbers of agricultural producers in the 45 to 64 years-of-age category has remained nearly the same between 1997 and 2002, decreasing by only 2.3%. The greatest losses in the numbers of agricultural producers are occurring in the younger than 44 age group. There are 29% fewer agricultural producers in this age group in 2002 than there were in 1997 (Table 5-9). Clearly the farmer population is aging and few young people are going into farming.

Farmers, other agricultural producers and individuals in the area who work with the agricultural industry tend to be in general agreement with the 2002 Census of Agriculture data. Over 70% of the people interviewed agree that the use of land for agriculture is on the decline in the region. Most people also consider this change to be occurring at a moderate or rapid pace and that a trend away from the agricultural use of land will continue at a moderate to rapid pace.

Table 5-9. *Connecticut Highlands: Farmer statistics from the Census of Agriculture Summary for 1997 and 2002 by county. County data were apportioned to the Highlands based on the percentage of each county that lies within the Highlands.*

	# under 45 in 1997	# under 45 in 2002	% change from 1997	# 45 to 64 in 1997	# 45 to 64 in 2002	% change from 1997	# 65 or older in 1997	# 65 or older in 2002	% change from 1997
Litchfield County*	250	166	-34%	443	432	-3%	223	191	-14%
Portion in Highlands Region (82.6%)	206	137		367	357		184	158	
Hartford County*	206	192	-7%	347	337	-3%	250	195	-22%
Portion in Highlands Region (22.0%)	45	42		76	74		55	43	
Fairfield County*	75	50	-33%	152	155	2%	118	82	-31%
Portion in Highlands Region (17.5%)	13	9		26	27		21	14	
Totals for Highlands Region	264	188	-29%	469	458	-2%	260	215	-17%

*Values are for the entire county indicated.

Concern about this trend varies, with individual farmers being only slightly concerned for the most part, but with individuals who work with farmers being very concerned.

One of the major concerns voiced by agricultural producers was on the subject of leased land. It is not always the case that when a farmer retires or goes out of business the land is immediately sold for some other use. Often the farmer may retire, but the land may stay in the family while the fields and pastures are leased by other farmers for agricultural production. Leases of this nature often remain in place even when the ownership of the land changes. Many owners of large parcels, whether resident or absentee, may have land in active agricultural use within their holdings, but do not actually farm the land themselves. Generally the mowing, grazing or cultivation is done by a local farmer who pays the landowner a rental fee for the privilege.

For many agricultural producers a significant proportion of their production, and their income, are derived from leased land and the loss of the ability to use that land would make a difference in whether they could continue farming. So the conversion of large tracts, particularly subdivision for residential purposes, is seen as a threat, even though they may have no intention of selling their own property. On the other hand, in certain cases it is felt that some agricultural lands are lost to other uses simply due to the lack of someone to farm them.

Protection efforts in the Highlands region are spotty. By overlaying the protected lands map with the active farmland map, we estimate that about 7,800 acres of the 43,440 acres of active farmland are protected from development by a conservation easement. This is only 18% of the land under active agricultural use. Opinions about protection efforts are mixed, and are linked to opinions about the value of land for uses other than agriculture. Among people who feel strongly about keeping agriculture active in the region there is never enough effort or funding by private organizations for protecting agricultural land. Some people, however, (approximately one-third of the interviewees) consider government efforts to be at odds philosophically with how they feel their tax dollars should be spent, and think that such efforts should be entirely the role of local and national private organizations. Most agricultural producers who own land care deeply about the farming business and want to see agriculture thrive in the region. They may have no intention of getting out of the business in the near future, but reserve the right to take whatever advantage they can from the value of their land in that eventuality.

The high value of land coupled with the retirement of farmers tops the list as the principle reason stated by the interviewees as to why land is being converted to other uses. Regulations, prices and costs of operations are all common issues associated with the difficulty of farming as a business, but are not seen as directly responsible for land use change. Several agricultural producers stated they would try a different crop or product before getting out of the business completely; diversification is also a common strategy. Whether an interest exists on the part of young people to pursue agricultural careers is a question that poses interesting challenges. In many cases the children of farmers and agricultural producers have no interest in farming or continuing the family business, but among other young people a strong interest may exist in taking up farming as a career. The value of land for other purposes presents a constraint, however, because those who wish to take up the business of farming can rarely afford to compete with the residential real estate market to acquire farm land. In many cases the only hope for agriculture to continue is for individuals who inherit farms to continue the farming operation.

Pennsylvania Agricultural Resources

Methods and Data Sources

This section outlines recent trends in agricultural land use in the Pennsylvania Highlands. Data were gathered from the United States Census of 1970, 1980, 1990 and 2000 (GEOLYTICS 2005), the

United States Department of Agriculture Census of Agriculture of 1997 and 2002 (USDA 2002), and a key informant survey. Survey results and census data were synthesized to help understand key drivers and mitigating factors in the conversion of agricultural land to other uses. Unless otherwise indicated, all data are for zip codes that are partially or wholly within the Highlands boundary.

Results

Trends in Agricultural Land Use

In the Pennsylvania Highlands the vast majority of agricultural land is in cropland, with pasture and rangeland making up the balance. The USDA Census of Agriculture indicates that agricultural land use declined between 1997 and 2002 in all Highlands counties except for Lebanon, where it increased moderately (Table 5-10 and Figure 5-7). Bucks County lost agricultural land at the fastest rate among Highlands Counties between 1997 and 2002. In total, the Highlands region lost 44,930 acres of farmland between 1997 and 2001 according to census data. This compares favorably to the higher estimates derived from the land use change analysis of between 22,600 and 52,600 acres of farmland lost between 1992 and 2001.[11]

11 See extensive discussion of agricultural land use in Chapter 7, *Analysis of Land Use/Land Cover*.

Table 5-10. *Pennsylvania Highlands: Census of Agriculture statistics for 1997 and 2002 by county. County data were apportioned to the Highlands based on the percentage of each county that lies within the Highlands.*

County	Farmland acres within Highlands 2002	Farmland acres within Highlands 1997	Percent change in farmland acres within Highlands 1997 to 2002	Total change in farmland acres within Highlands 1997 to 2002
Berks	106,894	120,496	-11.3%	-13,602
Bucks	27,370	35,008	-21.8%	-7,638
Chester	40,356	47,324	-14.7%	-6,967
Dauphin	10,727	10,928	-1.8%	-201
Lancaster	185,304	195,413	-5.2%	-10,109
Lebanon	39,518	37,881	4.3%	1,638
Lehigh	27,042	30,966	-12.7%	-3,924
Montgomery	15,807	17,204	-8.1%	-1,396
Northampton	19,087	21,483	-11.2%	-2,396
York	17,925	18,259	-1.8%	-334
Total	490,032	534,962	-8%	-44,930

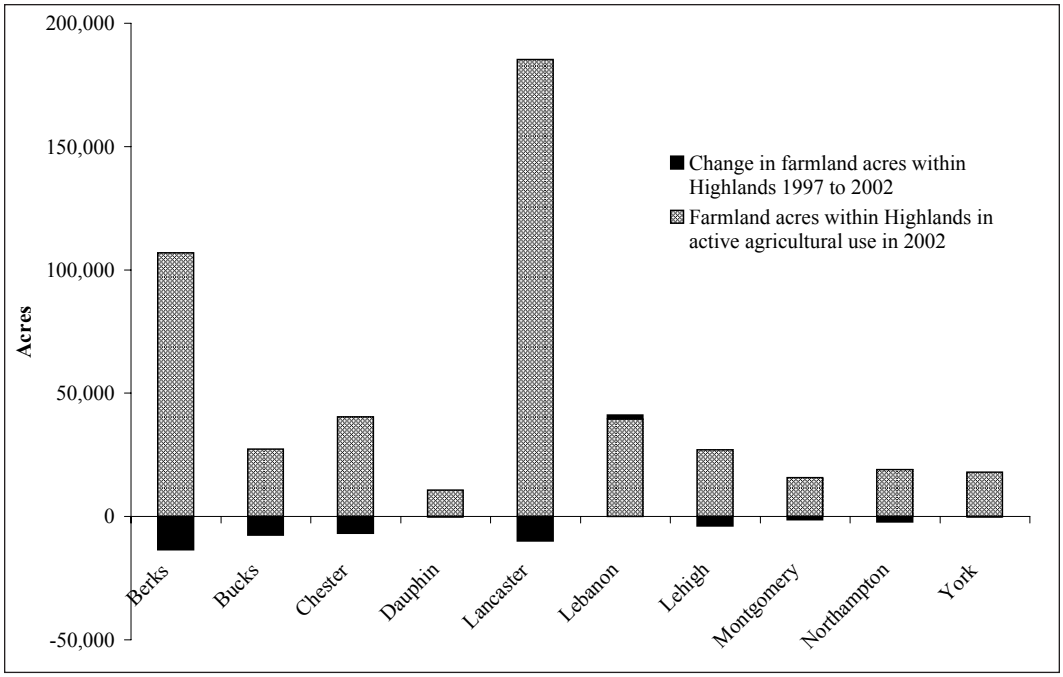


Figure 5-7. *Pennsylvania Highlands: Farmland acreage in 2002 and change from 1997 to 2002 by county.*

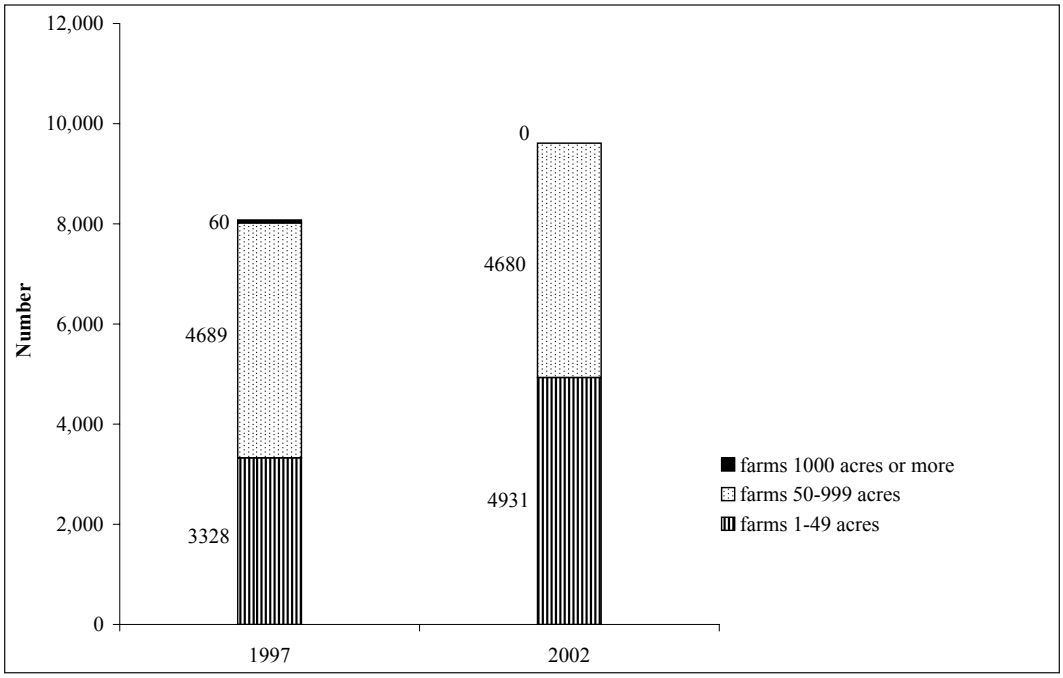


Figure 5-8. *Pennsylvania Highlands: Change in farm size composition from 1997 to 2002.*

According to the 2002 Census of Agriculture there were 9,611 farms in the zip codes that are partially or fully within the boundary of the Pennsylvania Highlands. Most were small to medium sized farms in both acres and sales. There were 4,931 farms between 1 to 49 acres, and 4,680 farms between 50 and 999 acres (Figure 5-8). Sixty-two percent had annual agricultural sales less than $50,000 in 2001; twenty-nine percent had sales $50,000 to $250,000; and only 9% had sales over $250,000.

Many Plain Sect farms, which may take in less cash from sales than other production operations, probably have sales less than $50,000. Plain Sect farmers appear to respond to the Census of Agriculture at about the same rate as non-Plain Sect farmers, but conclusive evidence is not available because the USDA National Agricultural Statistics Service is not permitted to ask the religious affiliation of census respondents.

From 1997 to 2002, there was a 48% increase in smaller farms and the number of small farms (1 to 49 acres) surpassed the number of medium farms (50 to 999 acres) (Figures 5-9 and 5-10). The total number of medium farms declined by 9, and farms larger than 999 acres disappeared entirely. Fragmentation of farmland is driving the increase in the number of small farms. A medium-sized production farm of several hundred acres with a full-time operator can be split into smaller farms that are managed by part-time operators or are used for rural lifestyle purposes.

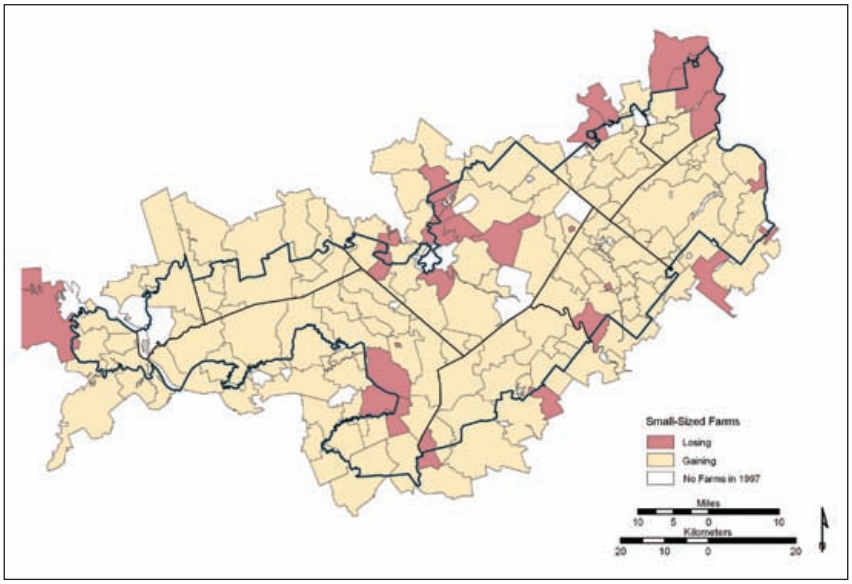


Figure 5-9. *Pennsylvania Highlands: Zip codes gaining and losing farms of less than 50 acres from 1997 to 2002.*

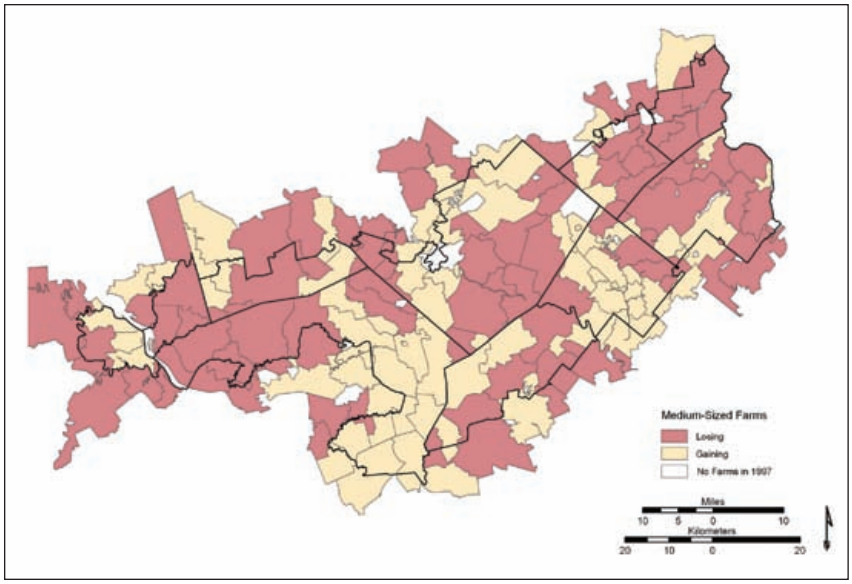


Figure 5-10. *Pennsylvania Highlands: Zip codes gaining and losing farms from 50 to 999 acres from 1997 to 2002.*

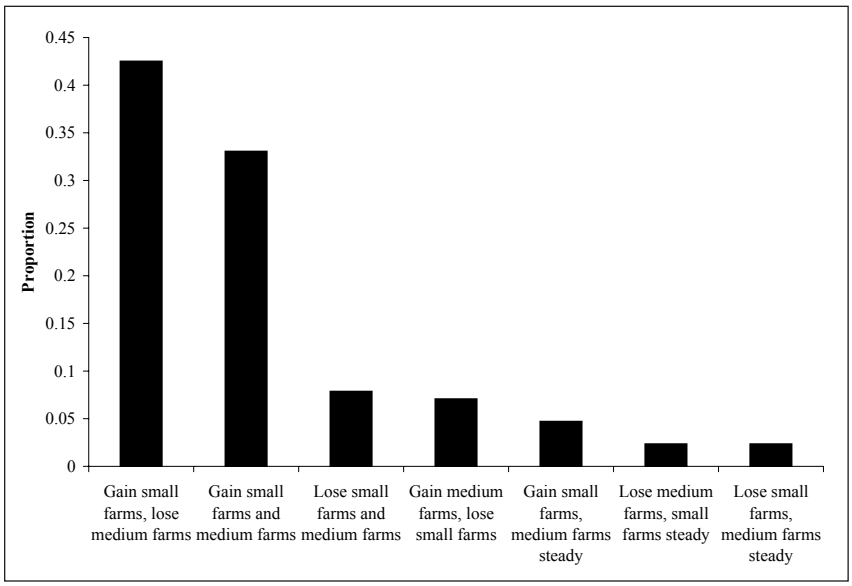


Figure 5-11. *Pennsylvania Highlands: Proportion of Pennsylvania Highlands zip codes which changed in farm size composition from 1997 to 2002, for all possible scenarios.*

Small farms increased in number in 76% of zip codes in the Pennsylvania Highlands. Zip codes were most likely to lose medium farms and gain small farms between 1997 and 2002 (Figure 5-11). If a zip code lost medium farms between 1997 and 2002, it gained small farms in 80% of cases. The movement of urban professionals to rural areas is driving the boom in small farms. Several key informant survey respondents indicated that these farms are operated for lifestyle purposes and sell very few agricultural products. In general, the change in the total number of small farms was greater than the change in the total number of medium farms, suggesting the higher cost of beginning a larger operation and therefore a less-active market for larger farms. Small farms are less capital-intensive and easier to maintain under mounting development pressure. Loss of farms and gain in housing works synergistically to the disadvantage of medium farms that remain, by increasing the chance of conflicts with neighbors and reducing competition among suppliers of agricultural goods and services.

The loss of a larger farm represents a greater loss to the agricultural community than the loss of a small farm, since larger farms produce more, contribute more to the local economy, and keep more open space out of development. On the other hand, in some areas, farmers are realizing economies of scale by consolidating cropland, indicated by the increase in farms 50 to 999 acres in some Highlands zip codes.

Larger, higher-income farms remain clustered in and around the Lancaster County. As agricultural production in the Pennsylvania Highlands declines, many medium-sized farms remain in business on the good soils in and around Lancaster County, the leading agricultural producer among Highlands counties.

This area, along with southern Lebanon County and the northwestern edge of Berks County was previously identified as the area with the highest agricultural resource value in the Pennsylvania Highlands Resource Assessment (Figure 5-12). County-wide data in Table 5-11 indicate that only Lebanon, York and Montgomery counties did not lose farm acres from 1997 to 2002.

Table 5-11. *Pennsylvania Highlands: County farm statistics from Census of Agriculture (USDA) for 1997 and 2002.*

	Berks	Bucks	Chester	Dauphin	Lancaster	Lebanon	Lehigh	Montgomery	Northampton	York
Percent of county in Highlands	58%	44%	29%	14%	51%	35%	36%	42%	28%	8%
Number of farms 2002	1,791	917	1,918	852	5,293	1,104	618	792	487	2,546
Percent change from 1997	-14%	-14%	-3%	-1%	-7%	-4%	5%	12%	-11%	8%
Acres in farms 2002	215,679	76,831	168,165	94,983	411,848	125,066	91,304	48,327	77,556	285,336
Percent change from 1997	-10%	-17%	-14%	-4%	-4%	5%	-6%	0%	-8%	1%
Average farm acres 2002	120	84	88	111	78	113	148	66	159	112
Percent change from 1997	3%	-2%	-10%	-20%	4%	10%	-10%	-11%	3%	-7%
Average market value of production 2002	$160,233	$67,219	$196,440	$54,562	$150,831	$173,101	$80,694	$48,608	$44,870	$57,985
Percent change from 1997	27%	-13%	1%	-19%	4%	12%	-20%	-12%	-20%	0%
production 2002 (millions of $s)	$287.0	$61.6	$376.8	$46.5	$798.3	$191.1	$49.9	$35.4	$21.9	$147.6
Percent change from 1997	10%	-25%	-2%	-20%	-3%	8%	-16%	-2%	-29%	8%

*All values are for the entire county indicated.

These numbers reflect the influence of many factors beyond a physical conversion of farmland to other uses. If cropland is sold to a non-farmer, that exchange will be reflected as a loss of farmland in the Census of Agriculture, even if the land remains under cultivation through an annual lease to a farmer.

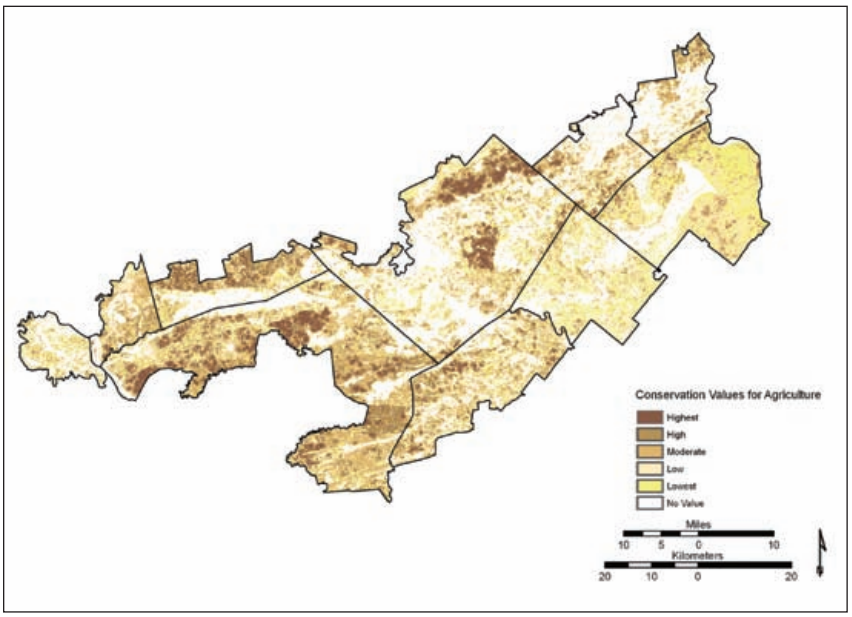


Figure 5-12. *Pennsylvania Highlands: Conservation values for agriculture.*

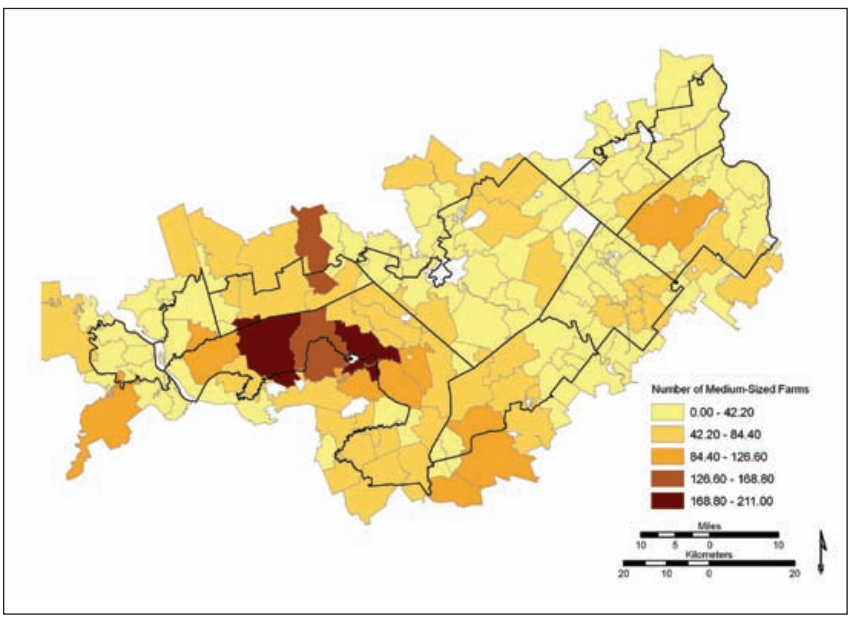


Figure 5-13. *Pennsylvania Highlands: Acres in farms 50 - 999 acres in 2002 by zip code.*

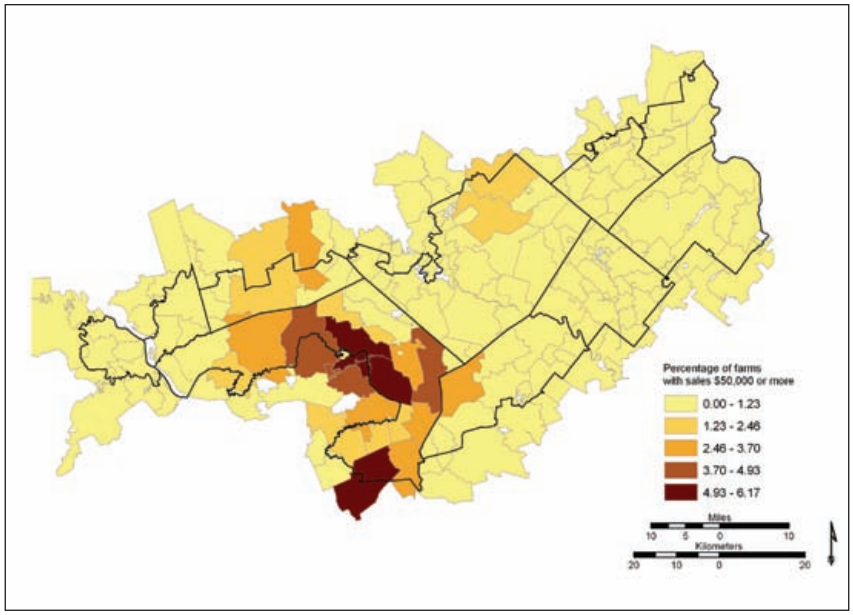


Figure 5-14. *Pennsylvania Highlands: Proportion of farms with sales $50,000 or more in 2002 by zip code.*

All key agricultural indicators declined around the major cities of the greater Highlands region, and along the state highways between them. Proximity to developed centers is still an important factor in the loss of agricultural resources. Many people are seeking a rural lifestyle by buying developed agricultural land. The state highway system provides the means for professionals to work in urban centers and live in rural townships. Results of the key informant survey corroborated this. All respondents indicated that residential development was by far the most important use of land lost from agriculture. In the northern Pennsylvania Highlands, commuters live in rural areas but drive daily to Newark or New York City, up to two hours away, to work. The Highlands of Chester and Lancaster counties are only an hour's drive from Philadelphia; therefore many commuters live in those counties. At the southern end of the Pennsylvania Highlands, professionals from Maryland are moving into agricultural areas to capitalize on lower land prices. Survey respondents overwhelmingly felt that the loss of agricultural land was occurring as entire farms in areas not zoned for agriculture were sold to land developers. Several respondents reported that they received unsolicited offers to buy their farmland, either through the mail or over the phone, on a weekly basis.

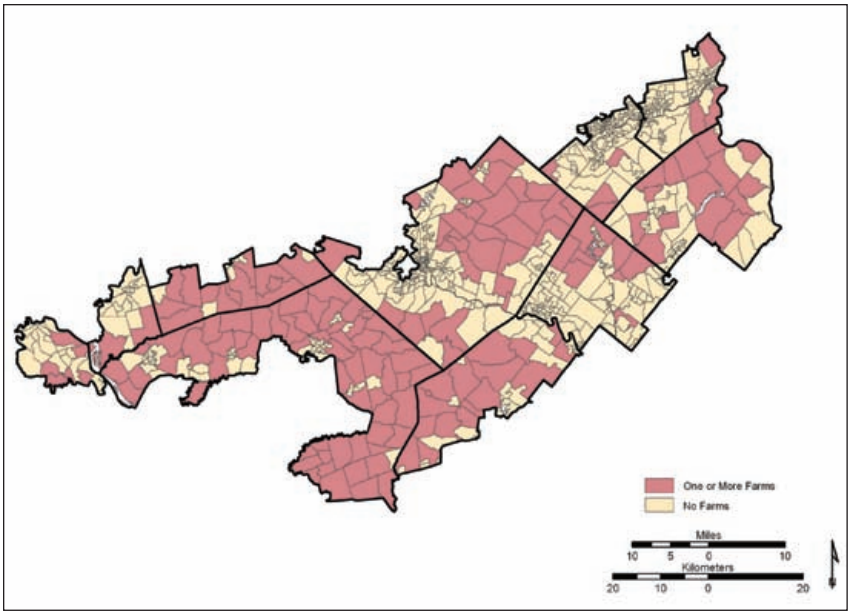


Figure 5-15. *Pennsylvania Highlands: Census blocks with and without farm population in 2000.*

As a result of these trends the on-farm population from 1980 to 2000 thinned and disappeared around developed centers and along the state highways between them (Figure 5-15).

Employment in farming, forestry or fishing disappeared around major Highlands cities by 2000, and thinned along the corridors connecting them in a pattern similar to the on-farm population (Figure 5-16).

The number of full-time farm operators (Figure 5-17) is an important indicator for the health of the agricultural community. Many areas had less than 30 full-time farmers in 2002. This map was generated from the Agricultural Census. Comparatively, there were few people employed in farming, forestry and fishing in these same areas according to the 2000 US Census (Figure 5-16). The loss of the agricultural industry around cities in the Pennsylvania Highlands is evident in both images.

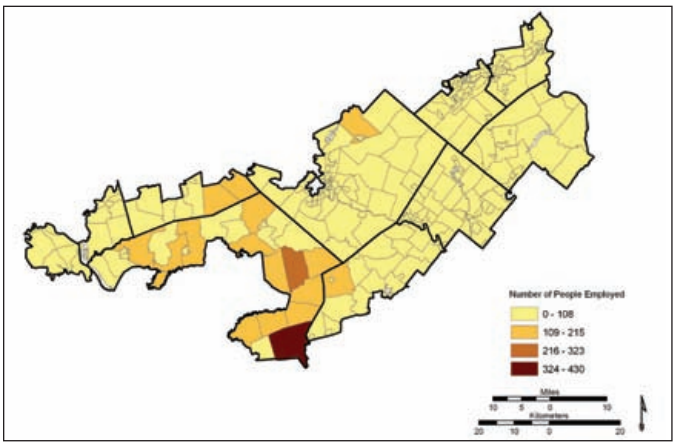


Figure 5-16. *Pennsylvania Highlands: Employment in farming, forestry, or fishing in 2000 by census block.*

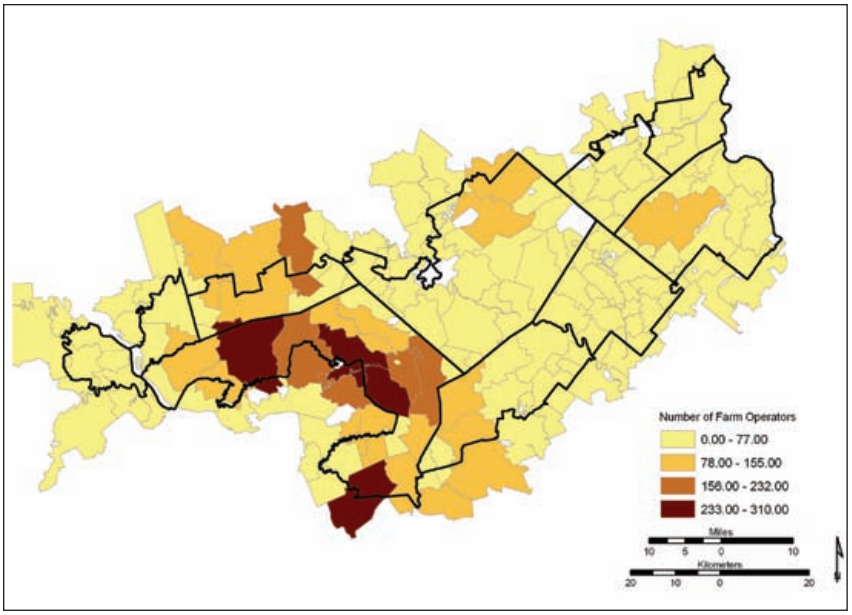


Figure 5-17. *Pennsylvania Highlands: Number of farm operators reporting principal occupation as farming in 2002 by census block.*

Key Survey Findings

Twenty-seven people working in farmland conservation and agriculture in or near the Pennsylvania Highlands were interviewed by telephone to gauge perceptions of agricultural land use in the region. We interviewed 6 farmers, 5 agricultural educators, 9 farm agency personnel and 10 individuals working on agricultural conservation (3 people fall into multiple categories). Eighty-nine percent of respondents perceived agricultural land use on the decline in the Highlands, and thought that this trend would continue at least through the next decade. One hundred percent of those responding perceived that farmland was primarily being lost to housing development.

The loss of farmland was regarded with concern by all respondents. Conversion to developed uses was considered irreversible by respondents, and the loss of farmland is usually accompanied by the loss of a secure local food source, by the loss of the agricultural economic engine, as well as by the loss of the community of agricultural producers and their families. Many indicated that agriculture was central to the culture and identity of eastern Pennsylvania.

Survey respondents overwhelmingly supported the work of the county agricultural preservation programs in the Pennsylvania Highlands. The state is renowned for its agricultural preservation and spends a significant amount annually to buy development rights on prime farmland. The amount spent on farmland preservation varied widely between counties, as did the average price paid per acre for development rights on farmland (Table 5-12). These numbers reflect the supply of prime agricultural land in each county relative to the others. Conservation money is best spent in townships with large, intact agricultural communities rather than in places with just a few farms left. The counties of the Highlands already receive well over half of total allotted state funding for farmland preservation.

Table 5-12 shows the magnitude of investment to date in agricultural land preservation in the Highlands region. The first section shows state spending by county (Commonwealth of Pennsylvania 2007). Notably, 64% of state funding for agricultural land preservation went to the 10

Table 5-12. *Pennsylvania Highlands: Magnitude of investment to date in agricultural land preservation in the Highlands region by county.*

	Berks	Bucks	Chester	Dauphin	Lancaster	Lebanon	Lehigh	Montgomery	Northampton	York
Percent area in Highlands	57.6%	43.8%	28.8%	13.5%	50.8%	35.4%	36.0%	41.8%	28.1%	7.5%
Total state funding for agricultural land preservation in 2006 (millions of $s)	$8.2	$6.5	$8.8	$2.1	$9.3	$2.6	$6.3	$8.1	$6.9	$5.3
Percent of state funding by county in 2006	8.0%	6.4%	8.6%	2.1%	9.1%	2.6%	6.2%	7.9%	6.8%	5.2%
Farms preserved to date	394	85	185	92	464	88	186	99	65	166
Acres preserved to date	44,858	8,044	17,163	9,337	41,311	10,635	15,920	6,662	7,804	29,262
Total expenditures to date (millions of $s)	$87.7	$65.4	$80.6	$12.5	$95.6	$15.7	$40.0	$52.2	$24.0	$41.9
Average price of easement per acre	$1,955	$8,132	$4,695	$1,343	$2,315	$1,481	$2,514	$7,831	$3,078	$1,432
Farmland acres within Highlands in active agricultural use 2002,	106,894	27,370	40,356	10,727	185,304	39,518	27,042	15,807	19,087	17,925
Farmland acres within Highlands in active agricultural use 1997	120,496	35,008	47,324	10,928	195,413	37,881	30,966	17,204	21,483	18,259
Percent change in farmland acres within Highlands, 1997 to 2003	-11.3%	-21.8%	-14.7%	-1.8%	-5.2%	4.3%	-12.7%	-8.1%	-11.2%	-1.8%
Total change in farmland acres within Highlands, 1997 to 2002	-13,602	-7,638	-6,967	-201	-10,109	1,638	-3,924	-1,396	-2,396	-334
Acres preserved under agricultural preservation programs in Highlands	18,293	3,870	7,350	649	28,228	7,286	3,623	6,199	142	2,397
Average acres of property preserved under agricultural preservation programs in Highlands	46	38	51	59	46	82	66	58	71	40

Farmland preservation statistics from http://www.agriculture.state.pa.us/agriculture/cwp/view.asp?a=3&q=128824

Farmland acres estimated from county totals reported by the USDA, 2002 Census of Agriculture. Data available at http://www.nass.usda.gov/census/census02/volume1/pa/st42_2_008_008.pdf

Parcel number and size statistics from preserved land GIS layer prepared for this study.
Note: Complete information was not available for Bucks County.

Highlands counties (including parts of the counties that are outside the Highlands boundary). The most money went to Lancaster County, which holds the most preserved farms of all the Highlands counties. Berks County has preserved the most total acreage, and has done so at a lower cost than Lancaster County. Montgomery County has spent heavily on agricultural easements on a per acre basis and as a percentage of state funding, but ranks at the bottom of total preserved acres and near the bottom for total preserved farms. This may be due to differences in land values within the region, or it could be an indicator of efficiency of conservation spending.

The majority of the conservation work is being done in the counties with the most farmland, led by Lancaster and Berks counties (Figure 5-18). Despite the gains made in conservation, Berks County still lost active farmland at a rate of 11.3% between 1997 and 2002, the second highest rate of loss. By comparison, Lancaster County lost only 5.2% of its farmland during the same time period, despite similar size and spending on agricultural conservation.

The final two rows in Table 5-12 were derived from spatial data provided largely by the county agricultural preservation agencies, showing properties conserved under their programs.[12] The statistics are provided for comparison with the county-wide data.

12 Bucks County did not provide data on preserved agricultural lands. The Bucks County data shown in Table5-12 and Figure 5-18 are from 1999.

Most of the survey respondents indicated that a shortage of funds was limiting the ability of the boards to meet farmer demand for agricultural land preservation. The Highlands counties are generally able to provide funding for less than half of the farms that apply to sell their development rights annually. Respondents indicated that for some Highlands counties less than 10% of the farms applying for the farmland conservation program were being accepted each year, largely due to budget constraints.

Several survey respondents expressed concern over the impact of the agricultural land conservation program. Widespread conservation and strong agricultural zoning laws in some counties are causing homebuilders and buyers to look further into rural areas for developable land, increasing the pressure on farmland there. Finally, several respondents pointed out that land conservation was only part of the solution. Healthy markets for transportation, processing and other services farmers rely upon help to keep farm costs down. Better access to east coast markets for farm products through marketing and transport cooperatives could provide the next generation with enough cash flow to survive.

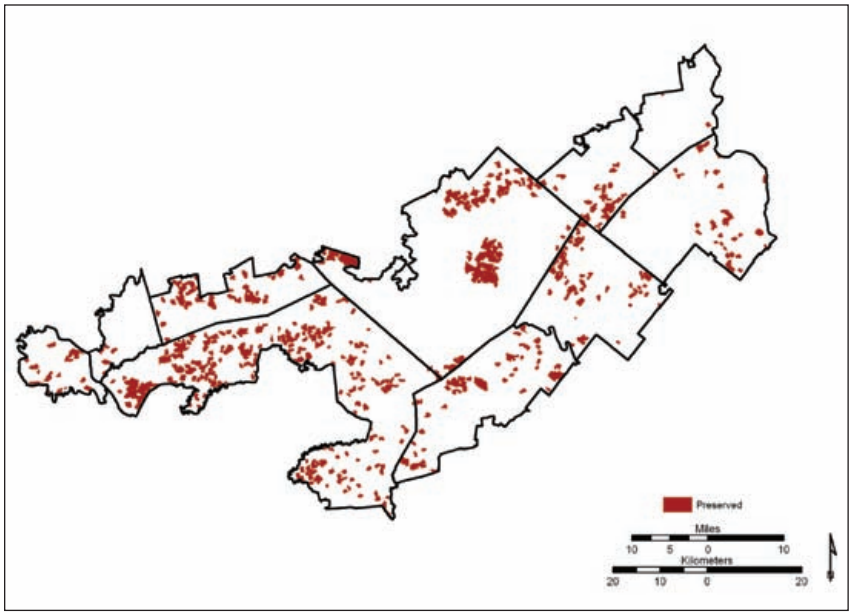


Figure 5-18. *Pennsylvania Highlands: Preserved agricultural land. Sources: Agricultural Land Preservation Programs of Montgomery, Chester, Berks, Lancaster, Lebonanon, Lehigh, Dauphin, Northampton and York Counties; and Natural Lands Trust.*

Planning and zoning capacity varies widely among townships, and reflects the level of organization of the municipal government, the tax income, and the political climate within the municipality. Survey respondents from the agricultural land conservation community indicated that cooperation and synergy between municipal governments, farmers and the county were critical for effective conservation. Without county Purchase of Development Rights (PDR) programs, zoning laws that prohibit residential development on farmland are often perceived as regulatory takings by landowners. Land is an important asset to farmers, who often have very little cash savings but rely on the eventual sale of land for retirement. And without zoning laws farmers have less incentive to agree to a PDR deal with the county. To encourage municipalities to enact agricultural zoning, the county agricultural preservation programs value farmland within agricultural zones more highly than farmland outside of agricultural zoning. This factor, as well as the variability in soil quality within the Highlands has led to the current clumped distribution of preserved farmland.

The wide disparity between counties in farmland preservation is reflected in the numbers shown in Table 5-12. Lancaster County has many square miles of good farmland in the Highlands as well as a strong agricultural land preservation program, and therefore has the most total number of acres preserved and the most properties preserved compared to other county programs. However, Lancaster County's average property size is one of the lowest. As the largest farms are preserved, county agricultural preservation boards may need to turn their attention to preserving small and medium sized farms to secure the agricultural land base. This trend is likely to be seen among all the other counties in the next decade.

CHAPTER 6 ZONING BUILD-OUT ANALYSIS

Key Findings

Connecticut

- Eighty-seven percent of the Connecticut Highlands is zoned for residential use, mostly in one to two-acre lots.
- Total developable land is 230,148 acres under a *low environmental constraints* scenario and 164,453 acres under a *high environmental constraints* scenario.
- The *low constraints* scenario, representing a low standard for protecting environmentally sensitive areas, would increase housing in the region by 135% and population by 132%.
- The *high constraints* scenario, representing a high standard for protecting environmentally sensitive areas, would increase housing in the region by 96% and population by 94%.

Pennsylvania

- Fifty-two percent of the Pennsylvania Highlands is zoned for residential use, mostly in one- to two-acre lots. An additional 25% is zoned for agriculture, which allows for single family housing.
- Total developable land is 596,207 acres under a *low environmental constraints* scenario and 498,401 acres under a *high environmental constraints* scenario.
- The *low constraints* scenario, representing a low standard for protecting environmentally sensitive areas, would increase housing in the region by 108% and population by 115%.
- The *high constraints* scenario, representing a high standard for protecting environmentally sensitive areas, would increase housing in the region by 93% and population by 102%.

Introduction

A build-out analysis was conducted to evaluate potential residential growth based on municipal zoning regulations for the Pennsylvania and Connecticut Highlands. The intention was to (1) present a picture of the current built environment and potential growth trends under existing zoning regulations for the municipalities within the region, and (2) provide information about how well current municipal zoning regulations fit with larger regional or state plans for the Highlands region. The former will be accomplished using geographic information system (GIS) tools, and the latter, by reviewing the build-out analysis results with the Connecticut State Conservation and Economic Development Plan and existing Pennsylvania County Comprehensive Plans.

The build-out analysis offers a broad overview of a locality's development potential; it helps determine how much development can occur and at what densities, as well as resulting consequences of the complete build-out of a region. Zoning-based build-out analyses are used to derive the best possible estimate of the extent and configuration of future land use if all developable lands are built upon. Such a state of development is considered a "worst case" scenario. If the outcome of the analysis is not amenable to the stakeholders, there are preventative measures or conservation strategies that can be implemented to ensure it does not become a reality. Most often, a second scenario is conducted in tandem to demonstrate the land conservation approach. This scenario focuses on preserving important natural areas, building away from wetlands, floodplains and riparian corridors, and allows for more compact conservation-oriented development patterns. It is important to note that the build-out analysis makes some assumptions about events that may or

may not take place, one of which is that all current land-owners will sell every bit of their buildable land for residential purposes.

In combination, these methods have been proven, through their implementation in many other regions, to be a useful planning tool by helping planners better understand what factors affect build-out, the range of development possibilities, and the possible consequences of not taking appropriate action in a timely fashion.

he scale upon which a build-out analysis is based varies by project. For example, a build-out analysis can focus on the more general satellite-derived urban extent of a region, or it can examine very specific change on the level of sites within a tax parcel. The appropriateness of the scale of the build-out analysis is dictated by both the goals of the project and type of data available. The zoning build-out can be used to determine the maximum number of new residential, commercial and industrial buildings allowed in a zoning district based on current zoning regulations. It should be noted that build-out analyses do not predict when build-out will occur, but rather how it can occur under a given set of conditions.

Methods – Identifying Areas Available for New Residential Development

Zoning ordinances establish land use regulations, including the type of development allowed in each zoning district as seen in Figures 6-1 and 6-2 (*i.e.,* residential, commercial, industrial etc.) and the density of that development. For this analysis, we were concerned with only those regulations applicable to new single family detached residential development. Locations having the potential to be residentially developed were identified through an analysis of municipal zoning maps and ordinances. The analysis was conducted for 25 of the 28 municipalities in the Connecticut Highlands and 154 of the 179 municipalities in the Pennsylvania Highlands. Some municipalities had to be excluded because they either do not have specific zoning regulations, or the information was not available.

Among the zoning districts there was a wide range of descriptions for the residential zoning categories (*i.e.,* rural residential, suburban residential, neighborhood residential, etc). We developed a single zoning district map for each region based on each zoning district's as-of-right single family lot requirement for a minimum lot size. For those zoning districts, we extracted from the zoning regulations the area allotted for single family residential development and the allowable minimum residential lot size (Figures 6-3 and 6-4). Throughout the Highlands region there exists a wide range of residential lot sizes from 1/10th of an acre (5,000 sq ft) to 10 acres.

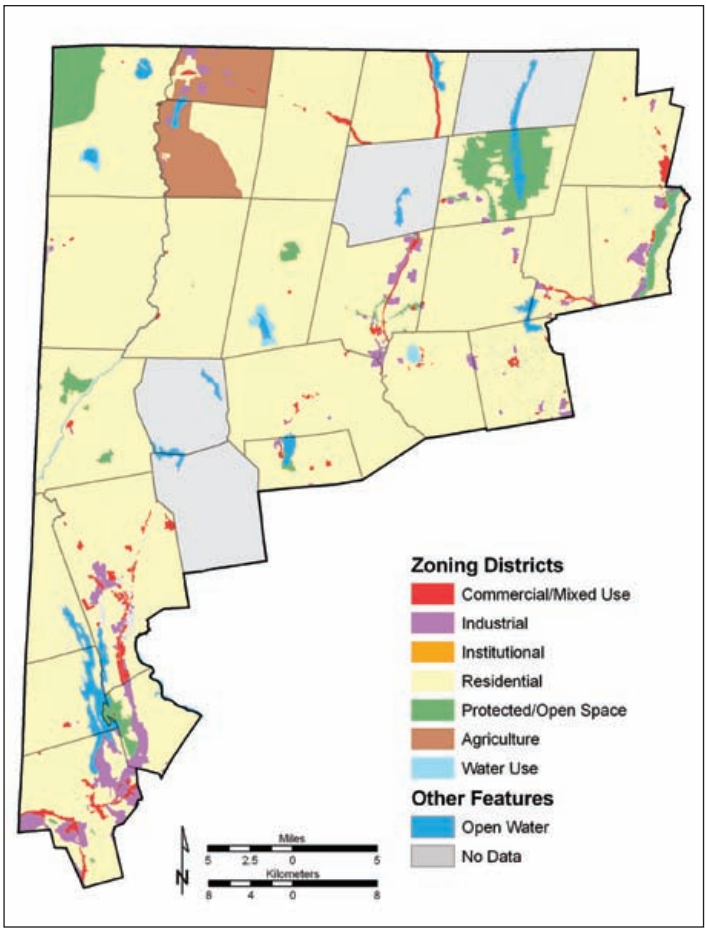


Figure 6-1. *Connecticut Highlands: Generalized land use by zoning districts.*

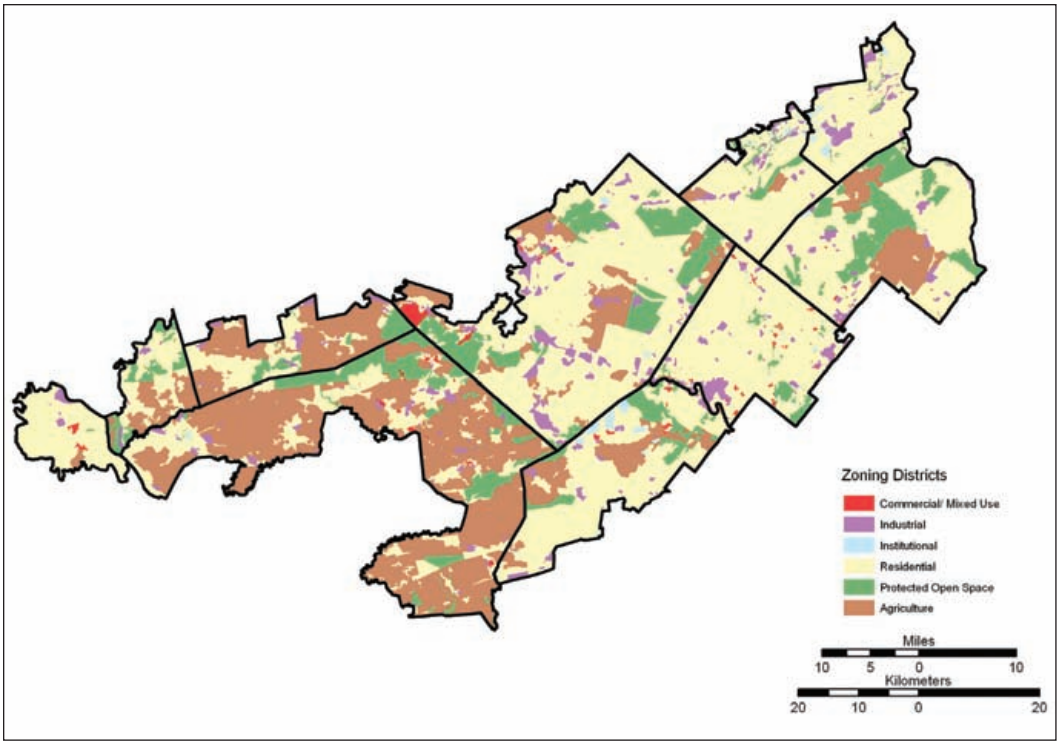


Figure 6-2. *Pennsylvania Highlands: Generalized land use by zoning districts.*

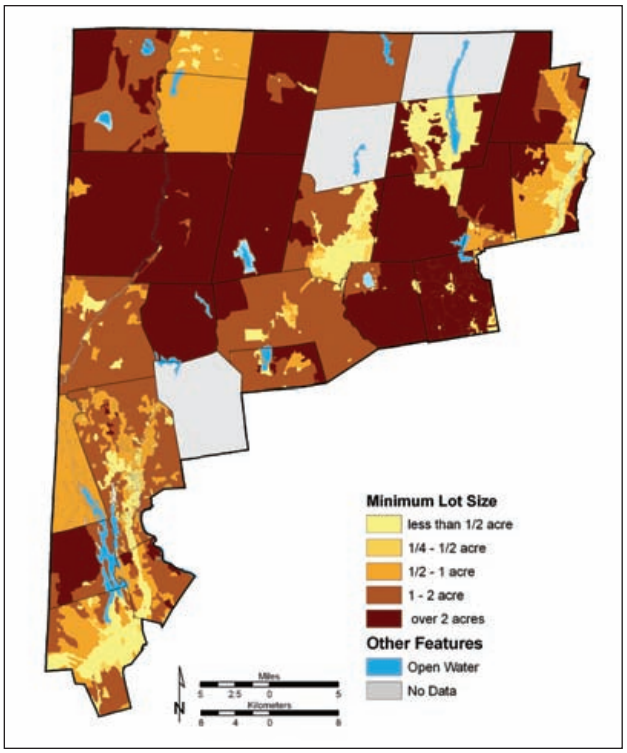


Figure 6-3. *Connecticut Highlands: Minimum allowable lot size within zoning districts.*

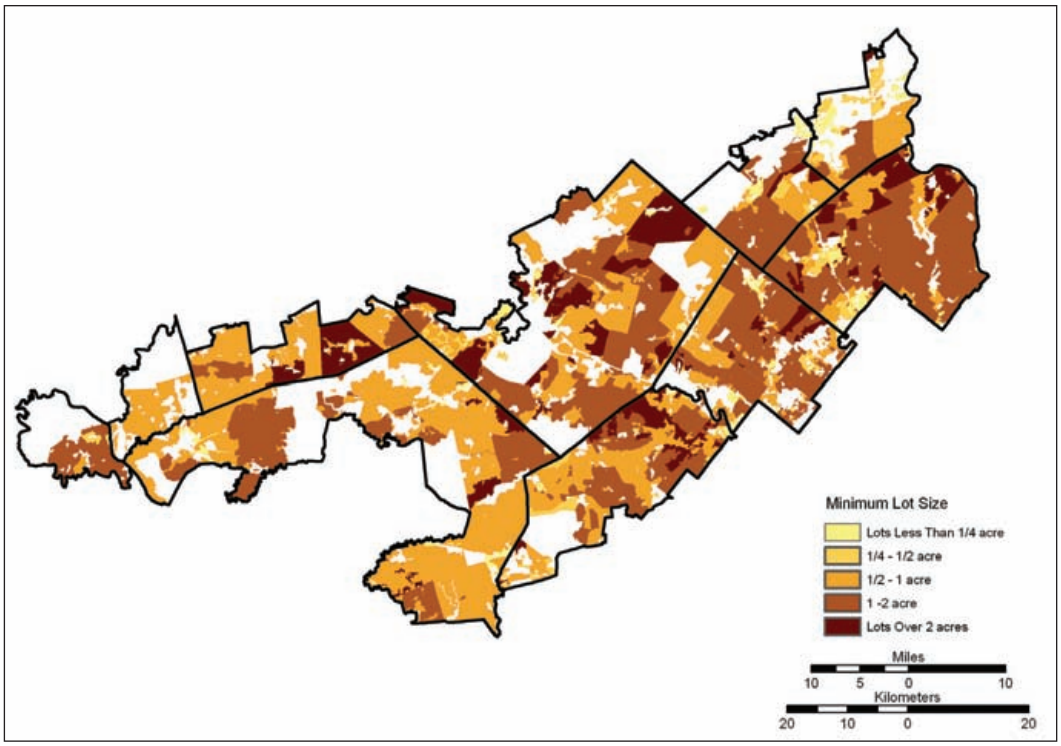


Figure 6-4. *Pennsylvania Highlands: Minimum allowable lot size within zoning districts.*

The next step was to identify areas that are not available for new development either because they were already developed, or were conserved from development through a conservation easement or public ownership. Already developed land was identified using the 2002 Connecticut Land Cover Change Maps (CLEAR) for Connecticut and the 2001 National Land Cover Dataset Change Product for Pennsylvania. Conserved lands were identified with the conserved lands GIS layers prepared for this study.

Connecticut Zoning Districts

As of 2000, roughly 87% of the Connecticut Highlands is zoned for residential use (Table 6-1). Although only 5% of the Connecticut Highlands is zoned as protected open space/outdoor recreation, 24% of the region is currently conserved as protected open space. Agricultural districts comprise only 4% of the area.

In the Connecticut Highlands it was determined that residential development could take place in the residential, agricultural, and mixed use zoning districts which comprise 91.5% of the study area. The Connecticut Highlands is almost completely zoned (97%) for large lot residential use. As can be seen in Figure 6-5, most of the land is zoned for 1 to 2 acre lots. Figure 6-6 depicts typical 1 to 2 acre lot sizes being developed in the region.

Table 6-1. *Connecticut Highlands: Summary of zoning district types.*

Connecticut Zoning Districts	% Study Area
Residential	87%
Open Space/Outdoor Recreation	5%
Agriculture	4%
Industrial	3%
Commercial/Mixed Use	1%

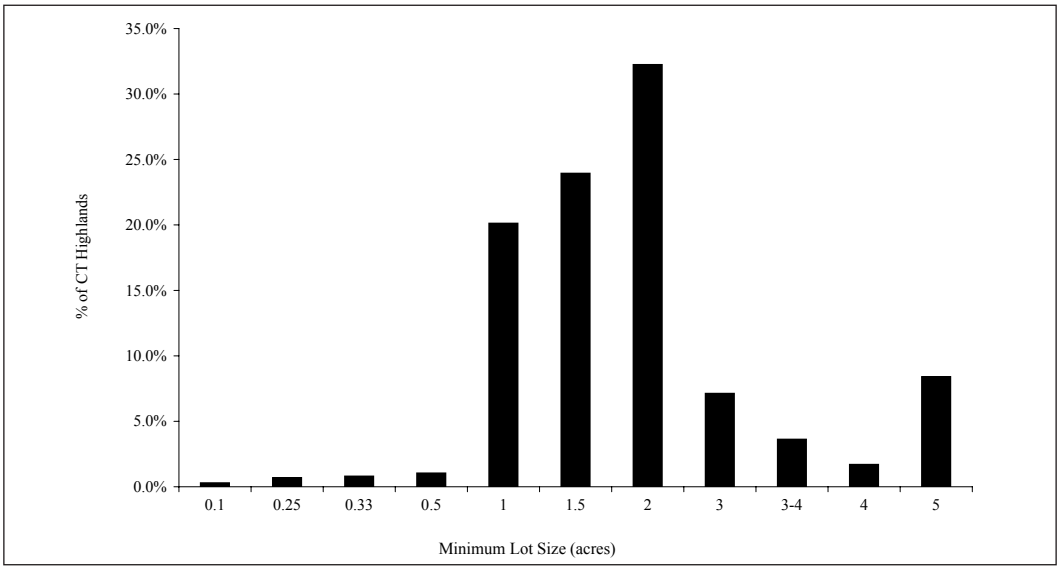


Figure 6-5. *Connecticut Highlands: Percentage of Highlands area by minimum allowable lot size across all zoning districts.*

Figure 6-6. *Connecticut Highlands: Aerial photo of residential development.*

Pennsylvania Zoning Districts

Currently, 52% of the Pennsylvania Highlands is zoned for residential use (Table 6-2 and Figure 6-7). An additional 25% is zoned for agricultural use, which allows for single family housing. Therefore it is considered residentially developable in this study. Thirteen percent of the land is zoned as protected open space. At least 16% is currently in protected open space either through conservation easements or by virtue of being in public ownership.

Table 6-2. *Pennsylvania Highlands: Distribution of zoning district types.*

Pennsylvania Zoning Districts	% Study Area
Residential	52%
Agriculture	25%
Protected Open Space	13%
Commercial/Mixed Use	5%
Industrial	5%
Institutional	1%

Residential development can take place in the residential, agricultural, and mixed use zoning districts which comprise 78% of the study area. As can be seen in Figure 6-7, most of the land is zoned for 1 to 2 acre lots. Figure 6-8 depicts the range of 1 acre to 5 acre lot sizes being constructed in the residential districts in Bucks County. Figure 6-9 depicts the more compact new development being constructed in the agricultural districts of Lancaster County.

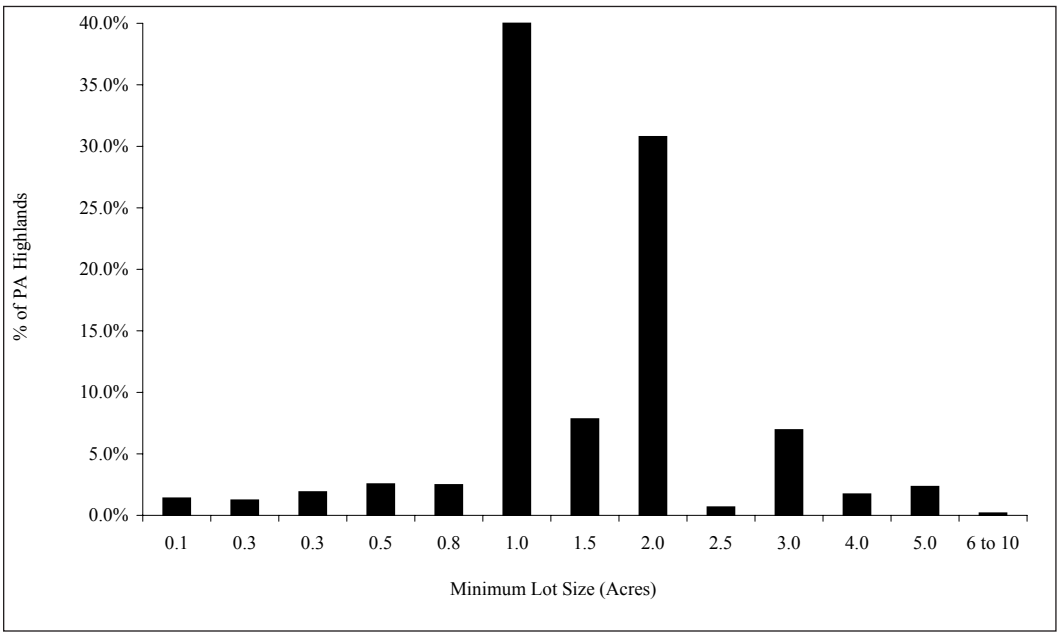


Figure 6-7. *Pennsylvania Highlands: Percentage of Highlands area by minimum allowable lot size across all zoning districts.*

Figure 6-8. *Pennsylvania Highlands: Aerial photo of residential development in Bucks County.*

Figure 6-9. *Pennsylvania Highlands: Aerial photo of development on agricultural land in Lancaster County.*

Constraints on Development

The build-out analysis was done under two conditions that are referred to as *low constraints* and *high constraints*, meaning constraints to development in order to preserve environmental or conservation values. The only legal constraints to development are permanently protected open space, and federal wetlands regulations. However, most municipalities within the region have zoning guidelines for protection of sensitive environmental areas, particularly riparian areas, wetlands, and steep slopes. These *constraints* to development are imposed by a permit process whereby all new development must be reviewed by the local planning board. In the Highlands, these constraints are not typically written into zoning regulations, or if they are, they are considered guidelines, not hard and fast restrictions.

In order to determine what parameters to use for the high and low constraint scenarios, the project teams held two stakeholder meetings, one in each region, to review current practices (low) and get agreement on what would be considered environmental and conservation best practices (high) for protecting environmentally sensitive areas. The *low constraints* scenario is pretty much business as usual, with minimal restrictions on development. The *high constraints* scenario is presented as a high standard for protecting environmentally sensitive areas.

The environmental constraints layer includes the following five features: protected open space, which includes private or public conservation ownership and easements; water bodies and riparian buffers; floodways and 100-year floodplains; wetlands, wetland buffers, and hydric soils; and steep slopes (Table 6-3).

Table 6-3. *Constraints to development assumed in low and high scenarios. *See Appendices 6 (Connecticut) and 7 (Pennsylvania) for complete description of sources.*

Constraint	Low Constraint Scenario (Minimum Conservation)	High Constraint Scenario (Best Practice)	Source*
Protected Lands	Protected open space	Protected open space	PA/CT compiled by Yale University
Waterbodies	Waterbodies	Waterbodies	CT DEP GIS PASDA
Floodplains	FEMA floodway	FEMA 100yr floodplain	FEMA
Riparian Buffer	None	100ft riparian buffer	CT DEP GIS PASDA
Wetlands	All NWI + hydric soils	All NWI + hydric soils	USWFS NWI USDA SSURGO
Wetland Buffer	None	50ft wetland/ hydric soil buffer	US FWS
Steep Slopes	Greater than 25%	Greater than 15%	USGS NED

The zoning build-out analysis essentially looks at land that is available for development and projects how much development can occur on that land under current zoning regulations. Figure 6-10 shows the amount of land in each region that is not available for new development, either because it is already developed, or is constrained from development due to legal protection or environmental constraints.

Connecticut has 20% more of its developable land constrained under both scenarios than Pennsylvania. This is because Connecticut has more steep slopes and hydric soils, and more land in protected open space (Figures 6-11 and 6-12). Under the low constraint scenario, about 40% of the land in the Connecticut Highlands is available for new development. Under a high constraint scenario, this drops to 29%, mainly because of additional restrictions on building on steep slopes. In Pennsylvania, approximately 51% of the land is available for new development under the low constraint scenario. This drops to 42% under the high constraint scenario.

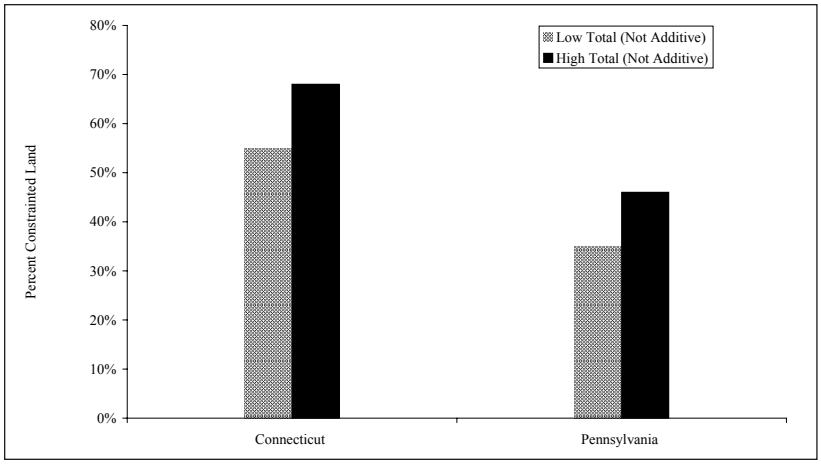


Figure 6-10. *Percent of Connecticut and Pennsylvania Highlands within constrained lands.*

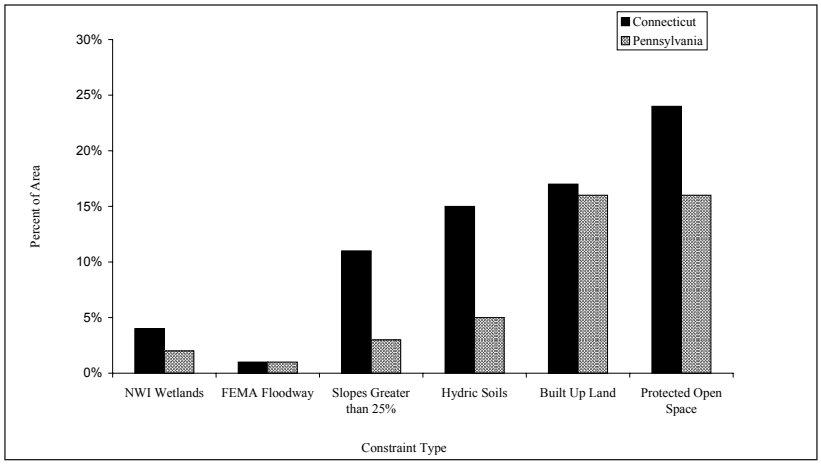


Figure 6-11. *Percent of Connecticut and Pennsylvania Highlands within each constraint type in* low constraint *scenario.*

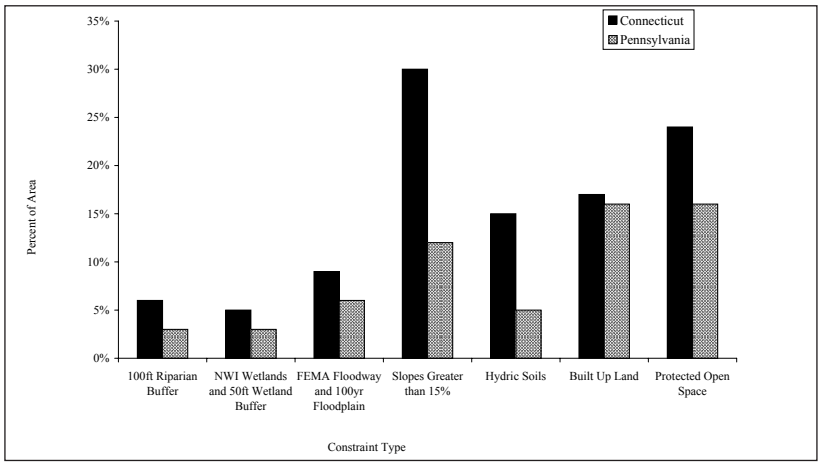


Figure 6-12. *Percent of Connecticut and Pennsylvania Highlands within each constraint type in* high constraint *scenario.*

Methods - Residential Zoning Build-Out

The residential build-out analysis was conducted using ArcGIS 9.2 GIS software. The build-out is restricted to zoning districts, which means parcel data were not examined for this study. The data were prepared by developing a *zoning district minimum lot size* layer, developed first as a vector-based file, and then converted into a raster (GRID format) to match the constraints data.

All areas that cannot be developed were removed by eliminating from the *zoning district minimum lot size* layer all areas within the *low* and *high constraint* maps. This produced two separate *zoning build-out* raster layers for each region: (1) *low constrained zoning build-out* and (2) *high constrained zoning build-out*.

Next, these two layers, *low* and *high constrained zoning build-out*, were combined with a map of municipalities. This generated a unique *municipal zoning district* dataset for both the *low* and *high constraints*. The two new datasets maintain two important attributes for each cell in the raster: (1) minimum lot sizes per zoning district and (2) the town in which the zoning districts are located.

The *low* and *high constrained zoning build-out* grid layers were converted to vector layer. This step merged adjacent cells (king's rule) within the same zoning district and municipalities into a single polygon within the vector layer. The perimeter and area of each polygon were then calculated. The area of each polygon was multiplied by a factor of 0.85 to account for areas within the polygons that are streets or utilities.[13] The total developable acreage per zoning district was then extracted from these corrected area values.

The final steps were to calculate the number of new dwelling units and residents per polygon. The number of new dwelling units was calculated by dividing the developable land per polygon by the minimum lot size in that zoning district.

To calculate the number of new residents, we multiplied by the average residents per housing unit in each municipality recorded in the 2000 US Census. In the Connecticut Highlands, the average number of residents per housing unit was 2.5 and in the Pennsylvania Highlands it was 2.6. For individual municipality multipliers see Appendix 3.

Methods - Calculating Impervious Surface

For the water resource analysis,[14] the USGS required data on the total new acres of impervious surface under the full zoning build-out. To obtain the new acres of impervious surface we used the existing impervious surface data and the housing census data to calculate the relationship between housing unit density and impervious surface. Existing impervious surface data were extracted from the NLCD 2001 percent impervious surface map, for those cells within zoning districts that allowed housing units (residential, agricultural, and mixed-use districts). The number of residential dwelling units was extracted from the 2000 US Census Tract data. We plotted mean percent impervious surface as a function of dwelling units per acre at the tract-level and derived the relation between the two using simple linear regression (Figures 6-13 and 6-14).

We then used the inverse of the minimum lot size per zoning district to represent dwelling units per acre at build-out. This value for each zoning district was used as input to the regression equations. For each zoning district, the mean percent impervious surface was then multiplied by the total acres of developable land within the district.

13 The 0.85 factor comes from the town of Charlton, NY Build-Out Analysis conducted by Community Planning and Environmental Associates http://www.townofcharlton.org/C_Plan/buildout.html.

14 The Connecticut and Pennsylvania Highlands Water Resources Analysis was conducted by the US Geological Survey and is available as a separate technical report.

Connecticut regression equation:

Mean % Impervious Surface Coverage = 16.061 + 7.8665*(dwelling units/acre)

Pennsylvania regression equation:

Mean % Impervious Surface Coverage = 25.427 + 3.9545*(dwelling units/acre)

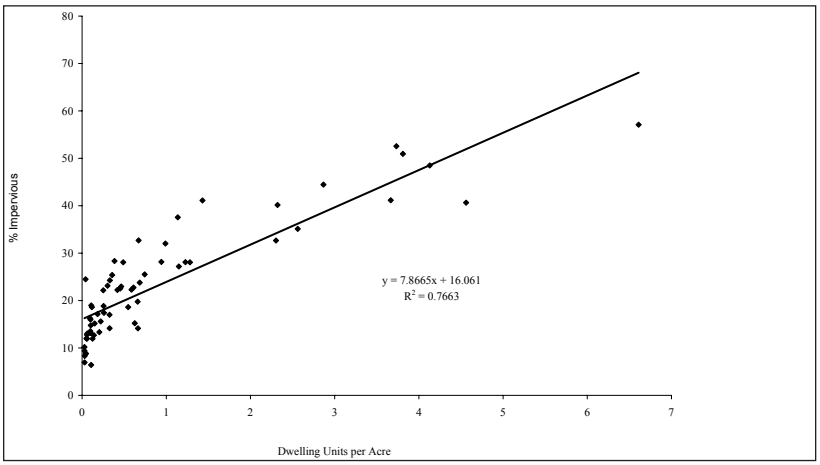


Figure 6-13. *Connecticut Highlands: Relation of mean percent impervious surface as a function of dwelling units/acre based on NLCD 2001 percent impervious surface map and 2000 US Census tracts.*

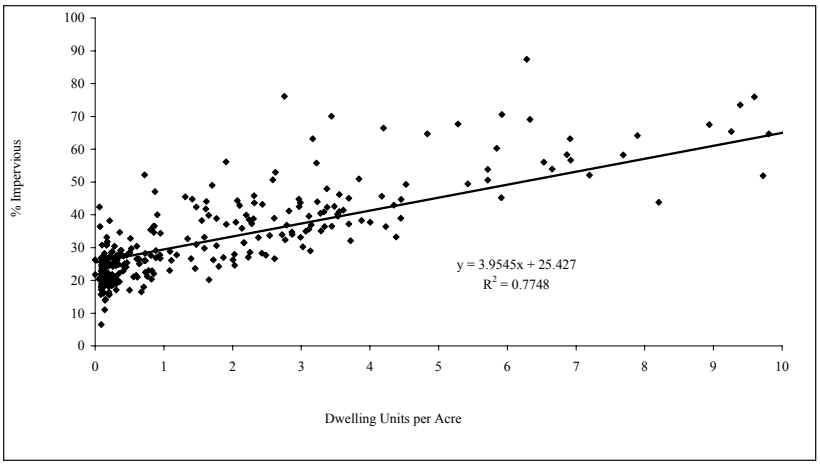


Figure 6-14. *Pennsylvania Highlands: Relation of mean percent impervious surface as a function of dwelling units/acre based on NLCD 2001 percent impervious surface map and 2000 US Census tracts.*

Build-out Results – Connecticut

Total developable land under the *low constraints* scenario is approximately 230,148 acres. The build-out analysis yields 148,602 new single family residential units and 376,560 new residents based on current average persons per housing unit across the Connecticut Highlands. This is 42,917 more single-family residences than under the high constraints, or the best management practices, scenario. This would create 48,016 additional acres of impervious surface. (Table 6-4)

Total developable land under the *high constraints* scenario is approximately 164,453 acres. The build-out analysis yields 105,685 new single family residential units and 268,158 new residents based on current average persons per housing unit across the Connecticut Highlands. This would create 33,872 additional acres of impervious surface.

Table 6-4. *Connecticut Highlands: Zoning build-out results.*

	Low Constraints	High Constraints
Buildable Acres	230,147	230,147
Single Family Dwelling Units		
Actual 2000	109,766	109,766
Additional under Zoning Build-Out	148,602	105,685
% New Units	135%	96%
Residents		
Actual 2000	285,730	285,730
Additional under Zoning Build-Out	376,560	268,158
% New Residents	132%	94%
Impervious Surface (acres)		
Actual 2001	16,333	16,333
Additional under Zoning Build-Out	41,754	27,860
% New Impervious Surface	256%	171%

Build-out Results – Pennsylvania

The low constraints build-out analysis for Pennsylvania yields 499,677 new single family residential units and 1.39 million new residents based on current municipal average persons per housing unit across the Pennsylvania Highlands. This would create 161,136 additional acres of impervious surface (Table 6-5). There were a total of 26,006 polygons in the final *low constraints* scenario, which is a rough estimate of new parcels.

The *high constraints* build-out analysis for Pennsylvania yields 431,621 new single family residential units and 1.2 million new residents based on current municipal average persons per housing unit across the Pennsylvania Highlands. This would create 142,259 additional acres of impervious surface. There were 35,544 more polygons under this best practices scenario.

Results vary widely by county, a reflection of the amount of land available for development. For example, Lebanon and Lancaster counties still have a lot of farmland as compared to the portion of Lehigh County that is in the Highlands, which is more developed (Figures 6-15 and 6-16).

Table 6-5. *Pennsylvania Highlands: Zoning build-out results.*

	Low Constraints	High Constraints
Buildable Acres	596,207	498,401
Single Family Dwelling Units		
Actual 2000	461,833	461,833
Additional under Zoning Build-Out	499,677	431,621
% New Units	108%	93%
Residents		
Actual 2000	1,216,725	1,216,725
Additional under Zoning Build-Out	1,393,741	1,241,952
% New Residents	115%	102%
Impervious Surface (acres)		
Actual 2001	68,790	68,790
Additional under Zoning Build-Out	161,136	138,378
% New Impervious Surface	234%	201%

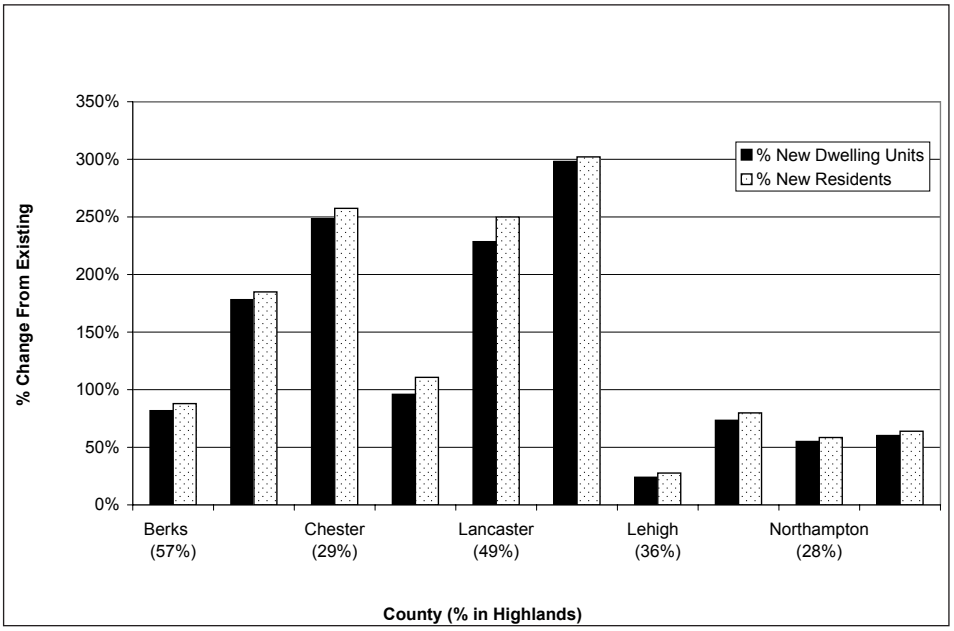


Figure 6-15. *Pennsylvania Highlands: New units and population proteectioin under* low constraints.

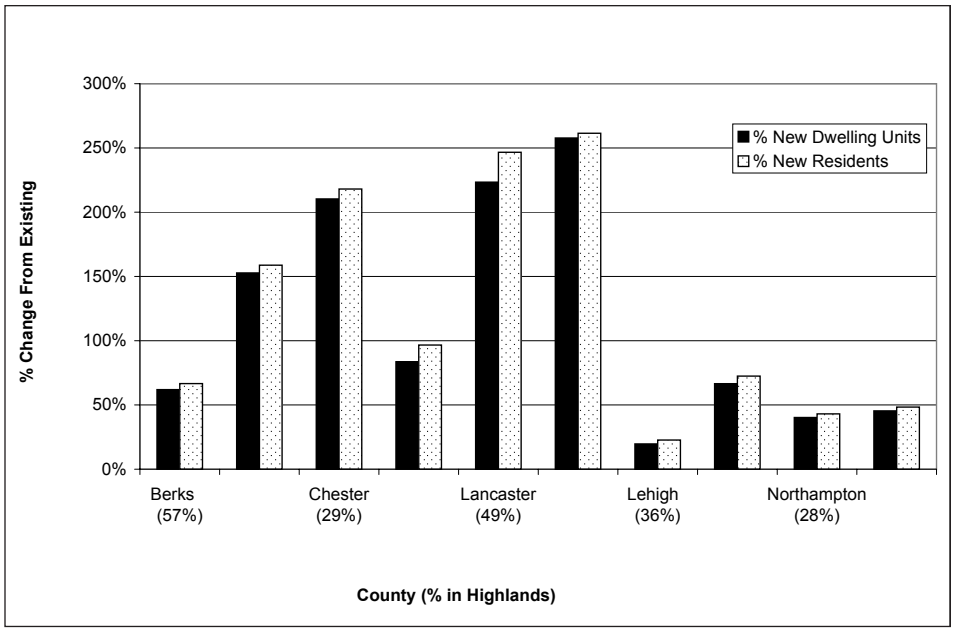


Figure 6-16. *Pennsylvania Highlands: New units and population proteectioin under* high constraints.

Implications

Connecticut

This analysis shows that under the *low constraints* build-out scenario, 376,560 potential new residents could reside in the Connecticut Highlands region with 148,602 new single family homes, consuming 230,148 acres. The *high constraints* build-out scenario, the conservation oriented development approach, will result in 108,402 fewer residents moving into the Highlands region, with 42,917 fewer homes, consuming 65,694 fewer acres of land. This 29% reduction in built land will preserve the most environmentally sensitive land in the Connecticut Highlands.

The State of Connecticut has adopted a comprehensive conservation and development plan that lays out explicit goals and objectives for future land use (State of Connecticut undated). There is an emphasis on the conservation of open space and the clustering of new development near existing transportation nodes. A stated goal is to have at least 10% of Connecticut's land area (320,576 acres) owned by the state as permanently protected open space as well as an additional 11% (352,634 acres) owned by municipalities and non-profits. This would result in 21% of the state's land being preserved as protected open space.

The highest priority land identified for conservation in the Connecticut State Conservation and Economic Development Plan shares many of the same characteristics as the land excluded by the constraints in the *high constraints* build-out scenario in this analysis. The plan calls for conserving 100-year floodplains, tidal and inland wetlands, and habitats for endangered or threaten species. The 65,694 acres not developed under the *high constraints* build-out scenario includes land in the 100-year floodplain, land on steep slopes, land within 50 feet of a wetland, and land within 100 feet of a river. This is 9% of the total land area of the Highlands.

Pennsylvania

The *high constraints* residential build-out scenario will result in 97,806 fewer acres of development than under the *low constraints* build-out. This represents 7% of the total land area in the Pennsylvania Highlands that potentially can be converted to permanently protected open space. This additional 4% (under *high* vs. *low constraints*) includes steep slopes, the 100-year flood plain, wetlands and land within 100 feet of rivers. Conservation of these lands, although only 4% of the total area, will conserve the most environmentally sensitive areas of the Highlands and bring the land use policies in these Pennsylvania counties closer to the stated goals contained within their respective plans.

Several of the counties within the Pennsylvania Highlands have area wide plans that set out a preferred vision for future land use. In aggregate, these plans place an emphasis on preservation of open space and farmland. The plans of Lehigh and Northampton go further and emphasize the preservation of floodplains and wetlands, and minimizing environmental impacts of development on steep slopes. The goals set forth by these plans are consistent with the *high constraints* build out scenario.

However, the current zoning in many areas is not consistent with this land conservation approach. In Lehigh and Northampton counties roughly 75% of the total land area that is located within the Highlands is currently zoned residential, with only 7% and 2% designated as protected open space respectively. Given that the Highlands is a high priority conservation area, this zoning is not compatible with the stated goals of these county plans. The counties of Berks and Bucks have more than 50% of the land within the Highlands zoned residential, and nearly 80% of land in Montgomery county is zoned residential. If the "business as usual" approach is to be avoided, policies must be put in place to make the goals of the county plans a reality.

Conclusion

With continued growth emanating from the urban centers of the region and encroaching on the Highlands themselves, natural environments crucial to the well-being of all those who live in the region are increasingly threatened. Build-out analyses are helpful tools to predict growth and plan for potential adverse impacts. The build-out scenarios for the Connecticut and Pennsylvania Highlands demonstrate that the current zoning is inadequate to preserve the natural landscape. Even with the *high constraint* build-out scenario, which allows for compact conservation-oriented development patterns, large amounts of the Highlands could be developed into single family residential housing. In order to meet the goals set forth in the Connecticut State Plan and numerous Pennsylvania County plans, conservation must surpass that of the *high constraint* build-out scenario.

CHAPTER 7 ANALYSIS OF LAND USE / LAND COVER

Key Findings

Connecticut

- The Connecticut Highlands are predominantly forest (67 percent); 6 percent is in active agricultural fields; and 18 percent is developed.
- Developed land use increased by 25,000 acres (26%) between 1985 and 2002; 60% of the development occurred between 1985 and 1990.
- Developed land use has increased at more than double the rate of population and housing growth.
- Development has affected both forests and farmlands, about equally.
- Development tended to occur near larger towns and main roads.

Pennsylvania

- The Pennsylvania Highlands is changing from an agricultural/pastoral landscape to one where development, agriculture, and forestland are interspersed. About one-third of the land is in agricultural fields; a third is in forest or wetlands; a third is developed/grass/turf.
- We estimate that total developed land use increased by 43,900 acres (12%) between 1992 and 2001.
- Development is occurring more rapidly and to a greater extent in Northampton, Lehigh and Dauphin counties and along route 422 in Berks and Montgomery counties. In general, this development occurs near roads and previously developed areas.
- Housing and population grew faster than developed land use from 1992 to 2001.
- Development has occurred mostly on farmland.

Introduction

The goal of the land use/land cover analysis (LULC) was to quantify development growth trends in the Connecticut and Pennsylvania Highlands over time. LULC trends were analyzed using available data derived from satellite imagery. For Connecticut, we used the 1985, 1990, 1995, 2002 time series produced by the University of Connecticut's Center for Land use Education And Research (CLEAR). In Pennsylvania we did not have the good fortune to have a time-series such as the one for Connecticut, or the one that was developed for the New York-New Jersey study. However, we did have access to the US Geological Survey's new 1992-2001 Land Cover Change Product derived from both the 1992 and 2001 NLCD (National Land Cover Data), and additional 1992 imagery in order to detect change.

To capture all of the major trends we quantified five different transitions in land cover. These trajectories of change include *agriculture* to *developed*; *agriculture* transitioning back to *forest*; *forest* to *agriculture*; *forest* to *developed*; and *wetlands* to *developed* land.

Sometimes there is confusion about the terms land *use* and land *cover*, and they are often mistakenly used interchangeably. In this study we analyzed changes in land *cover*, by virtue of the nature of the data we had to work with, which is essentially land *cover* derived from satellite imagery according to scientific techniques used for converting spectral reflectances into a classification such as *forest, agriculture, urban, etc.*. Land *cover* classification is often the same as land *use* (*e.g.,* forest). However, some types of similar land *cover*, especially grasses, can be in different *uses* (*e.g.,* pasture,

lawn, golf course) and this *use* is difficult to detect from satellite imagery. Another difficulty is distinguishing between forest and low density residential in rural areas. Because of the resolution at which the original reflectances are captured by the satellite sensors (30 meters), a suburban backyard with trees will be classified as forest. And it is difficult to distinguish structures beneath trees in low-density residential areas from satellite imagery, so they are often classified as forest. Strictly speaking, the land *cover* in these instances is trees (forest), but the land *use* is low-density residential/developed. Nevertheless, the common term used throughout the literature is land use/land cover (LULC), which we will use in this report.

Connecticut Methods

We derived the amount and pattern of land use change over 17 years from a land cover time series (1985, 1990, 1995 and 2002) created by CLEAR (Figure 7-1). Each of these maps consists of 11 classes of land cover information as follows: *development, turf & grass, other grasses & agriculture, deciduous forest, coniferous forest, water, non-forested wetlands, forested wetlands, tidal wetlands, barren and utility right-of-way* (definitions found in Appendix 6).

An accuracy assessment using all 11 classes, performed by CLEAR (James Hurd, personal communication) resulted in overall classification accuracies of 86%, 85%, 88%, and 82% for years 1985, 1990, 1995, and 2002, respectively (Appendix 6). More importantly, since we are modeling spread of development, the user's accuracies for development were 90%, 93%, 93%, and 95% for years 1985, 1990, 1995, and 2002, respectively.

For each of the four time periods, we quantified the area of each of the 11 LULC categories at three levels:

1) Connecticut highlands region as a whole,
2) Twenty-eight towns located in the region (Figure 1-2), and
3) Forty-five watersheds that either wholly or partially intersect the study area (Figure 7-7). The digitally delineated watersheds were provided by the USGS and are identified by their 12 digit hydrologic unit code (HUC 12).

Data Aggregation

LULC classes were aggregated at three levels in order to aid in interpreting trends at various scales. The first level condensed the 11 LULC classes into 6 new classes, (*water, barren, developed, agriculture, forest, and wetlands*) combining those that share similar characteristics. *Agriculture* is a combination of *other grasses & agriculture*, *turf & grass*, and *utility row*; *forest* is a combination of the coniferous and deciduous classes; and the wetland class includes forested wetlands and non-forested wetlands. This combination of classes reflects as closely as possible those used in the New York-New Jersey Highlands Study.

At a second level of aggregation the six LULC classes were condensed further to evaluate large-scale shifts in LULC. Three classes were created to express degree of alteration by human activity. Class 1 (*developed* and *barren*) includes areas with high amounts of impervious surface. Class 2 (*other grasses & agriculture/turf & grass/utility row*) includes areas which have been altered by agricultural use or are maintained as grassy open space, and Class 3 (*forests/wetlands*) includes forests and wetlands. *Water* was treated as a separate class. Area and changes were assessed at this level of aggregation by the three stratification zones of region, town, and watershed. After aggregating to three categories, the overall classification accuracies in years 1985, 1990, 1995 and 2002 were 89%, 90%, 90%, and 86%, respectively (Appendix 6).

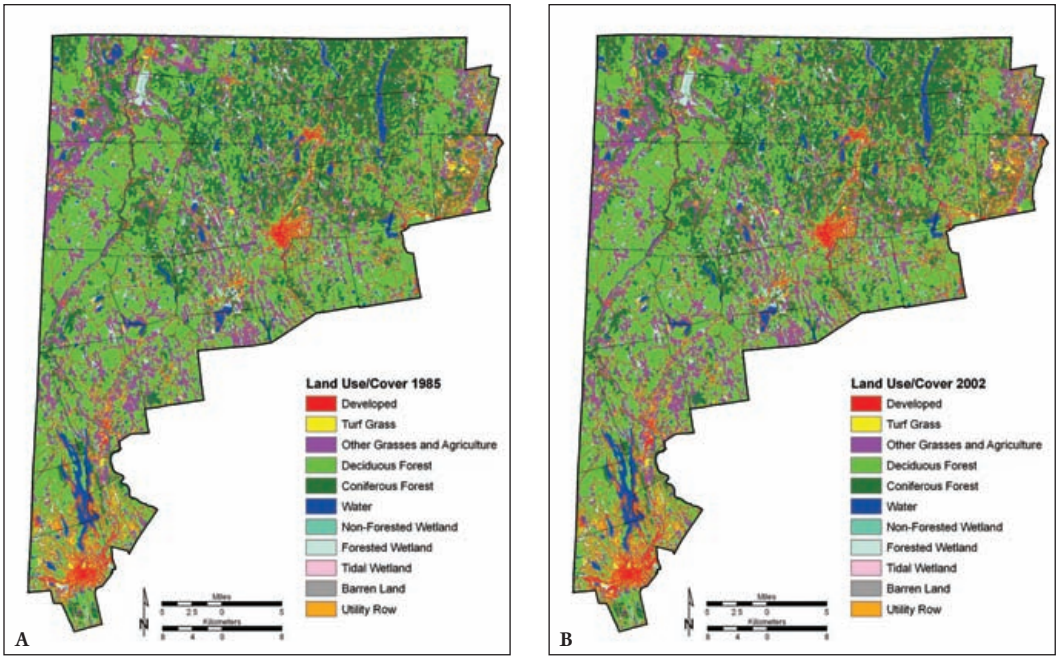


Figure 7-1. *Connecticut Highlands: Land use / land cover in A) 1985 and B) 2002.*

At the third level, land classes were aggregated into just two categories that we called *altered* and *unaltered* land use to determine the amount of native vegetation recently altered by human use. *Altered* combined development, utility infrastructure, and agriculture, while *unaltered* aggregated all forest and wetland categories. As before, water was treated as a separate class. After aggregating to two categories, the overall accuracies in years 1985, 1990, 1995 and 2002 were 92%, 93%, 93%, and 92%, respectively (Appendix 6).

We created transition matrices to assess the quantity of land conversion between different LULC types for each of the following time periods: 1985 to 1990, 1990 to 1995, 1995 to 2002 and 1985 to 2002. Each column of the matrix represents the instance of a LULC class at the earlier time period, *e.g.,* 1985, while each row represents the instance of a LULC class at the later time, *e.g.,* 1990. This matrix (Table 7-1) makes it possible to see how many cells of each class changed or stayed the same during the period of analysis. For those that changed, it shows the class *to which* the earlier classification converted, and the class *from which* the later classification converted. For example, looking at Table 7-1, we can see that 135,688 acres of coniferous forest in 1985 were still forest in 2002; and that 1,270 had been converted to development.

Table 7-1. *Connecticut Highlands: Matrix of land use / land cover conversion from 1985 to 2002 (in acres).*

	1985 Land Use/Land Cover										
2002 Land Use/Land Cover	**Developed**	**Turff & Grass**	**Other Grass & Agriculture**	**Decidious Forest**	**Coniferous Forest**	**Water**	**Non-Forested Wetland**	**Forested Wetland**	**Barren Land**	**Utility r-o-w**	**Total acres in 2002**
Developed	62,197	193	829	5,249	1,270	11	4	187	251	20	70,211
Turf & Grass	0	12,918	138	416	70	0	0	12	30	0	13,583
Other Grass & Ag	0	126	77,659	2,394	697	73	11	210	32	0	81,202
Deciduous Forest	1	20	125	318,507	285	870	16	829	61	0	320,714
Coniferous Forest	0	28	69	226	135,688	213	3	204	23	0	136,453
Water	0	26	139	648	512	23,449	91	208	313	0	25,386
Non-forested Wetland	1	1	27	208	99	1,857	1,082	391	1	0	3,666
Forested Wetland	0	1	14	53	23	337	13	19,780	2	0	20,223
Tidal Wetland	0	0	0	2	0	0	2	0	0	0	5
Barren Land	1	10	313	1,316	312	259	11	51	2,434	0	4,707
Utility ROW	0	0	0	1	0	0	0	0	0	1,286	1,287
Total acres in 1985	62,199	13,323	79,313	329,019	138,956	27,068	1,233	21,872	3,148	1,306	677,437

Connecticut Results

Regional Results

Using the CLEAR LULC classification, there were 9,812 acres of new development and associated land uses (*i.e.,* LULC categories of *developed, turf and grass, utility right-of-way,* and *barren*) between 1985 and 2002 (Tables 7-2 and 7-3). This represents a 12.2% increase in developed land use. However, this does not count development-associated grasses, that due to the difficulties in distinguishing them from agricultural fields, are included in the *other grasses and agriculture* LULC class. Using the USDA Agricultural Census data and the 2004 active agriculture map digitized from aerial photography, (described in Chapter 5, *Agricultural Resources Characteristics and Trends*), we were able to determine that in this category much of the land is actually development-associated grassland such as golf courses, baseball fields, etc, that should have been categorized as *turf and grass*. In 2002 this *other grasses* amounted to 40% of the *other grasses and agriculture* class. This means that farmland did not remain stable, as might be inferred from table 7-2, but rather decreased, by 13,484 acres between 1995 and 2002 (Table 7-4), while development-associated grasses increased by 13,341 acres in that same 7 year period. Including the latter in our calculation of total development, between 1995 and 2002, we estimate that all land covers associated with development increased by at least 16,400 acres, or 15%.

It is more difficult to estimate the proportion of *other grasses* vs. *agriculture* in the CLEAR LULC data prior to 1995 because we don't have another data source on farmland for comparison. Older USDA Agricultural Censuses were done using a different methodology and cannot be compared to the 1997 or 2002 census. Thus we decided to keep the farmland acreage constant for the periods 1995, 1990, and 1985, at the number of acres that were in farmland in 1995, for the purpose of determining what amount of the total *other grasses and agriculture* to allocate to development-associated grasses in those time periods. This assumption that farmland remained stable in the mid 1990s may or may not be true. Thus our estimates of both farmland loss and increase in development-associated land uses may be conservative (Table 7-4).

In summary, the total increase in *developed* land use between 1985 and 2002 is estimated to be 25,000 acres, or 26% more than in 1985. This adjustment implies an impact to the "natural" landscape 2.5 times that based on the *developed, turf and grass, utility right-of-way,* and *barren* categories alone (9,812 acres).

Nonetheless, this is still a mostly forested region with 67.5% of total land area in *forest* (Figure 7-1). Most of the new development occurred in the southern and eastern portions of the Highlands. The northwest corner of the Highlands, which is predominantly forested, experienced very little new development (Figures 7-2 and 7-3). Development slowed considerably after 1990; more than half of the development in the 17-year period of analysis took place between 1985 and 1990 (Figure 7-4).

Table 7-2. *Connecticut Highlands: Land use / land cover (in acres and as percent of region) derived from the CLEAR satellite image time series classification using four levels of aggregation at four time periods fro 1985 to 2002.*

11- Class

	1985		1990		1995		2002	
Land Use	**Acres**	**Percent**	**Acres**	**Percent**	**Acres**	**Percent**	**Acres**	**Percent**
Developed	62,199	9.2	67,013	9.9	68,053	10.0	70,211	10.4
Turf&Grass	13,323	2.0	13,499	2.0	13,581	2.0	13,583	2.0
Other Grass & Ag	79,313	11.7	80,107	11.8	81,345	12.0	81,202	12.0
Deciduous Forest	329,019	48.6	323,835	47.8	322,288	47.6	320,714	47.3
Coniferous Forest	138,956	20.5	137,408	20.3	136,898	20.2	136,453	20.1
Water	27,068	4.0	28,118	4.2	27,014	4.0	25,386	3.7
Non-forested Wetland	1,233	0.2	2,371	0.4	3,017	0.4	3,666	0.5
Forested Wetland	21,872	3.2	20,451	3.0	20,170	3.0	20,223	3.0
Tidal Wetland	0	0.0	4	0.0	3	0.0	5	0.0
Barren Land	3,148	0.5	3,334	0.5	3,774	0.6	4,707	0.7
Utility ROW	1,306	0.2	1,297	0.2	1,294	0.2	1,287	0.2
Total	677,437	100.0	677,437	100.0	677,437	100.0	677,437	100.0

6-Class

	1985		1990		1995		2002	
Land Use	**Acres**	**Percent**	**Acres**	**Percent**	**Acres**	**Percent**	**Acres**	**Percent**
Developed	62,199	9.2	67,013	9.9	68,053	10.0	70,211	10.4
Ag/Turf/Utility	93,942	13.9	94,903	14.0	96,220	14.2	96,072	14.2
Forest	467,976	69.1	461,243	68.1	459,186	67.8	457,167	67.5
Water	27,068	4.0	28,118	4.2	27,014	4.0	25,386	3.7
Wetland	23,105	3.4	22,826	3.4	23,191	3.4	23,894	3.5
Barren Land	3,148	0.5	3,334	0.5	3,774	0.6	4,707	0.7
Total	677,437	100.0	677,437	100.0	677,437	100.0	677,437	100.0

4-Class

	1985		1990		1995		2002	
Land Use	**Acres**	**Percent**	**Acres**	**Percent**	**Acres**	**Percent**	**Acres**	**Percent**
Developed	65,347	9.6	70,347	10.4	71,827	10.6	74,918	11.1
Ag/Turf/Utility	93,942	13.9	94,903	14.0	96,220	14.2	96,072	14.2
Forest and Wetlands	491,080	72.5	484,069	71.5	482,376	71.2	481,061	71.0
Water	27,068	4.0	28,118	4.2	27,014	4.0	25,386	3.7
Total	677,437	100.0	677,437	100.0	677,437	100.0	677,437	100.0

3-Class

	1985		1990		1995		2002	
Land Use	**Acres**	**Percent**	**Acres**	**Percent**	**Acres**	**Percent**	**Acres**	**Percent**
Altered	159,289	23.5	165,250	24.4	168,047	24.8	170,990	25.2
Unaltered	491,080	72.5	484,069	71.5	482,376	71.2	481,061	71.0
Water	27,068	4.0	28,118	4.2	27,014	4.0	25,386	3.7
Total	677,437	100.0	677,437	100.0	677,437	100.0	677,437	100.0

Table 7-3. *Connecticut Highlands: Land use / land cover changes from 1985-2002 using four levels of aggregation (in acres and as a percentage of 1985 area).*

	Acres gained/lost	% from 1985
11- Class		
Developed	8,012	12.9%
Turf&Grass	260	2.0%
Other Grass & Ag	1,889	2.4%
Deciduous Forest	-8,305	-2.5%
Coniferous Forest	-2,503	-1.8%
Water	-1,682	-6.2%
Non-forested Wetland	2,433	197.3%
Forested Wetland	-1,649	-7.5%
Tidal Wetland	5	N/A
Barren Land	1,559	49.5%
Utility ROW	-19	-1.4%
6-Class		
Developed	8,012	12.9%
Ag/Turf/Utility	2,130	2.3%
Forest	-10,808	-2.3%
Water	-1,682	-6.2%
Wetland	789	3.4%
Barren Land	1,559	49.5%
4-Class		
Developed	9,571	14.6%
Ag/Turf/Utility	2,130	2.3%
Forest and Wetlands	-10,019	-2.0%
Water	-1,682	-6.2%
3-Class		
Altered	11,701	7.3%
Unaltered	-10,019	-2.0%
Water	-1,682	-6.2%

Table 7-4. *Connecticut Highlands: Development land use 1995-2002. Farmland acres derived from USDA census of agriculture (1997 and 2002) and digitized active agriculture layer (2004). 1995 farmland acres estimaged from the rate of change between 1997 and 2004; farmland prior to 1995 assumed to be relatively constant.*

	1985	1990	1995	1997	2002	2004	95-02	85-02
Land Use (in Acres)			**Farmland vs. Other Development-Associated Grasses**					
Other Grass & Agriculture (LULC class)	79313	80107	81345		81202		-143	
Farmland	61500	61500	61500	57608	48016	43516	-13484	
Other grasses	17813	18607	19845		33186		13341	
			Summary of All Development Classes					
Developed	62199	67013	68053		70211		2158	8012
Turf & Grass	13323	13499	13581		13583		2	260
Other Grass	17813	18607	19845		33186		13341	15373
Barren Land	3148	3334	3774		4707		933	1559
Utility Right-Of-Way	1306	1297	1294		1287		-6	-19
Total	97789	103750	106547		122974		16427	25185
Percent of the Total Highlands Area	14%	15%	16%		18%			

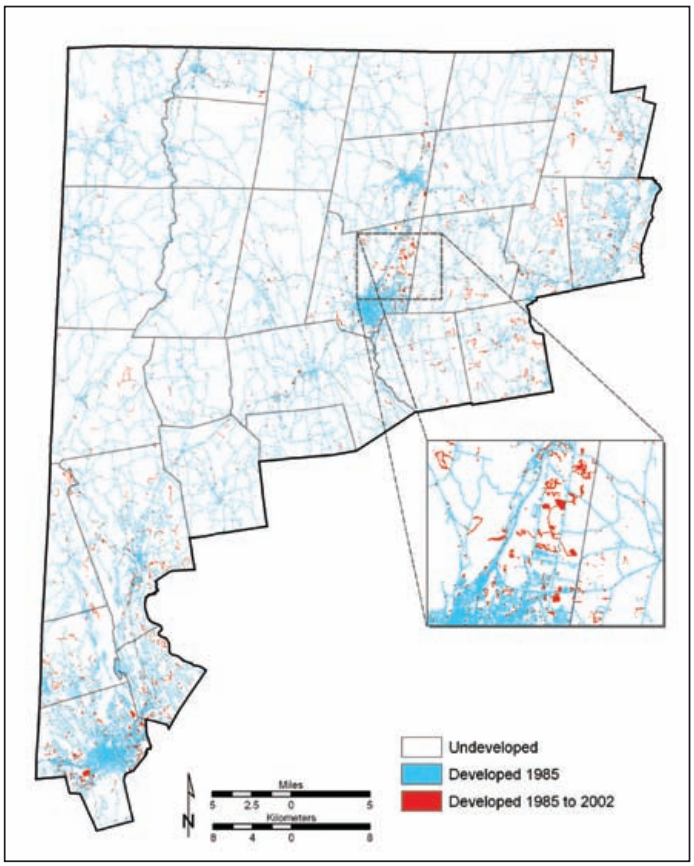


Figure 7-2. *Connecticut Highlands: Areas developed prior to 1985 and between 1985 and 2002.*

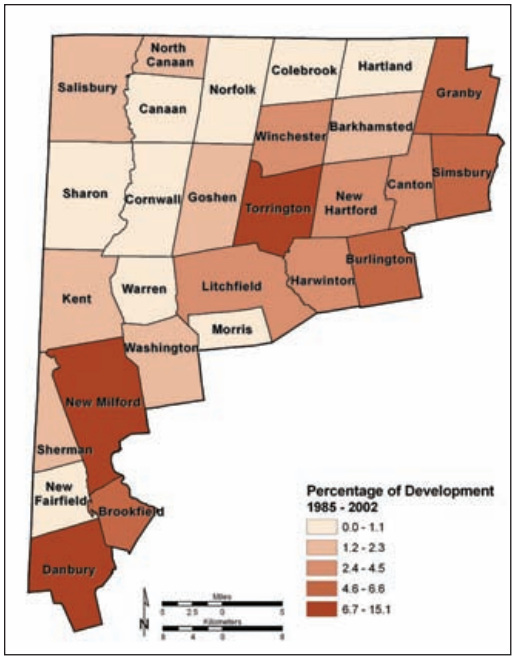


Figure 7-3. *Connecticut Highlands: Percentage of total development in the Highlands region that occurred in each town between 1985 and 2002.*

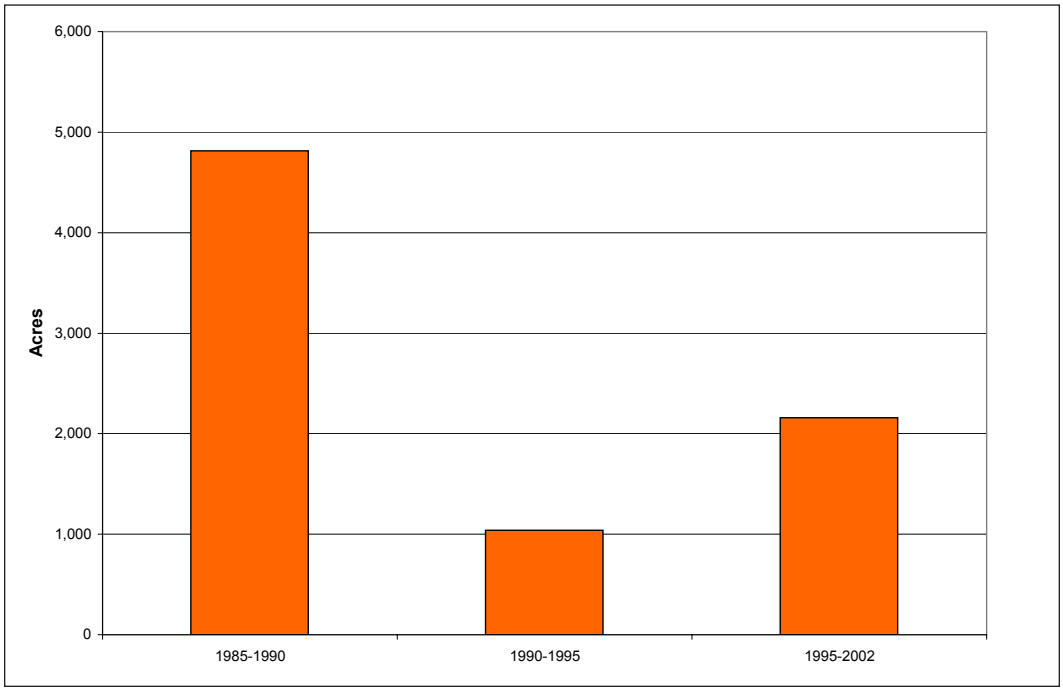


Figure 7-4. *Connecticut Highlands: Acres of new development by time period from 1985 through 2001.*

Forests

The overall rate of forest loss is small, at 2.3% over 17 years. In 1985 there were approximately 468,000 acres of *forest*. Between 1985 and 2002, 13,270 acres were converted to other uses. Most of this loss was to development and associated land cover classes (8,555 acres to *developed, turf & grass, and barren*) (Figure 7-5). Three thousand acres were lost to *other grasses & agriculture*, most likely grass associated with new development. During the same time period, the data show that about 2,500 acres of mostly *water* and *wetlands* were converted to forests. This is probably an artifact of changes in apparent land cover from wet to dry years. Thus the data show a net loss of forest cover of 10,700 acres. Of the 8,020 acres of land that were developed in this time period, 81% came from *forest*, while 13% came from *agriculture/turf/utility* (Figure 7-6).

Conversion of *forest* to *developed* land was greatest between 1985 and 1990 (Table 7-5). *Forest* was converted to the *other grasses & agriculture* class in all time periods with most of the change occurring in the 1985 – 1995 time period. The conversion to development slowed considerably from 1990 to 1995, but picked up again between 1995 and 2002.

Table 7-5. *Connecticut Highlands: Acreages of selected land use / land cover conversion over four time periods.*

Time Period	Land Use Conversion	Acres
1985 - 1990	Agriculture to Developed	346
1990 - 1995	Agriculture to Developed	113
1995 - 2002	Agriculture to Developed	331
1985 - 2002	Agriculture to Developed	791
1985 - 1990	Agriculture to Forest	163
1990 - 1995	Agriculture to Forest	34
1995 - 2002	Agriculture to Forest	6
1985 - 2002	Agriculture to Forest	203
1985 - 1990	Forest to Agriculture	1,475
1990 - 1995	Forest to Agriculture	1,307
1995 - 2002	Forest to Agriculture	310
1985 - 2002	Forest to Agriculture	3,091
1985 - 1990	Forest to Developed	3,963
1990 - 1995	Forest to Developed	796
1995 - 2002	Forest to Developed	1,681
1985 - 2002	Forest to Developed	6,441
1985 - 1990	Wetlands to Developed	134
1990 - 1995	Wetlands to Developed	18
1995 - 2002	Wetlands to Developed	31
1985 - 2002	Wetlands to Developed	184

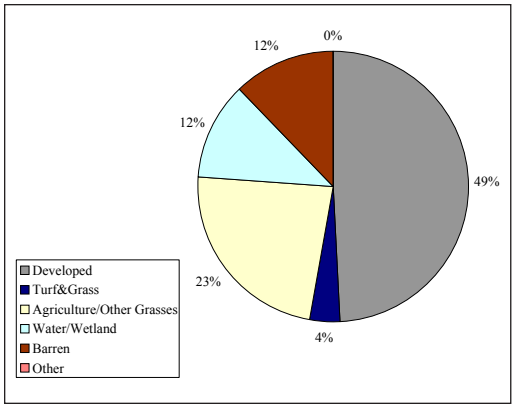


Figure 7-5. *Connecticut Highlands: Fate of 13,270 acres of forest lost between 1985 and 2002.*

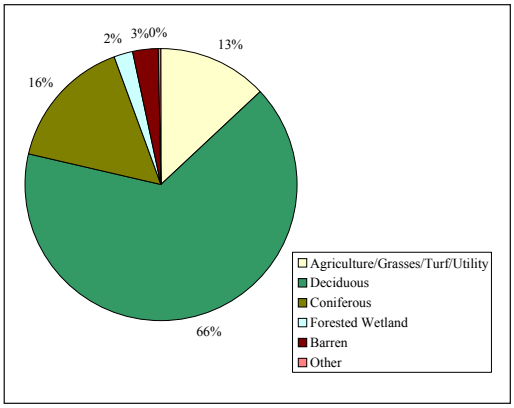


Figure 7-6. *Connecticut Highlands: Source of 8,020 acres converted to developed classes from 1985 to 2002.*

Agriculture

It is difficult to assess what happened to agricultural lands using the CLEAR LULC time series. In the CLEAR data, the agriculture class includes other grasses, such as found along transportation routes and non-maintained grassy areas. The spectral characteristics of grassy fields, suburban backyards, and open recreational areas are easily confused with agricultural fields, so there is likely some confusion between *turf and grass* and *agriculture*. For this reason, we have combined *other grasses & agriculture, turf & grass, and utility row* into one class, which tells us something about what is happening on open fields/grassy areas in general, but does not give us the ability to parse out what is happening to agricultural lands. There were 2,130 more acres of *agriculture/turf/utility* in 2002 than in 1985, most likely open areas associated with development.

For a recent picture of the extent of active agricultural lands, we turn to the work done for the agricultural resources analysis, whereby all active farm fields were digitized from aerial photos (see Chapter 5, *Agricultural Resources Characteristics and Trends*). According to this work, there were 43,516 acres of active agricultural lands in 2004. This compares well with the 48,016 acres of cropland, pasture, and range measured by the USDA's Census of Agriculture in 2002, which shows a loss of 9,592 acres between 1997 and 2002 (a 16.7% reduction). Using these numbers, we can estimate that about half of the LULC class *other grasses and agriculture* is active farm land, the other half open grassy areas either associated with development or inactive farm fields. We estimate that about 13,500 acres of agricultural lands were converted to development-associated turf/grasses between 1995 and 2002. This represents 22% loss of farmland in 7 years, for an average annual rate of 3.1%.

Water and Wetlands

Assessing changes observed in the *wetland* and *water* categories is often problematic due to wet/dry conditions at the time of image capture. The data show that *forested wetlands* had the greatest percent total loss over the entire time period (Table 7-5). The *water* class decreased in all sequential time periods other than 1985-1990. On the other hand, the *non-forested wetland* category appears to have increased almost 200%. Often this change in classification can be attributed to differences in soil and leaf moisture conditions and water levels, or to leaf-on/leaf-off conditions, depending on the season of image capture.

Town and Watershed Results

Some towns in the region experienced very little change over the 17 years and others had upwards of 1,000 acres of new development. Most of the new development occurred in towns closer to Hartford to the east and Danbury to the south. Development tended to occur near larger towns (*e.g.,* Torrington) and main roads (*e.g.,* Route 8) (Figures 7-2 and 7-3 and Table 7-6).

Brookfield, Danbury, and Torrington, the towns with the most development in 1985, also experienced the fastest rates of forest loss from 1985 to 2002. All three were among the 10 least forested towns in the region as of 2002 with 43%, 50% and 58% *forest* cover respectively (Table 7-7). The greatest increases in development occurred from 1985 to 1990. Although development continued to increase between 1990 and 2002, the rate was less than half that of the earlier time period. Danbury, Torrington and New Milford had the greatest increases in developed acreage across all time periods; while Burlington, Granby and Canton had the greatest percent increases (30%, 29%, and 23%) above their 1985 levels.

The watersheds of the Mine Brook, Pequabuck River, the Farmington River from Burlington Brook to Thompson Brook, and the Still River in Torrington experienced greater than 25% increase in *developed* land from 1985 to 2002 (Table 7-8 and Figure 7-7). This is an indicator of where development is concentrated, as some of these small watersheds experienced much larger increases in developed areas than any town in the region.

Table 7-6. *Connecticut Highlands: Acreage of new development by town over four time periods and percentage of new development in the Highlands region that occurred within each town.*

Town	1985-1990	1990-1995	1995-2002	1985-2002	1985-2002 % of New Development
Barkhamsted	136	7	30	174	2.2%
Brookfield	332	83	111	526	6.6%
Burlington	322	30	124	475	5.9%
Canaan	34	10	9	52	0.7%
Canton	182	36	145	362	4.5%
Colebrook	43	4	25	72	0.9%
Cornwall	49	3	23	75	0.9%
Danbury	711	141	361	1,213	15.1%
Goshen	76	12	14	103	1.3%
Granby	212	79	216	508	6.3%
Hartland	59	5	9	73	0.9%
Harwinton	155	16	71	242	3.0%
Kent	102	27	25	154	1.9%
Litchfield	180	17	48	244	3.1%
Morris	28	3	14	44	0.6%
New Fairfield	158	80	56	294	3.7%
New Hartford	207	32	65	304	3.8%
New Milford	436	126	208	770	9.6%
Norfolk	50	10	10	69	0.9%
North Canaan	66	22	33	122	1.5%
Salisbury	56	9	40	105	1.3%
Sharon	48	11	32	91	1.1%
Sherman	87	24	74	185	2.3%
Simsbury	305	79	106	490	6.1%
Torrington	490	134	206	830	10.4%
Warren	40	2	11	52	0.7%
Washington	68	17	30	115	1.4%
Winchester	184	20	61	265	3.3%
Total	4,814	1,040	2,158	8,012	100.0%

Table 7-7. *Connecticut Highlands: Ten towns with highest and lowest rates of forest loss and least and most forest cover. Loss is expressed as the percentage of 1985 forest cover. Forest cover is percentage of town covered by forest in 2002. Towns highlighted occur in both lists.*

Towns with highest rate of forest loss (1985-2002)	% Loss 1985-2002	Towns with lowest rate of forest loss (1985-2002)	% Loss 1985-2002
Brookfield	-8.0%	Canaan	-0.5%
Danbury	-7.1%	Salisbury	-0.8%
Torrington	-5.6%	Sharon	-0.9%
North Canaan	-4.9%	Goshen	-0.9%
Burlington	-4.4%	Norfolk	-0.9%
Simsbury	-4.3%	Kent	-1.0%
New Milford	-4.1%	Cornwall	-1.0%
New Fairfield	-4.1%	Warren	-1.1%
Canton	-3.4%	Hartland	-1.2%
Granby	-3.1%	Colebrook	-1.3%

Towns least forested (2002)	% Forest 2002	Towns most forested (2002)	% Forest 2002
Danbury	43.0%	Hartland	83.7%
Brookfield	50.6%	Cornwall	80.7%
North Canaan	52.2%	Colebrook	80.4%
Simsbury	52.7%	Norfolk	80.2%
Morris	54.0%	Barkhamsted	77.6%
New Fairfield	55.0%	Kent	76.0%
New Milford	57.9%	Warren	75.3%
Torrington	58.5%	Canton	73.7%
Salisbury	62.8%	Burlington	73.3%
Litchfield	63.5%	New Hartford	73.1%

Table 7-8. *Connecticut Highlands: Area of developed land by HUC 12 watersheds (in acres and percent coverage of town) in 1985 and 2002, and change during the intervening time period in acres and as a percent of developed land in 1985. Figure 7-7 shows locations of each watershed.*

		1985		2002		Change 1985 - 2002	
Map Code	Watershed	Developed Acres	% of Watershed	Developed Acres	% of Watershed	Acres	%
19	Bantam River	2,912	8.3%	3,137	9.0%	225	7.7%
27	Blackberry River	1,350	7.8%	1,492	8.7%	142	10.5%
41	Branch Brook	626	7.7%	663	8.1%	37	5.9%
36	Candlewood Lake	3,287	13.2%	3,626	14.5%	339	10.3%
42	East Aspetuck River	1,578	9.8%	1,718	10.6%	140	8.9%
44	East Branch Croton River-headwaters to Haviland Hollow Brook	489	21.1%	540	23.3%	51	10.4%
11	East Branch Farmington mainstem	1,227	5.0%	1,282	5.3%	55	4.5%
22	East Branch Naugatuck River	1,863	20.6%	2,012	22.2%	149	8.0%
1	Farmington River-Burlington Brook to Thompson Brook	1,095	11.1%	1,410	14.3%	315	28.8%
5	Farmington River-headwaters to Burlington Brook	1,526	9.5%	1,847	11.5%	322	21.1%
4	Farmington River-Hop Brook to mouth	2,384	16.7%	2,699	18.9%	315	13.2%
2	Farmington River-Thompson Brook to Hop Brook	1,362	19.6%	1,562	22.5%	200	14.7%
45	Haviland Hollow Brook	236	5.8%	270	6.6%	34	14.3%
25	Hollenbeck River	928	3.4%	973	3.5%	45	4.9%
18	Housatonic mainstem-Furnace Brook to Tenmile River	1,989	5.1%	2,140	5.5%	151	7.6%
28	Housatonic mainstem-Konkapot River to Furnace Brook	1,733	6.4%	1,797	6.6%	63	3.7%
35	Housatonic mainstem-Still River to Pootatuck River	1,213	13.7%	1,538	17.4%	325	26.8%
38	Housatonic mainstem-Tenmile River to Still River	2,409	9.7%	2,860	11.5%	451	18.7%
31	Hubbard Brook	464	8.9%	482	9.2%	18	3.9%
32	Konkapot River	122	5.1%	138	5.8%	15	12.6%
17	Leadmine Brook	1,475	9.8%	1,757	11.7%	282	19.1%
16	Macedonia Brook	371	4.5%	384	4.7%	13	3.6%
7	Mad River	1,702	8.4%	1,795	8.8%	93	5.4%
13	Mine Brook	459	6.8%	626	9.4%	168	36.5%
24	Mudge Pond Brook	995	8.5%	1,048	9.0%	53	5.3%
15	Naugatuck mainstem-East Branch to Hancock Brook	2,180	12.2%	2,411	13.5%	231	10.6%
3	Nepaug River	1,397	6.8%	1,687	8.2%	290	20.7%
14	Pequabuck River	134	3.1%	176	4.0%	42	31.2%
9	Salmon Brook	1,447	8.6%	1,800	10.7%	352	24.3%
29	Salmon Creek	1,545	6.4%	1,606	6.7%	61	4.0%
12	Sandy Brook	906	5.6%	961	6.0%	55	6.0%
43	Saugatuck River-headwaters to Aspetuck River	197	6.9%	222	7.8%	25	12.6%
39	Shepaug River-Bantam River to mouth	1,502	7.9%	1,658	8.8%	156	10.4%
20	Shepaug River-headwaters to Bantam River	1,537	5.9%	1,618	6.2%	81	5.3%
6	Still River mainstem	1,576	13.8%	2,042	17.8%	466	29.6%
33	Still River-headwaters to Limekiln Brook	6,196	32.0%	7,035	36.3%	839	13.5%
34	Still River-Limekiln Brook to mouth	3,132	25.8%	3,845	31.7%	713	22.8%
21	Webatuck Creek	431	5.0%	447	5.2%	16	3.6%
26	Webatuck Creek-headwaters to Wassaic Creek	143	7.1%	153	7.5%	10	7.1%
37	Weekeepeemee River	217	5.9%	225	6.1%	8	3.8%
40	West Aspetuck River	1,079	6.6%	1,183	7.3%	104	9.7%
10	West Branch Farmington River-Clam River to mouth	1,672	6.5%	1,894	7.4%	222	13.3%
23	West Branch Naugatuck River	1,716	7.9%	1,837	8.4%	121	7.1%
8	West Branch Salmon Brook	1,068	6.3%	1,272	7.5%	205	19.2%
30	Whiting River	272	5.7%	283	5.9%	11	4.1%
	Total	62,142		70,153		8,011	12.9%

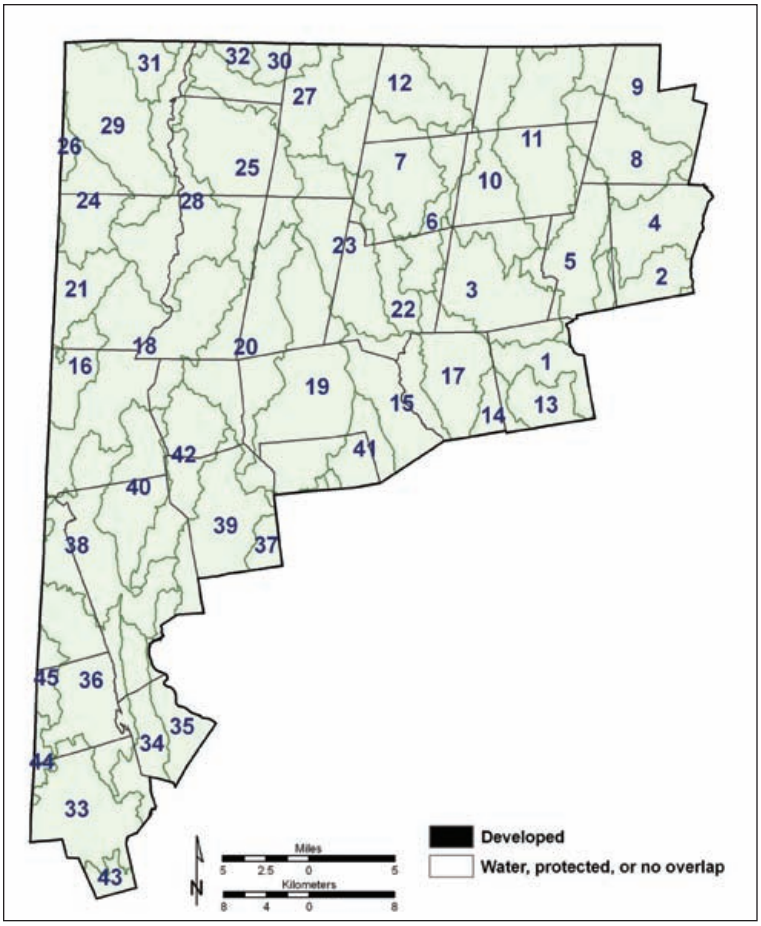


Figure 7-7. *Connecticut Highlands: HUC 12 watersheds intersecting the region. Names for each numeric code in the map are in Table 7-8*

Other grasses and agriculture increased in 26 of the 28 towns (for details, see Appendix 6). This is certainly due to the increase in development-associated grasses as agriculture has declined throughout the region. The greatest increases in acreage occurred in Cornwall, Norfolk, Sharon and Washington while the greatest increases as a percentage of 1985 agricultural/grass area were in Hartland, Norfolk, and Colebrook (12.1%, 11%, and 10.5% respectively). Only Danbury and New Milford lost agricultural/grass lands from 1985 to 2002. Most watersheds (46 out of 51) experienced an increase in *other grasses and agriculture* over the entire time period (Appendix 6).

From the work done to digitize active farm land, we know that the town of Sharon has the most land in active agriculture (4,713 acres) and New Fairfield the least (109 acres). By percent coverage, North Canaan has the greatest density of agricultural land (18.2%) and New Fairfield the least (less than 1%).

Forest land decreased in acreage across all time periods in all towns (Appendix 6). The largest losses occurred in New Milford, Danbury, and Torrington. Seven of the 10 least forested towns in 2002 had the highest deforestation rates between 1985 and 2002, while six of the ten most forested towns had the lowest rate (Table 7-7). The watershed lands most impacted by forest loss were the Konkapot, the Housatonic mainstem-Still River to Pootatuck River, and the Farmington River from Hop Brook to mouth and from Burlington Brook to Thompson Brook. (Appendix 6).

It is difficult to draw any conclusions about changes in *wetlands*. As discussed earlier, there are numerous problems with comparing year-to-year changes in *wetlands* as seen from satellite imagery. A wet or dry year will show up with more or less *water* and *wetlands* in the imagery. It is common to see water pooling in open areas making them look from space like wetlands. The data are presented in Appendix 6 by town and watershed, respectively, for all years for the classes of *forested wetlands*, *non-forested wetlands*, and *water*.

Pennsylvania Methods

The analysis of land cover change for the Pennsylvania Highlands is based on the United States Geological Survey (USGS) National Land Cover Data (NLCD) Change Product. This newly developed product allows users to compare aggregated land cover classifications between an adjusted 1992 classification and the subsequent aggregated 2001 classification, something that was not possible to do with the two original NLCD classifications (see Coan 2006). The data set used for the Pennsylvania Highlands analysis was clipped from zones 60, 61, and 64 of the NLCD Change Product. This map indicates the class membership of each grid cell in 1992 and 2001 among seven Anderson Level 1 classes (definitions found in Appendix 7) where 1 = *water,* 2 = *urban,* 3 = *barren,* 4 = *forest,* 5 = *rangeland,* 6 = *agriculture,* and 7 = *wetland* in both time periods, *as well as* classes such as 42, that indicate a cell's transition, in this case from *forest* (class 4) in 1992 to *urban* (class 2) by 2001. We converted this single data set into individual maps for 1992 and 2001 each consisting of the 7 classes that represent the land cover in that time period (Figure 7-8). Each raster-format data set consists of a grid of 5,986 columns by 4,440 rows, where each row/column position represents 30 by 30 meters on the ground. Due to its southwest-northeast orientation, the study area represents only 23% of the rectangular grid.

We used a second data set of black and white digital aerial photographs, known as digital orthographic photo quarter quads (DOQQs) from 1992 and 1999[15] to conduct an accuracy assessment of the NLCD Change Product and to evaluate how much of the NLCD agriculture class is farmland versus development-associated grasses. These photos were prepared and made available by the USDA as part of the National Agriculture Imagery Program (www.pasda.psu.edu).

Accuracy Assessment of NLCD 1992 – 2001 National Land Cover Change Product

With all satellite-derived classifications, an accuracy assessment should be conducted for the region of interest in order to characterize the uncertainty in the data used for analysis. Typically overall accuracy of the classification will range from 50% to 90% depending on a variety of factors that may influence the original spectral measurement (Jensen 2005), the classifier's bias (Powell *et al.,* 2004), the number of classes incorporated, and/or the reference frame (Stehman *et al.,* 2003a). For example, Stehman *et al.,* (2003b) reported a 75% overall accuracy for the portion of the 1992 NLCD covering the northeastern United States using homogenous classes within a 3x3 pixel window, but only 58% on a per pixel basis.

At the time of this report, the Change Product was not released to the public and a formal accuracy assessment had not been undertaken. Therefore, we conducted our own accuracy assessment for both the 1992 and 2001 maps of the region that we had extracted from the NLCD Change

15 Photos from 1999 were the most recent available for the region, and hence the closest match we could make to the year 2001 NLCD product.

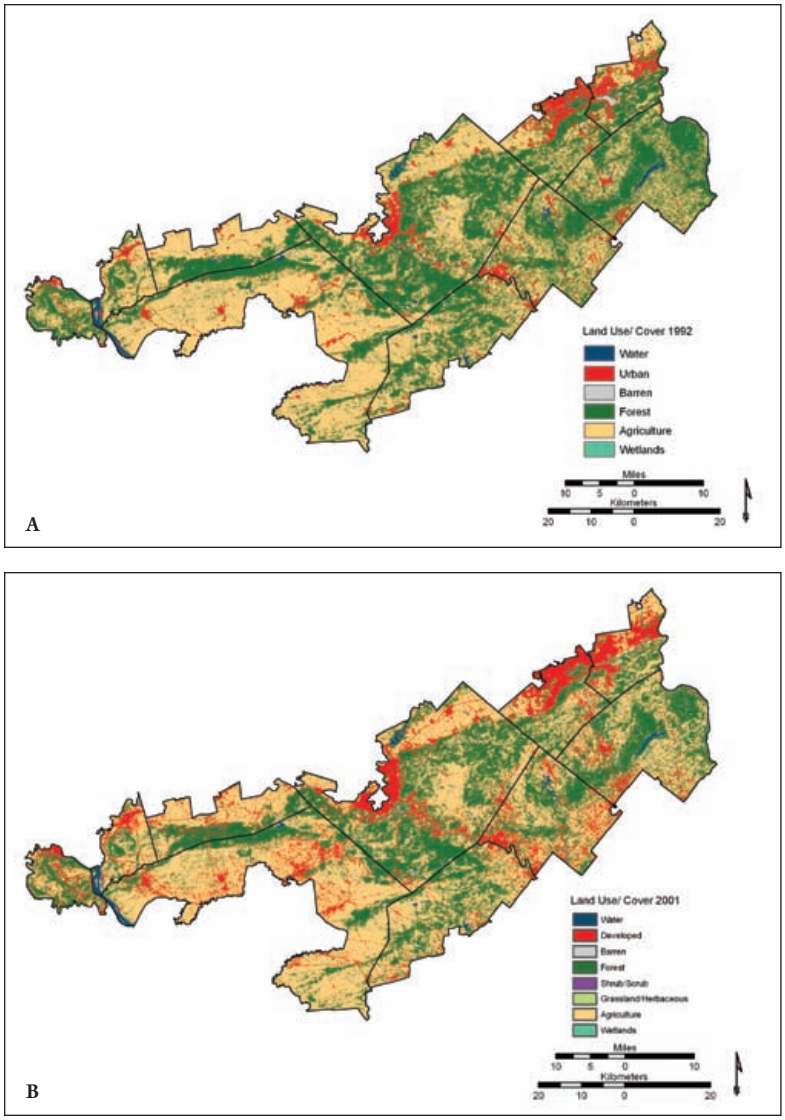


Figure 7-8. *Pennsylvania Highlands: Land use / land cover i A) 1992 and B) 2001.*

Product. This effort consisted of four different accuracy assessments in order to characterize to the best of our ability our confidence in the remotely-sensed on-the-ground changes in land use and land cover that have taken place in this region.

General Accuracy Assessment

The accuracy assessment was done according to methods described in Stehman (1997). Land cover data that are derived from per-pixel classification are considered point sample data. The suitable accuracy assessment method for this data is the absence/presence method that utilizes the Error Matrix and Kappa statistics as accuracy reporting measures (Stehman 1997). Following guidelines for sample size determination in Goodchild *et al.*, (1994) an adequate sample for an individual LULC category is between 27 and 173 points per class, given the size of the area.

We selected a value intermediate between these two and used a simple random selection protocol to identify 500 sample cells from the NLCD Change Product grid. We superimposed these on the DOQQs from 1992 and visually classified each cell to its Anderson Level 1 classification based upon what we observed in the aerial photo. This classification was then compared to the 1992 NLCD Change Product classification. We repeated this procedure, superimposing the same 500 cells over the DOQQs taken in year 1999, and comparing the reference classification to the 2001 NLCD Change Product classification. We computed overall accuracy, which is the agreement between the DOQQ classification and the satellite-based land cover classification, and user's accuracy, which is the frequency with which a sample from the land cover map matches what is found in the DOQQ reference photo, or "truth" map for that time period. We had to exclude four cells in 1992 and three cells in 2001 that landed in areas without aerial photograph coverage.

Accuracy Assessment Excluding Persistent Forest and Water

In land cover maps such as the NLCD Change Product that were created by classifying remotely-sensed imagery, it is often the case that forest and water cells that do not undergo transition, (*e.g.,* did not change land cover class from year 1992 to 2001) are classified with a greater accuracy than are cells that do undergo a transition from one land cover class to another (*e.g.,* cells that are changed from agriculture in 1992 to urban in 1999). To examine the possible effects these persistent forest and water cells may have on the accuracy of the NLCD Change product, we carried out a second accuracy assessment in which we excluded cells that were: (1) *forest* in both 1992 and 2001; or (2) *water* in both 1992 and 2001. From this we hoped to derive a more realistic evaluation of the accuracy of the transitioning cells, which were our major focus. After excluding cells of persistent *forest* and *water* identified in the NLCD Change Product, we randomly selected 150 cells from those remaining. The sample size represents approximately 30 cells for each remaining land cover type.

We found these 150 locations on the 1992 DOQQs and visually classified each cell using the Anderson Level 1 class descriptions. This classification was then compared to that of the 1992 NLCD Change Product. We repeated this procedure for 1999 DOQQs and compared the results to the 2001 NLCD Change Product classifications. From this analysis, overall and user's accuracies were computed for both years.

Accuracy Assessment Accounting for Spatial Misregistration of Grids

Visual comparison of the DOQQs to each other and to the NLCD Change Product for both time periods suggested there might be some spatial mis-registration between grids. This factor may explain some of the apparent classification error that we found in the 1992 and 2001 NLCD classifications. We hypothesized that this effect could be especially pronounced in areas where two or more different land cover types meet (*i.e.,* boundaries or edges between different types).

To explore the influence of spatial misregistration, we examined the "neighborhood" around each of 150 cells that we had employed for the accuracy assessment in which *persistent forest* and *persistent water* were excluded. This "neighborhood" consists of the eight surrounding cells with which each sample cell shares either an edge or a corner. The reference data set extracted for each time period was comprised, therefore, of the 150 randomly selected cells plus each of their 8 neighbors for a total of 1,350 cells.

We overlaid DOQQs from 1992 with the 1,350 cells and visually classified each cell using Anderson Level 1 class descriptions. We repeated this procedure with the 1999 DOQQs. We then compared each year's reference classifications based on the DOQQs to the NLCD Change

Product classifications. We labeled a NLCD Change Product cell as correctly classified if either the cell itself or one of its eight neighbors was of the same land cover type as that observed in the DOQQ reference data set. From this analysis, we were able to compute overall and user's accuracies for both years.

Accuracy Assessment of Cells Undergoing Transition

According to the NLCD Change Product, the largest shifts between classes involved *agriculture*, *forest*, and *urban* LULC types. Transitions of *forest* and *agriculture* to *urban,* reflect the experience of those familiar with the area. However, the transition of *forest* to *agriculture* and *agriculture* to *forest* as shown by the NLCD Change Product (Table 7-11) are counter to the experience of many in the area. In order to gain insight into whether or not these changes were actually taking place, or were just an artifact of the difficulty in classifying edge cells in a highly heterogeneous environment via remote sensing, we looked closely at three samples of these "transition" cells.

First, we identified 78,678 cells that according to the NLCD Change Product transitioned from a non-urban (*barren, forest, rangeland, agriculture,* or *wetland*) to an *urban* LULC type. Of these, we randomly selected 50 cells and used the reference data set of DOQQs from 1992 and 1999 to determine visually what, if any, land cover transition had occurred within each sample cell. We repeated this procedure for the cells transitioning from both *agriculture* to *forest* (66,538 cells) and *forest* to *agriculture* (40,434 cells). Again, 50 cells were randomly selected from each of these transition sets and their actual change, if any, determined through assessment of land cover at those sites on the 1992 and 1999 DOQQs.

Analysis of 1992 and 2001 Land Use and Land Cover Change

We characterized land cover in 1992 and 2001 in the Pennsylvania Highlands at three different scales (regional, county, and watershed) using the NLCD Change Product classification and three different levels of information aggregation (seven classes, three classes and two classes). We also did a refined assessment of just one NLCD category, *agriculture and other grasses,* in order to estimate the percentage of agricultural land that is in actual farmland versus non-agricultural grasses, as these two often share the same spectral properties and are easily confused in the classification process.

Analysis Using the NLCD Change Product

For each of the two time periods (1992 and 2001) we quantified the area of the seven land cover categories at three levels of stratification:

1. Pennsylvania Highlands region as a whole,
2. Ten counties that either wholly or partially intersect the study area (Figure 1-3), and
3. Thirty-three watersheds that either wholly or partially intersect the study area (See map in Appendix 7). The digitally delineated watersheds were provided by the USGS and are identified by their 11 digit hydrologic unit code (HUC 11).

Analysis Using Data Aggregation

We condensed the seven land cover classes into three categories to evaluate large-scale shifts in land cover. The three classes were created to express degree of alteration due to human activity. Class 1 (*developed*) includes altered areas with high amounts of impervious surface (*urban* and *barren*). Class 2 (*agriculture/rangeland*) includes areas maintained for agricultural use or as grassy open

space that may be associated with development, and Class 3 (*forests/wetlands*) includes forests and wetlands. Water was treated as a separate class. Acreage at each time period and changes in acreage in each of the three categories were calculated at the region, county, and watershed level.

Finally we collapsed the land cover classes into just two categories that we called *altered* and *unaltered.* This was done in order to determine the amount of native vegetation recently impacted by human activity. *Altered* combined *developed, barren, agriculture,* and *rangeland* classes, while *unaltered* aggregated the *forest* and *wetland* categories. As before, *water* was treated as a separate class.

Analyses were conducted using cross-tabulation to create a matrix in which each column represents the instances of a LULC class at the earlier time period, 1992, while each row represents the instances of a LULC class at the later time, 2001. This matrix (Table 7-9) makes it possible to see how many cells of each class changed or stayed the same during the period of analysis. For those that changed, it shows the class *to which* the earlier classification converted, and the class *from which* the later classification converted. For example, in Table 7-9 we can see that according to the NLCD Change Product, 429,506 acres of forested land in 1992 were still forest in 2001, but that 3,339 acres had become urbanized and 8,992 were converted to the *agriculture and other grasses* category.

Table 7-9. *Pennsylvania Highlands: Matrix of land use / land cover conversin from 1992 to 2001 according to the USGS Change Product (in acres).*

		1992							
		Water	**Urban**	**Barren**	**Forest**	**Rangeland**	**Agriculture**	**Wetland**	**Total**
	Water	12,818	345	67	124	0	923	136	14,413
	Urban	62	199,838	166	3,339	0	13,756	175	217,336
	Barren	10	77	11,329	279	0	896	3	12,594
2001	**Forest**	26	273	115	429,506	0	14,798	8	444,726
	Rangeland	0	2	0	0	44	1	0	47
	Agriculture	56	1,614	191	8,992	0	655,336	186	666,375
	Wetland	140	238	6	468	0	5,033	21,318	27,203
	Total	13,112	202,387	11,874	442,708	44	690,743	21,826	1,382,694

Analysis of Agriculture Using Digital Aerial Photographs

The Anderson Level 1 classification system used in the NLCD Change Product combines both farmlands and grassy areas associated with development into one class. This class is called *agriculture.* To be able to assess the proportion of these two very different categories within the *agriculture* class, and to capture development pressure on agricultural lands, we quantified how many cells classified as *agriculture* on the NLCD Change Product in each time period were truly in agricultural use according to the DOQQs, versus how many were non-agricultural grasses associated with development. To do this we selected from the 500 sample locations used for the overall accuracy assessment a subset of the DOQQ reference locations that we had identified as *agriculture*, using the NLCD Anderson Level 1 definition of *agriculture*. There were 232 such cells in 1992 and 219 in 1999. For each time period we re-examined the DOQQs and reclassified each reference cell into either (1) *agricultural crops, pasture or hay,* or (2) *non-agricultural grasses*. This gave us an estimate of the percent of this category that is in farmland versus in non-agricultural grasses, such as turf around homes.

Pennsylvania Results

Accuracy Assessment of NLCD 1992 – 2001 National Land Cover Change Product

General Accuracy Assessment

The user's accuracy varied by land cover type (Table 7-10.A). *Water* had user's accuracies of 100% in 1992 and 86% in 2001. *Forest* had a user's accuracy above 94% in both years. The user's accuracies for the *urban* class were relatively low at 50% and 60% in 1992 and 2001, respectively. When aggregated to six classes, the user's accuracy for *agriculture* was 82% in both 1992 and 2001. The overall accuracies of the 1992 and 2001 NLCD Change Product classifications are 79% and 80% respectively (Table 7-10.B). As is normally the case, aggregation of classes resulted in higher overall accuracy. In 1992, of the cells classified as *agriculture* by the NLCD Change Product, 66% of these were farmland and 16% were non-agricultural grasses. The remaining 18% were incorrectly classified (Table 7-10.E). In 2001, approximately 65% were farmland and 17% were non-agricultural grasses, while the remaining 18% were incorrectly classified. The LULC classes *barren and wetland* were not represented in the 500-cell sample and so user's accuracies were not computed.

Accuracy Assessment Excluding Persistent Forest and Water

The accuracy of the NLCD classification calculated without persistent *forest* and *water* was 76% and 78% for 1992 and 2001, respectively (Table 7-10.D) but improved significantly when neighboring areas were included to account for potential spatial misalignment (see below). Due to the small sample size and exclusion of the majority of forest and water cells, user's accuracies could be computed only for the *agriculture* and *urban classes*. For the *urban* category the 1992 user's accuracy is 62%, whereas for 2001 it is 75% (Table 7-10.C). The user's accuracy for *agriculture* was 87% in 1992 and 85% in 2001, each of which is higher than that determined from our assessment of agricultural cells alone (see below).

Neighborhood-scale Accuracy Assessment Accounting for Border Cells and Spatial Misregistration of Grids

There are three sources of error when doing a pixel-by-pixel comparison of land cover from different sources and over multiple time periods: cells that contain a border between two land cover classes; spatial misregistration between the two grids used for comparison; and temporal mismatch of the data sources.

Of the 150 cells and surrounding neighbors examined in the reference DOQQs for 1992, we found that 20 of the 35 misclassified cells were bordering a land cover type that matched their NLCD classification. Similarly for 2001 we found that of the 33 misclassified cells, 19 were adjacent to a cell determined visually on the DOQQs to match the NLCD product. In 1992, 38% of all *forest* cells touched an *agriculture* cell and 25% of all *agriculture* cells were adjacent to a *forest* cell. Similarly, 30% of *forest* cells in 2001 were adjacent to an *agriculture* cell and 20% of *agriculture* cells were touching a *forest* cell. These border cells are more difficult to correctly classify using remote sensing techniques and so may shift among classes between the 1992 and 2001 NLCD product.

There may have been some misalignment spatially between the NLCD grid and the reference DOQQs. The NLCD was in Albers Equal Area projection. The DOQQs, originally in the UTM coordinate system, were re-projected from Lambert Conic to Albers Equal Area to match the NLCD product using the ArcMap projection tool. The shifts inherent in re-projection may explain the lack of perfect alignment between the two products.

And finally, there was a slight temporal mismatch between the acquisition dates of the available DOQQs (1992 and 1999) and that of the LANDSAT imagery used by the USGS (1992 and 2001).

Given these three sources of error at a pixel-by-pixel scale of comparison, we recalculated the overall accuracy using a 3x3 cell neighborhood to determine whether or not a cell was correctly classified within this neighborhood of nine cells. In this case, the overall accuracy of the NLCD Change Product improved to 90% in 1992 and 91% in 2001 (Table 7-10.D).

Accuracy Assessment of Cells Undergoing Transition

Of the 50 cells randomly selected from those cells indicated by the NLCD Change Product as transitioning from non-urban (*barren, forest, rangeland, agriculture,* or *wetland*) to *urban*, only 20 (40%) were correctly classified according to the reference data set. However, there is a two year gap between the DOQQs (1999) and the NLCD (2001). Therefore, if a constant development rate over time is assumed, then between 1992 and 1999 (the seven years between aerial photograph acquisition times) only 77.8% (*i.e.,* (1999-1992)/(2001-1992)x100) of the change between 1992 and 2001 would be observable on the DOQQs. Therefore, our accuracy assessment of the cells transitioning from non-urban to *urban* is most likely conservative. Assuming that only 77.8% of the 50 cells selected actually transitioned to urban use from 1992 to 1999, the accuracy of the 2001 data set is more likely around 51% (*i.e.,* 40%/(77.8%/100)).

Of the 50 cells randomly selected from those cells indicated by the NLCD Change Product as transitioning from *agriculture* to *forest*, only 10 of the 50 did, in fact, transition from *agriculture* to *forest* upon inspection of aerial photographs. We also found that only 9 of the 50 cells examined actually transitioned in the opposite direction, *i.e.,* from *forest* to *agriculture.* Therefore, although some transitions between these classes did occur, the magnitude of this change is vastly overstated by the NLCD Change Product.

Results of all accuracy assessments are shown in Table 7-10.

Table 7-10. *Accuracy assessments of the 1992 and 2001 land use/cover data derived from the USGS Change Product. A) User's accuracy using 500 random points, B) Overall accuracy using 500 random points at 3 levels of aggregation, C) User's accuracy excluding persistent (unchanged between 1992 and 2001) forest and water using 150 random points, D) Overall accuracy excluding persistent (found in 1992 and 2001) forest and water using 150 random points with additional statistic showing overall accuracy when a 3x3 cell neighborhood is placed around each cell, and E) Of the 500 random points that were agriculture cells according to the USGS change product (238 and 226 in 1992 and 2001, respectively), the percentage of these that upon visual inspection were agriculture (*e.g., *row crop or pasture), non-agricultural grasses (*e.g., *turf grass), and other (mis-classified).*

A	**% User's Accuracy**		
LULC Class	**1992**	**2001**	**Average**
Water	100.0%	85.7%	92.9%
Urban	50.0%	60.4%	55.2%
Barren*	N/A	N/A	N/A
Forest	94.4%	95.7%	95.0%
Agriculture	81.5%	81.9%	81.7%
Wetland*	N/A	N/A	N/A
		Average†	81.20%

B	**% Overall Accuracy**		
Level of Aggregation	**1992**	**2001**	**Average**
6 Categories	79.2%	80.5%	79.9%
3 Categories	81.0%	82.3%	81.7%
2 Categories	89.1%	90.1%	89.6%

C	**% User's Accuracy**		
LULC Class	**1992**	**2001**	**Average**
Water*	N/A	N/A	N/A
Urban	61.5%	75.0%	68.3%
Barren*	N/A	N/A	N/A
Forest*	N/A	N/A	N/A
Agriculture	87.1%	85.3%	86.2%
Wetland*	N/A	N/A	N/A
		Average†	77.23%

D	**% Overall Accuracy**		
Metric	**1992**	**2001**	**Average**
Overall Accuracy (OA)	76.4%	78.0%	77.2%
OA W/Neighbors	89.9%	90.7%	90.3%

E			
Metric	**1992**	**2001**	**Average**
% Agriculture	65.5%	64.6%	65.1%
% Non-Agric Grass	16.0%	17.3%	16.6%
% Other	18.5%	18.1%	18.3%
% User's Accuracy	81.5%	81.9%	81.7%

*Categories were not adequately sampled for statistics to b
†User's accuracies of excluded classes were not included in

Analysis of Land Use Land Cover

Our assessments of land use change between 1992 and 2001 provide several perspectives on landscape dynamics in the region. The aggregate results indicate that the acreage of land altered by humans has increased while unaltered land has decreased (Table 7-12). However, these are small changes (1% - 1.6%). Forest, the predominant land cover class in the unaltered category, remained stable. The real story is within the altered category: agriculture is decreasing while urban land is increasing, amounting to a negligible change in total altered land.

Regional Results Using the NLCD Change Product

According to our analysis of the NLCD Change Product, about half the land is in open agricultural field and grasses (*agriculture* class); a third is in *forest* or *wetlands*; and 16% is urban (pixels with greater than 30% impervious surface). Visual comparison of maps of land use/cover and elevation reveal that most forest is found at higher elevations while urban and agricultural land uses are predominant at lower elevations.

Agriculture (which includes agricultural fields and other grasses, such as large residential yards) was the dominant class in both 1992 and 2001 covering 50% (690,742 acres) and 48% (666,375 acres) of the Pennsylvania highlands, respectively (Table 7-12). According to the NLCD Change Product, the region experienced a net loss of about 24,367 acres of agricultural/grass land in the 9 years between 1992 and 2001. *Forest* cover increased very slightly, remaining at 32% of the area in both 1992 and 2001. *Urban* increased from 15% (202,387 acres) in 1992 to 16% (217,336 acres) in 2001, a change of 14,948 acres. The remaining four classes (*water, barren, rangeland,* and *wetlands*) together covered approximately 4% of the region in both years.

According to the NLCD Change Product, the largest shifts between classes in the nine years between 1992 and 2001 involved *agriculture*, *forest*, and *urban* (Table 7-11). The largest class-to-class transition by acreage was *agriculture* to *forest* (14,798 acres), followed by *agriculture* to *urban*. Although some *forest* land transitioned to *agriculture* during this same time, the net result of the transitions involving *agriculture* are reflected in the decrease in *agriculture* from 1992 to 2001. Furthermore, with more land transitioning from *agriculture* to *forest* than from *forest* to *agriculture* or *urban*, there was a slight increase in *forest* from 1992 to 2001. We know, however, from the accuracy assessment, that the transitions from agriculture to forest and vice-versa are likely greatly overstated. Both *agriculture* and *forest* transitioned to *urban* at modest rates resulting in an increase in *urban* from 1992 to 2001 at a rate of about 1,661 acres per year.

Table 7-11. *Conversion of history of barren, forest, agriculture, and wetland from 1992 to 2001, according to the NLCD Change Product.*

Land Use/Cover Transition	Acres	% of 1992 LULC
Barren to Urban	166	1.4%
Barren to Forest	115	1.0%
Barren to Agriculture	191	1.6%
Barren to Wetland	6	0.0%
Forest to Urban	3,339	0.8%
Forest to Barren	279	0.1%
Forest to Agriculture	8,993	2.0%
Forest to Wetland	468	0.1%
Agriculture to Urban	13,756	2.0%
Agriculture to Barren	896	0.1%
Agriculture to Forest	14,798	2.1%
Agriculture to Wetland	5,033	0.7%
Wetland to Urban	175	0.8%
Wetland to Barren	3	0.0%
Wetland to Forest	8	0.0%
Wetland to Agriculture	186	0.9%

Regional Results Using Data Aggregation

When LULC classes were condensed, the acreage of *altered* land (*developed, barren, agriculture,* and *rangeland*) decreased by 1% and unaltered land (*forest* and *wetland*) increased by 1.6% (Table 7-12). These are relatively small shifts. The most likely explanation is that the amount of land in both categories is fairly stable, with major land use changes occurring between agriculture and urban, both of which are in the *altered* category. That is to say, the loss of agriculture land is offset by the gain in urban land in the *altered* category and therefore, the aggregation to just these two classes does not capture the major shift taking place.

Table 7-12. *Pennsylvania Highlands: Land use/land cover according to the NLCD Change Product (in acres and as percent of region) using three levels of aggregation for 1992 and 2001.*

7-Class

	1992		2001		Change 1992-2001	
Land Use	**Acres**	**Percent**	**Acres**	**Percent**	**Acres**	**Percent**
Water	13,112	0.9%	14,413	1.0%	1,301	9.9%
Urban	202,387	14.6%	217,336	15.7%	14,948	7.4%
Barren	11,874	0.9%	12,594	0.9%	720	6.1%
Forest	442,709	32.0%	444,726	32.2%	2,017	0.5%
Rangeland	44	0.0%	48	0.0%	4	8.5%
Agriculture	690,742	50.0%	666,375	48.2%	-24,367	-3.5%
Wetland	21,825	1.6%	27,202	2.0%	5,377	24.6%
Total	1,382,693	100.0%	1,382,693	100.0%	–	–

4-Class

	1992		2001		Change 1992-2001	
Land Use	**Acres**	**Percent**	**Acres**	**Percent**	**Acres**	**Percent**
Urban/Barren	214,261	15.5%	229,929	16.6%	15,668	7.3%
Agriculture/Rangeland	690,786	50.0%	666,423	48.2%	-24,364	-3.5%
Forest/Wetland	464,534	33.6%	471,928	34.1%	7,394	1.6%
Water	13,112	0.9%	14,413	1.0%	1,301	9.9%
Total	1,382,693	100.0%	1,382,693	100.0%	–	–

3-Class

	1992		2001		Change 1992-2001	
Land Use	**Acres**	**Percent**	**Acres**	**Percent**	**Acres**	**Percent**
Altered	905,048	65.5%	896,352	64.8%	-8,695	-1.0%
Unaltered	464,534	33.6%	471,928	34.1%	7,394	1.6%
Water	13,112	0.9%	14,413	1.0%	1,301	9.9%
Total	1,382,693	100%	1,382,693	100%	–	–

Regional Results for Agriculture Using Digital Aerial Photographs

We conducted two analyses to estimate changes in agriculture as distinct from development-associated grasses: (1) NLCD Change Product *general accuracy assessment*; and (2) analysis of agriculture using DOQQs. We did not compare the land cover change found in the NLCD Change Product to an extrapolation of land cover area based on our 500-point random sample due to the absence of two categories in the sample and the use of a non-stratified sample, as described in Stehman and Czaplewski (1998). This methodology is more complicated than the pixel by pixel assessment as it would have required classifying as many as 5,000 reference cells. We, therefore, did not attempt it due to time constraints.

(1) NLCD Change Product General Accuracy Assessment

As reported under the general accuracy assessment, the NLCD classification for *agriculture* included 16% grasses associated with development in 1992 and 17.3% in 2001 (Table 7-10.E). Applying these percentages to the NLCD data, results in a decrease of 22,649 acres of agricultural land between 1992 and 2001, and an increase in non-agricultural grasses of 4,764 acres (Table 7-13). Although this method takes into account mis-classifications in the agriculture class (calling a cell *agriculture* when it's another land cover class), it does not take into account mis-classifications in the other direction (calling a cell another land cover class when it's actually *agriculture*).

It is difficult to determine what to do about the high number of mis-classified cells. Mis-classifications go in both directions (other classes mis-classified as *agriculture*, and *agriculture* mis-classified as other classes), so it is not possible to accurately do the accounting in both directions based on the data available from the accuracy assessment. In other words, it is not possible to get a truly accurate number for the amount of land in the *agriculture* class to use as a basis.

(2) Analysis of Agriculture Using DOQQs

Closer examination of the 232 locations on the 1992 DOQQs and the 219 locations on the 1999 DOQQs identified as *agriculture* revealed that 21% in 1992 and 25% in 1999 were in fact non-agricultural grasses (Table 7-14). Applying these percentages to the acres reported in the NLCD Change Product *agriculture* class, we have another estimate of changes in agricultural lands and changes in development-associated grasses. According to this analysis, agricultural lands have decreased by 52,570 acres between 1992 and 2001 (5,840 acres/year) (Table 7-15). Admittedly, this is not a perfect analysis either, since by using the NLCD Change Product totals for the *agriculture* class as a basis, we did not take into account mis-classifications.

Using the same methodology, we have estimated an increase in development-associated grasses of 28,200 acres between 1992 and 2001. This brings the total increase in developed land use to close to 44,000 acres, or almost 5,000 acres/year (Table 7-16).

In summary, the land cover analysis shows that agricultural lands have declined by between 2,500 and 5,840 acres per year over the 9 year period, for a total loss of between 22,650 and 52,570 acres. Comparatively, the census of agriculture indicates there was a decrease of 44,930 acres, or 8,986 acres/year between 1997 and 2002.

Table 7-13. *Pennsylvania Highlands: Estimate of changes in agricultural lands and non-agricultural grasses using NLCD Change Product data and applying percentages of active agriculture and non-agricultural grasses in the total agriculture class as found in general accuracy assessment using DOQQs.*

	1992		2001		Change 1992 - 2001	
	%	Acres	%	Acres	%	Acres
Active Agriculture	66%	453127	65%	430478	-5%	-22649
Non-agricultural grasses	16%	110519	17%	115283	4%	4764
Mis-classified	19%	127787	18%	119948		
Total	100%	690742	100%	666375		-24367

Table 7-14. *Pennsylvania Highlands: Pennsylvania Highlands: Estimates of active agriculture and non-agricultural grasses from analysis of agriculture using DOQQs. Shows number of sample cells classified as agriculture on the DOQQs, that are either farmland or non-agricultural grasses. Numbers for 2001 are derived from a linear extrapolation of the change between 1992 and 1999 out to 2001.*

	1992		1999		2001 linear extrapolation
	# of Sample Cells	% of Total Agriculture	# of Sample Cells	% of Total Agriculture	% of Total Agriculture
Active Agriculture	183	79%	164	75%	74%
Non-agricultural grasses	49	21%	55	25%	26%
Total	232	100%	219	100%	100%

Table 7-15. *Pennsylvania Highlands: Estimate of change in active agriculture and non-agricultural grasses. Total acres are from the NLCD Change Product agriculture class; percentage split between active agriculture and non-agricultural grasses is from the sample analysis of agriculture class using DOQQs (see Table 7-14).*

	1992		2001		Change 1992 - 2001	
	%	Acres	%	Acres	%	Acres
Active Agriculture	79%	545686	74%	493118	-10%	-52569
Non-Agricultural Grasses	21%	145056	26%	173258	19%	28202
Total		690742		666375		-24367

Synthesis of Findings: Regional Results

The Pennsylvania Highlands is changing from an agricultural/pastoral landscape to one where development, agriculture and forests are interspersed. According to our analyses, *agriculture* is the most prevalent LULC type in, followed by *forest* and then *urban*. *Forest* cover is relatively stable, while *agriculture* is decreasing in acreage and *urban* land is increasing.

One of the concerns about the NLCD Change Product is that it does not differentiate between agricultural fields and other grasses associated with development. Our in-depth analysis of agricultural cells, however, does allow us to make some adjustments to the NLCD findings. The NLCD Change Product shows a loss of 24,367 acres of *agriculture*, which is a net result of both loss of agricultural lands and the gain of non-agricultural grasses associated with development. Based on our

analysis of the proportion of *agriculture* lands comprised of urban grasses versus actual farmland, the amount of urban grass grew between 1992 and 1999 by somewhere between 4% and 19% percent, with an increase of between 4,764 and 28,202 acres. Farmland decreased by between 5% and 10%, with a loss of between 22,649 and 52,569 acres (Tables 7-13 and 7-15).

The detailed analysis of agricultural lands supports our assumption that *urban* area is increasing faster than indicated by the NLCD Change Product classification since the *urban* class is based solely on impervious surface detection (greater than 30% of the pixel). It is likely, therefore, that new development between 1992 and 2001 could be as high as 43,900 acres (Table 7-16). This is the total of 15,000 urban, 700 barren, and 28,200 grasses. This is corroborated in recent work by Irwin and Bockstael (2007) in which they found in Maryland that the 2001 NLCD underestimated the amount of urbanization that they were able to identify in aerial photos, particularly in low density residential sprawl, such as is occurring in the Highlands. In our projection of future development in the region we applied a development rate of 1,870 acres/year, which is the historical rate of transition from non-developed cells to developed cells according to the NLCD *urban* class between 1992 and 2001. This is a very conservative rate given our estimate of an increase of between 2,274 and 4,877 additional acres of development and development-associated grasses each year.

Table 7-16. *Pennsylvania Highlands: Estimates of new development between 1992 and 2001. Both estimates are from the accuracy assessment of the NLCD Change Product using DOQQs. Low estimate is based on % of cells that were classed as agriculture in the NLCD Change Product that were found to be development-associated grasses; the high estimate is based on the % of cells that were found to be development-associated grasses looking at only those cells that were correctly classified as agriculture/grasses. The difference between the two is largely due to mis-classification of cells in the agriculture/grasses class.*

	Low		**High**	
	1992	**2001**	**1992**	**2001**
Urban/Barren	214261	229929	214261	229929
Development-Associated Grasses	110519	115283	145056	173258
Total Developed Land	324780	345212	359317	403187
Acres of New Development		20432		43870
Change from 1992 to 2001		6%		12%
Agricultural Fields	453127	430478	545686	493118
Acres of Agriculture Lost		-22649		-52568
Change from 1992 to 2001		-5%		-10%
Forest	442709	444726	442709	444726
Acres of Forest Lost		2017		2017
Change from 1992 to 2001		0.5%		0.5%

County and Watershed Results Using the NLCD Change Product

All results reported here are for only the portion of the county that lies within the Highlands boundary. Table 7-17 shows the percent of each county that is in the Highlands.

Table 7-17. *Pennsylvania Highlands: Percentage of each county that is within the Highlands Region.*

County	% in Highlands
Berks	57.2%
Lancaster	49.1%
Bucks	42.8%
Montgomery	41.5%
Lehigh	35.9%
Lebanon	35.4%
Chester	28.7%
Northampton	27.7%
Dauphin	12.8%
York	7.4%

The dynamics we observed vary by county. According to the NLCD Change Product, development is occurring more rapidly and to a greater extent in Northampton, Lehigh and Dauphin counties, predominantly near roads, previously developed areas, and larger cities (Figure 7-11). Bucks County, on the other hand, which is closest to the NY/NJ metropolitan area, had the least amount of new development (Figures 7-9 and 7-10). Figure 7-11 shows the percent of undeveloped land that became developed between 1992 and 2001 for each county.

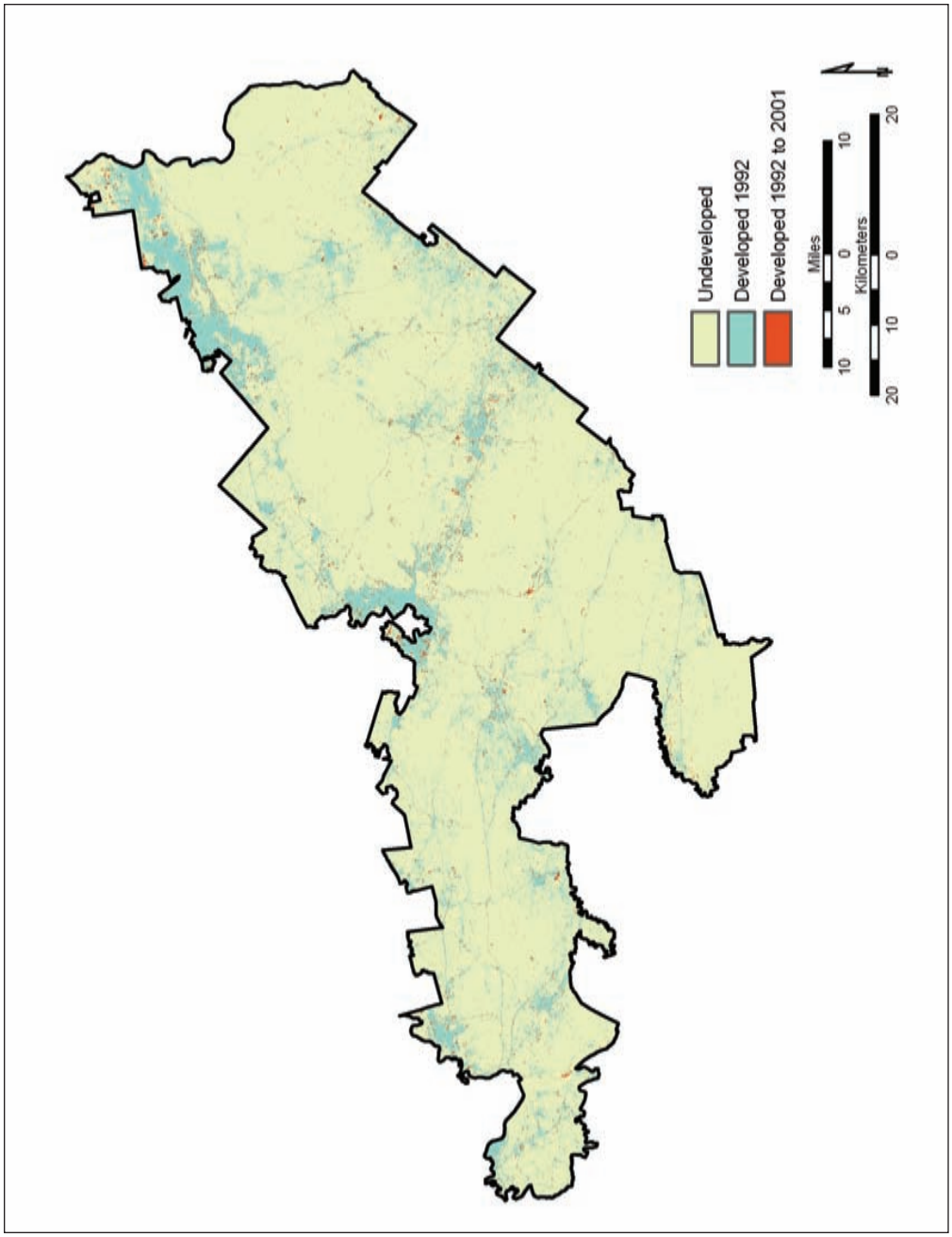


Figure 7-9. *Pennsylvania Highlands: Areas developed prior to 1992 and between 1992 and 2001.*

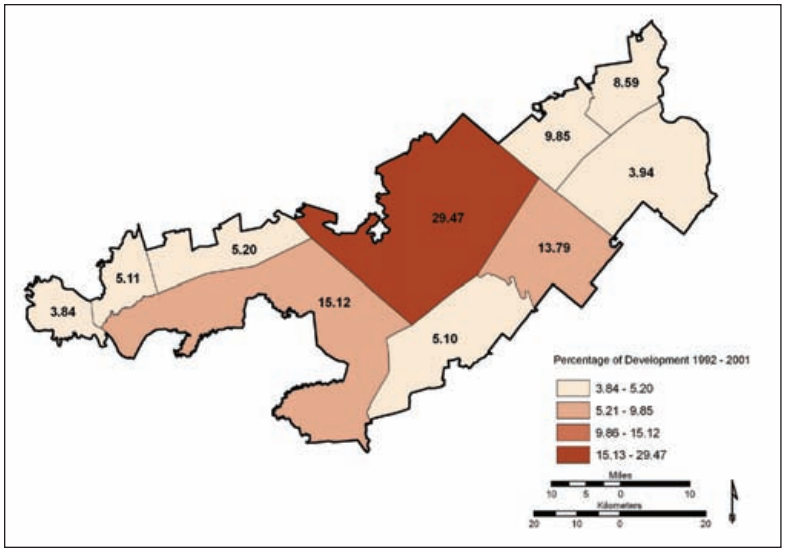


Figure 7-10. *Pennsylvania Highlands: Percentage of total new development in the Highlands region that occurred in each county between 1992 and 2002*

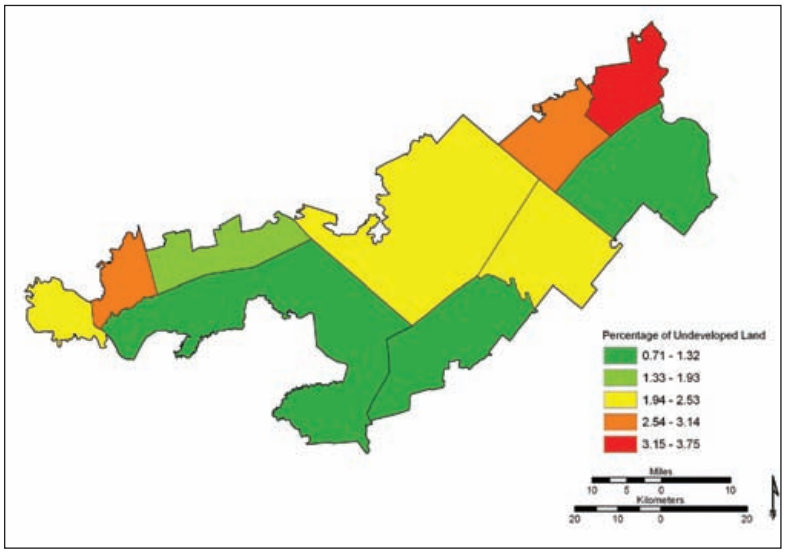


Figure 7-11. *Pennsylvania Highlands: Percentage of 1992 undeveloped land in the portion of each county that is in the Highlands that became developed between 1992 and 2001.*

Berks and Lancaster were the counties with the most *urban* area in both 1992 and 2001, whereas Northampton and Lehigh were proportionally the most urbanized with 34% and 33% each (Table 7-18). *Urban* land cover increased in all counties from 1992 to 2001. The counties with the most acreage converted to *urban* in the 9 year period were Berks, Lancaster, and Montgomery (Table 7-19). Berks, Dauphin, and Montgomery had the greatest increase in development, expressed as percent increase from 1992 (Table 7-18). All watersheds increased in development acreage with the Middle Schuylkill River having the greatest increase, and also the most developed land by 2001 (Appendix 7).

Table 7-18. *Area of urban land by county (in acres and percent of the portion of the county that is in the Highlands) in 1992 and 2001, and change during the intervening time period in acres and as a percent of urban land in 1992.*

	1992		2001		Change 1992-2001	
County	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**
Berks	43,524	13.7%	47,929	15.1%	4,405	10.1%
Bucks	13,678	8.0%	14,267	8.4%	588	4.3%
Chester	9,482	6.8%	10,244	7.3%	762	8.0%
Dauphin	8,597	18.9%	9,361	20.6%	764	8.9%
Lancaster	36,105	11.7%	38,365	12.4%	2,260	6.3%
Lebanon	9,633	11.7%	10,411	12.7%	777	8.1%
Lehigh	25,969	32.5%	27,442	34.3%	1,472	5.7%
Montgomery	24,086	18.6%	26,147	20.2%	2,061	8.6%
Northampton	23,059	34.4%	24,343	36.3%	1,284	5.6%
York	8,254	19.1%	8,828	20.4%	573	6.9%
Total	202,387		217,336		14,948	7.4%

Table 7-19. *Pennsylvania Highlands: Acreage of new development by county from 1992 to 2001, and percentage of new development in the Highlands that occurred within each county.*

	1992 - 2001	
County	**Acres**	**% of Total**
Berks	4,405	29.5%
Lancaster	2,260	15.1%
Montgomery	2,061	13.8%
Lehigh	1,472	9.9%
Northampton	1,284	8.6%
Lebanon	777	5.2%
Dauphin	764	5.1%
Chester	762	5.1%
Bucks	588	3.9%
York	573	3.8%
Total	14,948	100%

Lancaster and Berks had the most land in *agriculture* in both time periods. All counties, except York, decreased in agricultural land from 1992 to 2001. The greatest losses occurred in Berks, Montgomery, and Lancaster, with a combined loss of 15,600 acres over 9 years. This represents 4% of the 1992 agricultural lands for these counties combined, but this number is inflated by the very high losses in Montgomery County. During this period, it lost approximately 8% of its agricultural land. (See tables in Appendix 7.) Twenty-six of the 33 watersheds lost agricultural lands, with Perkiomen Creek having the greatest loss (see tables in Appendix 7).

Dauphin, Northampton, and York had the least amount of *forest* in 1992 and 2001, and Lancaster, Dauphin, and Northampton Counties had the lowest percent coverage of *forest.* (See tables in Appendix 7.) *Forest* land decreased in acreage from 1992 to 2001 in five of the ten counties, but increased in the other five. York County had the greatest decrease in *forest* acreage, and Montgomery County had the greatest increase.

All counties, and 30 of 33 watersheds, gained *wetlands* from 1992 to 2001. (See tables in Appendix 7.) Berks County experienced the greatest increase in *wetland* acreage over the nine year time period, while at the watershed scale, Perkiomen Creek had the greatest increase in *wetland* acreage from 1992 to 2001.

CHAPTER 8 MODELS OF LAND USE / LAND COVER CHANGE

Key Findings

Connecticut

The factors that were best able to predict where development occurred within each town were:
- proximity to roads, existing development, lakes, and agricultural lands
- topography
- soils

The factors that were best able to predict where development occurred within the region were:
- poverty rate
- population over age 65
- income
- unemployment
- proximity to development
- elevation

With a medium development rate, there would be 8,930 acres of new development plus an estimated 17,100 acres of development-associated grasses by 2022.

Pennsylvania

The factors that were best able to predict where development occurred within each county were:
- proximity to roads, existing development, and contiguous land use
- employment in the construction sector.

The factors that were best able to predict where development occurred within the region were:
- proximity to existing development, roads, railroad lines, and urban centers
- bedrock geology

Using the historical development rate, there would be 39,260 acres of new development plus an estimated 70,700 acres of development-associated grasses by 2022.

Introduction

Our goals in modeling land use/land cover change were to:

- understand the factors that have contributed to both the rate and the spatial distribution of land use change in the region
- create a map of development *suitability* showing the places most vulnerable to change post-2001 in Pennsylvania and post-2002 in Connecticut based on those factors that have made land historically attractive for development
- use that map of development *suitability* to project where development is most likely to occur between now and 2022

Throughout we will use the word *suitability* when referring to maps that illustrate those areas that, although not yet developed, have the land qualities that have been historically attractive for development. In the modeling arena something is "suitable" for an activity or use based on agreed upon criteria, in which case our agreed upon criteria are those that humans have used, whether consciously or unconsciously, in the past to decide where to build homes, shopping centers, businesses, roads, airports, etc. Therefore "suitable" means "historically preferred" for those activities, but to say "percent historically preferred" throughout this report would have been very cumbersome. Our assumption is that land that shares those characteristics that determined where development occurred in the past is going to be attractive for more of that activity. Suitability is, therefore, a value judgment from the perspective of humans over time, not from the viewpoint of the beaver, the frog, the buffalo, the snake, the butterfly or the conservationist. Furthermore, what's suitable for a forester is not suitable for a farmer.

General Modeling Approach

To accomplish our goals we compiled a comprehensive suite of spatially-distributed variables for Connecticut and Pennsylvania that included (1) a time series of land use/land cover (LULC) derived from satellite image classification, and (2) those spatially-distributed biophysical, economic, and demographic variables that we hypothesized have influenced human land use decision making in the last 10 - 15 years. We have summarized here those data sets, their source, creation, and spatial structure and then explained how they allowed us to identify the factors, among those tested, that best explain the historical spatial pattern of development in the region.

Analysis of the ability to predict land use change was done comparing two approaches. The first, the land use change model known as GEOMOD, was developed at State University of New York, College of Environmental Science and Forestry (Hall *et al.,* 1995, Pontius *et al.,* 2001), and is now part of the IDRISI geographical information system (GIS) software package. The second uses logistic regression via the LOGISTICREG module in IDRISI to create a suitability image. This was done to match the type of model used in the New York/New Jersey Highlands study and to select the best model possible. GEOMOD results were used in the final modeling because it had a slightly higher predictive ability.

We constructed separate land use change models for Connecticut and Pennsylvania utilizing the same basic methodology with some modifications where needed. Separately, for each variable, we created development *suitability* maps using the GEOMOD model. We used the statistical procedure called the receiver operating characteristic (ROC) to evaluate the "fit" of each of the 100+ *suitability* maps to a validation map of LULC. For multiple combinations of factors, which often explain more spatial variability than can factors in isolation, we created development *suitability* maps using both logistic regression and the GEOMOD weighting procedure. For this step, sets of individual *suitability* maps with "better" fit among those tested individually were combined for analysis. Again, the ROC statistic was used to evaluate the fit of these multiple factor *suitability* maps to the validation map. Once the method (logistic regression or GEOMOD) and the set of variables that yielded the best validation fit were identified we projected future land use change to year 2022.

Data

All mapped data sets included in the analysis, both vector and raster format, were converted to grids or re-sampled to grids that match the spatial extent and resolution of the time series LULC maps.

For Connecticut, all grids were projected to Connecticut State Plane, units = feet, North American Datum 1983. Each grid consists of 3,009 rows and 2,497 columns with each grid cell representing 100 feet x 100 feet on the ground.

For Pennsylvania, all grids were projected to Albers Equal Area Conic, units = meters, North American Datum 1983. Each grid consists of 4,440 rows and 5,986 columns with each grid cell representing 30 meters x 30 meters on the ground.

Dependent Variable

The dependent variable was the presence/absence of transition over time of undeveloped land uses (*e.g.,* forest or agriculture) to developed land use. We derived the amount and pattern of transition to developed land use from existing LULC time series created by classifying satellite imagery.

Connecticut

We used LULC data produced by CLEAR for years 1985, 1990, 1995, and 2002 (see Chapter 7, Analysis of Land Use/Land Cover). Each of these maps consists of 11 classes of LULC information as follows: development, turf and grass, other grasses and agriculture, deciduous forest, coniferous forest, water, non-forested wetlands, forested wetlands, tidal wetlands, barren lands and utility row. For example, for each undeveloped cell in 1985, we could determine via map overlay if a transition to development by year 1995 had occurred or not.

An accuracy assessment using all 11 classes, performed by CLEAR (James Hurd, personal communication) resulted in overall classification accuracies of 86%, 85%, 88%, and 82% for years 1985, 1990, 1995, and 2002, respectively. More importantly, since we are modeling spread of development, the user's accuracies for development are 90%, 93%, 93%, and 95% for years 1985, 1990, 1995, and 2002, respectively.

Pennsylvania

For Pennsylvania, we used the 1992 – 2001 LULC Change Product created by the USGS. From this, we extracted data sets of LULC for 1992 and 2001 (see Chapter 7, Analysis of Land Use/Land Cover). Each of these maps consists of 8 classes of LULC information corresponding to Anderson Level 1 categories: water, urban, barren, forest, rangeland, agriculture, wetland, and perennial ice/snow. With these two points in time, for each undeveloped cell in 1992, we determined via map overlay if a transition, for example, to the urban LULC class by year 2001 had occurred or not.

At the time of this report, the change product was not released to the public and a formal accuracy assessment was not yet completed by the USGS. A preliminary assessment by the USGS of the product for Kentucky and Utah indicates approximately an 85% agreement between the change product and a manual interpretation of "meaningful" change (Coan 2006, p. 32). We conducted our own accuracy assessment for the product within our study area and found an overall accuracy of 76% and 78% for the 1992 and 2001 LULC data sets, respectively (see Accuracy Assessment of NLCD 1992 – 2001 National Land Cover Change Product in Chapter 7, *Analysis of Land Use/Land Cover*). The user's accuracy of *urban* was 50% and 60% in 1992 and 2001, respectively.

Independent Variables

In order to determine which factors are most highly correlated with the location of land use change during the time period of analysis, we compiled or created over 120 spatially-distributed data sets for the Connecticut and Pennsylvania Highlands (see Appendices 6 and 7). They include physical factors that may increase the cost of building and/or make a site more or less desirable to

buyers or builders. These are often related to terrain and include such things as slope, soil stability, sunlight, scenic view, water availability and suitability for agriculture. Others, also related to the economics of site selection, are infrastructure considerations such as distance from important towns, or distance from roads, that give people access to goods, services, and social connections. Historically in the years of early development, settlements were located near navigable waterways. Demographic factors may also be significant, although they may be correlated with the biophysical and economic factors. For instance, we hypothesized that density of age class (age > 65) may play a role in determining what lands will be for sale, or (age <20) desirable to young families with children.

Constraints Map

The basic constraints maps (Figure 8-1) delineate areas that are excluded from analysis. Excluded areas were those classified as water in any year of the LULC data or in protected open space (*e.g.,* conservation easements, conservation ownerships, or public ownership).

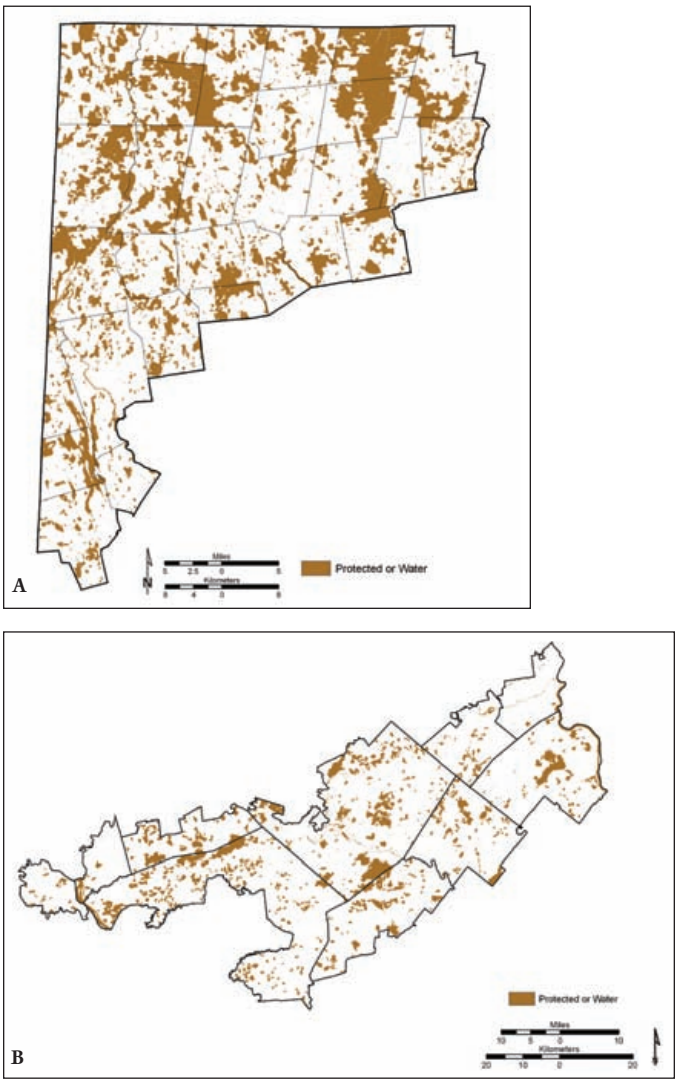


Figure 8-1. *Water and protected land in A) Connecticut Highlands and B) Pennsylvania Highlands.*

General Introduction to GEOMOD

GEOMOD tests the assumption that factors that made land desirable for development in the past are good predictors of where future development is likely to occur. Through an iterative process of testing individual factors, and combinations of factors, this approach allowed us to identify land most vulnerable to new development pressure in the Highlands. In order for this study to be comparable to the NY/NJ study we also tested the predictive strength of GEOMOD-based maps of "likelihood of change" to those created using binomial logit regression, as used in the NY/NJ study. Our intent was to deliver an analysis that is consistent with the methods used in the NY/NJ study in order to guarantee across-region comparisons, but also to improve upon the earlier approach through the use of sensitivity analysis and model validation, which are central to the GEOMOD approach. For a fuller description of GEOMOD and a comparison of GEOMOD to the methodology employed in the NY/NJ study, see Appendix 4.

Stratified and Non-Stratified Modeling

We tested the importance of a long list of factors that make a location more or less suitable, or attractive, for development. Using GEOMOD, there are two ways to create a *suitability* map for a large region. The first method creates discrete classes within each data set (*e.g.,* dividing an elevation gradient in a number of intervals) and computes the *suitability* for development of each class of each factor using the data *pooled across the region* (*e.g.,* the proportion of cells in each class of each factor available for development at the beginning of the calibration time period (1985 in Connecticut and 1992 in Pennsylvania) that became developed during the calibration time period, across the whole region). We refer to this hereafter as *non-stratified* calibration. The second method computes the *suitability* for development for each class of each factor *separately by political unit* or other spatial strata (towns in Connecticut and counties in Pennsylvania). A stratified *suitability* map is created by determining for each town or county in isolation the proportion of cells in each class of each factor available for development at the beginning of the calibration time period (1985 in Connecticut and 1992 in Pennsylvania) that became developed during the calibration time period in that town or county. This we call *stratified* calibration. Factors were tested with and without stratification, unless the unit of observation was coincident with the unit of stratification (*e.g.,* factors with data collected at the town-level in Connecticut).

GEOMOD Suitability Maps

Methods

Model Calibration

By binning (*i.e.,* dividing) each factor into multiple numbers of intervals or classes, we were able to test the sensitivity of the model to data aggregation and retain the scheme with the highest predictive ability. Within each area (Connecticut and Pennsylvania), we binned the attribute values that are measured on an interval- or ratio-scale into 10, 20, 30, 50, and 100 classes of equal quantity of cells (*i.e.,* quantile reclassification). We did not bin factors measured on nominal- or ordinal-scale.

We then used the IDRISI (Andes release 2006) version of GEOMOD (Hall *et al.,* 1995, Pontius *et al.,* 2001) to create a *suitability* map for each factor individually. Both stratified and non-stratified calibrations were carried out for most factors so that two *suitability* maps were created for each. The *suitability* value is calculated for each bin, or division, in a factor map. GEOMOD does

this by calculating the proportion of cells in each bin that were available for development in the calibration data that actually became developed over the calibration time period. In our models, cells available for development were those not classified as developed in the LULC map from the earliest time period (1985 in Connecticut and 1992 in Pennsylvania), not classified as water in any of the years for which LULC imagery are available, and not within protected areas.

When LULC data sets for more than two time periods are available, calibration is normally carried out using the LULC change between two of the earlier time periods. LULC change between two later time periods is then used for validation. This being the case for Connecticut, we used the 1985 to 1995 time period for calibration and 1995 to 2002 for validation. In Pennsylvania, we had access to LULC data sets from only two time periods (1992 and 2001). In order to have separate calibration and validation data sets, we randomly selected 80% of the cells available for development in 1992 to be used in calibration and set aside the remaining 20% for use in model validation.

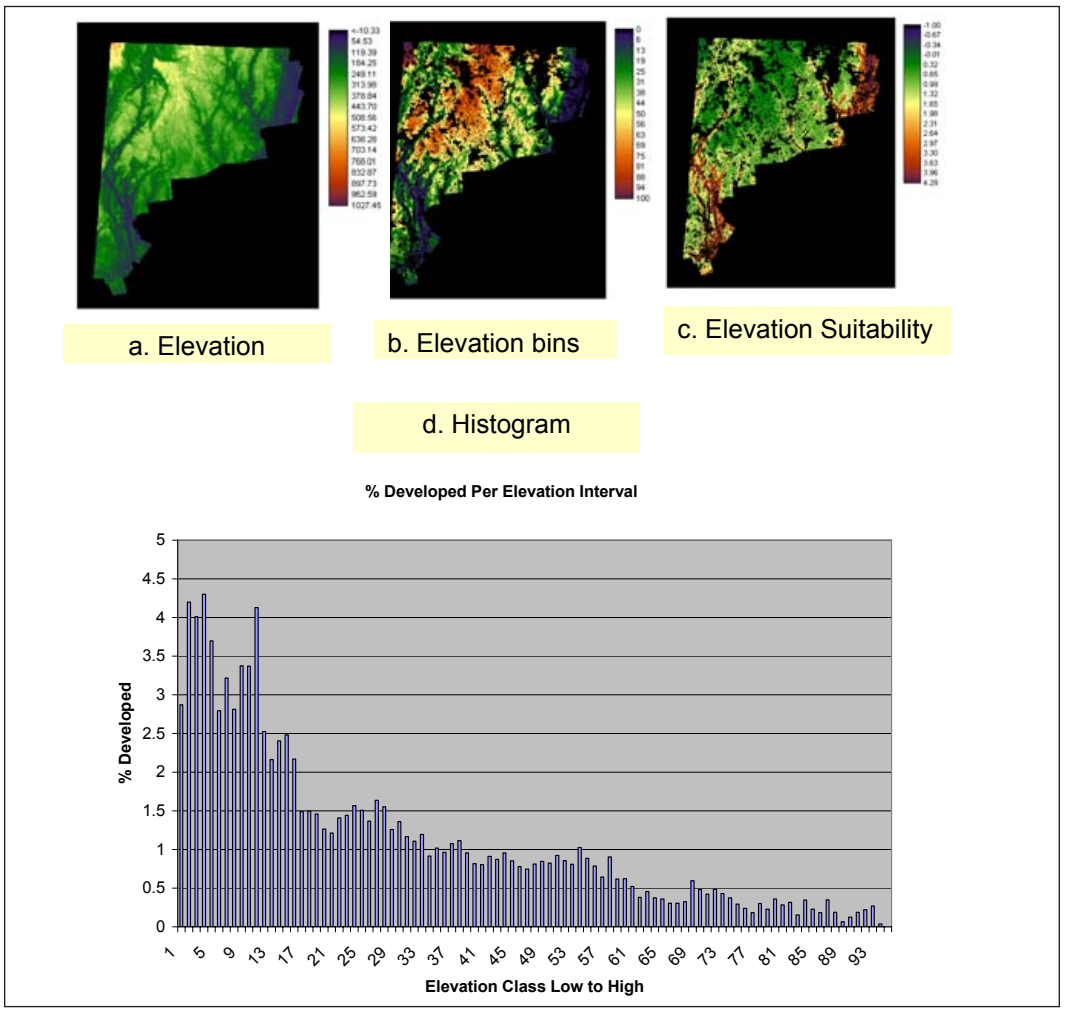


Figure 8-2. *Illustration of operations involved in creation of individual suitability map based on topographic slope. A) Map of elevation. B) Map of elevation classified into intervals. C) Suitability map created by assigning percent developed values in histogram (D) to elevation interval map (B). D) Histogram showing percent of cells available for development in each elevation interval that were developed between starting and ending time periods. Much more development is observed at lower versus higher elevations.*

GEOMOD produces a text file, from which frequency histograms can be created that show the percent of development that occurred in each bin for each factor (*e.g.,* slope). The pattern of this histogram reveals a lot about the predictive strength of individual factors (Figure 8-2.D). This "percent developed" value might also be thought of as an impact index indicating the historical development impact averaged across cells possessing that same land quality. The *suitability* value thus derived for each bin of each factor map is assigned back to the cells that will be used for validation (or future simulation), depending on the type of validation used. This is called the *suitability* map. The *suitability* number in each map cell is, therefore, a relative value that separates one plot of land from another with respect to its potential likelihood of being selected for development.

This sequence is illustrated in Figure 8-2. With the example given it is clear that lower elevations were preferred over higher elevations during the calibration period. In general, high variation in *suitability* values across bins will be a more powerful predictor of where change is likely to occur in the future than low variability (*e.g.,* all bins of approximately equal percentage). Also, a general trend in the histogram of "percent developed" values across bins is a visual indicator of possible predictive power prior to more formal testing. The sequence of variable map, binned variables, histogram, and suitability map is shown in appendix 6 (Connecticut) and 7 (Pennsylvania) for each factor retained in the final models.

In Connecticut, because sequential time periods were used for calibration and validation, factors that may have changed from 1985 to 1995 for which we had newer information (*e.g.,* distance from 1995 development) were re-binned for the 1995 to 2002 model run with the class breaks used for the 1985 factor maps, but with new *suitability* values, based on the 1995 data, assigned to these updated factor maps. As the calibration and validation data sets were not separate in time, this procedure was unnecessary in Pennsylvania.

Validation

After creating *suitability* maps, based upon the calibration using 80% of candidate cells in Pennsylvania and all candidate cells in Connecticut, we then compared each *suitability* map to the validation data for that area using the receiver operating characteristic (ROC) statistic to assess "goodness of fit." This procedure allowed us to find the *suitability* map that will identify the most likely locations of future development in each region. In Connecticut, the 1995 suitability map was validated by comparison to the observed LULC change, or lack thereof, between 1995 and 2001 on all land available for development as of 1995. In Pennsylvania, the validation data set consisted of the withheld 20% of cells available for development in 1992. The suitability map was validated by comparison to the observed transition or non-transition of these candidate cells to development between 1992 and 2001.

We used the ROC statistic to estimate "goodness of fit" between the suitability map and what actually happened in the validation period, because it is an appropriate means to compare continuous scale data such as *suitability* or likelihood measures to categorical scale data such as presence/absence. We used the ROC module available in IDRISI, which required that we mask out from the analysis all cells meeting one or more of the following criteria: (1) developed class in earliest time of the validation period (1992 in Pennsylvania and 1995 in Connecticut); (2) water class in any of the years for which LULC data were available (two time periods in Pennsylvania and four in Connecticut); or (3) protected lands. In Pennsylvania, we also excluded the cells used in calibration (80%). We evaluated the match between the *suitability* map created from each factor and the validation data set in 200 equal-interval thresholds going from high to low suitability. At each threshold, the ROC module assesses how many cells in that interval became developed and uses

this information in computing the overall ROC value, the output of interest. Higher values of the ROC statistic indicate a "better" fit and generally range from 0.5 to 1, with 0.5 indicating a random fit (*i.e.,* no ability to predict spatial location of development) and 1 indicating a perfect fit. A list of all factors tested, the number of bins per factor that produced the highest ROC, and highest ROC statistic for each factor tested are summarized in Appendices 6 and 7.

Combining Suitability Maps

To create a composite *suitability* map, one or more *suitability* maps for individual factors are entered into a weighted average. This is done because often a combination of factors will explain variation in the validation data better than any one factor alone. Cells take on the average of *suitability* values as follows:

suitability for development per grid cell= $(\text{Weight}_1 * \text{SUIT}_{(\text{factor1})} + \text{Weight}_2 * \text{SUIT}_{(\text{factor2})} + \text{Weight}_3 * \text{SUIT}_{(\text{factor3})} \ldots\ldots)/\text{Sum of all weights}$

where SUIT = *suitability* map of each individual factor retained in the model.

The relative importance of one *suitability* map over another can be incorporated by applying a weight. Often equal weights are applied, but methods such as principle components analysis, proportional difference analysis, or multi-criteria assessment can be used to assess relative influence. All of these seemed rather cumbersome, however, given the number of independent factors to be tested. We therefore developed a FORTRAN model to iteratively adjust weights on each factor with the goal of maximizing ROC. This program allowed us to test multiple combinations of final *suitability* maps and driver weights in the attempt to achieve the maximum possible ROC statistic.

We explored several groupings of 12 *suitability* maps each in order to find the one combination of factors that would produce a composite *suitability* map with the highest ROC. We divided the *suitability* maps into those that were created with stratification (by town or county depending upon region) and those that were not. Within each of these two categories we lumped and evaluated four groups based on ROC values: (1) top 12 physio-economic drivers; (2) top 12 demographic drivers; (3) overall top 12 drivers; and (4) top 6 demographic and top 6 physio-economic factors (Appendices 6 and 7).

Each set of 12 were entered into the FORTRAN optimization program, which adjusts individual factor weights to optimize the group's ROC value. As before, this was done by comparing the *suitability* map to the validation data set. After one optimization run with all 12 drivers included, the program sequentially removes individual drivers from the set until none are left and repeats the iterative adjustment of factor weights after each removal. The removal procedure is carried out twice, in order of increasing individual ROC and also in order of increasing weights derived from the first run with all drivers included. A weight of zero indicates that the factor was eliminated from the set during the calibration process.

Comparison of Suitability Maps

It is not possible to directly compare *suitability* values between maps, either at the individual cell location or the total range of values derived. Differences in the weighting schemes employed to create the different *suitability* images influence the range of values obtained in each. Therefore, a particular cell's risk of becoming developed should be assessed by comparing that cell's *suitability* value to others within the same *suitability* image only. Comparison of the value in one *suitability* image to that in another is meaningless.

In Connecticut and Pennsylvania, we compared the four *suitability* images created with GEOMOD with the observed pattern of development in the time period that followed, *i.e.,* the validation time period. To do this we binned the *suitability* values of each map into 100 bins and looked for the proportion of cells within each bin that became developed in the validation time period. As the *suitability* value increases we would expect to see an increase in the proportion of cells in the bin that became developed.

Results

Connecticut

ROC values for all individual factors tested ranged between 0.758 and 0.500 when stratified by town, versus between 0.739 and 0.507 when not stratified (Appendix 6). Although the difference is only 0.019, stratification by town captured slightly more of the variation in the development pattern and intensity than non-stratification, producing a slightly better model fit. The three individual *suitability* maps with the highest ROC value (0.758) created *with stratification* were 1) distance from major roads, 2) percent population over 65, and 3) population density ages 18 to 29. The lowest factor was distance from forest cover with an ROC of 0.50.

The highest ROC values among suitability maps created *without town-level stratification* were (1) percent of population below poverty threshold (0.739), (2) percent of population over age 65 (0.736), and (3) median household income (0.736). Tables in Appendix 6 report all individual factors tested under both the *stratified* and *non-stratified* calibration scheme, the number of bins that produced the best ROC statistic, and individual ROC values.

The highest ROC for a composite suitability map, shown in Figure 8-3, was 0.788, which is higher than the highest individual ROC of 0.758. It is based on retaining 10 of the 12 physio-economic drivers stratified by town (Table 8-1). Those retained are:

1. distance from major roads,
2. distance from utility right-of-ways (1995),
3. density of 1995 development in a 4,200 ft radius,
4. distance from densely developed areas (50% developed within 600 ft radius in 1995),
5. drainage class of major soil component,
6. distance from lakes of size 4,264 to 852 acres,
7. distance from primary routes,
8. runoff potential class for soils,
9. distance from other grasses & agriculture (1995), and
10. topographic slope.

Those dropped were (1) distance from interstate exits, and (2) starting time (1995) land cover.

The group with the second highest ROC ranking included the top six physio-economic drivers and top six demographic drivers combined, also stratified by town. Although, this suite of factors includes all three of the top individual stratified factors, its ROC of 0.781 was slightly lower than that of the first group. Final *suitability* values ranged from 0.787 to 0.749, all of which were higher than that achieved by any individual factor by itself. The results of all groupings both stratified and non-stratified are summarized in Appendix 6. This table reports the groups of individual *suitability* maps entered into the optimization program to create composite *suitability* maps, the

final weight assigned to each factor within each group, the positive or negative direction of the influence of each factor, and the final composite ROC value attained. A weight of zero indicates that the factor was eliminated from the set during the calibration process.

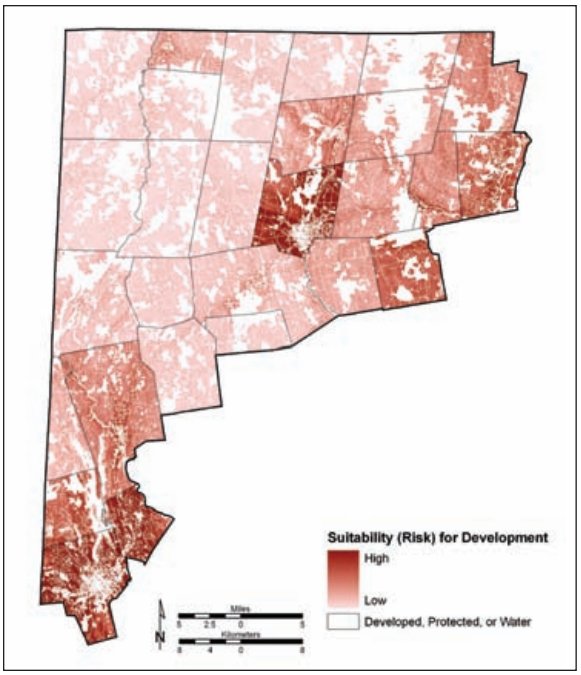


Figure 8-3. *Connecticut Highlands: Most predictive 1995 suitability map created using GEOMOD-approach and drivers stratified by town. (ROC = 0.788)*

Table 8-1. *Connecticut Highlands: Final set of drivers used to create the GEOMOD-based best-fit suitability map stratified by town. The number of bins per factor, individual factor ROCs, weights assigned to each driver during optimization, and the sign of the relationship between the driver and development are shown.*

Driver name (stratified by town)	Number of bins	ROC	Weight	Sign
Distance from major roads	10	0.758	3.190	Negative
Distance from utility right-of-ways (1995)	10	0.755	1.857	Negative
Density of 1995 development in a 4,200 ft radius	10	0.755	2.048	Postive
Distance from densely developed areas (50% developed within 600 ft radius in 1995)	10	0.754	1.286	Negative
Drainage class of major soil component	N/A	0.754	1.381	N/A
Distance from lakes of size 4264 to 852 acres	10	0.754	1.238	Negative
Distance from primary routes	10	0.754	2.190	Negative
Runoff potential class for soils	N/A	0.753	1.619	N/A
Distance from other grasses & agriculture (1995)	20	0.751	2.381	Negative
Topographic slope	10	0.749	1.000	Negative
Composite Suitability Map		0.788		

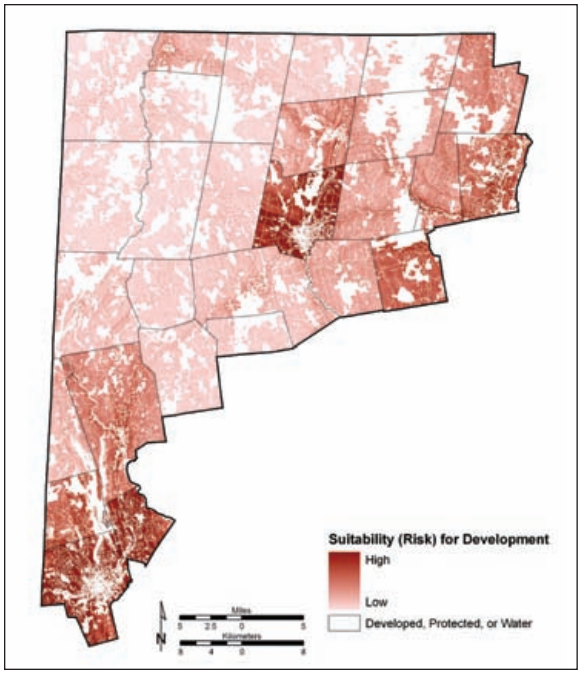


Figure 8-4. *Connecticut Highlands: Most predictive 1995 suitability map created using GEOMOD-approach and non-stratified (regional) drivers. (ROC = 0.777)*

The highest ROC for a composite suitability map created with non-stratified calibration is shown in Figure 8-4. It is also based on the combined top six physio-economic drivers and top six demographic drivers. With an ROC of 0.777 it ranks third among all groupings tested (Appendix 6). Final weights for each factor are given in Table 8-2. In the non-stratified calibration, demographic factors tend to explain more of the variation in development patterns than do physio-economic variables. These have less explanatory power at the local level, *i.e.,* when the analysis is *stratified*, because most of the socio-economic factors are aggregated at the census block level and hence, do not vary much within an individual town. There is significantly higher correlation between hot spots for development within a town and the biophysical factors or existing infrastructure that varies across the town as shown by the set of variables that produced the highest ROC. Without stratification by town it is apparent that demographic factors vary across the region and attract or constrain new development accordingly.

Table 8-2. *Connecticut Highlands: Final set of drivers used to create the GEOMOD-based best-fit suitability map without stratification. The number of bins per factor, individual factor ROCs, weights assigned to each driver during optimization, and the sign of the relationship between the driver and development are shown.*

Driver name (non-stratified by town)	Number of bins	ROC	Weight	Sign
Percent in poverty	100	0.739	1.963	Negative
Percent of population over age 65	100	0.736	1.444	Negative
Median household income	100	0.736	1.444	Negative
Percentage of the civilian labor force that is unemployed	50	0.735	1.889	Negative
Density of 1995 development in a 5,100 ft radius	20	0.701	1.000	Positive
Distance from densely developed areas (50% developed within 600 ft radius in 1995)	50	0.689	1.148	Negative
Elevation	20	0.669	1.556	Negative
Distance from barren land (1995)	30	0.668	1.037	Negative
Composite Suitability Map		0.777		

Pennsylvania

The top three individual *suitability* maps, each with an ROC value of 0.935, were: 1) density of 1992 development in a 200 ft radius; 2) distance from the 1992 *urban* class; and 3) distance from densely developed areas (50% developed within 600 ft radius in 1995). ROC values for each of these were the same whether calibration was carried out with or without county-level stratification. The lowest ROC was attained for "size of scenic view" with or without stratification (0.640/0.500). ROC values of the 100+ suitability maps evaluated, ranging between 0.935 and 0.500, are reported in Appendix 7. These tables report all individual factors tested under both the *stratified* and *non-stratified* calibration scheme, the number of bins that produced the best ROC statistic, the individual ROC values, and the direction, positive or negative, of that relation.

Among the composite suitability maps both the stratified and non-stratified achieved the same ROC of 0.956 (Appendix 7). The best stratified combination was attained using the combination of top six physio-economic and top six economic drivers, stratified by county. Eight of the 12 variables were retained to produce the suitability map shown in Figure 8-5. Those factors retained are:

1. density of 1992 development in a 200 ft radius,
2. minimum distance from urban land use/cover class (1992),
3. minimum distance from densely developed areas (50% developed within 600 ft radius in 1995),
4. minimum distance from grid cells with greater than 34% impervious surface coverage in 1985,
5. size of patch of contiguous land use/cover (1992),
6. minimum distance from edge of patch of contiguous land use/cover (1992),
7. number of people in construction,
8. minimum distance from state or local road.

Those dropped were:

1. minimum distance from urban area,
2. percentage of houses that have four+ bedrooms,
3. percent of people 18 and older who have had 1 or more years of college,
4. percent of population under age of 18.

Individual Weights are Reported in Table 8-3.

The *suitability* map with the highest ROC value created with non-stratified calibration is shown in Figure 8-6. It is based on 11 physio-economic factors, mostly related to existing development densities and infrastructure. See Table 8-4 for a summary of included variables and their respective weights.

The eight groups entered into the optimization program to create composite *suitability* maps, the final weights assigned to each factor within each group, and the final composite ROC value attained are reported in Appendix 7. A weight of zero indicates that the factor was eliminated from the set during the calibration process. Final individual *suitability* values ranged from 0.956 to 0.79.

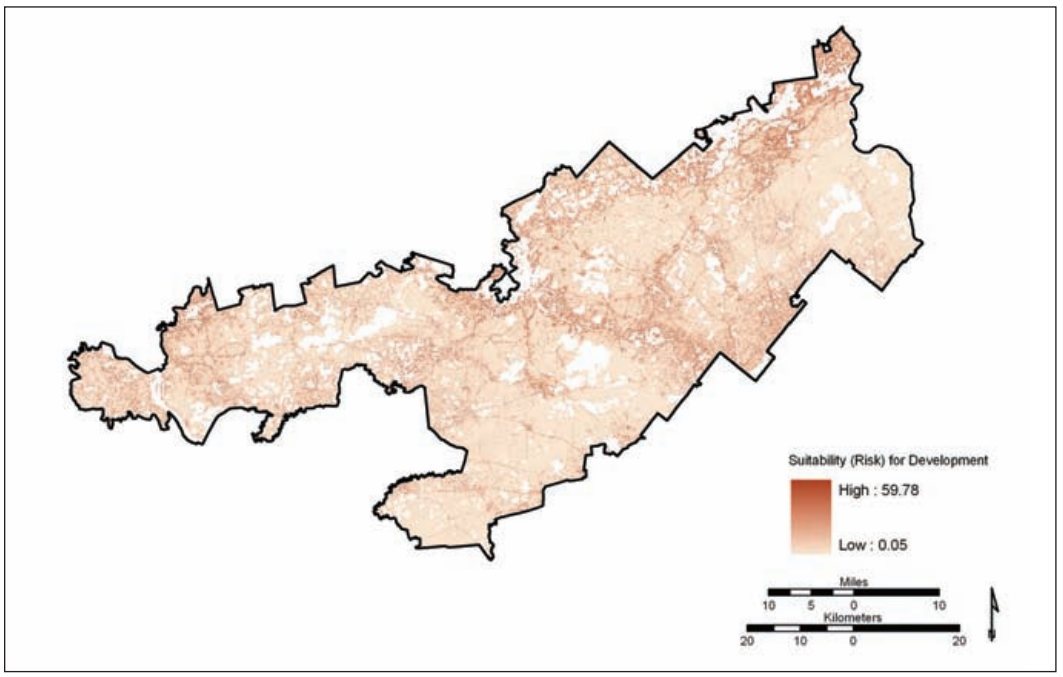


Figure 8-5. *Pennsylvania Highlands: Most predictive 1992 suitability map created using GEOMOD-approach and drivers stratified by county. (ROC = 0.956)*

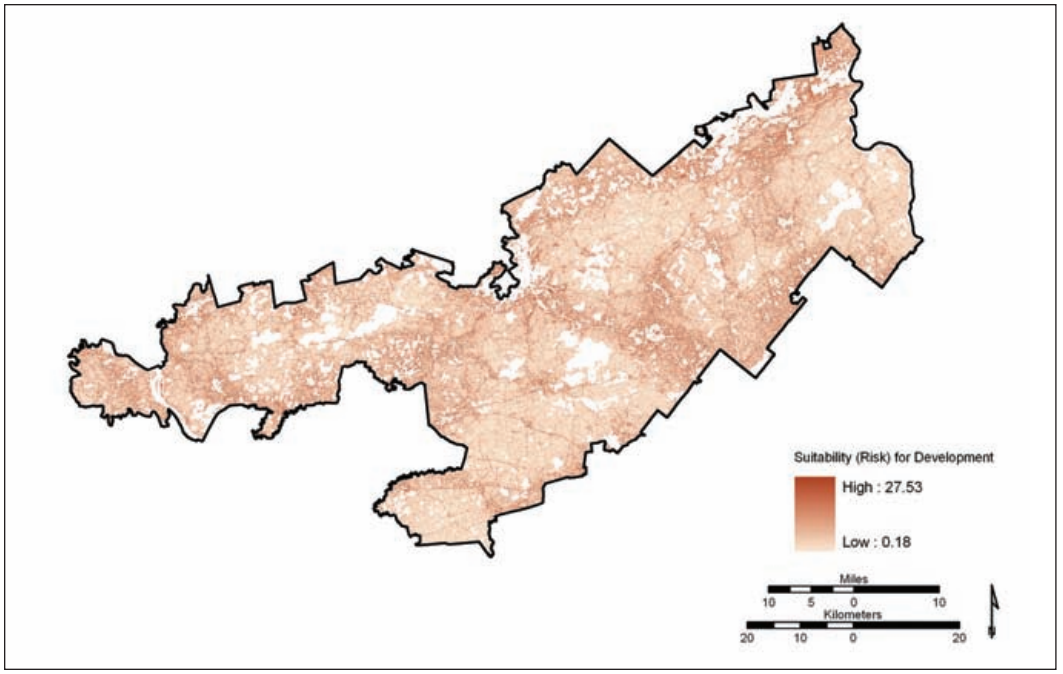


Figure 8-6. *Pennsylvania Highlands: Most predictive 1992 suitability map created using GEOMOD-approach and non-stratified (regional) drivers. (ROC = 0.956)*

Table 8-3. *Pennsylvania Highlands: Final set of drivers used to create the GEOMOD-based best-fit suitability map with stratification by county. The number of bins per factor, individual factor ROCs, weights assigned to each driver during optimization, and the sign of the relationship between the driver and development are shown.*

Driver name (stratified by county)	Number of bins	ROC	Weight	Sign
Density of 1992 development in a 200 ft radius	20	0.937	39.0	Positive
Minimum distance from urban land use/cover class (1992)	30	0.932	25.0	Negative
Minimum distance from densely developed areas (50% developed within 600 ft radius in 1995)	30	0.877	16.0	Negative
Minimum distance from grid cells with greater than 34% impervious surface coverage in 1985	50	0.844	4.5	Negative
Size of patch of contiguous land use/cover (1992)	100	0.833	11.0	Negative
Minimum distance from edge of patch of contiguous land use/cover (1992)	20	0.819	1.0	Negative
Minimum distance from urban area	50	0.788	0.0	
Percentage of houses that have 4+ bedrooms	100	0.787	0.0	
Percent of people 18 and older who have had one or more years of college	100	0.786	0.0	
Number of people in construction	100	0.786	11.5	Negative
Percent of population under age of 18	100	0.784	0.0	
Minimum distance from state or local road	20	0.780	11.5	Negative
Composite Suitability Map		**0.956**		

Table 8-4. *Pennsylvania Highlands: Final set of drivers used to create the GEOMOD-based best-fit suitability map without stratification. The number of bins per factor, individual factor ROCs, weights assigned to each driver during optimization, and the sign of the relationship between the driver and development are shown.*

Driver name (non-stratified)	Number of bins	ROC	Weight	Sign
Density of 1992 development in a 200 ft radius	20	0.935	6.2	Positive
Minimum distance from urban land use/cover class (1992)	100	0.920	6.3	Negative
Minimum distance from densely developed areas (50% developed within 600 ft radius in 1995)	100	0.872	3	Negative
Minimum distance from grid cells with greater than 34% impervious surface coverage in 1985	10	0.832	2.3	Negative
Size of patch of contiguous land use/cover (1992)	100	0.798	2.6	Negative
Minimum distance from edge of patch of contiguous land use/cover (1992)	20	0.787	3.1	Negative
Minimum distance from urban area	50	0.758	1.8	Negative
Minimum distance from state or local road	50	0.752	5.6	Negative
Minimum distance from city center	50	0.726	1	Negative
Minimum distance from interstate exits	100	0.721	3.9	Negative
Name of bedrock geologic unit.	N/A	0.716	4.3	Negative
Minimum distance from active railroad lines	100	0.712	2.4	Negative
Composite Suitability Map		**0.956**		

Logistic Regression-Derived Suitability Maps

Methods

In addition to the GEOMOD-approach, we created *suitability* maps using logistic regression via the LOGISTICREG module in IDRISI. The dependent variable is a categorical variable (presence/absence) indicating whether a cell became developed during the calibration period (1985-1995 in Connecticut and 1992-2001 in Pennsylvania). A mask was used to exclude from analysis cells that were already developed at the beginning of the calibration period (1985 in Connecticut and 1992 in Pennsylvania), protected from development, or classified as water during any time period. The same calibration data set used by GEOMOD was used to fit the logistic regression. Again, the calibration data were presence/absence of transition to developed LULC for 80% of cells available for development in Pennsylvania in 1992 and all cells available for development in Connecticut in 1985. The sampling option in LOGISTICREG was not used so every cell not masked was included in the regression analysis.

We conducted regressions using two sets of independent variables (Tables 8-5 to 8-8). For the first regression, the independent variables are the factors that combined to form the composite *suitability* map in GEOMOD with the highest overall ROC, when *stratified* by town in Connecticut and by county in Pennsylvania. The second regression uses the factors that gave the highest ROC in GEOMOD, for each area, when *not stratified*. Continuous independent variables available for the beginning of the calibration period (1985 in Connecticut and 1992 in Pennsylvania) were used as independent variables without binning or other modification (*e.g.,* slope values were used without binning). Categorical variables were represented as binary variables for each level, except for those excluded to minimize multi-collinearity. For example, when five classes of soil drainage were used, five binary (0 or 1) variables were used to represent the values of soil drainage with each binary variable indicating presence or absence of a particular class value. In Pennsylvania, a categorical variable, bedrock geology, was excluded from the logistic regression of the non-stratified drivers because the 65 categories of data were too numerous to be included as dummy variables in a regression.

The independent variables recorded for each cell were used as inputs to the fitted logistic regressions to create *suitability* maps (Figures 8-7 to 8-10). For Connecticut, independent variables recorded at the beginning of the validation period (1995) were used for factors that may have changed since the beginning of the calibration period (1985). As the calibration and validation data sets were not separate in time, this procedure was unnecessary in Pennsylvania.

The *suitability* maps were then compared to validation data using the ROC statistic as described above in the GEOMOD *Validation* section. The validation data sets were the same as used for assessment of *suitability* maps created by GEOMOD. In Pennsylvania, the validation data were observations of presence or absence of transition to developed LULC on those cells not included in calibration (remaining 20% of cells). In Connecticut, the validation data were observations of presence or absence of transition to developed LULC on cells available for development in 1995 (not developed, not water, and not in protected areas).

Connecticut

For Connecticut, independent variable values for 1985 were analyzed using logistic regression to determine which explained most of the variation in the change observed between 1985 and 1995 (the calibration time period). Among those found to be mostly highly explanatory, some were updatable with 1995 information, *e.g.,* distance to the *urban* class. These along with

the other non-changing variables, like elevation or slope, were then used to create *suitability* images for post-1995 development using the equations derived from the 1985-1995 calibration period. This new *suitability* image was then compared using ROC to the observed change from 1995 to 2002 (the validation time).

Pennsylvania

In Pennsylvania, values of the independent variables recorded in 1992 were used to fit logistic regressions to the calibration data (random sample of 80% of cells available for development in 1992 and the observed change or non-change in these cells between 1992 and 2001); the best-fit logistic regression equation was used to create a *suitability* map that was compared to the validation data (remaining 20% of cells available for development in 1992 and their observed transition or lack thereof between 1992 and 2001).

Results

Connecticut

The logistic regression-derived 1995 *suitability* maps produced ROC values of 0.75 with a *stratified* driver set and 0.76 without stratification when compared to actual 1995 – 2002 change (Figures 8-7 and 8-8). This compares to 0.787 and 0.777 respectively using the GEOMOD approach. The most important factor explaining 1985-1995 development in the *stratified* analysis was density of pre-existing (1985) development within a 4,200 ft radius of each 1985 developed cell. In the *non-stratified* it was the same but within a 5,100 ft radius. The independent variables used (12 for the *stratified* analysis and 5 for the *non-stratified*), and their regression coefficients are reported in Tables 8-5 and 8-6, respectively. The higher regression coefficients indicate that a one unit increase in the independent variable has a strong effect in increasing the probability of development.

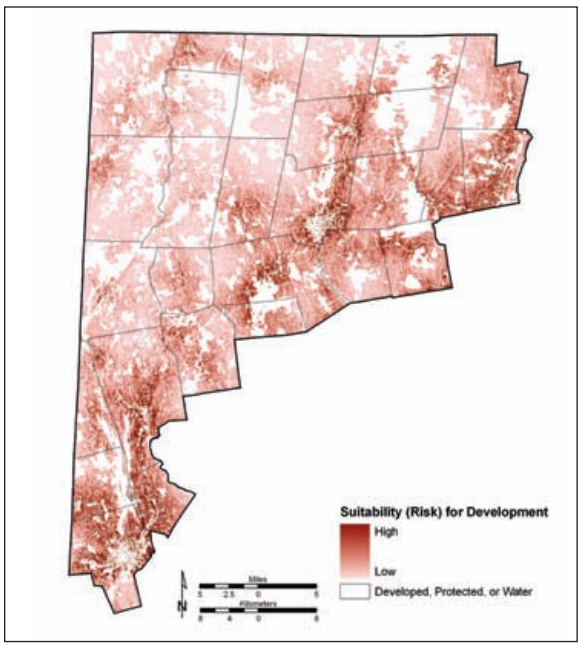


Figure 8-7. *Connecticut Highlands: 1995 suitability map using logistic regression with the set of variables identified via the stratified GEOMOD calibration as the strongest predictors of future development.*

Table 8-5. *Connecticut Highlands: Logistic regression results for the variables derived from the GEOMOD calibration stratified by town.*

Variable	Coefficient
Intercept	-2.089
Distance from utility right-of-ways (1985)	0.000
Density of 1995 development in a 4,200 ft radius	3.619
Distance from densely developed areas (50% developed within 600 ft radius in 1995)	0.000
Distance from lakes of size 4263.87 to 852.34 acres	0.000
Distance from primary routes	0.000
Drainage class of major soil component (variables entered as dummy variables, classes 1 and 7 removed to eliminate multicollinearity)	
Class 2 - well drained	-0.199
Class 3 - moderately	-0.409
Class 4 - very poor	-0.923
Class 5 - poorly drained	-0.575
Class 6 - excessively	0.082
Runoff potential class for soils (variables entered as dummy variables, classes 1 and 6 removed to eliminate multicollinearity)	
Class 2 - low	-0.804
Class 3 - medium	-0.460
Class 4 - negligible	-0.963
Class 5 - very low	-1.008
Class 7	-1.043
Distance from other grasses & agriculture (1995)	0.000
Topographic slope	-0.102
Distance from major roads	0.000

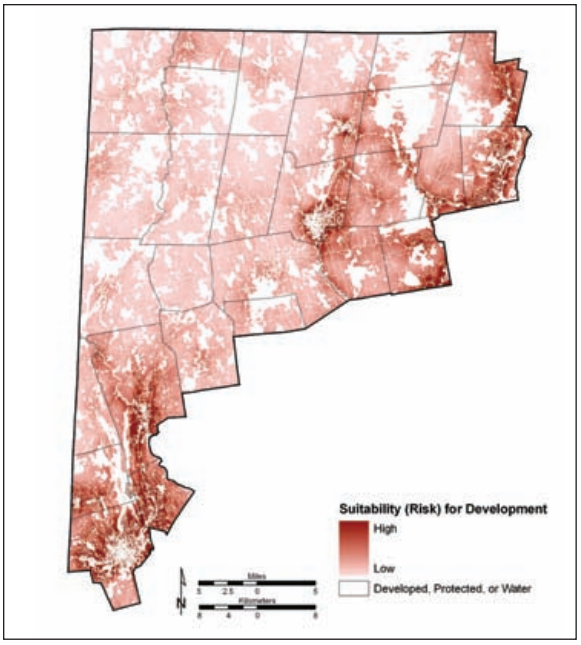


Figure 8-8. *Connecticut Highlands: 1995 suitability map using logistic regression with the set of variables identified via the non-stratified GEOMOD calibration as the strongest predictors of future development.*

Table 8-6. *Connecticut Highlands: Logistic regression results for variables derived from the non-stratified GEOMOD calibration.*

Variables	Coefficient
Intercept	-0.866
Distance from densely developed areas (50% developed within 600 ft radius in 1995)	0.000
Distance from barren land (1995)	0.000
Elevation	-0.002
Percentage of the civilian labor force that is unemployed	-0.033
Percent of population over age 65	-0.091
Percent in poverty	-0.013
Density of 1995 development in a 5,100 ft radius	4.159
Median household income	0.000

Pennsylvania

Both logistic regression-derived *suitability* maps (Figures 8-9, *stratified* and 8-10, *non-stratified*) produced ROC values of 0.952. The independent variables used and regression coefficients for the driver sets are reported in Tables 8-7 and 8-8, respectively. The higher the regression coefficient the more a one-unit increase in the independent variable will increase the probability of development. The most important factor explaining 1992-2001 development in both the *stratified and non-stratified* analysis was density of development in a 200 ft radius around each cell (Table 8-7).

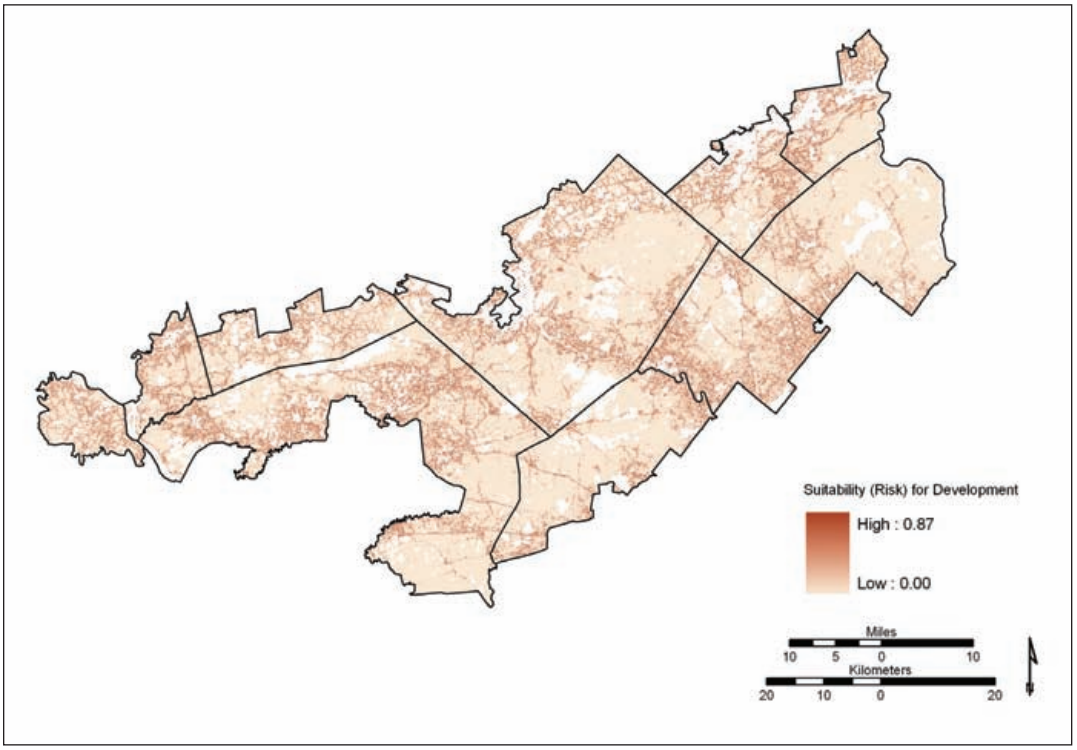


Figure 8-9. *Pennsylvania Highlands: 1992 suitability map using logistic regression with the set of variables identified via the stratified GEOMOD calibration as the strongest predictors of future development.*

Table 8-7. *Pennsylvania Highlands: Logistic regression results for variables derived from the GEOMOD calibration stratified by county.*

Variables	Coefficient
Intercept	-3.318
Density of 1992 development in a 200 ft radius	5.955
Minimum distance from urban land use/cover class (1992)	-0.014
Minimum distance from densely developed areas (50% developed within 600 ft radius in 1995)	0.000
Minimum distance from grid cells with greater than 34% impervious surface coverage in 1985	-0.001
Size of patch of contiguous land use/cover (1992)	-0.001
Minimum distance from edge of patch of contiguous land use/cover (1992)	-0.010
Number of people in construction	-0.003
Minimum distance from state or local road	-0.001

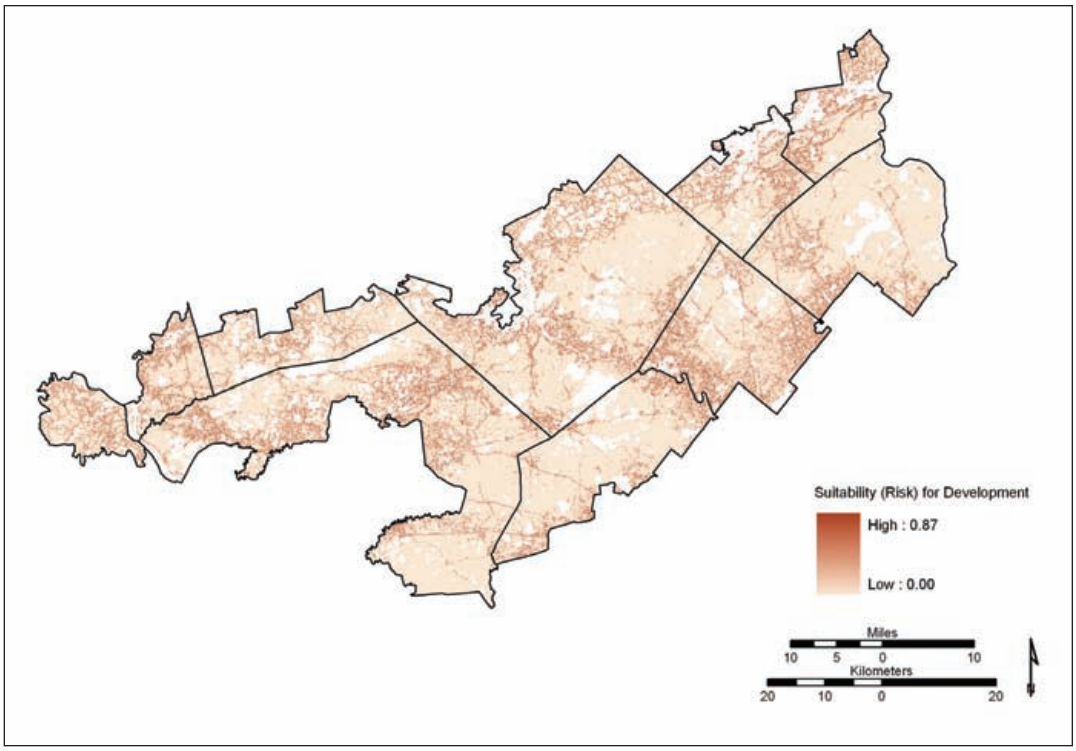


Figure 8-10. *Pennsylvania Highlands: 1992 suitability map using logistic regression with the set of variables identified via the non-stratified GEOMOD calibration as the strongest predictors of future development.*

Table 8-8. *Pennsylvania Highlands: Logistic regression results for variables derived from the non-stratified GEOMOD calibration.*

Variables	Coefficient
Intercept	-3.171
Density of 1992 development in a 200 ft radius	5.965
Minimum distance from urban land use/cover class (1992)	-0.014
Minimum distance from densely developed areas (50% developed within 600 ft radius in 1995)	0.000
Minimum distance from grid cells with greater than 34% impervious surface coverage in 1985	0.000
Size of patch of contiguous land use/cover (1992)	-0.001
Minimum distance from edge of patch of contiguous land use/cover (1992)	-0.010
Minimum distance from urban area	0.000
Minimum distance from state or local road	-0.001
Minimum distance from city center	0.000
Minimum distance from interstate exits	0.000
Name of bedrock geologic unit.	
Minimum distance from active railroad lines	0.000

Comparison of Suitability Maps - Connecticut

The ROC value for the GEOMOD suitability image, calibrated by town, was 0.79, whereas the non-stratified was 0.78. The logistic regression-derived 1995 *suitability* maps produced ROC values of 0.75 (stratified variables) and 0.76 (non-stratified) respectively (Table 8-9). Both *suitability* maps produced by GEOMOD (*town-stratified* and *non-stratified*) had a "better" fit to the validation data than either of the logistic regression-created maps (as measured by the ROC statistic), with the *stratified* map having the highest ROC. The strength of each *suitability* map's values in predicting future development can be seen in figures 8-11 to 8-14, which show the frequency histogram of actual development in each of the bins for each of the four *suitability* images in Connecticut. This type of analysis is closely related to the mathematics behind the ROC statistic. Images of this type can be used to evaluate the probability of a cell becoming developed within a similar time period given its *suitability* value. The *suitability* map with the highest ROC (GEOMOD, stratified) shows the clearest positive correlation between *suitability* value and proportion developed (see Figures 8-11 to 8-14).

Table 8-9. *Connecticut Highlands: Receiver operating characteristic values (ROC) for final suitability maps.*

Final suitability map	ROC
GEOMOD approach, stratified by town	0.788
GEOMOD approach, non-stratified	0.777
Logistic regression using variables from stratified GEOMOD model	0.749
Logistic regression using variables from non-stratified GEOMOD model	0.756

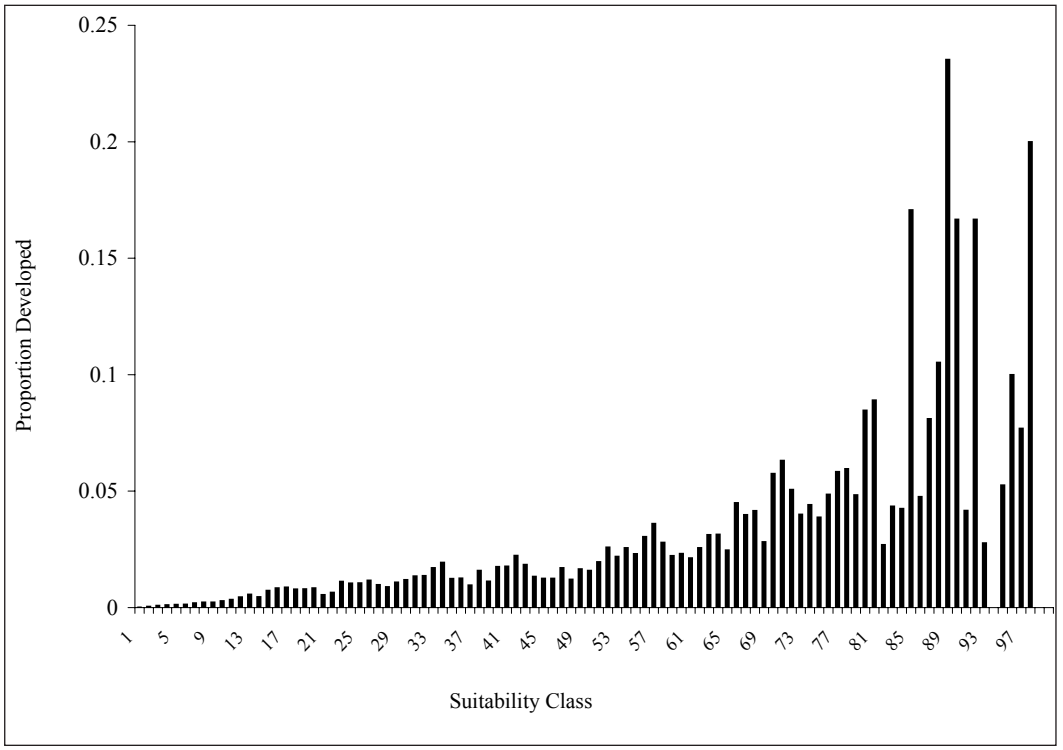


Figure 8-11. *Connecticut Highlands: Proportion of cells developed per interval in 1995 suitability image created with GEOMOD and stratified drivers.*

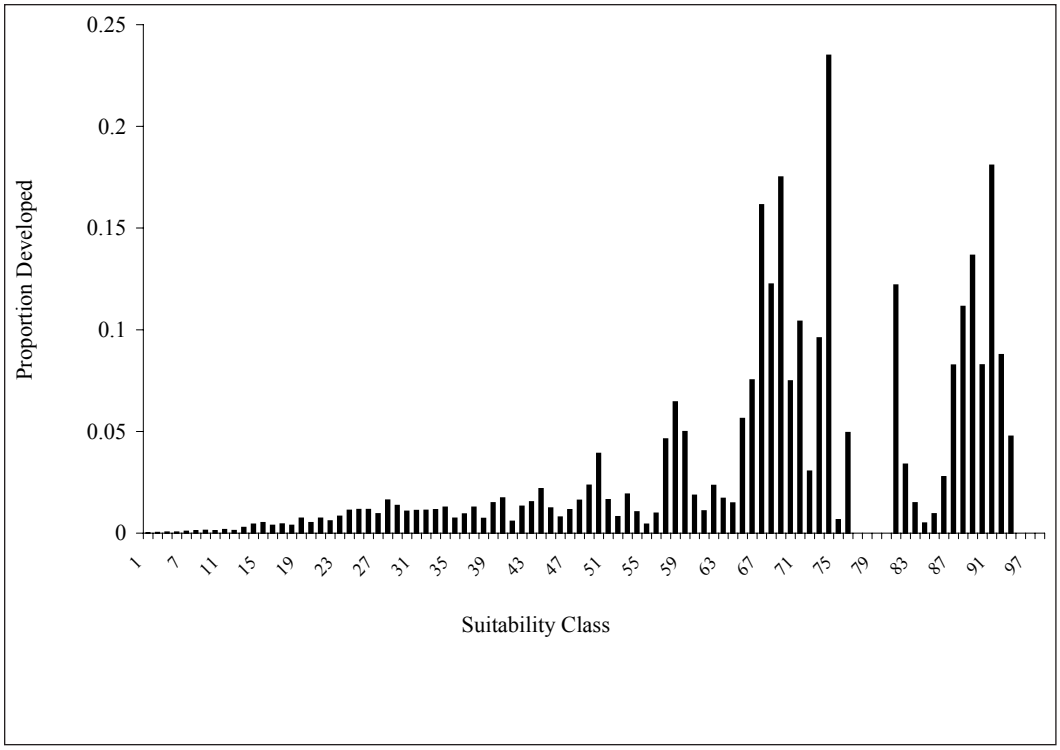


Figure 8-12. *Connecticut Highlands: Proportion of cells developed per interval in 1995 suitability image created with GEOMOD and non-stratified drivers.*

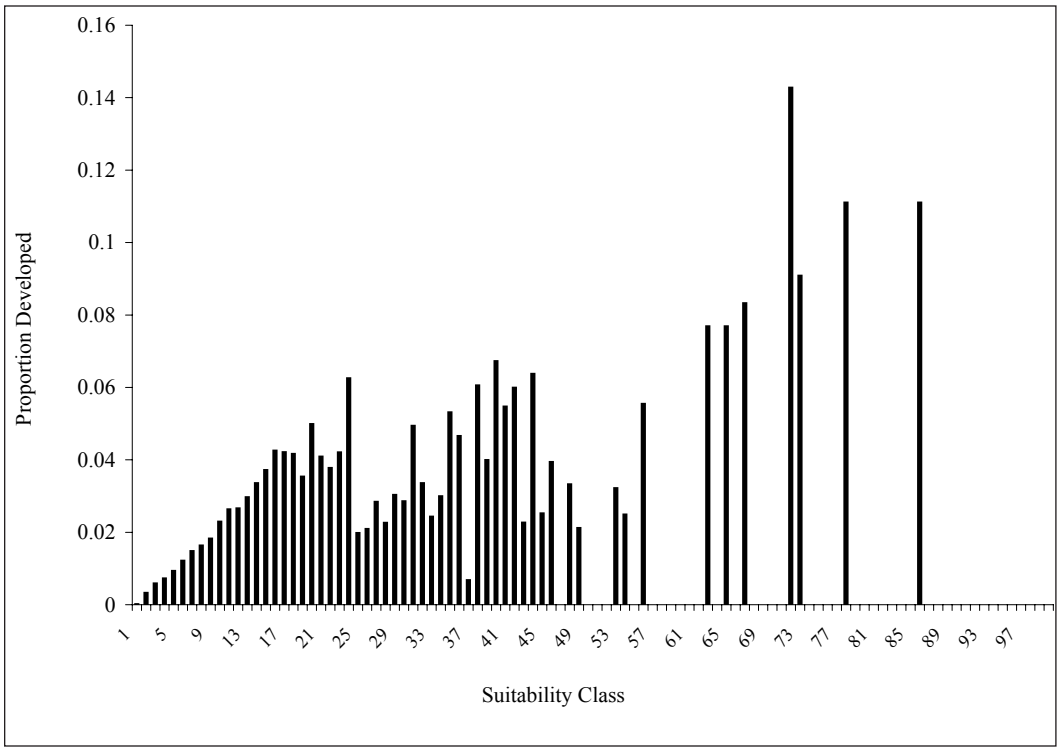


Figure 8-13. *Connecticut Highlands: Proportion of cells developed per interval in 1995 suitability image created with logistic regression and stratified drivers.*

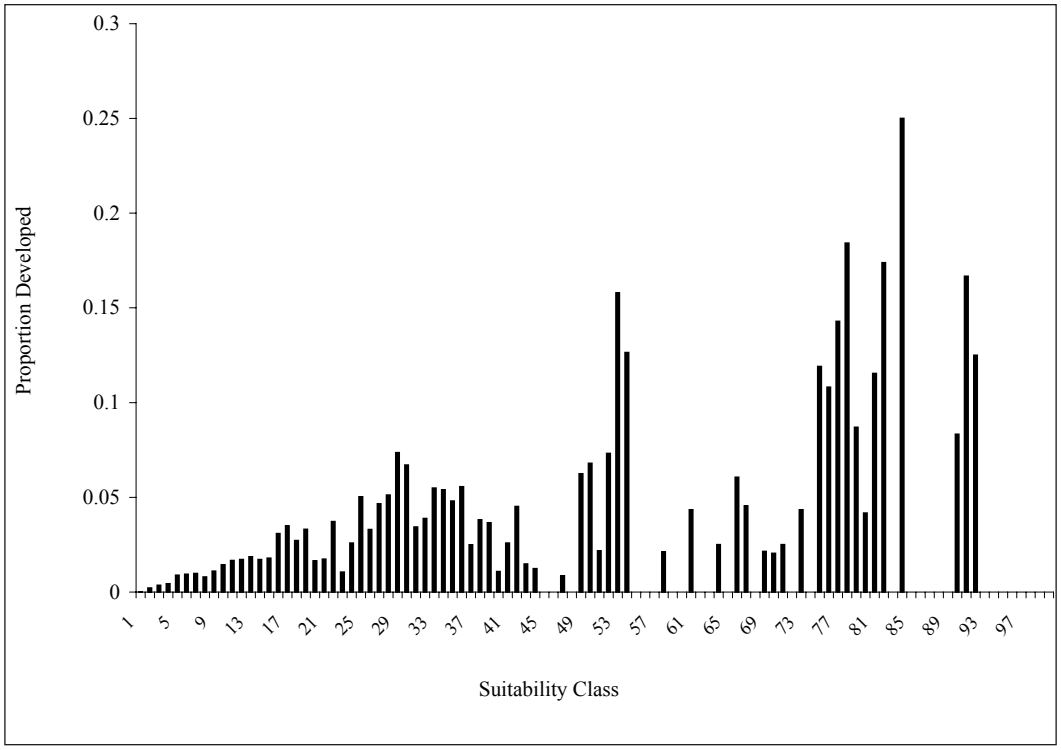


Figure 8-14. *Connecticut Highlands: Proportion of cells developed per interval in 1995 suitability image created with logistic regression and non-stratified drivers.*

Comparison of Suitability Maps - Pennsylvania

The ROC values were the same (0.956) for the GEOMOD-produced *suitability* maps calibrated by county and non-stratified. Both the logistic regression-derived *suitability* maps produced ROC values of 0.952 (Table 8-10). Both GEOMOD-produced maps had a slightly "better" fit to the validation data than either logistic regression-produced map. Again, this can be seen intuitively in Figures 8-15 to 8-18, which show the frequency histogram of actual development in each of the bins for each of the four *suitability* images in Pennsylvania.

Table 8-10. *Pennsylvania Highlands: Receiver operating characteristic values (ROC) for final suitability maps.*

Final suitability map	ROC
GEOMOD approach, stratified by county	0.956
GEOMOD approach, non-stratified	0.956
Logistic regression using variables from stratified GEOMOD model	0.952
Logistic regression using variables from non-stratified GEOMOD model	0.952

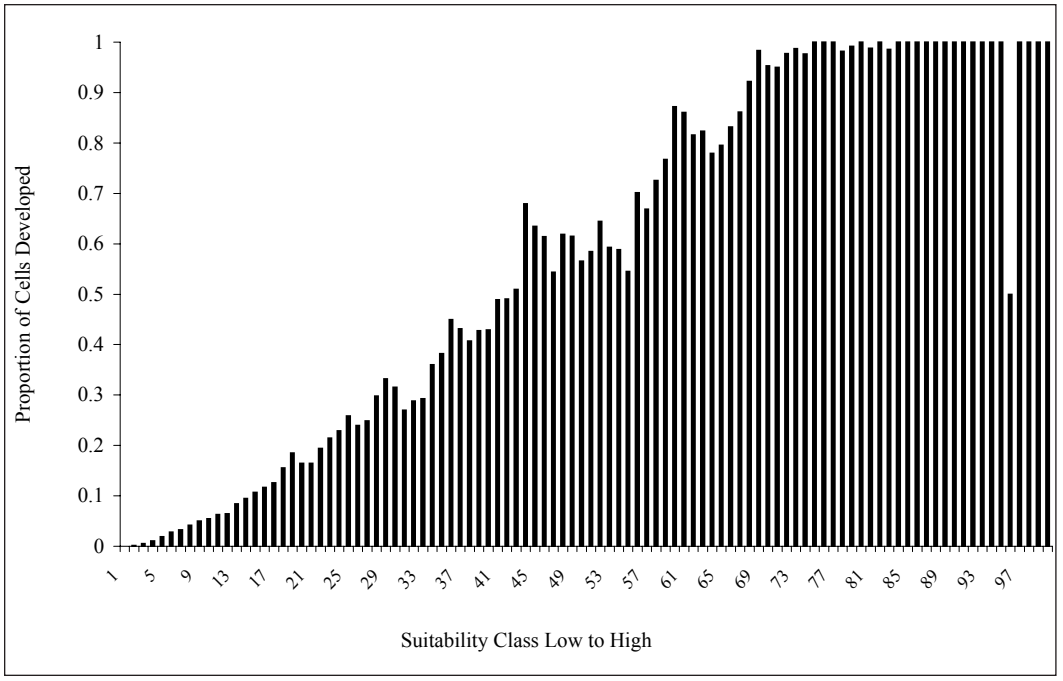


Figure 8-15. *Pennsylvania Highlands: Proportion of cells developed per interval in 1992 suitability image created with GEOMOD and county-stratified drivers.*

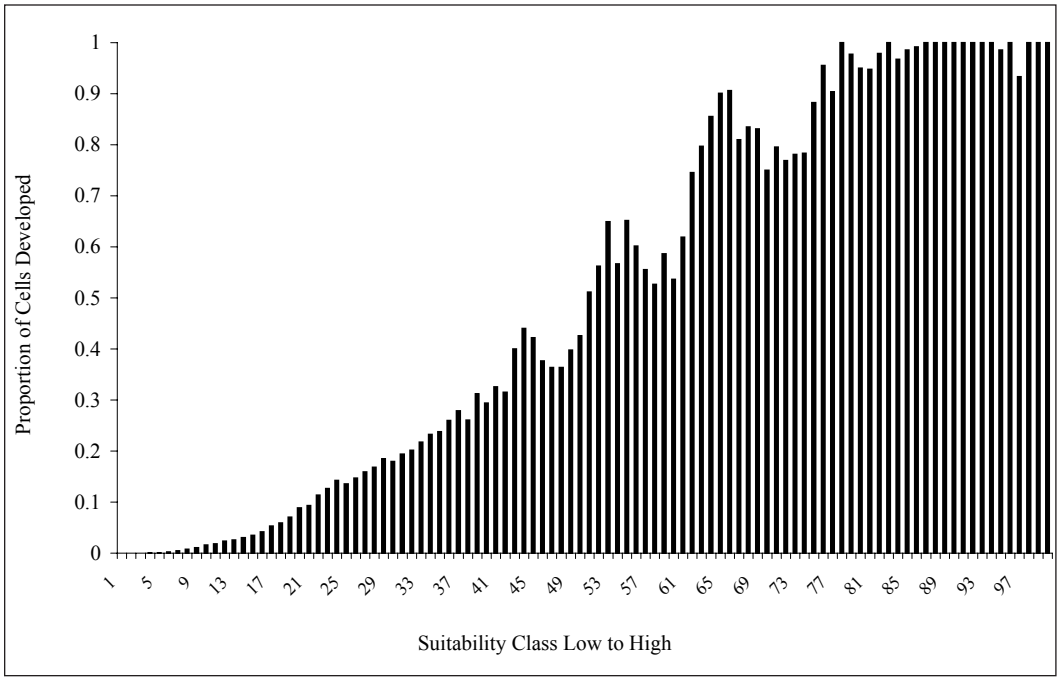


Figure 8-16. *Pennsylvania Highlands: Proportion of cells developed per interval in 1992 suitability image created with GEOMOD and non-stratified drivers.*

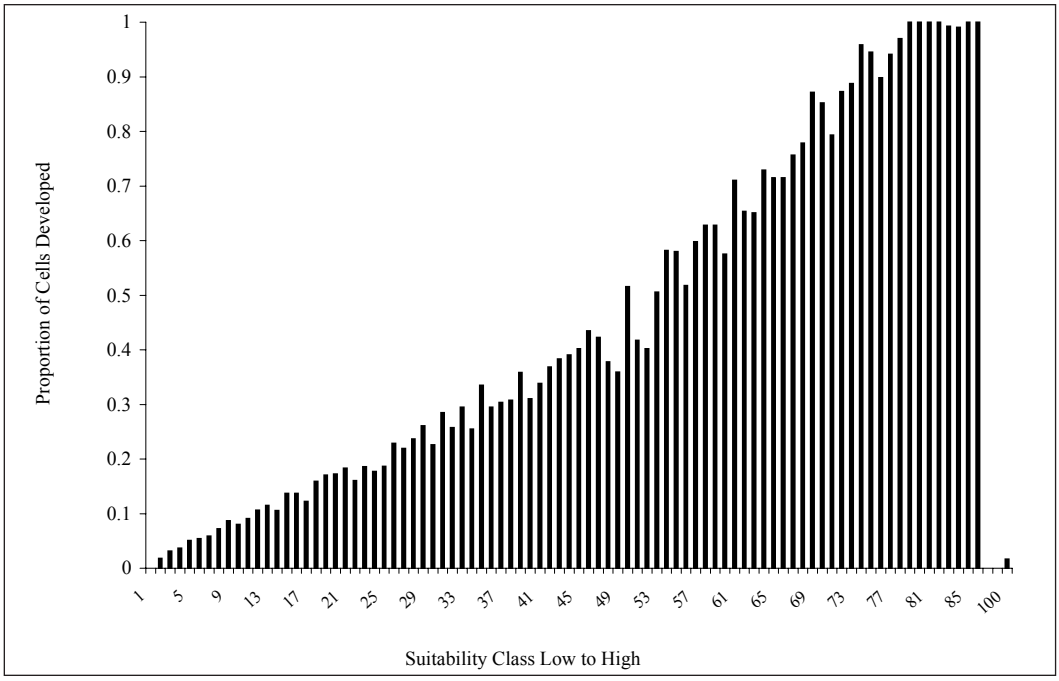


Figure 8-17. *Pennsylvania Highlands: Proportion of cells developed per interval in 1992 suitability image created with GEOMOD and non-stratified drivers.*

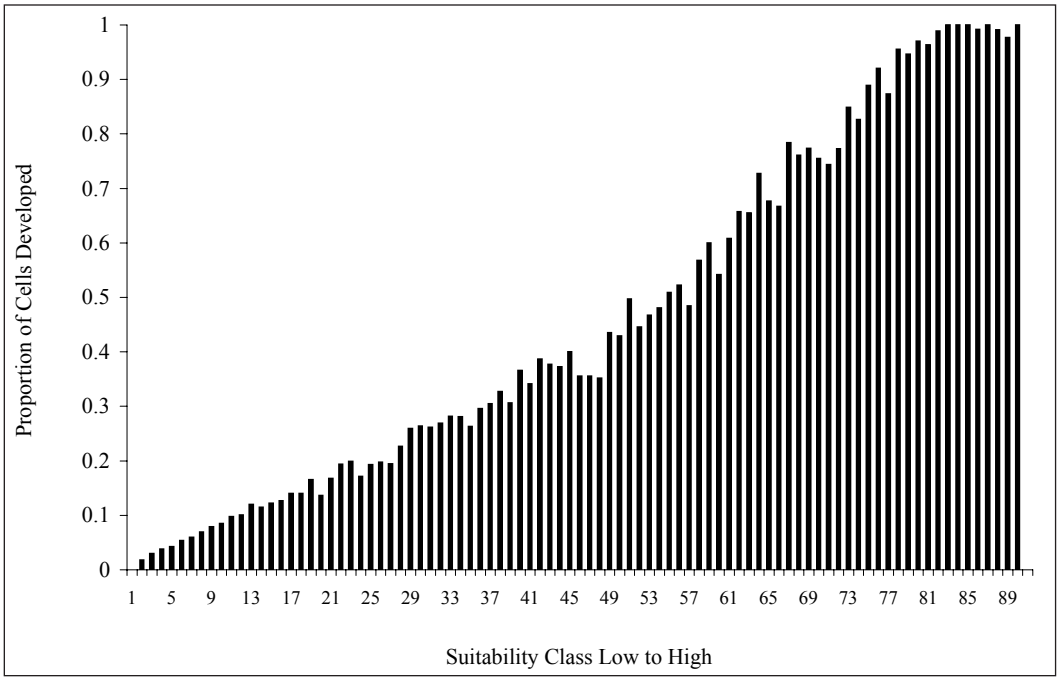


Figure 8-18. *Pennsylvania Highlands: Proportion of cells developed per interval in 1992 suitability image created with logistic regression and non-stratified drivers.*

Selecting Projection Models

Methods

To project development forward in time GEOMOD needs both a *suitability* map representing spatial variability in likelihood of development and an estimate of the quantity of developed cells at the end of the simulation period. The program then "develops" individual cells equal to this quantity in order of decreasing *suitability* value. GEOMOD can carry out this assignment with or without stratification by political unit, watershed, or other spatial boundary. When no stratification is used, GEOMOD assigns to the developed class a number of cells equal to the overall development rate and picks these in order of decreasing *suitability* value without regard to a cell's location among the towns/counties. Conversely, when stratification is used, a separate development rate is required for each stratum. Ranking of cells according to *suitability* is then carried out separately for each stratum (*e.g.,* town or county) and the number of cells within each stratum assigned to the developed class is equal to the stratum-derived development rate.

Rate of Change: Connecticut

We tested the ability of four historical rates to reproduce the actual amount of land developed between 1995 and 2002. These were a best fit line through years 1985, 1990, and 1995 and separate linear extrapolations of the 1985-1990, 1990-1995, and 1985-1995 trends illustrated in Figure 8-19. These rate estimation methods were carried out in two ways, at the town-level and for the whole study area in aggregate. Rate estimation and assignment with and without town-level stratification were tested for influence on model accuracy. When compared to the actual number of 2002 developed cells for the region as a whole, a linear extrapolation of the 1985-1990 trend resulted in a significantly higher number of developed cells, whereas the linearly extended more recent 1990-1995 trend was closest to the 2002 actual (Table 8-11).

We then used GEOMOD, with each of the four 1995 *suitability* images (two each from logistic regression and GEOMOD), as inputs to the model to project development from 1995 to 2002 and compared the model output to the actual 2002 developed land using four measures of "fit": overall accuracy; the kappa statistic; user's accuracy; and producer's accuracy. In all cases a higher value is favorable.

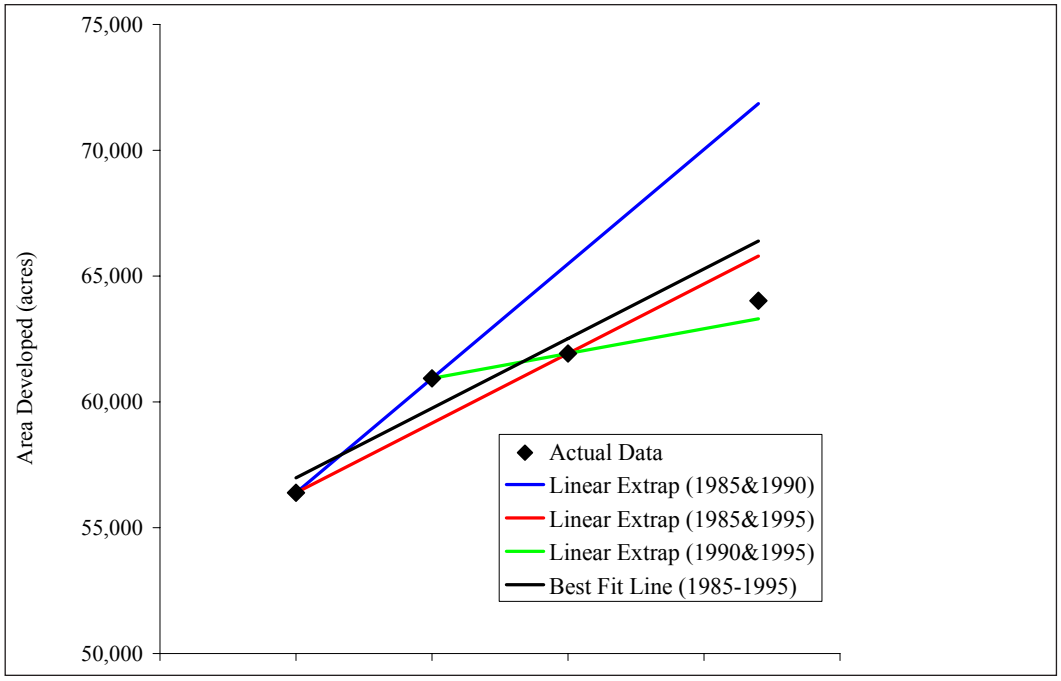


Figure 8-19. *Connecticut Highlands: Actual amount developed in 1985, 1990, 1995, and 2002 and four methods to estimate development in 2002.*

Table 8-11. *Connecticut Highlands: Projection of area developed (acres) using linear extrapolations with multiple year pairings and best-fit lines. Deviation from actual shown for 2002.*

Method	Projection for 2002	Deviation from Actual 2002	Projection for 2022	Scenario for 2022
Linear Extrapolation 1985&1990	71,853	7,833	82,214	High
Linear Extrapolation 1985&1995	65,797	1,778	75,090	
Linear Extrapolation 1990&1995	63,304	-716	67,966	Low
Best-Fit 1985-1995	66,391	2,371	77,462	
Linear Extrapolation 1985&2002	N/A	N/A	72,999	
Linear Extrapolation 1990&2002	N/A	N/A	69,159	
Linear Extrapolation 1995&2002	N/A	N/A	70,011	
Best-Fit 1985-2002	N/A	N/A	72,952	Medium

Rate of Change: Pennsylvania

We used GEOMOD to project development only within the cells not used in calibration (remaining 20% in validation data set). We determined the development rate at the regional- and county-level as the number of cells in the validation set that became developed between 1992 and 2001. We used each of the four 1992 *suitability* maps previously described (two each from logistic regression and GEOMOD) as inputs to the model to project development from 1992 to 2001. Rate estimation and assignment with and without county-level stratification were tested for influence on model accuracy. We then compared the model output to the actual 2001 development using four measures of "fit": overall accuracy; the kappa statistic; user's accuracy; and producer's accuracy. In all cases a higher value is favorable.

Neighborhood of Change

When running a GEOMOD projection one can indicate whether assessment of "suitability," and hence transition to a developed cell, must be constrained to a neighborhood near already developed cells, or not. Using the unconstrained method means that cells are selected based only upon their *suitability* value compared to all other *suitability* values in the entire strata of analysis (region, town, county, etc.). On the other hand, enforcement of the neighborhood rule requires the model to select cells in order of decreasing *suitability* value within a user-specified distance from previously developed cells. To test for the effect of constraining projection to a neighborhood, we made projections with no constraints, as well as within a 3x3, 5x5, and 7x7 cell neighborhood around cells already developed at the start of the simulation.

Projection Permutations

For both areas, we tested all combinations of: (1) development rate; (2) *suitability* map; (3) *stratification*; and (4) neighborhood rule, to see how accurately they could reproduce the final time-series LULC map (2002 in Connecticut, 2001 in Pennsylvania). This gave a total of 128 combinations in Connecticut and 32 in Pennsylvania. The difference is attributable to the fact that four development rates were possible in Connecticut and only one in Pennsylvania. For each run the following statistics were calculated by comparison to validation data: overall accuracy; kappa statistic; and user's and producer's accuracies (Appendix 7).

User's Accuracy and Multi-Scale Validation

In most land use change modeling applications, particularly those covering a relatively short period of time, large areas of persistent land cover (usually forest) combined with relatively low development rates tend to have a strong positive influence on accuracy statistics computed on model outputs, such as overall accuracy and kappa statistic. The reason is that if few cells change, there are a limited number of opportunities to incorrectly place these cells on the landscape. The user's accuracy for development (*i.e.,* the proportion of cells projected to become developed that actually do become developed) is a useful check on model accuracy that avoids the accuracy-inflation caused by low development rates and large areas of forest.

In Pennsylvania, the highest user's accuracy for predicting 2001 development among the model permutations is approximately 45%. In Connecticut, the highest for predicting to 2002 is much lower at approximately 8%, possibly caused by the much lower development rates in Connecticut. This is low, but understandable, given that we are attempting to predict the exact location of new development at a scale of a grid cell 100 ft across. To account for near misses, meaning that the model predicts the general, but not exact location of development, we employed a validation

method that looks within an expanding square search window around cells projected to be developed. If any cell within this search window is developed in the reference image, it is counted as a true positive and will have a positive effect on user's accuracy for development. Increasing the size of the search window to include near misses increases user's accuracy substantially. For example, in Connecticut the model accurately predicted development within a 1,000 foot search radius (101 acre window) 69% of the time (Figure 8-20).

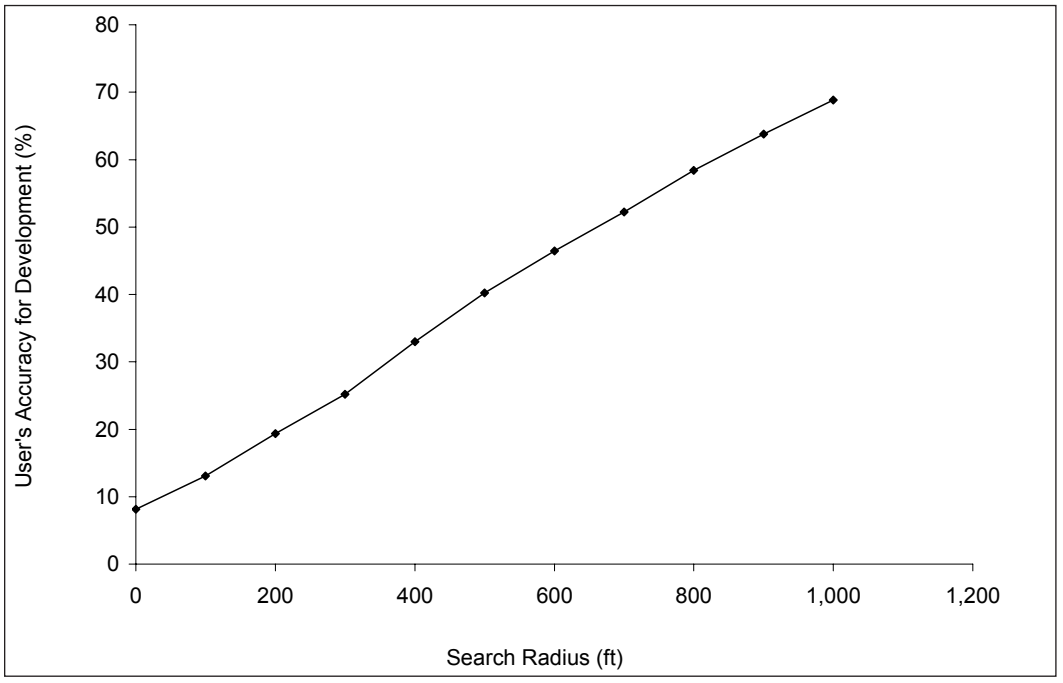


Figure 8-20. *Connecticut Highlands: User's accuracy of projected development as a function of search radius for 2002 projection using medium development rate, stratified suitability map, and stratified projection method.*

Results

Connecticut

The greatest overall accuracy (99.49%) and kappa statistic (98.98) for the simulated 2002 LULC map were attained using the GEOMOD *suitability* image created without town-level stratification, extrapolating the linear 1985-1990 development rate trend *stratified by town*, constrained within a 100-foot neighborhood (3x3 window) from already developed cells. The kappa statistic, and overall accuracy, to which it is highly correlated, appears to vary little across scenarios, probably due to high persistence of forest cover between the calibration and validation time periods. In fact, it is difficult not to get a high kappa when there is little change to be predicted. A difference of 0.0044 between the 1st and 2nd models is insignificant. However, the overall accuracy and kappa statistic drop about one percentage point when the non-stratified projection method is employed. Hence the kappa statistic and overall accuracy do help us evaluate which model parameters can reproduce the "real world" best. Descriptions of each run and overall accuracy, kappa statistics, and user's and producer's accuracies are reported in Appendix 6 in order of decreasing overall accuracy.

Pennsylvania

Three models are tied for greatest overall accuracy (98.17%) and kappa statistic (96.34%). In all three, the models used the GEOMOD *suitability* map created via calibration *stratified by county* and selected new cells for development without stratification by county. The models differ in neighborhood constraint with no constraints, a 100-foot and 200-foot radius neighborhood (3x3 and 5x5 window) achieving identical accuracy statistics. The kappa statistic, and overall accuracy, to which it is highly correlated, appears to vary little across scenarios, probably due to high persistence of vegetated cover between the calibration and validation time periods. As with the Connecticut data, it is difficult not to get a high kappa when there is little change to be predicted. A difference of 0.0007 % between the kappa of the top three and that of the fourth model is insignificant. However, there is more spread evident in both user's and producer's accuracy for development. Descriptions of each run and overall accuracy, kappa statistics, and user's and producer's accuracies are reported in Appendix 7 in order of decreasing overall accuracy.

Future Land Use Projections

Connecticut

We projected future land use from 2002 to 2022 using an updated 2002 *suitability* map, three different rate scenarios and three development constraint levels (none, low, and high). We had to decide which rules to apply, given our various projection accuracy assessments. Even though the projected 2002 map that had the best kappa statistic was achieved with a non-stratified suitability map and imposition of the 100-foot neighborhood rule, the kappa statistic was highly influenced by persistence of forest and varied only slightly between all simulations. Therefore, we chose to use the *suitability* image created by GEOMOD, stratified by town, because it had attained the highest ROC value and also produced a simulated 2002 map that had the second highest overall accuracy, kappa statistic, and user's accuracy for developed class (*i.e.,* percent true positives among cells projected as developed), using a pixel per pixel comparison. We used the stratified projection method, meaning that cells were selected based on their rank within their town, because, in validation, stratified projection consistently yielded the "best" match to the 1995-2002 development, as measured by the overall accuracy and kappa statistic. The unconstrained neighborhood simulation was selected because it allows for low-density rural development to be captured.

Projected Rate of Development (2002 – 2022)

Of the eight different satellite classification-derived rates of development observed between 1985 and 2002 (Table 8-11), we chose to run the lowest, highest, and middle estimates. They represent: 1) a most conservative extrapolation based on the linear 1990 – 1995 trend; 2) a moderate extrapolation based on the best fit line through all four points in time (1985, 1990, 1995, and 2002); and 3) the most aggressive projection based on the linear 1985-1990 trend. For each extrapolation, the amount of development in 2002 was used as a starting value.

Creation of the Final Suitability Map Used for Future Projections (2002-2022)

To identify the location of areas likely to transition to development post-2002, we recalibrated the final *suitability* map using all information from 1985 – 2002, and updated those drivers for which information as of 2002 was available. This required the following steps:

1) Determine new *suitability* values per bin of each of the ten factor maps (Table 8-1) upon which the best fit *suitability* map was based. This means that the suitability per bin was calculated using the grid cells that transitioned to development between 1985 and 2002 divided by all possible candidate cells in that bin that had been available for future development as of 1985.
2) Update four of the ten composite factors with the most current information available from the 2002 CLEAR LULC classification. These factors were: (1) distance from *utility right-of-way*; (2) 2002 development density within a 4,200 foot radius; (3) distance from 2002 densely developed areas; and (4) distance from 2002 *other grasses and agriculture*.
3) Bin each of these four updated factor maps to match the number of bins used in their corresponding original best fit 1985 factor maps.
4) the new *suitability* values (based on 1985-2002 calibration) to each bin of each of these four updated maps, to create individual *suitability* maps for each.
5) Combine all 10 individual *suitability* maps into one composite *suitability* image as before, using the weights previously derived from the optimization program.

The final 2002 suitability map showing areas of highest likely pressure for future development in the Connecticut Highlands (Figure 8-21) reveals the influence of the most important factors identified, such as proximity to existing population centers, particularly those of high density. Development suitability is positively correlated with distance to major roads, but negatively correlated with all other variables as shown by the logistic regression coefficients. Suitability values also reflect the fact that future development is likely to avoid soils with poor drainage and steeper slopes as has been empirically documented using GEOMOD.

We have simplified the 2002 *stratified suitability* map using a quantile classification (*i.e.,* an equal number of cells in each class) that reduces the gradient of suitabilities to three classes indicating high, medium and low suitability for development as of 2002 (Figure 8-22). This map can be used to assess areas of conflict between conservation goals and development pressure.

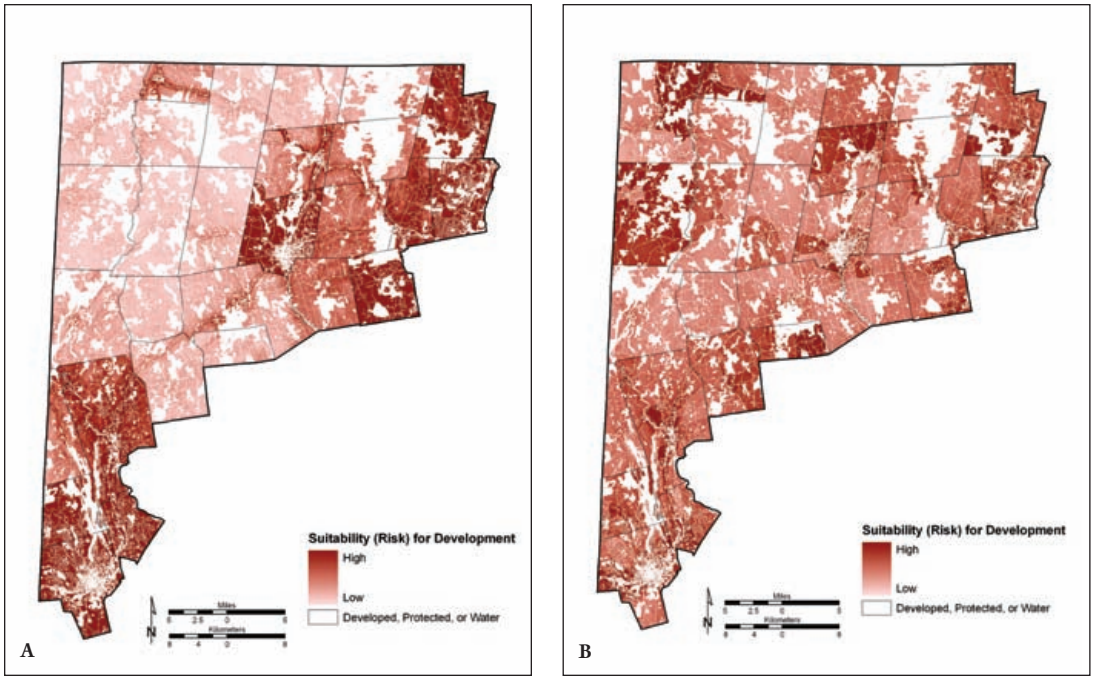
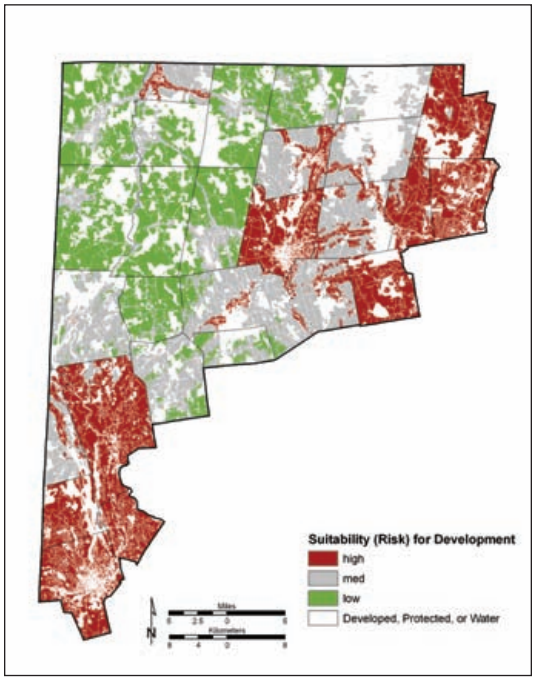


Figure 8-21. *Connecticut Highlands: Map showing areas of low to high suitability for new development as of 2002 used in projecting land use change to 2022 stratified by town (A) and for the whole reagion (B).*



Connecticut Highlands: 2002 Suitability Map reclassed into areas of high, medium and low potential for development across the region. White areas are those not considered candidates for future development because they are: 1) already developed; 2) protected from development; or 3) water.

Projection Scenarios

Using each of the three rates *stratified by town* and the final 2002 *stratification-based suitability* map, we projected the transition of forest, agriculture, and wetlands to development to the year 2022 under three development constraint scenarios. The first is the no-constraints scenario, which excluded from potential development only cells found in protected areas or classified as water. The second and third are the low and high constraints scenarios used in the build-out analysis (see Chapter 6, *Zoning Build-out Analysis*). This gave a total of nine combinations of rate and development constraints.

Stratified projection applies each town's individual trend rate, defined as each town's empirical proportion of development across the region, to just that town. Had we not used this approach, most development would have been placed in the highest suitability locations, which are found primarily in Torrington and Danbury. Development elsewhere would have been missed.

Projection Results

The map of projection of development to year 2022 using the medium development rate scenario and no development constraints is illustrated in Figure 8-23. Projections using medium development rate and each of the three different development constraint-levels (none, low, and high) can be found in Appendix 6. There are in total nine projections (three rates x three development constraint scenarios). Projected development follows a similar pattern under all three constraint scenarios with some minor differences as a result of the decreased amount of land available for development under the higher constraint scenarios.

At the medium development rate, there would be 8,930 acres of new development, a 12.7% increase from 2002. The acres of development added to each town vary widely, with Danbury receiving over 1,000 acres of new development and Morris less than 50 acres (Table 8-12). The high weights given to distance from major roads, development density, and distance from densely developed areas cause projected new development to cluster around road features, previously developed areas, and the following population centers: Danbury, Torrington, New Milford, Brookfield, Granby, Burlington, and Simsbury. Simulated future development tends to occur near areas where development had occurred during the previous 17 years.

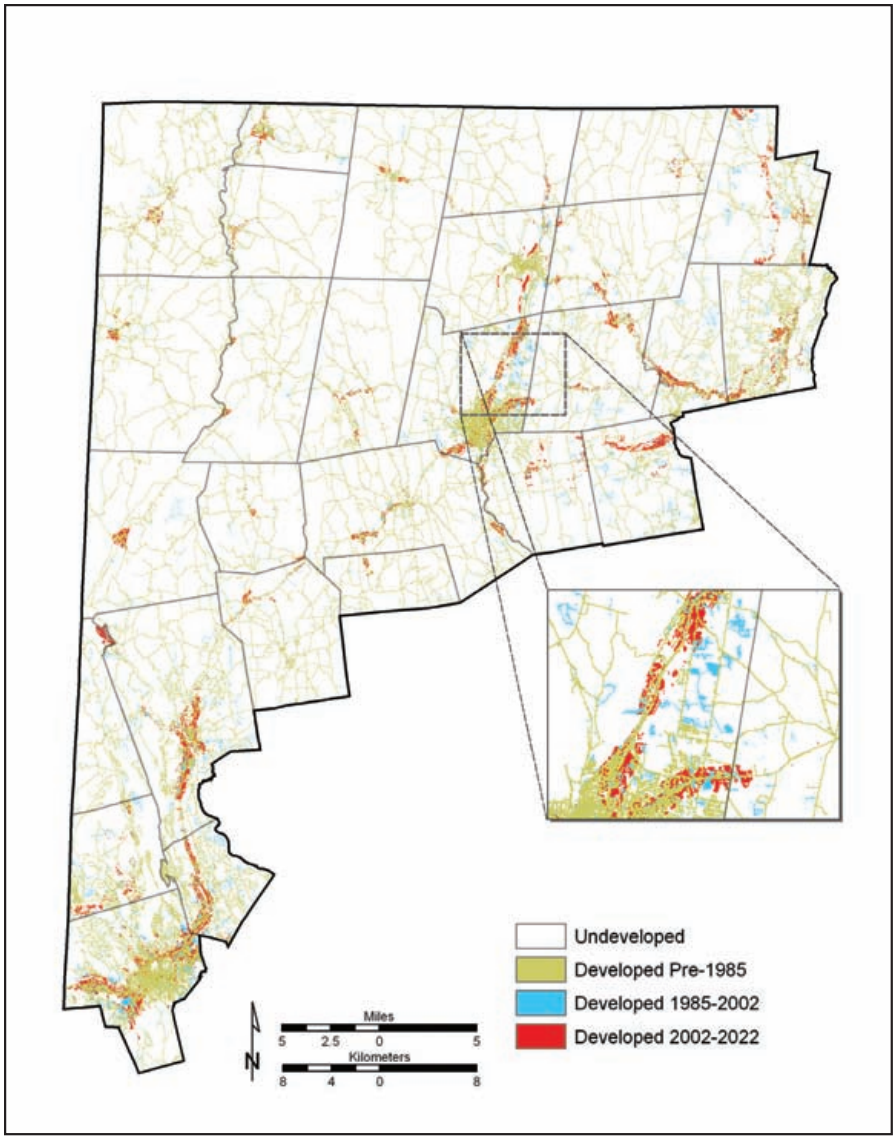


Figure 8-23. *Connecticut Highlands: Projection of development to year 2022 using the medium development rate and no constraints.*

Table 8-12. *Connecticut Highlands: Acres of new development projected for each town from 2002 to 2022 under medium development rate.*

Projected New Development 2002 - 2022				
	Acres of New Development	**% Change from 2002**	**Total Developed Acres by 2022**	**Area Developed by 2022**
Danbury	1,374	15%	10,565	38%
Torrington	958	16%	6,790	26%
New Milford	899	16%	6,399	16%
Brookfield	613	19%	3,875	30%
Granby	553	23%	2,999	11%
Burlington	521	25%	2,597	13%
Simsbury	512	12%	4,764	22%
Canton	397	20%	2,402	15%
New Fairfield	352	15%	2,631	16%
New Hartford	324	15%	2,535	10%
Winchester	300	12%	2,881	13%
Harwinton	268	15%	2,012	10%
Litchfield	267	8%	3,689	10%
Sherman	206	15%	1,542	10%
Barkhamsted	185	10%	1,954	8%
Kent	163	9%	1,922	6%
North Canaan	140	12%	1,355	11%
Washington	125	6%	2,230	9%
Goshen	108	6%	1,780	6%
Salisbury	106	4%	2,900	8%
Sharon	102	4%	2,377	6%
Colebrook	80	7%	1,149	5%
Norfolk	80	5%	1,620	5%
Hartland	74	6%	1,315	6%
Cornwall	61	4%	1,702	6%
Warren	59	6%	1,068	6%
Canaan	56	6%	1,049	5%
Morris	48	5%	1,040	9%
Total	8,931	13%	79,141	12%

Pennsylvania

We projected future land use from 2001 to 2022 using three development constraint levels (none, low, and high) and county-specific rates. We used the *suitability* map created by GEOMOD stratified by county, because it attained the best "fit" to the validation data set as judged by ROC, and greater projection accuracy than either of the *suitability* maps created by logistic regression according to all measures (*i.e.,* overall accuracy, kappa statistic, and user's and producer's accuracies). The unconstrained neighborhood rule was selected because the neighborhood rule had no effect on overall accuracy and kappa statistic for the 2001 simulated map, and because non-neighborhood constrained projections are more likely to allow low-density rural development to be captured. Cells were allocated during projection using county-specific development rates because this method achieved nearly identical accuracy statistics as allocation over the region, accounts for county by county variation in rate of growth, and prevents clumping of projected development in a few regions of particularly high suitability scores.

Projected Future Rate of Development (2002 – 2022)

Based upon the change in area of developed land from 1992 to 2001 within each county (Table 8-13), we used linear extrapolation to project the area developed in 2022. The development rate for the region in aggregate is given in Figure 8-24. The amount of development in 2002 was used as a starting value.

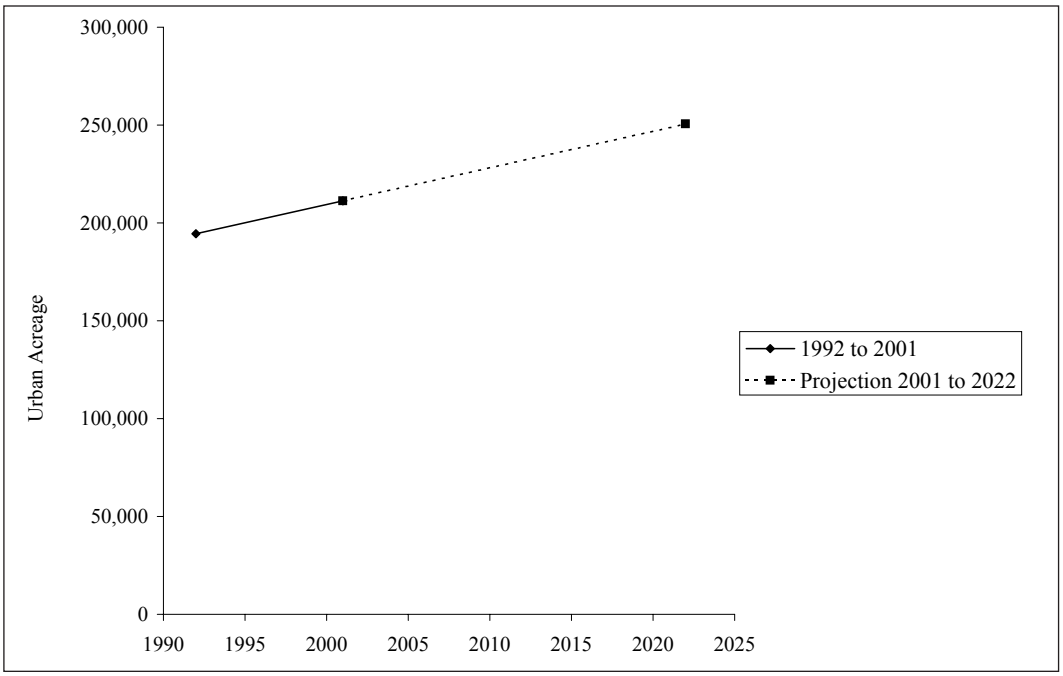


Figure 8-24. *Pennsylvania Highlands: Acres of urban land use in 1992 and 2001 and projection to 2022 using the 1992-2001 rate of increase.*

Table 8-13. *Pennsylvania Highlands: Rate of development from 1992 to 2001.*

	Rate 1992 - 2001 (acres/year)
Lancaster	304
Montgomery	247
Dauphin	98
Northampton	173
Chester	102
Berks	505
York	73
Bucks	109
Lehigh	168
Lebanon	91
Total	1,870

Creation of the Final Suitability Map Used for Future Projections (2001-2022)

To identify the location of areas likely to transition to development post-2001 we recalibrated the 1992 *suitability* map as follows:

1) Re-calibrated the *suitability* values per bin of each of the eight factor maps (Table 8-3) upon which the best composite suitability map was based, using 100% of the cells available for development in 1992. The suitability per bin was calculated using the grid cells that transitioned to development between 1992 and 2001 divided by all possible candidate cells available in 1992.
2) Updated six of the factors used to create the best fit suitability map with the most current information available from the 2001 LULC classification and 2000 impervious surface data. These factors were (1) density of development in a 200 ft radius, (2) distance from urban land use/cover class, (3) distance from densely developed areas (50% developed within 600 ft radius), (4) distance from grid cells with greater than 34% impervious surface coverage, (5) size of patch of contiguous land use/cover, and (6) minimum distance from edge of patch of contiguous land use/cover.
3) Binned these six updated factor maps so that the number of bins and the values used to create breaks between bins matched the corresponding best fit 1992 factor maps.
4) Assigned the new *suitability* values to the appropriate bin of each of these six updated maps.
5) Combined all individual *suitability* maps into a composite *suitability* map, as before, using the weights previously derived from the optimization program.

The final 2001 suitability map showing areas of highest likely pressure for future development in the Pennsylvania Highlands (Figure 8-25) reveals the influence of the most important factors such as density of development in a 200 ft. radius and proximity to previously developed areas, particularly areas of high density.

Using a quantile classification, *i.e.,* an equal number of cells in each class, we have reduced the *stratified* 2001 suitability map into three classes indicating high, medium and low suitability for development as of 2001. This allows for easy identification of areas of high development pressure. (Figure 8-26).

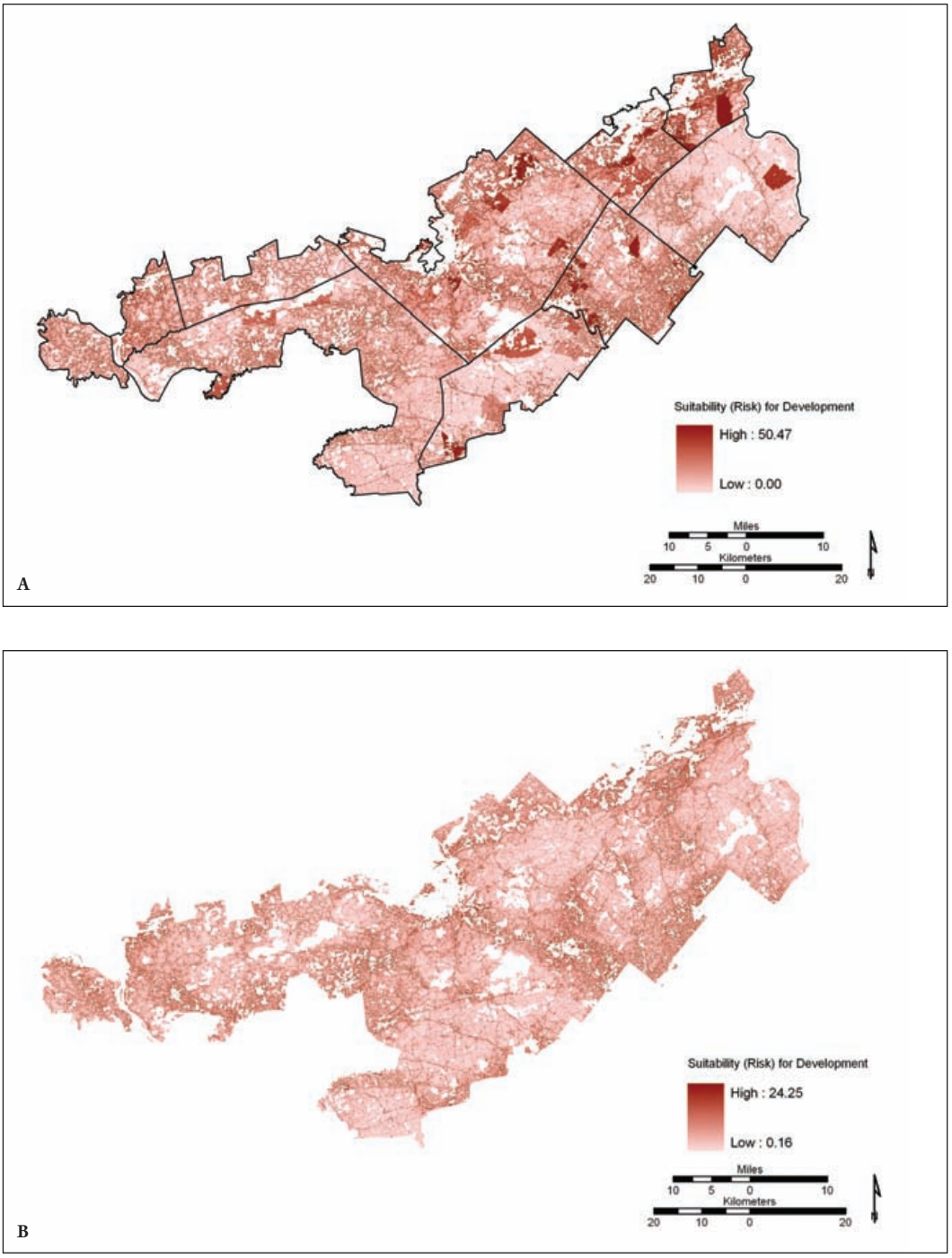


Figure 8-25. *Pennsylvania Highlands: 2001 Suitability map used in projecting to 2022, created using updated drivers and stratification by county (A) and for the whole reagion (B).*

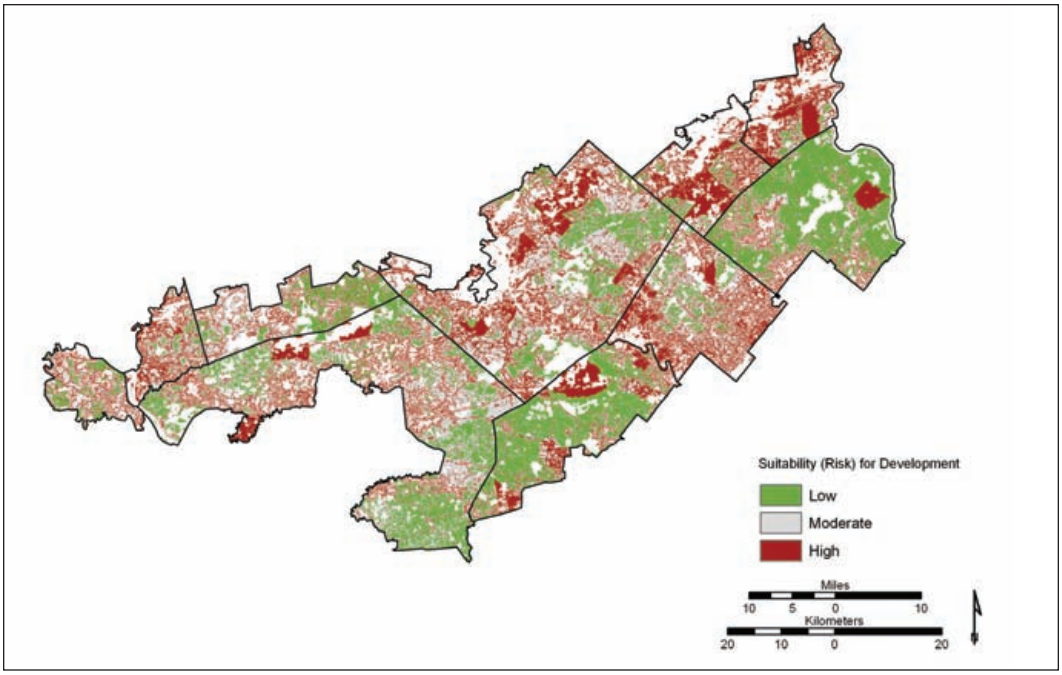


Figure 8-26. *Pennsylvania Highlands: 2001 Suitability Map showing places where development is most likely to occur across the region. White areas are those not considered candidates for future development because the are: 1) already developed; 2) protected from development; or 3) water. High, medium, and low development pressure are signified by the colors red, gray, and green, respectively.*

Projection Scenarios

Using the final *suitability* maps (*stratified by county*) we projected the transition of forest, agriculture, and wetlands to development out to the year 2022. The model selected cells for development using county-specific rates. We used three development constraint scenarios. Under the no constraints scenario only cells found in protected areas or classified as water were excluded from development. Under the low and high constraints scenarios exclusion was the same as that used in the build-out analysis (see Chapter 6, *Zoning Build-Out Analysis* section). This gave a total of three combinations of rate and development constraints.

Projection Results

The projection of development to year 2022 using the stratified *suitability* map, stratified allocation of development, and "business as usual" constraints is given in Figure 8-27, and projections using each of the three different constraint-levels (none, low, and high) can be found in Appendix 7). With this rate, 39,260 acres of development would be added between 2001 and 2022. This represents an 18% increase in 21 years. The largest acreage gains in new development would occur in Berks county (10,613 acres) followed by Lancaster county with 6,379 acres. Four counties would experience increases of 20% or more (Table 8-14).

Projected development follows a similar pattern under all three constraint scenarios with some minor differences as a result of the decreasing amount of land available for development in each scenario. The relatively high weights given to factors related to development density, distance from development, and distance from roads caused development projected to 2022 to cluster around

road features and previously developed areas in all scenarios. A visual comparison of the 2022 results to the map of development change from 1992 to 2001 (Figure 8-27) reveals that simulated future development tends to occur near areas where development had occurred during the previous nine years.

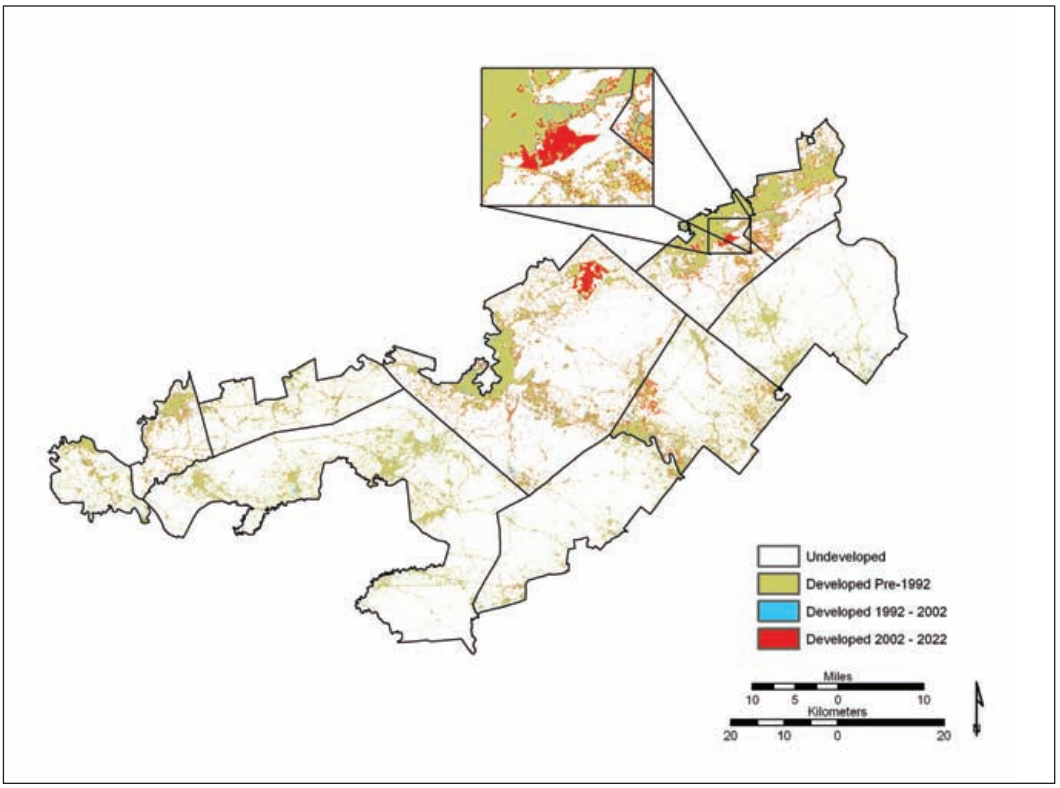


Figure 8-27. *Pennsylvania Highlands: Projected development in 2022 under no constraints and using GEOMOD county-stratified suitability map, non-stratified projection method, and no neighborhood constraints.*

Table 8-14. *Pennsylvania Highlands: Rate of development and estimate of developed area using linear extrapolation of trend from 1992 to 2001 out to 2022.*

Projected New Development 2002 - 2022				
County	**Acres of New Development**	**Increase from 2001**	**Total Developed Acres by 2022**	**Area Developed by 2022**
Berks	10,613	22%	58,542	18%
Bucks	2,285	16%	16,552	10%
Chester	2,145	21%	12,389	9%
Dauphin	2,052	22%	11,413	25%
Lancaster	6,379	17%	44,744	14%
Lebanon	1,919	18%	12,330	15%
Lehigh	3,518	13%	30,960	39%
Montgomery	5,191	20%	31,338	24%
Northampton	3,632	15%	27,975	42%
York	1,525	17%	10,353	24%
Total	39,259	18%	256,595	19%

CHAPTER 9 IMPACTS OF LAND USE CHANGE

Key Findings

Connecticut

- Close to a third of riparian buffers have been cleared of natural vegetation.
- Forests are more fragmented in 2002 than they were in 1985; unfragmented forest (patches larger than 25 acres) declined from 47% of the forest area to 43%.
- Twenty-seven percent of the land that is considered to be of high/highest conservation value is at high risk of being converted to development.
- High value water protection lands and agricultural lands are most at risk.
- Protection of riparian areas is very low in many towns. In half the towns over 25% of riparian areas (100 feet) are altered from their natural vegetation.

Pennsylvania

- The trend from 1992 to 2001 indicates some amount of re-vegetation of riparian buffers, however over half of the riparian buffers remain cleared of natural vegetation (forest or wetland).
- Only 12% of forests are unfragmented (larger than 25 acre patches).
- Twenty-three percent of the land that is considered to be of high/highest conservation value is at high risk of being converted to development.
- High value recreation and water protection lands are most at risk.
- The trend from 1992 to 2001 indicates some amount of re-vegetation of riparian buffers, however over half of the riparian buffers remain cleared of natural vegetation (forest or wetland). The amount of altered riparian area is particularly high in Lancaster and Lebanon Counties.

Introduction

In order to characterize the impacts of human activity on the landscape of the Highlands, both historic and projected, we have employed eight indicator metrics, which in various ways measure how development and land use change have altered the natural landscape.[16]

- Altered Land — percentage of land in altered state (all land uses except forest, wetland, and water)
- Impervious Surface Cover — percentage of land covered by impervious surface
- Riparian Corridors — percentage of riparian area in altered land use within 295 feet (90 meters) of stream corridors
- Riparian Corridors — percentage of riparian area in altered land use within 100 feet (30 meters) of stream corridors
- Forest Fragmentation —the percentage of land covered by interior forest (patches larger than 25 acres, and more than 295 feet from an edge)
- Forest Fragmentation —the percentage of land covered by largest forest patch
- Forest Fragmentation —the perimeter: area ratio for all forest patches
- Farmland Soils — percentage of important farmland soils (prime farmland or farmland of statewide importance) in developed land use

16 These are the same indicators used in the New York/New Jersey study.

In addition, we analyzed forest fragmentation type, which is the amount of forest in five fragmentation types: core; patch; transition; edge; and perforated.

Methods

Spatial and Temporal Characteristics of Analyses

In the Connecticut Highlands, we calculated indicator values on the historic LULC data from CLEAR and for each of the nine projections of development in 2022 at three spatial scales: the region; towns; and HUC 12 watersheds. The nine projections are all possible combinations of three development rates (low, medium, and high) and three constraint scenarios:

1. No constraints – only protected land and water were excluded from projections.
2. Low constraints – protected land, water, and areas used in the low constraint scenario developed in the build-out analysis were excluded from projections.
3. High constraints - protected land, water, and areas used in the high constraint scenario developed in the build-out analysis were excluded from projections. (See Chapter 6, *Zoning Build-out Analysis.)*

Intersecting the Connecticut Highlands with HUC 12 delineation of watersheds created the watershed unit of analysis. Only that portion of each watershed that is within the Highlands boundary was included in our analysis. In those cases where only small sections (less than 1,000 acres) of watersheds are within the Highlands boundary, we excluded them from the analysis.

In the Pennsylvania Highlands, we calculated indicator values using 1992 and 2001 LULC data and each of the three projections of development in 2022, based on the three constraint scenarios. These measures were calculated for the region, counties, and HUC 11 watersheds. Intersecting the Pennsylvania Highlands with the delineation of HUC 11 watersheds created the watershed unit of analysis.

Altered Land

Assessing how much of the region's forests and wetlands are altered versus unaltered provides a simple and readily comprehensible measure of the impacts of growth on the region's natural ecosystems. Based on our assumption that at one time this region was predominantly forested, we considered any land cover other than forest or wetlands to be altered. In Connecticut, altered lands were the following LULC classes: *developed*; *turf grass*; *other grasses and agriculture*; *barren*; or *utility right-of-way*. In Pennsylvania, *urban*, *barren*, *rangeland*, and *agriculture* LULC classes were considered altered land.

Impervious Surface Cover

Measures of impervious surface (*e.g.,* bedrock, pavement, or buildings) have become an important indicator for environmental planning and monitoring for several reasons. Impervious surface is a general indicator of the degree of human presence within a landscape. As development occurs, the number of roads, paved areas, and houses increases and impervious surface covers more of the landscape. As impervious surfaces increase, hydrologic regimes are altered by decreased surface infiltration; non-point source pollution associated with roads increases; habitat is lost; and increased surface temperatures contribute to the urban heat island effect, warmer stream conditions from heated runoff, and higher cooling energy demands. Alterations in water quality

and quantity can have important consequences to potable water supplies, ecosystem processes and wildlife habitat.

We analyzed past changes in impervious surface and used the relationships between development and impervious surfaces to quantify expected increases in impervious surface under the GEOMOD land-use projections.

Connecticut

We calculated the percentage of impervious surface for each of the 45 watersheds and 28 towns for the years 1985, 1990, 1995, and 2002 using impervious surface maps produced by the CLEAR program. The impervious surface maps are grid data with each grid cell assigned to 1 of 10 groups, where each group represents a range of values in multiples of 10, from 0 to 100%, based upon the percentage of impervious surface within the individual cell. We assigned to each cell the median value of the interval to which it belonged and then calculated the percent of land covered by impervious surfaces at the regional-, watershed-, and town-level.

In order to estimate future impervious surface cover under each of our development projections, we compared the CLEAR 2002 LULC map to the 2002 CLEAR percent impervious surface map and calculated the mean impervious surface percentage for each LULC class. The developed class had an average impervious surface of 33.3% and all other classes had an average of 4.75 %. All projected 2022 cells were then assigned percent impervious surface values according to their 2002 classification unless they had become developed in the simulation, in which case they received an impervious surface value of 33.3%. As before, these impervious surface maps were overlaid with digital maps of the HUC 12 watersheds and the towns, and the percentage of impervious surface was calculated for the area at the regional-, watershed-, and town-levels.

Pennsylvania

We calculated the percentage of impervious surface for each of the 33 watersheds and 10 counties for the years 1992 and 2001, using the NLCD Impervious Surface data. This data set is in grid format with each cell assigned a percentage of impervious surface coverage. We overlaid this with the 2001 LULC data and extracted the mean impervious surface value within each LULC class. We then assigned this mean to each cell in the 1992 and 2001 LULC data according to class membership. After assigning these values, we calculated the percentage of land covered by impervious surfaces at the regional-, watershed-, and county-level.

In order to estimate future impervious surface cover under each of our development projections, all projected 2022 cells were assigned percent impervious surface values according to their 2001 classification unless they had become developed in the simulation, in which case they received the mean impervious surface value for developed land (31.24%). These impervious surface maps were overlaid with digital maps of watersheds and counties, and the percentage of impervious surface was calculated at the regional-, watershed-, and county-levels.

Riparian Corridors

From an ecological perspective, riparian areas can be defined as land adjacent to a body of water that contains vegetation distinctly different from the vegetation of adjacent upland areas. From the point of view of water quality, they are generally considered important water purifying zones that catch sediment and take up nutrients moving toward the stream from upland areas. Riparian areas are frequently flooded during storm events, high in nutrients due to flood replen-

ishment and deposition from upland soils, and characterized by hydric soils. Development, agricultural uses, and vegetation clearing in riparian areas increases the likelihood of sediment and nutrient fluxes to stream water from both point and non-point sources. Many organisms utilize riparian areas as habitat, migration corridors, or breeding locations and are negatively influenced by anthropogenic disturbance.

We delineated riparian areas using two different methods. In the first method, we extracted freshwater streams and rivers from USGS 1:24,000 scale digital data and selected areas of (1) hydric soils as mapped by USDA National Resources Conservation Service or (2) wetlands as mapped by the U.S. Fish and Wildlife Service, that either intersect or are within 100 feet of these freshwater streams or rivers. These selected areas were buffered by 50 feet and merged with (1) 100 year flood zones as mapped by the Federal Emergency Management Agency and (2) a 100-foot buffer of freshwater streams and rivers.

The second method selects: 1) 100 year flood zones as mapped by the Federal Emergency Management Agency; 2) hydric soils as mapped by USDA National Resources Conservation Service; and 3) wetlands as mapped by the U.S. Fish and Wildlife Service that either intersect or are within 100 feet of these freshwater streams or rivers. These selected features are then merged with a 295-foot buffer[17] around freshwater streams and rivers.

Separately, we intersected the two digital maps of riparian areas with digital maps of HUC 12 (Connecticut) and HUC 11 (Pennsylvania) watersheds and towns/counties. This operation split the riparian areas where they crossed watershed or town boundaries and assigned them to the watershed or political unit in which they are found. For each of the four historic time periods for which classified LULC data were available (1985, 1990, 1995, and 2002 in Connecticut; 1992 and 2001 in Pennsylvania), we designated raster cells classed as *developed*, *turf and grass*, *other grasses and agriculture*, *barren*, or *utility right-of-way* (Connecticut) and *urban*, *barren*, *rangeland*, or *agriculture* (Pennsylvania) as being in an altered state. For each historical year, we summarized at the regional-, watershed-, and town/county-levels the percentage of the riparian areas contained in each that are in an altered state.

To assess the quantity of riparian altered land in our nine development projections to 2022 we added the projected developed cells to the existing altered cells (as of 2002 for Connecticut; 2001 for Pennsylvania). For each projected map, we then summarized at the regional-, watershed-, and town-levels the percentage of riparian areas in an altered state using both riparian area delineations.

Forest Fragmentation

Clearing of forest, whether for development, agriculture, road-building, or other uses, decreases forest cover and may also fragment into smaller patches the forest that remains. Fragmentation of forestland into smaller patches has many potential ecosystem effects. Smaller, fragmented patches have less interior area and so organisms are more exposed to human disturbances. They may be left with inadequate cover required for protection from predators, may be blocked by fences and roads from typical movement patterns, or simply more vulnerable to mortality from encounters with humans, predators, and traffic. Large, contiguous forest tracts contain microclimates important to interior-forest species. Fragmented forests have also been shown to be more susceptible to invasive species, and loss of forest cover has direct impacts on stream water quality.

17 This is the same size buffer as used in the NY/NJ Highlands study.

We calculated three fragmentation indices at three spatial scales: regional; watershed; and county. The first index is the percent coverage by the largest contiguous forest patch. The second is the percent coverage by interior forest. The third is the ratio of patch perimeter to patch area.

For each of the historic time periods for which we have LULC data in Connecticut and Pennsylvania, we separated forest cells. In Connecticut, these were coniferous forest, deciduous forest, and forested wetland classes. There is only one class of forest in Pennsylvania. To create a regional-level map of forest patches for each year, we grouped forest cells that are adjacent to each other (including on the diagonal or king's rule) into separate patches. To create town-level (Connecticut), county-level (Pennsylvania), and watershed-level forest patch maps, we intersected, separately, each regional-level map of forest patches with digital maps of watersheds and political units. This operation split patches found in more than one watershed or political unit into two or more patches along the watershed or political boundary.

Large Forest Patches

In each time period, we determined the forest patch in the regional-level map with the largest area and calculated the percent of the region it covers. Using the watershed- and political unit-level forest patch maps, we identified the largest forest patch found within each watershed and political unit and calculated the percent of the watershed or political unit it occupies. It must be noted that this "large patch" can actually be a very irregularly shaped contiguous series of forest cells, which would not necessarily be considered a "large forest patch" in ecological terms.

Interior Forest

In each time period, we delineated interior forest by removing from each patch created at the regional-level the 295 feet around the outer boundary of the patch to exclude edge habitat. After edge removal, we excluded from the map all patches less than 25 acres in surface area.[18] The percent coverage of remaining interior forest was calculated for the region and within individual watersheds and political units.

Perimeter:Area Ratio

We measured the perimeter (feet) and area (acres) of each forest patch in the regional-, watershed-, and political unit-level forest patch maps of each year. At the regional-level, the perimeters and areas of all forest patches in the study area were summed. The perimeters and areas of forest patches delineated using watershed, county, or town boundaries were summed within each watershed or political unit, respectively. We then divided the total perimeter length by the total area of patch for each time period.

Projections

To extrapolate into the future, we overlaid the original forest map (from 2002 in Connecticut and 2001 in Pennsylvania) with our projections of land use change. We eliminated from forest classification those grid cells projected to become developed. We then aggregated cells classified as forest into patches and calculated each fragmentation metric at the regional-, watershed-, and political unit-levels using the same methodology used for the historic data.

18 Size of patch and edge-exclusion are the same as used in the NY/NJ Highlands study.

Composition of Forest by Fragmentation Type

In order to provide a more robust picture of trends in forest condition over time, we used an additional set of fragmentation metrics. They are adopted from a series of algorithms developed by Riitters *et al.,* (2002) that classify forest grid cells into one of five categories (core, patch, transition, edge, or perforated) based upon the composition and spatial configuration of surrounding cells (Figure 9-1). These metrics were also used by Holdt *et al.,* (2004) to characterize the forests of Connecticut. We take our definitions for these five fragmentation classes directly from their work.

- Interior (core) forest – all pixels in the surrounding area are forest.
- Patch forest – very few forest pixels that are part of a forest patch on a non-forest background, such as a small wooded lot within an urbanized region.
- Transitional forest – about half of the cells in the surrounding area are forested and these may appear to be part of a patch, edge, or perforation depending on the local forest pattern.
- Edge forest – most of the pixels in the surrounding area are forested, but some appear to be part of the outside edge of forest, such as would occur along the boundary of a large urban area, or agricultural field.
- Perforated forest – most of the pixels in the surrounding area are forested, but some appear to be part of the inside edge of a forest patch, such as would occur if a small clearing was made within a patch of forest.

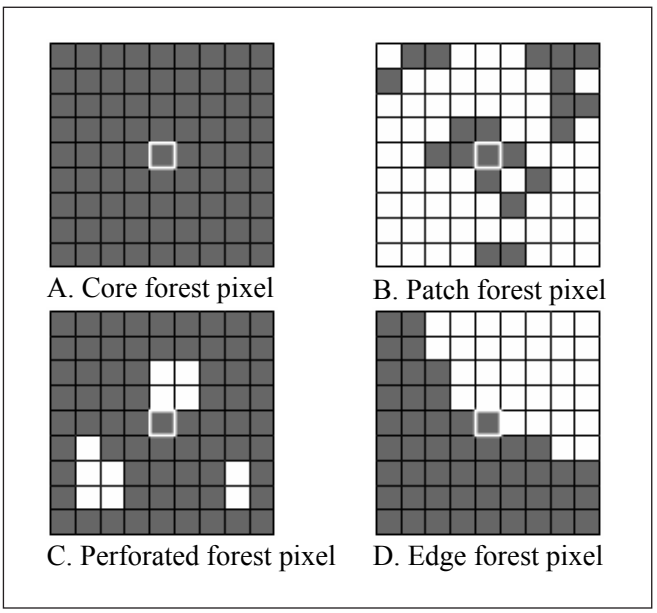


Figure 9-1. *Examples of forest fragmentation categories in a 9x9 pixel analysis window. Dark cells are forest, white cells are other land uses. Source: Hurd et al. 2006.*

Connecticut

In Connecticut, fragmentation maps were created for years 1985, 1990, 1995, and 2002 by CLEAR, using the Riitters *et al.,* methodology. We summarized the acreage and percent composition of each fragmentation type for all years at the regional-, watershed-, and town-level. These maps were produced with *coniferous forest*, *deciduous forest*, and *forested wetland* taken together as a general forest class and water and non-forested wetland as a non-fragmenting feature. Effectively, this meant that water, forest, and non-forested wetland were considered as a single class during the analysis, although values were only assigned to forest cells. The remaining classes (*developed*, *turf grass*, *other grasses and agriculture*, *barren land*, and *utility row*) were elements considered to be fragmenting land covers. The algorithms used a 9x9 cell (18.6 acres) moving window during analysis and are summarized by Riitters *et al.,* (2000).

The algorithm is performed using information on the cells within this 9x9 cell window, with the classification assigned to the cell at the center of the window. The analysis was carried out for the nine development projections in Connecticut by converting cells predicted to be developed to the developed class in 2002 LULC data.

Pennsylvania

In Pennsylvania, only one forest class exists in the 1992 and 2001 LULC data. *Water* and *wetland* were treated as non-fragmenting categories, and we defined *urban*, *agriculture*, *rangeland*, and *barren* as fragmenting LULC types. Effectively, this meant that water, forest, and wetland were considered as a single class within the window, although fragmentation values were assigned only to forest cells.

Fragmentation maps were not available for any time period for Pennsylvania, therefore, we created our own model to carry out the algorithm. We created a program that slid a 9x9 cell window across the map, pausing at each forested cell, and employing the algorithm of Riitters *et al.,* (2000) to classify the cell at the center of the window. This was done for the 1992 and 2001 historical LULC data and the 2022 development projections under three scenarios. Using each projection scenario separately, maps of LULC in 2022 were created for input to the model by converting non-developed cells in the 2001 LULC map to developed use if projected to be developed in 2022. Results for all years were summarized at the regional-, watershed-, and county-levels.

Farmland Soils

Connecticut

The State of Connecticut, Department of Environmental Protection has designated areas of prime farmland and farmland of statewide importance based upon SSURGO soils data created by U.S. Department of Agriculture, Natural Resources Conservation Service. The Connecticut Highlands contain 86,357 acres of prime farmland soils and 69,780 acres of farmland of statewide importance, representing 23% of the region.

We aggregated prime farmland and farmland of statewide importance into a single farmland soil category that we call important farmland soils. We then overlaid this with LULC data from 1985, 1990, 1995, and 2002. For each period, within the region, watershed and town, we determined the amount of important farmland soils that were in developed land use. To project into the future, we overlaid the aggregate farmland soils map with the results of our development projections and summarized the changes expected at the regional-, watershed- and town-level.

Pennsylvania

The U.S. Department of Agriculture, Natural Resources Conservation Service indicates areas of prime farmland soils (designated as prime farmland or farmland of statewide importance) as part of its SSURGO soils data product. The PA Highlands contain 829,600 acres (60% of total area) of prime farmland soils.

We overlaid prime farmland soils with LULC data from 1992 and 2001. For each period, within the region, watershed and county, we determined the percentage of prime farmland soils that were in developed land use. To project into the future, we overlaid the prime farmland soils map with the results of our development projections and summarized the changes expected at the regional-, watershed- and town-level.

Results

Connecticut

Regional

Although this is a heavily forested region, with 67% of the land in forest cover, it is a somewhat fragmented forest. Less than half of the forested area can be considered core, or interior, forest. Nonetheless, the Highlands forests are likely the least fragmented in all of Connecticut. A simple measure of fragmentation, the perimeter:area ratio, is about 132 feet of perimeter to every acre of forest in the Highlands. As a comparison, in the Thames watershed in northeastern Connecticut, the other heavily forested part of the state, the perimeter:area ratio was 381:1 in 2002 (Tyrrell *et al.,* 2004).

About a quarter of the land is in "altered" state. The rest is forest, wetlands, and water. Riparian areas are highly impacted – with almost a third in a condition other than what would be considered natural riparian vegetation.

Within the Connecticut Highlands as a whole, from 1985 to 2002, all measures indicate a slight increase in anthropogenic impacts (Table 9-1). This is because the area is mostly forested, with relatively little developed land. We see a small increase in impervious surface, directly proportional to the amount of new development that has occurred. Development has occurred mostly on prime farmland. About 27% of riparian areas are altered from what would be their natural land cover of either forest or wetland. The percent increase in altered land within riparian areas is approximately equal to that of the region as a whole, indicating that proximity to riparian areas tends to neither significantly attract nor inhibit development.

Forests are more fragmented in 2002 than they were in 1985, as measured by the perimeter:area ratio, and the amount of core/interior forest habitat. Interior forest decreased by 23,800 acres. The core forest metric, computed using the methods of Holdt *et al.,* (2000) at an 18.6 acre window, shows a decrease in core forest of 24,300 acres (Table 9-2), which is very close to the loss of interior forest. These two metrics, computed using different algorithms, confirm that the forests of the Connecticut Highlands have significantly less interior/core forest habit than they did in 1985. The only other significant change is that perforated forest increased by 12,370 acres. This indicates there is more small-scale development occurring within the forest, such as a new house, structure or road in the woods.

Table 9-1. *Connecticut Highlands: Impact indicators for 1985 and 2002 (actual) and 2022 (projected) for none-, low-, and high-constraints scenarios, using medium development rate. Note that "large forest patch" can actually be a very irregularly shaped contiguous series of forest cells, which would not necessarily be considered a "large forest patch" in ecological terms.*

			Projected - Medium Rate		
	Actual		No Constraints	Low Constraints	High Constraints
Indicator	**1985**	**2002**	**2022**	**2022**	**2022**
Perimeter:Area Ratio (ft/acres)	120.9	131.8	130.4	131.4	131.8
Interior Forest %	46.9	43.1	42.7	42.6	42.5
Largest Forest Patch %	3.3	3.3	3.0	3.0	3.3
Impervious Surface %	7.5	7.8	8.2	8.2	8.2
Altered Land %	24.5	26.2	27.2	27.2	27.1
Developed Prime Farmland %	14.8	16.3	18.4	18.5	18.7
Altered Riparian Area % (295 ft)	27.3	28.6	30.1	29.3	29.2
Altered Riparian Area % (100 ft)	26.0	27.1	28.6	27.4	27.2

Table 9-2. *Connecticut Highlands: Forest fragmentation types for 1985 and 2002 (actual) and 2022 (projected) for no-, low-, and high-constraints scenarios, using medium development rate.*

					No Constraints		Low Constraints		High Constraints	
Fragmentation	**1985**		**2002**		**2022**		**2022**		**2022**	
Type	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**
Core	46.7	228,458	42.6	203,370	42.2	198,980	42.1	198,391	42.0	197,926
Patch	2.4	11,930	2.7	12,966	2.6	12,349	2.7	12,683	2.7	12,711
Transition	6.0	29,551	6.6	31,632	6.7	31,705	6.8	32,003	6.9	32,308
Edge	24.9	122,115	24.9	118,845	27.1	127,597	27.1	127,834	27.1	127,997
Perforated	19.9	97,571	23.1	110,338	21.3	100,332	21.2	100,054	21.3	100,384

Overall, estimates of these measures in year 2022 under the nine development projection scenarios indicate that anthropogenic impacts will increase only slightly. One reason is the propensity of new development to occur near previously developed areas. For example, the projected perimeter:area ratio is shown as changing very slightly, even decreasing under the no constraints scenario. We believe this is caused by the model selecting high suitability cells at the rural-urban interface and thereby reducing the area of small forest patches and smoothing the forest edge. Cells deeper in the forest are not chosen in the projections generally, because those cells have lesser suitability values.

Another reason is that the amount of development projected to occur is low at 8,930 acres, or 1.5% of the available land, at the medium historical rate. This is an increase in developed land of about 12.7 % over the next 20 years. As development moves away from riparian areas, such as is the case with the high constraints scenario, it has more of an effect on the forested areas. As might be expected, as development rate increases from low to medium to high the estimates of impact also tend to increase. However, these changes are very slight.

Towns

We divided the towns in the Connecticut Highlands into four intervals based on the percent of the town in developed land use in 2002 and then applied a color coding system to identify each interval (Table 9-3). These towns, with color codes indicating general rank, were then sorted separately by each impact indicator value (as of 2002) in descending order (*i.e.*, more impacted towns are closer to the bottom of the list). This allows us to see general relationships between development and each indicator measure. In a sense, this is a visualization of rank analysis common in non-parametric statistics.

Overall, impact-levels as measured by the indicators are positively related to 2002 development. This is especially true for percent impervious surface, as expected given that development is the primary source of impervious surfaces. In several cases towns registered lowered impacts than expected given the general relationship between environmental quality and development. Notably, these towns are: Colebrook; Barkhamsted; New Fairfield; Burlington; and Winchester. Kent is developing at a higher rate than its cohorts, and Simsbury at a lower rate. New Fairfield, one of the most developed towns in the region, has more contiguous forest cover than any other town, as represented by the "largest forest patch" indicator. New Fairfield's development is concentrated in the southern part of town, with large blocks of intact forest further north.

Protection of riparian areas is very low in many towns. In half the towns over 25% of riparian areas (100 feet) are altered from their natural vegetation. If you look at a 295 foot riparian area, in over 70% of the towns more than 25% of these areas are altered. It is notable that Burlington, one of the more developed towns, has significantly less altered riparian areas than its cohorts. On the other hand, Sharon, Kent and Caanan have more altered riparian areas than their cohort of lesser-developed towns.

Table 9-3. *Connecticut Highlands: Impact indicators in 2002 by town with color indicating approximate percentage of development in 2002.*

TOWN	Developed 2002 %		Change in % developed 1985-2002		Interior Forest %		Perimeter-Area Ratio (ft/acres)		Largest Forest Patch %		Impervious Surface %		Altered Land %		Developed Prime Farmland %		Altered Riparian Area % (295 ft)		Altered Ripar Area % (100 ft)	
Canaan	5.1	Hart	0.2	Hart	63.2	Cole	81.3	N Fai	47.9	Cana	6.1	Har	9.3	Gosh	11.3	Gosh	13.7	Gosh		
Norfolk	5.4	Shar	0.2	Cole	62.3	Hart	82.4	Corn	40.6	Cole	6.3	Norf	12.4	Shar	11.9	Hart	14.7	Hart		
Cornwall	5.7	Norf	0.2	Norf	61.0	Cana	83.3	Cana	32.4	Norf	6.3	Cole	12.7	Wash	12.0	Norf	15.1	Norf		
Kent	6.1	Cana	0.3	Corn	59.7	Corn	84.7	Burl	29.1	Corn	6.4	Bark	13.0	Cana	12.1	Litc	19.8	Litc		
Sharon	6.1	Corn	0.4	Cana	59.6	Norf	85.0	Shar	27.3	Kent	6.4	Corn	15.2	Morr	12.3	Burl	20.1	Burl		
Goshen	6.2	Sali	0.4	Bark	57.9	Kent	93.5	Sali	26.4	Hart	6.5	Warr	16.5	Sali	12.7	Harw	21.2	Harw		
Hartland	6.2	Gosh	0.5	Warr	55.3	Warr	95.1	Harw	25.5	Gosh	6.5	Cana	17.4	N Can	13.2	Corn	23.1	Warr		
Warren	6.3	Bark	0.5	Kent	55.3	Bark	99.8	Hart	24.2	Warr	6.5	Kent	18.8	Kent	13.3	Cole	23.5	Bark		
Colebrook	7.4	Warr	0.5	Gosh	48.8	Shar	101.7	Gran	23.7	Shar	6.5	Winc	21.5	Norf	13.5	Bark	25.0	N Fai		
Salisbury	8.0	Wash	0.7	Sharon	47.5	Gosh	110.7	Kent	22.9	Bark	7.0	N Har	21.7	Sher	13.8	Sher	25.4	Sher		
Barkhamsted	8.1	Morr	0.8	Winc	47.3	Sali	123.1	Winc	21.6	Sali	7.0	Burl	21.8	Corn	13.8	Warr	25.4	Corn		
Washington	9.0	Kent	0.8	Gran	43.8	Winc	129.4	Norf	21.6	Wash	7.2	Gosh	22.2	Hart	13.9	N Fai	25.6	Cole		
Harwinton	9.5	Litc	0.8	N Har	43.8	Gran	136.6	Sher	21.2	Harw	7.3	Harw	22.3	Harw	14.1	Winc	26.8	Winc		
Morris	9.8	Cole	1.0	Sali	43.6	N Har	137.3	Cole	19.8	Morr	7.4	Cant	22.7	Warr	14.6	Kent	27.1	Morr		
Litchfield	9.8	Winc	1.4	Burl	43.3	Harw	138.9	Warr	19.7	Gran	7.4	Sher	24.3	Litc	14.8	Gran	27.4	Wash		
Sherman	9.9	Sher	1.5	Harw	42.7	Burl	139.9	Gosh	18.9	N Har	7.4	Gran	25.8	N Har	15.3	Cana	27.9	Kent		
New Hartford	10.1	N Har	1.5	Cant	41.4	Cant	152.1	N Har	17.9	Litc	7.5	Shar	27.6	Burl	15.8	Morr	28.7	Gran		
Granby	10.4	Harw	1.6	Sher	39.1	Sher	157.4	N Can	16.2	Sher	7.5	N Fai	29.1	Gran	16.0	N Har	28.8	Cana		
Burlington	12.7	Sims	2.4	Litc	35.6	Litc	157.7	Bark	15.6	N Can	7.5	Litc	30.0	Cole	17.1	Sali	30.5	N Har		
Winchester	13.2	Gran	2.4	N Fai	34.2	Wash	161.2	Danb	15.6	Burl	7.9	Sali	30.8	Bark	18.1	Wash	30.5	Shar		
Canton	13.2	Cant	2.5	Wash	33.3	N Can	162.1	Sims	10.3	Winc	8.3	Wash	31.3	N Mil	18.2	Shar	31.6	Sali		
North Canaan	15.2	N Fai	2.6	N Can	30.9	Morr	180.8	Litc	9.9	Cant	8.4	Morr	36.2	Sims	20.6	Broo	34.1	Broo		
New Milford	15.9	N Mil	2.7	Torr	30.1	Torr	187.7	Cant	9.1	N Mil	8.8	Torr	37.0	Cant	21.4	Cant	35.1	Torr		
New Fairfield	18.2	N Can	2.7	Morr	30.0	N Fai	188.9	Morr	7.4	N Fai	9.8	N Mil	37.7	Broo	24.5	Sims	36.8	Cant		
Simsbury	20.0	Burl	2.8	N Mil	28.2	N Mil	200.2	Wash	6.6	Sims	10.4	Sims	42.0	Winc	25.5	Torr	38.1	Sims		
Torrington	24.1	Torr	3.7	Sims	18.2	Sims	274.3	Torr	5.6	Torr	11.3	N Can	45.0	Torr	26.9	N Mil	42.0	N Mil		
Brookfield	28.1	Danb	4.1	Danb	16.9	Danb	283.2	N Mil	5.4	Brook	12.2	Broo	45.4	N Fai	27.2	Danb	48.2	Danb		
Danbury	35.6	Broo	4.5	Broo	13.2	Broo	312.0	Broo	3.7	Danb	14.7	Danb	50.5	Danb	29.8	N Can	54.6	N Cana		

The towns registering the lowest and highest impacts in both years are shown in the tables in Appendix 6. Two adjacent towns, Danbury and Brookfield each had the greatest measured impacts in 2002 in three of the eight metrics. This pair of towns also accounted for four of the eight greatest changes over time. Individual measures for each of the eight indicators for each town for years 1985 and 2002 are given in Appendix 6. All indicators, except for some variability in the two measuring altered riparian area, indicate an increase in impact from 1985 to 2002. The direction of change in altered riparian area is variable because of subtle changes in amount and location of water between the two years.

Estimates for all indicators in year 2022 using the nine development projection scenarios are given in Appendix 6. Using "business as usual" constraints and medium development rate as the most likely of the nine scenarios to reflect future development dynamics, in all towns estimates of almost all measures in year 2022 indicate that anthropogenic impacts, as quantified by these metrics, will increase from 2002 levels. By 2022 using the same projection (medium rate and business-as-usual building restrictions), the towns of Brookfield, Danbury, and North Canaan would undergo the most environmental degradation according to the metrics applied, while Goshen, Hartland, Colebrook, Canaan, and New Fairfield would experience the least.

Watersheds

Measures for the eight indicators for each watershed for years 1985 and 2002 are given in the tables in Appendix 6. In all watersheds, perimeter:area ratio, percent interior forest, percent impervious surface, and percent developed prime farmland indicate an increase in impacts from 1985 to 2002. Percent altered land increased in 44 of the 45 watersheds. Altered riparian area increased in 41 watersheds when using a 295 foot riparian buffer; and in 38 watersheds when using a 100 foot buffer.

Estimates for all indicators in year 2022 using the nine development projection scenarios and the least and most impacted under medium development rate and "business as usual" constraints are shown in Appendix 6. Using "business as usual" constraints and medium development rate as the most likely of the nine scenarios to reflect future development dynamics, in all watersheds the estimates of all measures (except variable direction of change in perimeter:area ratio and no change in percent largest patch in some watersheds) in year 2022 under the three development projection scenarios indicate that anthropogenic impacts, as quantified by these metrics, will increase from 2002 levels.

The Still River watershed had the highest projected impact score in most indicators regardless of the projection scenario. The Hollenback watershed has the least forest fragmentation and the Sandy Brook watershed has the most protection of riparian areas.

Pennsylvania

Regional

Impact indicators for 1992, 2001, and projections to 2022 are shown in Table 9-4. Percent interior forest increased slightly, which could be an artifact of the problems with classifying land use from satellite imagery along forest/agricultural edges, as it is unlikely that there were more large forest patches in 2001 than there were in 1992 (see discussion in Chapter 7, *Analysis of Land Use/Land Cover*). Perimeter-area ratio decreased between 1992 and 2001. This can happen when small forest parcels get developed, or when development happens along the edges of forests, essentially smoothing out the perimeter.

The percent developed prime farmland and percent impervious surface increased slightly over the same time period. It is notable that over half of the riparian buffers have been cleared of natural vegetation (forest or wetland). However, the percent of buffers in altered land use declined from 1992 to 2001, which is a positive trend reflecting some amount of re-vegetation of riparian buffers.

Overall, estimates of all measures (except forest perimeter:area ratio) in year 2022 under the three development projection scenarios indicate that anthropogenic impacts will increase somewhat from 2001 levels. Twenty-five thousand eight hundred acres of new development is projected to occur on farmland, with a resulting increase in impervious surface by almost 10,000 acres.

There is no dominant pattern in the influence the constraint level (none, low, or high) has on the level of each indicator (Table 9-4). Percent impervious surface, interior forest, largest forest patch, and altered land are roughly equal regardless of constraints imposed. Perimeter:area ratio increases with increasing constraint level, indicating less complex patch shapes, on average, with higher constraints. Percent altered riparian areas (both delineations) decrease with increasing constraint level, and percent developed farmland increases with increasing constraint level, a result of development being displaced from riparian areas onto farmland.

Counties

We divided the counties in the Pennsylvania Highlands into four intervals based on the percent of the county in developed (urban class) land use in 2002 and then applied a color coding system to identify each interval (Table 9-5). These counties, with color codes indicating general rank, were then sorted separately by each impact indicator value (as of 2001) in descending order (*i.e.*, more impacted counties are closer to the bottom of the list). This allows us to see general relationships between development and each indicator measure. In a sense, this is a visualization of rank analysis common in non-parametric statistics.

As would be expected, overall the indicators are positively related to development with higher impact measures generally more likely in more densely developed areas. For instance, percent impervious surface and development track each other exactly in terms of rank. This is expected because developed land is the primary source of impervious surfaces. A strict relationship between indicator and development ranks is not true for all indicators, however. For example, percent altered land is a function of not only development but also the area of agriculture, rangeland, and barren lands. Therefore, counties with more agriculture, such as Lancaster and Chester have a high ranking for altered land even though they are ranked lower for development.

Riparian buffer protection is low in all counties of the Pennsylvania Highlands – no county has more than one-third of its riparian area (100 foot buffer) in natural vegetation. The amount of altered riparian area is particularly high in Lancaster and Lebanon Counties.

In several cases counties registered lowered impacts than expected given the general relationship between environmental quality and development. Notably, the portions of York and Lebanon Counties that are in the Highlands have a relatively high amount of developed land, but also a high proportion of interior forest. On the other hand, Chester County forests are more fragmented than would be expected for the county with the lowest percentage of developed land.

In 1992, the greatest impacts were confined to three counties (Lancaster, Dauphin, and Northampton) (Appendix 7). In 2001, Lancaster and Northampton Counties had the highest impacts. As would be expected, overall the indicators are positively related to development with higher impact measures generally more likely in more densely developed areas.

In all counties, anthropogenic impacts are projected to increase by 2022 from 2001 levels in all measures, except forest perimeter:area ratio. In all three development scenarios (no, low and high constraints), the greatest and least impacts are projected to be distributed across the counties in the exact same pattern as they were in 2001. This is because the model followed the historical pattern of projecting development in proximity to areas that were already developed.

With the exception of percent altered land, the counties with the lowest impacts were the same in 1992 and 2001 (Appendix 7). In both years, Chester County had the lowest percent impervious surface coverage, percent developed prime farmland, and altered riparian area (295 ft); Bucks County had the lowest altered riparian areas (100 ft); and Lebanon County had the lowest perimeter:area ratio and greatest percent interior forest. Percent altered land was lowest in York County in 1992 and Bucks County in 2001.

In all counties, estimates of all measures (except perimeter:area ratio) in year 2022 under the three development projection scenarios indicate that anthropogenic impacts, as quantified by these metrics, will increase from 2001 levels. In all three development scenarios, the greatest and least impacts according to the eight indicators are distributed across the counties in the exact pattern as they were in 2001.

Table 9-4. *Pennsylvania Highlands: Regional-level impact metric values for years 1992 and 2001 using historic data, and in 2022 using three development projection scenarios. Note that "large forest patch" can actually be a very irregularly shaped contiguous series of forest cells, which would not necessarily be considered a "large forest patch" in ecological terms..*

Indicator	1992		2001		No Constraints 2022		Low Constraints 2022		High Constraints 2022	
Perimeter:Area Ratio (ft/acres)	N/A	258.2	N/A	212.7	N/A	212.7	N/A	215.8	N/A	215.3
Interior Forest	10.2%	139,507	11.7%	160,777	11.6%	158,966	11.6%	158,695	11.6%	159,028
Largest Forest Patch	5.3%	71,917	5.4%	74,521	5.4%	73,964	5.1%	70,100	5.4%	74,166
Impervious Surface	4.7%	64,057	5.1%	69,528	6.0%	81,757	6.0%	81,757	6.0%	81,757
Altered Land	66.1%	905,048	65.6%	897,208	66.3%	907,158	66.2%	906,074	66.1%	904,630
Developed Prime Farmland	12.7%	104,849	13.9%	115,322	17.0%	141,132	17.3%	143,388	17.5%	144,760
Altered Riparian Area (295 ft)	57.0%	111,383	54.1%	105,322	55.1%	107,378	54.8%	106,637	54.4%	105,855
Altered Riparian Area (100 ft)	54.6%	80,634	50.8%	74,658	52.0%	76,420	51.5%	75,677	51.0%	74,915

Note: Perimeter: area ratio measure is in ft/acres, all others are acres.

Table 9-5. *Pennsylvania Highlands: Impact indicators in 2001 by county with color indicating approximate percentage of development in 2001.*

County	% Developed in 2001		Change in % developed1992-2001		Perimeter:Area Ratio (ft/acres)		Interior Forest %		Largest Forest Patch %		Impervious Surface %		Altered Land %		Developed Prime Farmland %		Altered Riparian Area % (295 ft)		Altered Riparian Area % (100 ft)	
Chester	7.3	Berk	1.4	Leba	141.5	Leba	18.8	Buck	33.5	Ches	2.4	Buck	52.4	Buck	4.8	Buck	42.3	Ches	37.6	
Bucks	8.4	Buck	0.3	Berk	199.8	York	16.3	Leba	18.1	Buck	2.8	York	54.7	Ches	7.9	Ches	42.6	Buck	42.9	
Lancaster	12.4	Ches	0.5	York	214.1	Berk	16.0	Ches	17.0	Lanc	4.0	Berk	57.2	Lanc	12.6	Berk	47.5	Berk	44.4	
Lebanon	12.7	Daup	1.7	Buck	217.4	Buck	15.1	Mont	13.1	Leba	4.1	Ches	62.0	Leba	12.8	Mont	48.9	Mont	46.4	
Berks	15.1	Lanc	0.7	Lanc	222.1	Ches	12.0	Berk	12.6	Berk	4.9	Leba	66.5	Berk	14.6	York	50.4	York	51.3	
Montgomery	20.2	Leba	0.9	Ches	229.3	Mont	8.6	Lehi	7.9	Mont	6.5	Mont	66.6	Mont	19.7	Lehi	57.0	Lehi	54.3	
York	20.4	Lehi	1.8	Mont	264.1	Lanc	7.7	York	5.8	York	6.6	Lehi	69.4	York	21.0	Nort	59.2	Nort	55.3	
Dauphin	20.6	Mont	1.6	Daup	286.5	Lehi	7.3	Nort	5.5	Daup	7.0	Nort	73.9	Daup	22.2	Leba	60.7	Daup	56.9	
Lehigh	34.3	Nort	1.9	Lehi	286.8	Daup	5.6	Daup	5.3	Lehi	10.8	Daup	74.3	Lehi	31.9	Daup	62.9	Leba	65.1	
Northampton	36.3	York	1.3	Nort	301.3	Nort	5.4	Lanc	4.2	Nort	11.6	Lanc	79.7	Nort	37.3	Lanc	74.0	Lanc	70.8	

Watersheds

In 1992 and 2001, the greatest impacts were measured in the same two watersheds, Little Conestoga Creek and Jordan Creek. The least impacts in 1992 and 2001 were measured in four watersheds: Delaware River Tributaries had the lowest percent altered land; Paunnacussing Creek had the lowest percent impervious surface coverage, developed prime farmland, and altered riparian areas (295 ft); French Creek was the least impacted as measured by percent interior forest and percent coverage of largest forest patch; and Cocalico Creek had the lowest forest perimeter to area ratio.

In all watersheds, estimates of all measures (except forest perimeter:area ratio) in year 2022 under the three development projection scenarios indicate that anthropogenic impacts will increase from 2001 levels. In all three development scenarios, the greatest and least impacts are projected to be distributed across the watersheds in the exact same pattern as they were in 2001. This is because the model followed the historical pattern of projecting development to areas that were already developed.

CHAPTER 10 DEVELOPMENT RISK ON HIGH CONSERVATION VALUE LANDS

One of the main goals of this study was to understand which valuable natural resources are at risk of being lost to growth and sprawling development in the next 20 years. We can determine this by looking at where high conservation value lands overlap with lands at high risk of converting from forest or agriculture to development. This gives us a way to think about conservation priorities, taking into account both value and risk.

Value-risk overlay maps were constructed from the suitability (risk) maps produced for growth modeling, and the conservation value maps developed during Phase 1 of the study. The value-risk overlay maps show the relationship between likelihood of development (suitability) and conservation importance across the landscape. This was done for each of the five Conservation Values Assessment (CVA) factors individually (biodiversity, forests, water, recreation, and agriculture) as well as for the combined CVA map.

Two sets of maps were created: one using the stratified risk maps, and the other using the non-stratified risk maps. The stratified approach accounts for the town by town (or county by county) variation in rate of growth, and is the most realistic in terms of understanding *where* development pressure exists across the region (Figures 10-1 and 10-8). The non-stratified maps show those lands that have characteristics similar to lands where development has occurred in the past, but without regard to variation in rate across the region (Figures 10-2 and 10-9). Thus it is less realistic in terms of indicating where development pressure has existed historically. However, if factors change and regional development pressure points shift, the non-stratified approach is a good indication of what lands might be most at risk. In other words, it identifies land with characteristics that are attractive to developers, regardless of the historical local rate of development. The stratified maps, on the other hand, not only show desirable land, but the rate is adjusted to the historical local rate of development.

Results

Results discussed here are for the stratified risk maps, being the most realistic predictors of development pressure under current conditions. Relative suitability for development is displayed in three quantiles on the maps; conservation value is displayed in five quantiles. On the stratified maps, because the suitability analysis was stratified by town/county, its output accentuates political boundaries.

Connecticut

Thirty-one thousand acres (7%) of the land on the combined CVA map is high or highest conservation value and projected to be in the high *suitability* or risk for development category (Figure 10-1). High value water protection lands and agricultural lands are most at risk, with 39% and 33% of the high and highest value lands also in the high risk category (Table 10-1, Figures 10-7 and 10-3). Altogether, 27% of the land that is considered to be of high/highest conservation value is at high risk of being converted to development.

Table 10-1. *Connecticut Highlands: Acres of high/highest conservation value in each development risk category.*

	High/Highest Conservation Value Assessment					
	Combined	**Agriculture**	**Biodiversity**	**Forest**	**Recreation**	**Water Protection**
High Risk	31,000 (27%)	9,900 (33%)	250 (2%)	30,100 (18%)	6,200 (25%)	66,000 (39%)
Medium Risk	35,900 (32%)	12,000 (40%)	2,500 (18%)	55,000 (33%)	6,700 (27%)	59,000 (35%)
Low Risk	46,600 (41%)	7,900 (26%)	11,500 (81%)	80,300 (49%)	12,000 (48%)	45,400 (27%)

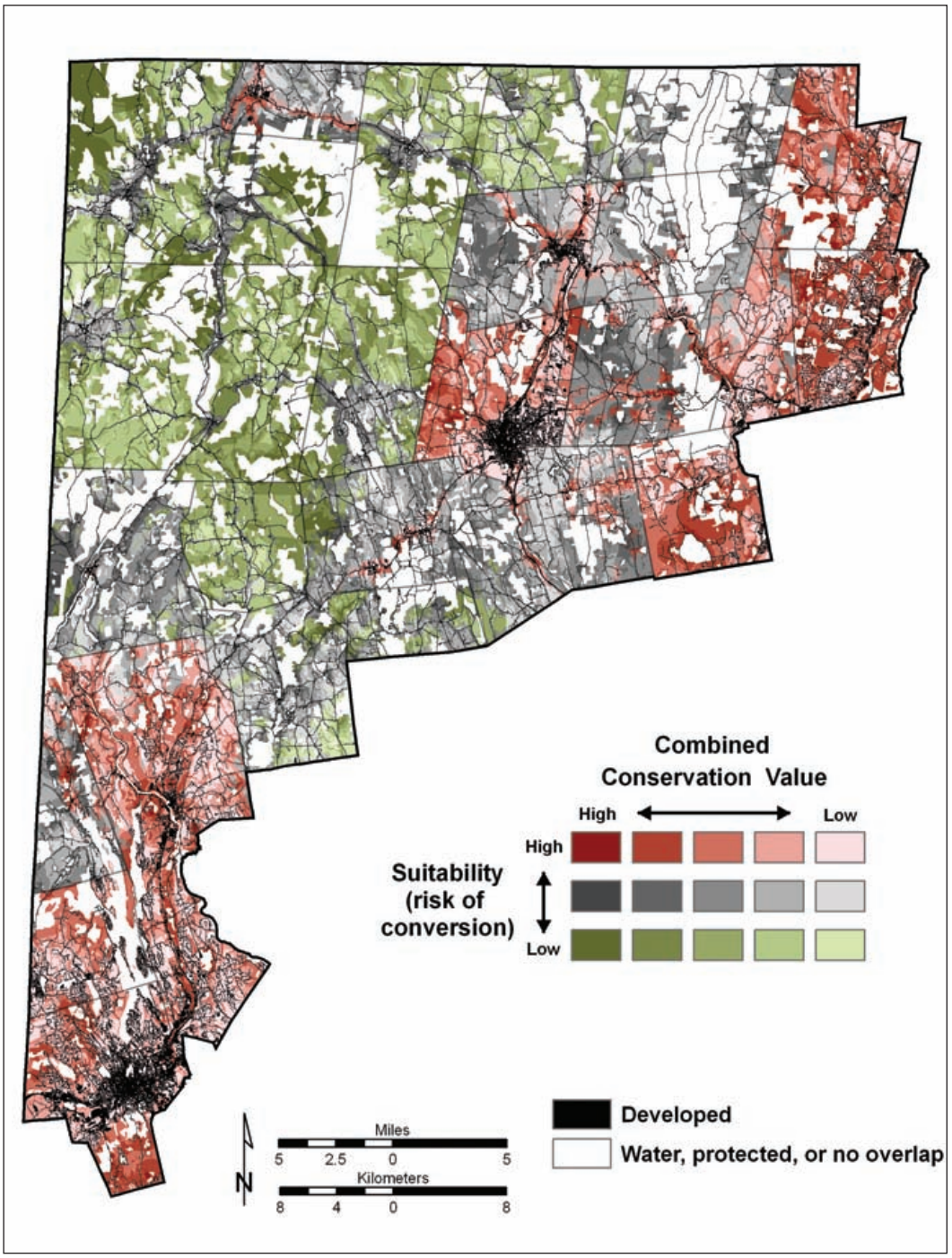


Figure 10-1. *Connecticut Highlands: Overlay of high to low conservation values (Combined) with high to low suitability (risk of conversion to development, stratified by town). Land that is already developed is shown in black and protected open space and water are shown in white.*

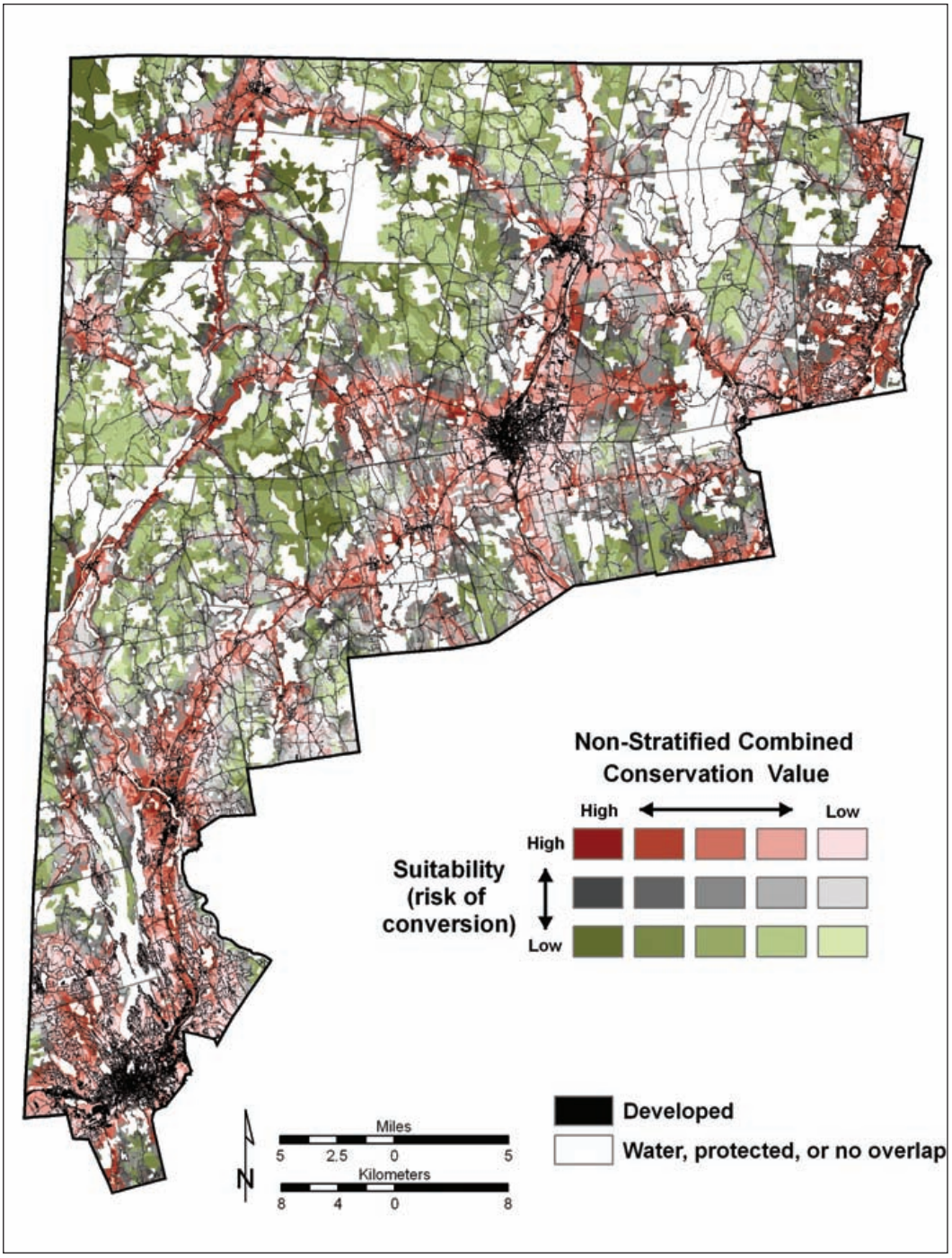


Figure 10-2. *Connecticut Highlands: Overlay of high to low conservation values (Combined) with high to low regional suitability (risk of conversion to development, non-stratified). Land that is already developed is shown in black and protected open space and water are shown in white.*

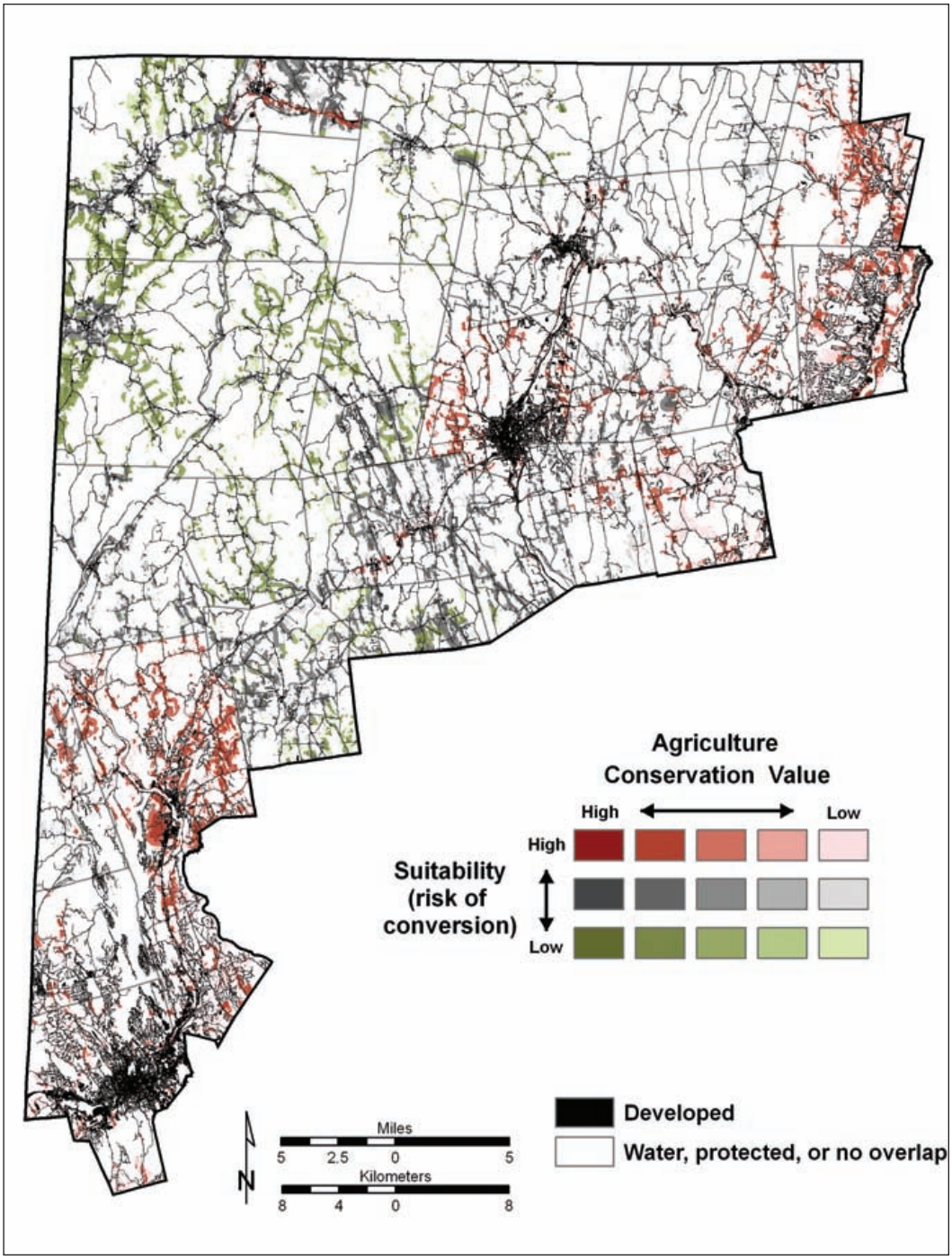


Figure 10-3. *Connecticut Highlands: Overlay of high to low agricultural conservation values with high to low suitability (risk of conversion to development, stratified by town). Land that is already developed is shown in black and protected open space and water are shown in white.*

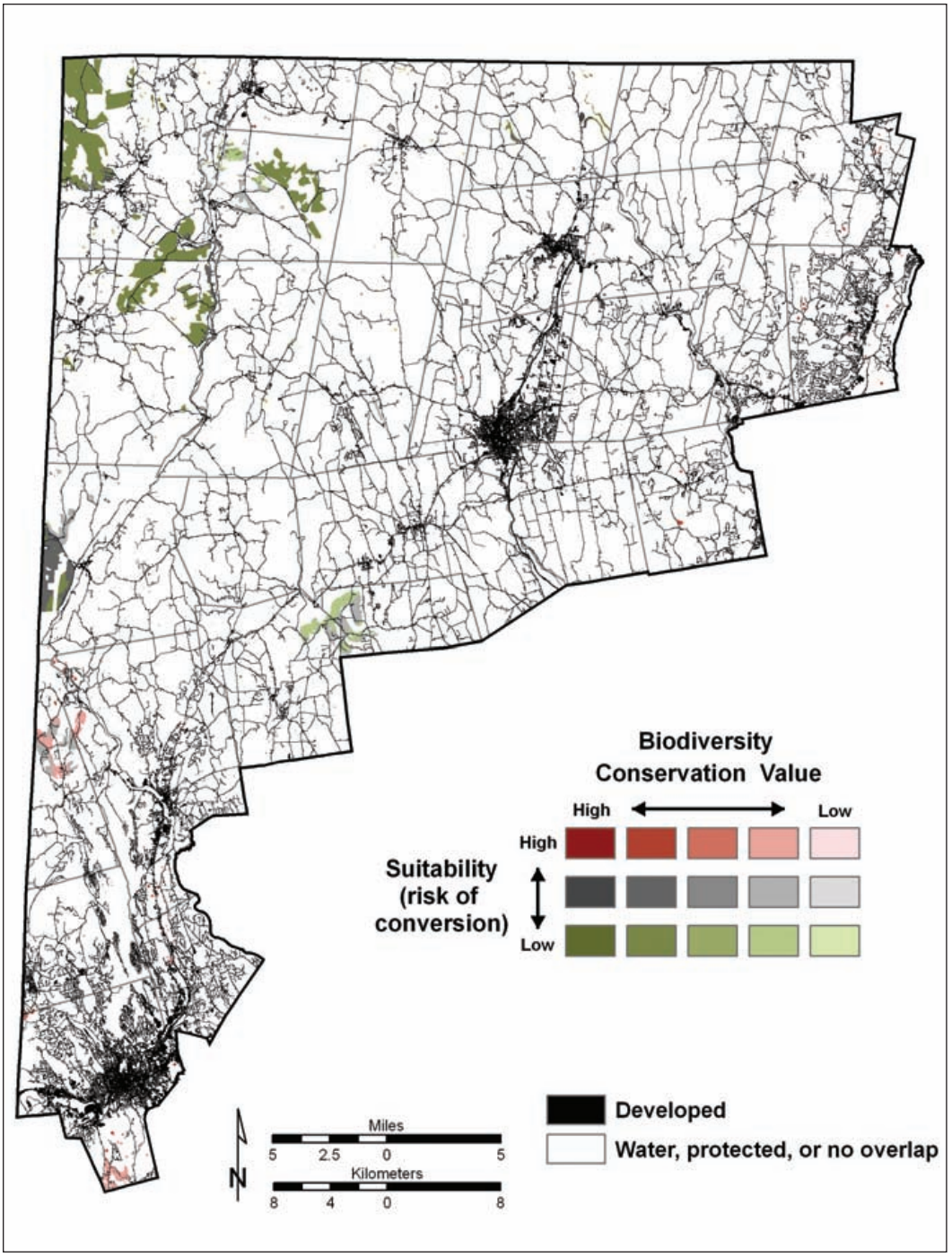


Figure 10-4. *Connecticut Highlands: Overlay of high to low biodiversity conservation values with high to low suitability (risk of conversion to development, stratified by town). Land that is already developed is shown in black and protected open space and water are shown in white.*

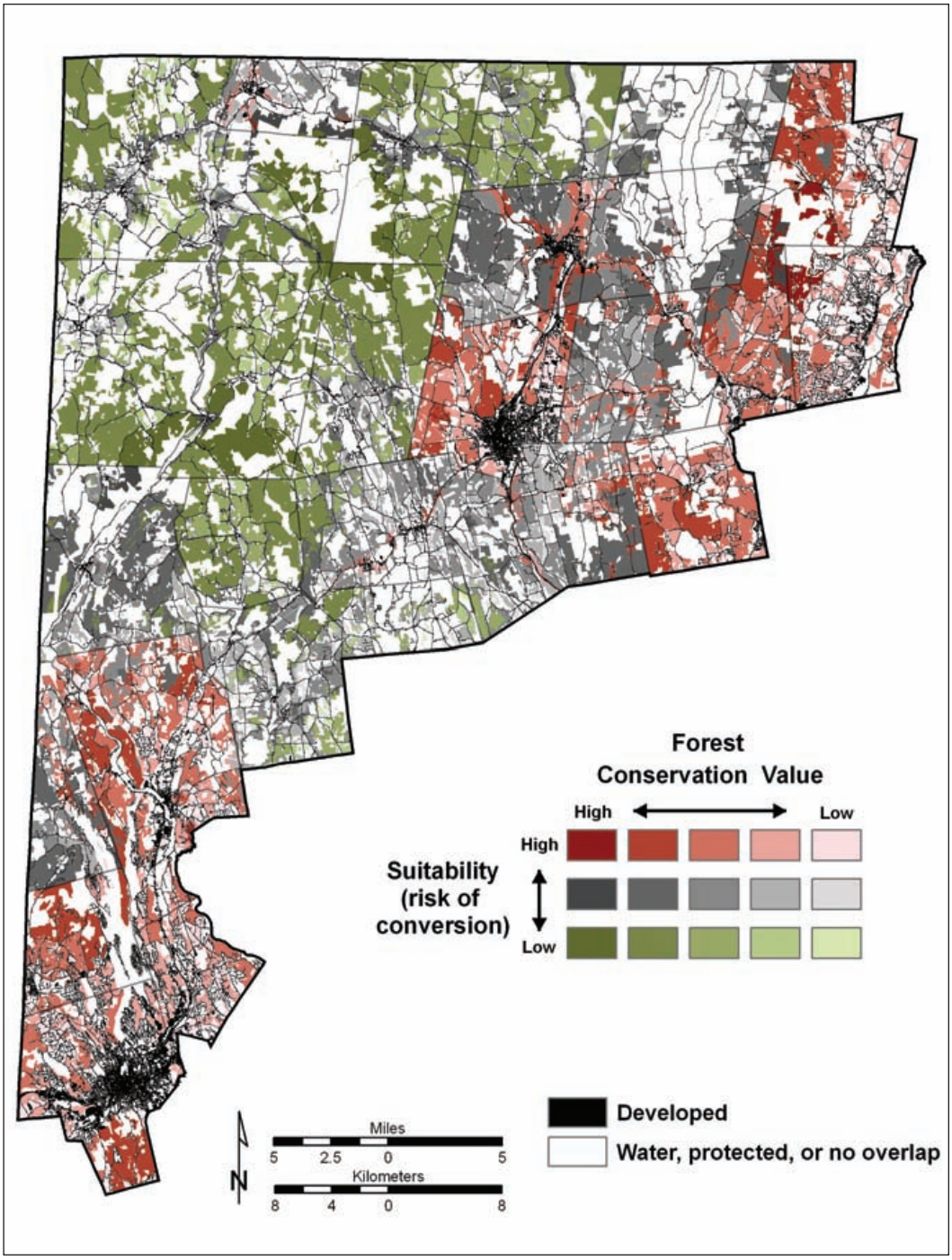


Figure 10-5. *Connecticut Highlands: Overlay of high to low forest conservation values with high to low suitability (risk of conversion to development, stratified by town). Land that is already developed is shown in black and protected open space and water are shown in white.*

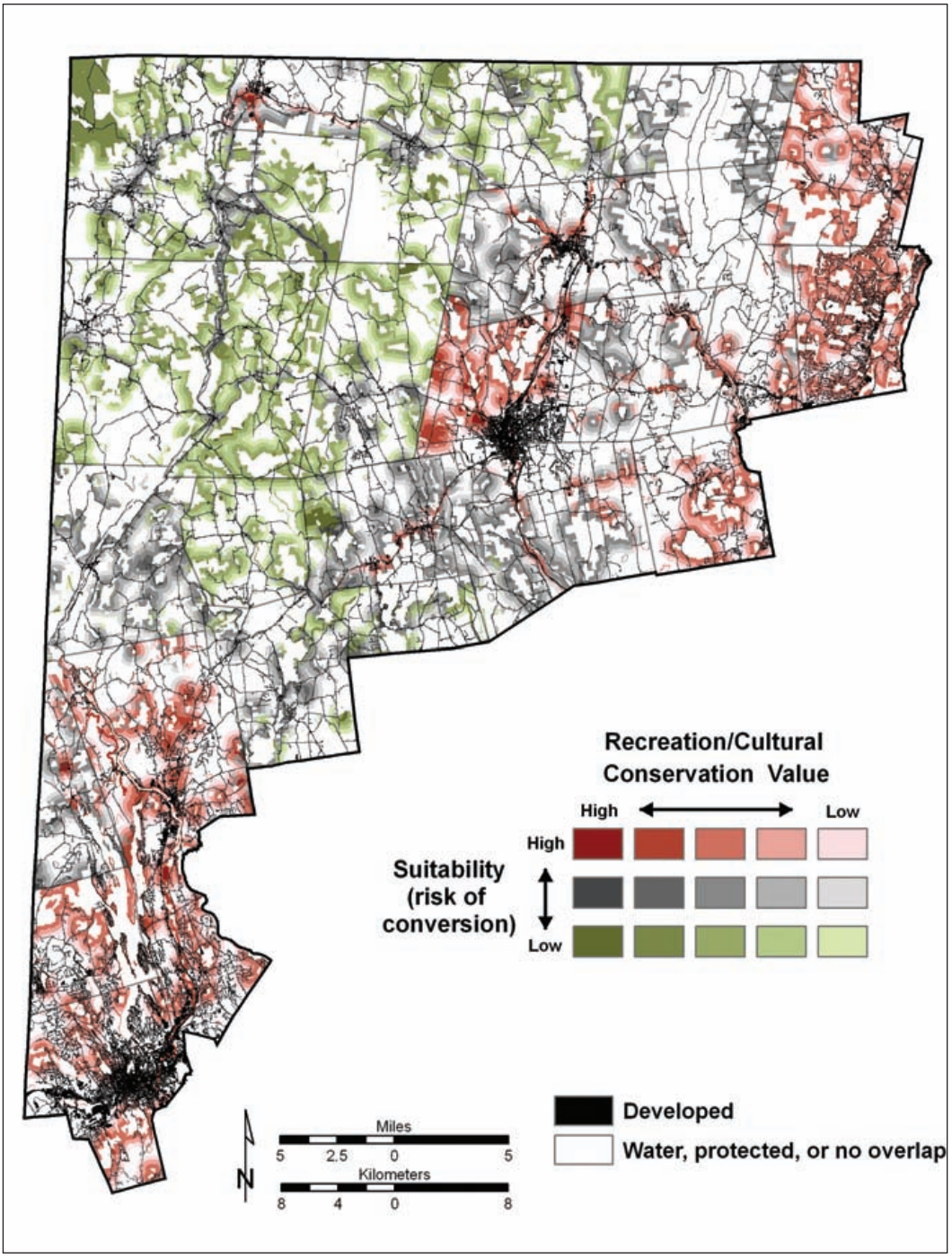


Figure 10-6. *Connecticut Highlands: Overlay of high to low recreation/cultural values with high to low suitability (risk of conversion to development, stratified by town). Land that is already developed is shown in black and protected open space and water are shown in white.*

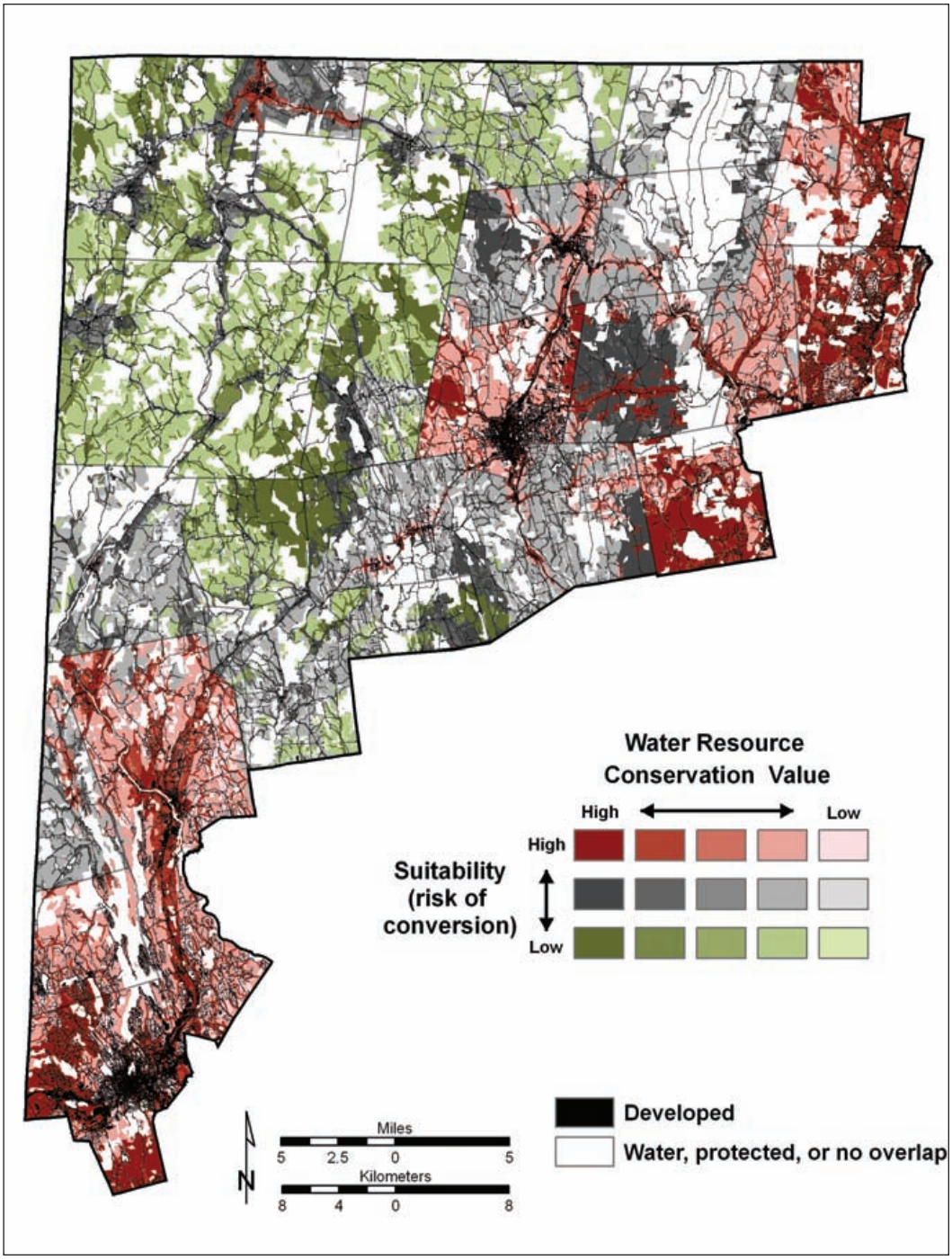


Figure 10-7. *Connecticut Highlands: Overlay of high to low water protection values with high to low suitability (risk of conversion to development, stratified by town). Land that is already developed is shown in black and protected open space and water are shown in white.*

Pennsylvania

Forty-nine thousand, one hundred acres (only 5%) of the land on the combined CVA map are both of high or highest conservation value and projected to be in the high *suitability* or risk for development category (Figure 10-8). Most of the high suitability areas are of moderate to low resource value. However, in southern Berks County, in the Borough of New Morgan and its vicinity a large area of dark red indicates high suitability and high resource value.

High value recreation and water protection lands are most at risk, with 37% and 30% of the high and highest value lands also in the high risk category (Table 10-2 and Figures 10-13 and 10-14). Altogether, 23% of the land that is considered to be of high/highest conservation value is at high risk of being converted to development.

Table 10-2. *Pennsylvania Highlands: Acres of high/highest conservation value in each development risk category.*

	High/Highest Conservation Value Assessment					
	Combined	**Agriculture**	**Biodiversity**	**Forest**	**Recreation**	**Water Protection**
High Risk	49,100 (23%)	37,000 (25%)	79,400 (21%)	37,500 (18%)	11,100 (37%)	87,000 (30%)
Medium Risk	76,100 (36%)	57,100 (39%)	140,300 (37%)	76,000 (36%)	9,400 (32%)	115,300 (39%)
Low Risk	87,100 (41%)	53,200 (36%)	162,700 (43%)	96,900 (46%)	9,200 (31%)	92,600 (31%)

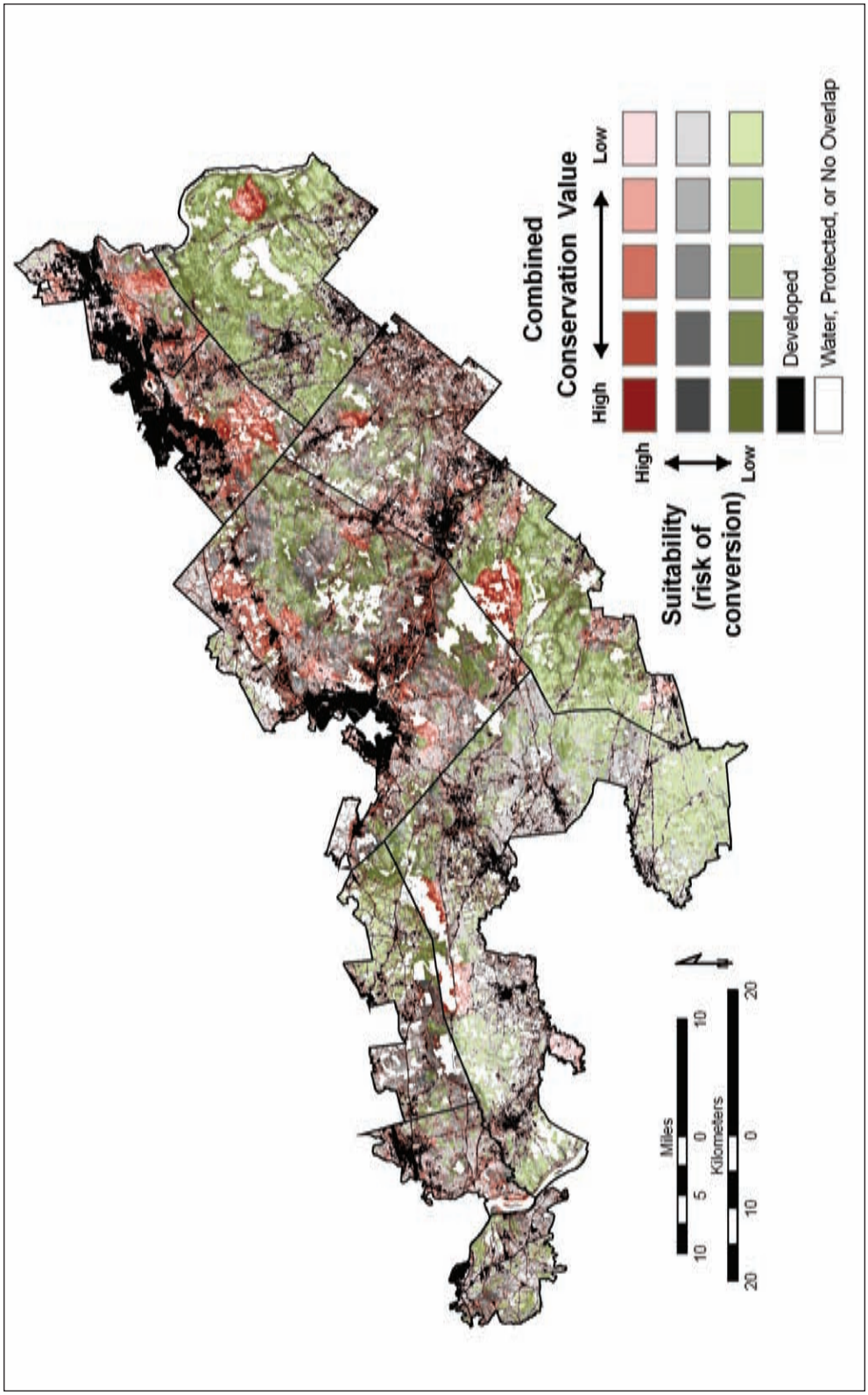


Figure 10-8. *Pennsylvania Highlands: Overlay of high to low conservation values (combined) with high to low suitability (risk of conversion to development, stratified by county). Land that is already developed is shown in black and protected open space and water are shown in white.*

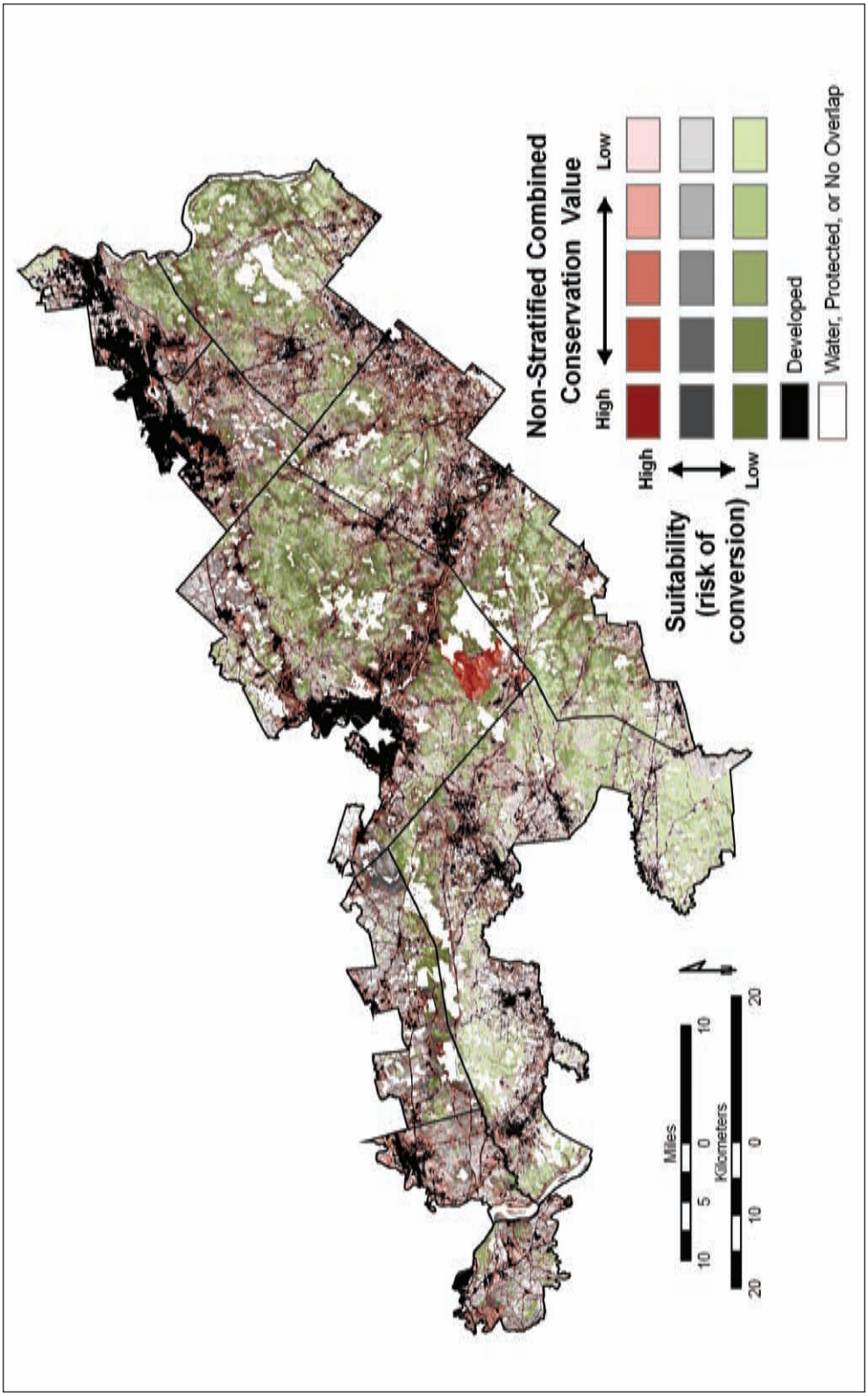


Figure 10-9. *Pennsylvania Highlands: Overlay of high to low conservation values (Combined) with high to low regional suitability (risk of conversion to development, non-stratified). Land that is already developed is shown in black and protected open space and water are shown in white.*

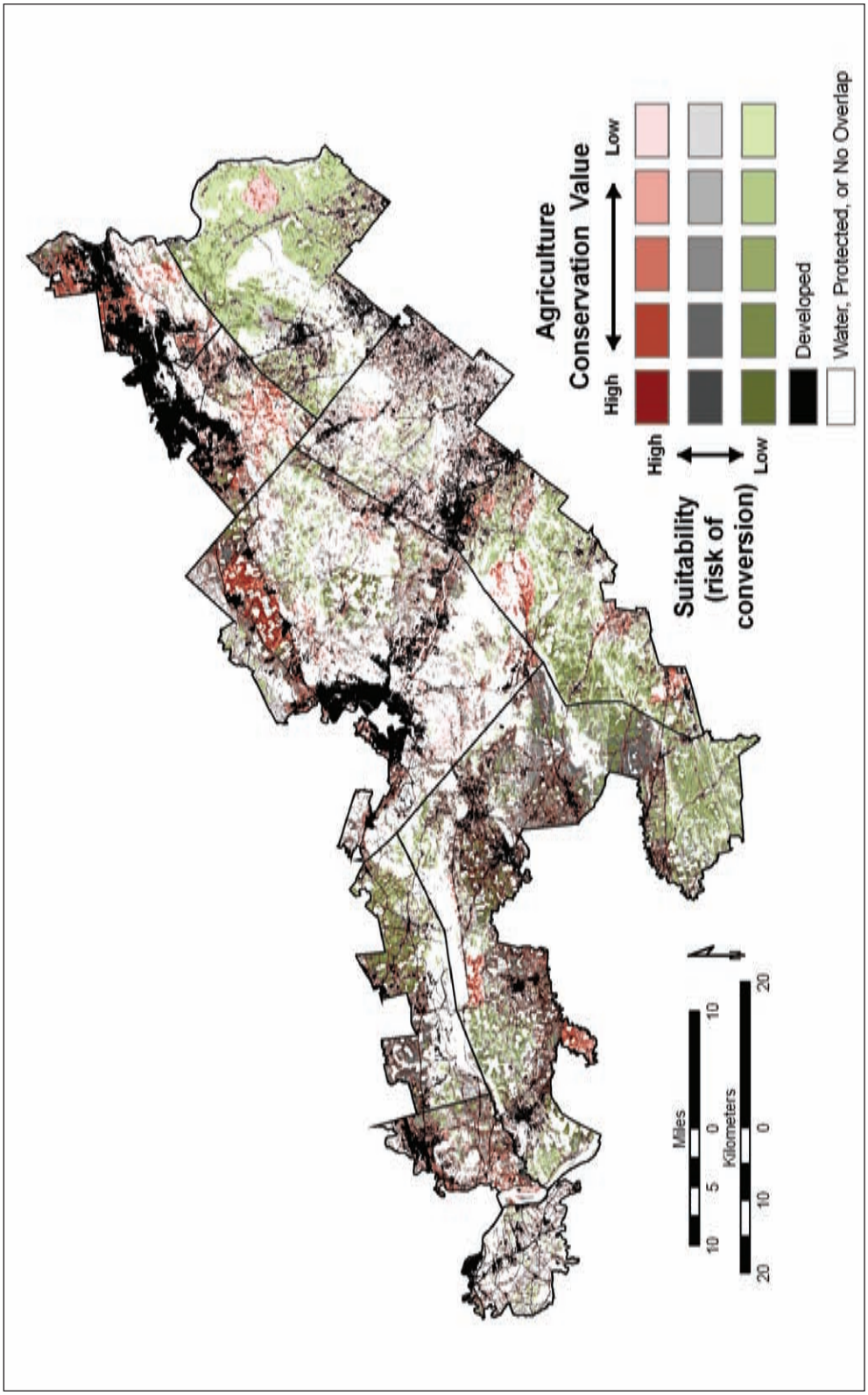


Figure 10-10. *Pennsylvania Highlands: Overlay of high to low agricultural conservation values (combined) with high to low suitability (risk of conversion to development, stratified by county). Land that is already developed is shown in black and protected open space and water are shown in white.*

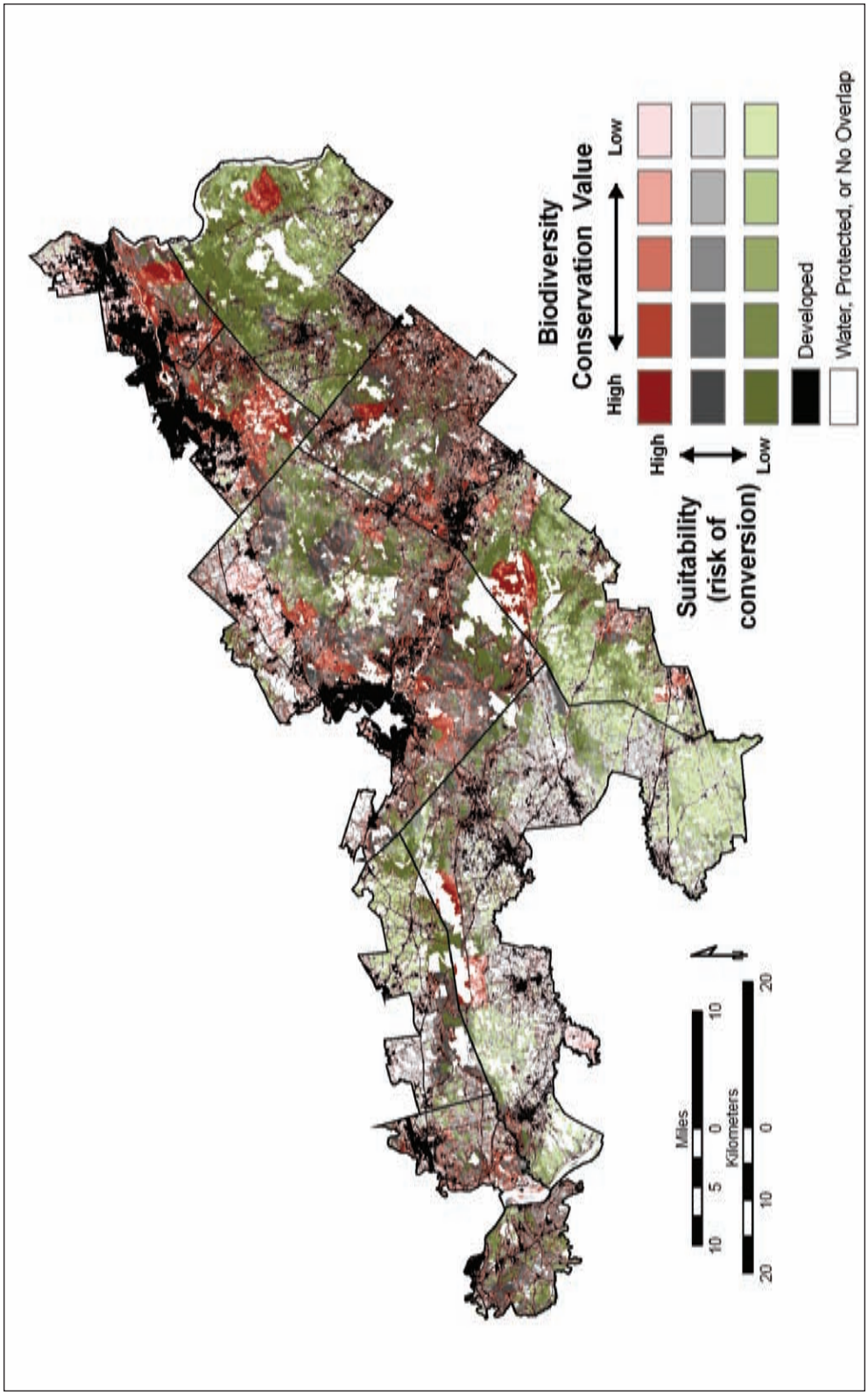


Figure 10-11. *Pennsylvania Highlands: Overlay of high to low biodiversity conservation values (combined) with high to low suitability (risk of conversion to development, stratified by county). Land that is already developed is shown in black and protected open space and water are shown in white.*

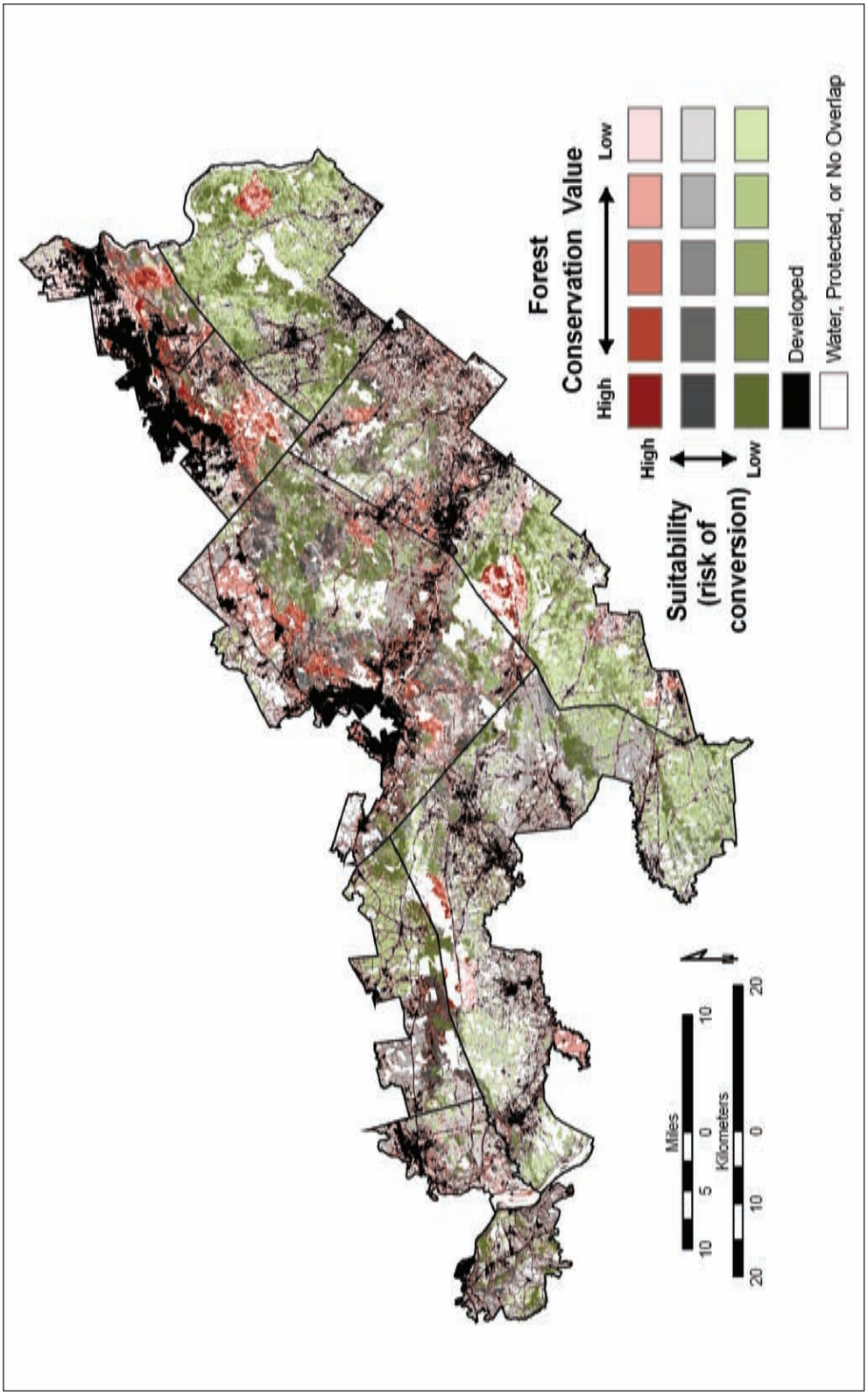


Figure 10-12. *Pennsylvania Highlands: Overlay of high to low forest conservation values (combined) with high to low suitability (risk of conversion to development, stratified by county). Land that is already developed is shown in black and protected open space and water are shown in white.*

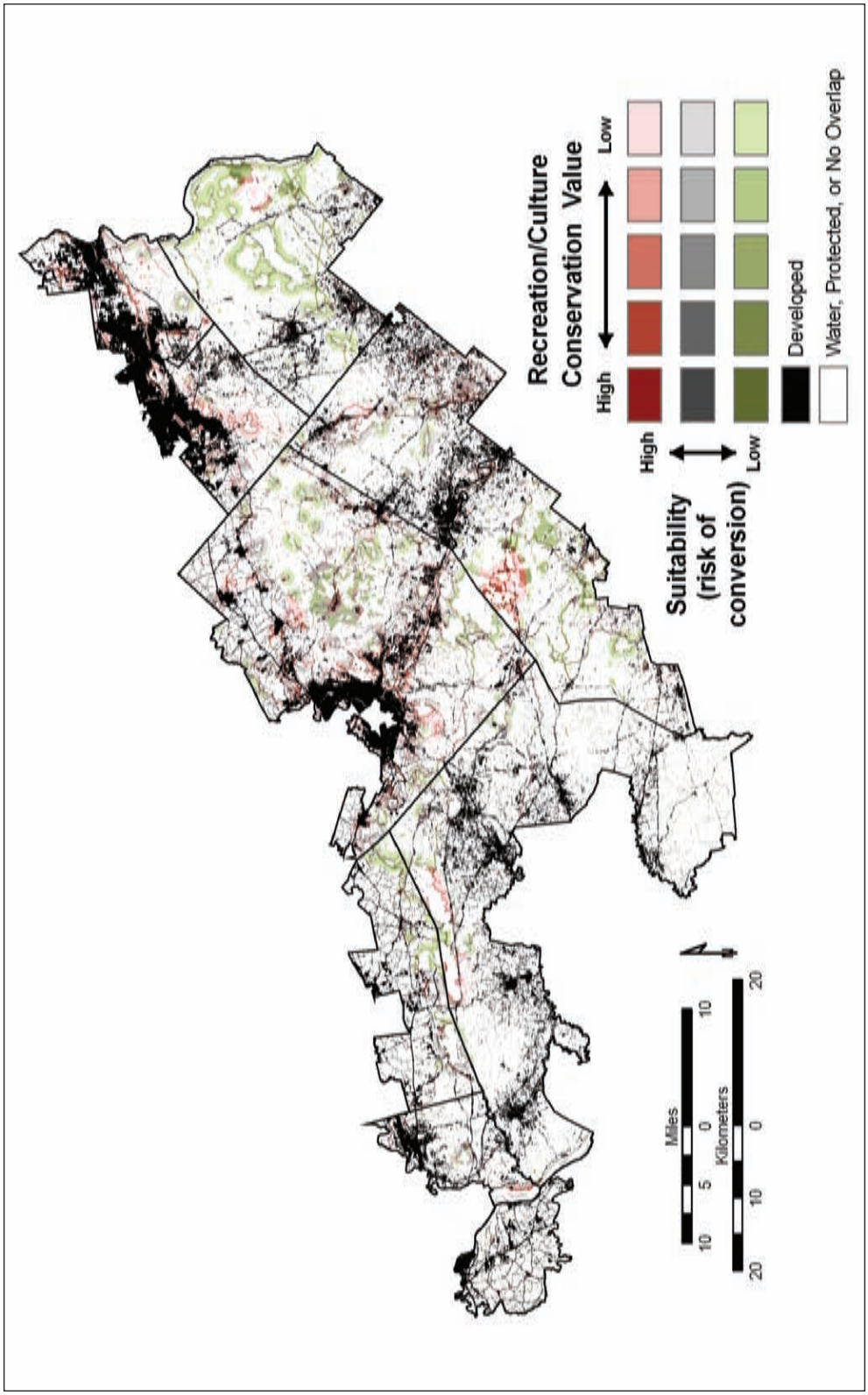


Figure 10-13. *Pennsylvania Highlands: Overlay of high to low recreation/cultural conservation values (combined) with high to low suitability (risk of conversion to development, stratified by county). Land that is already developed is shown in black and protected open space and water are shown in white.*

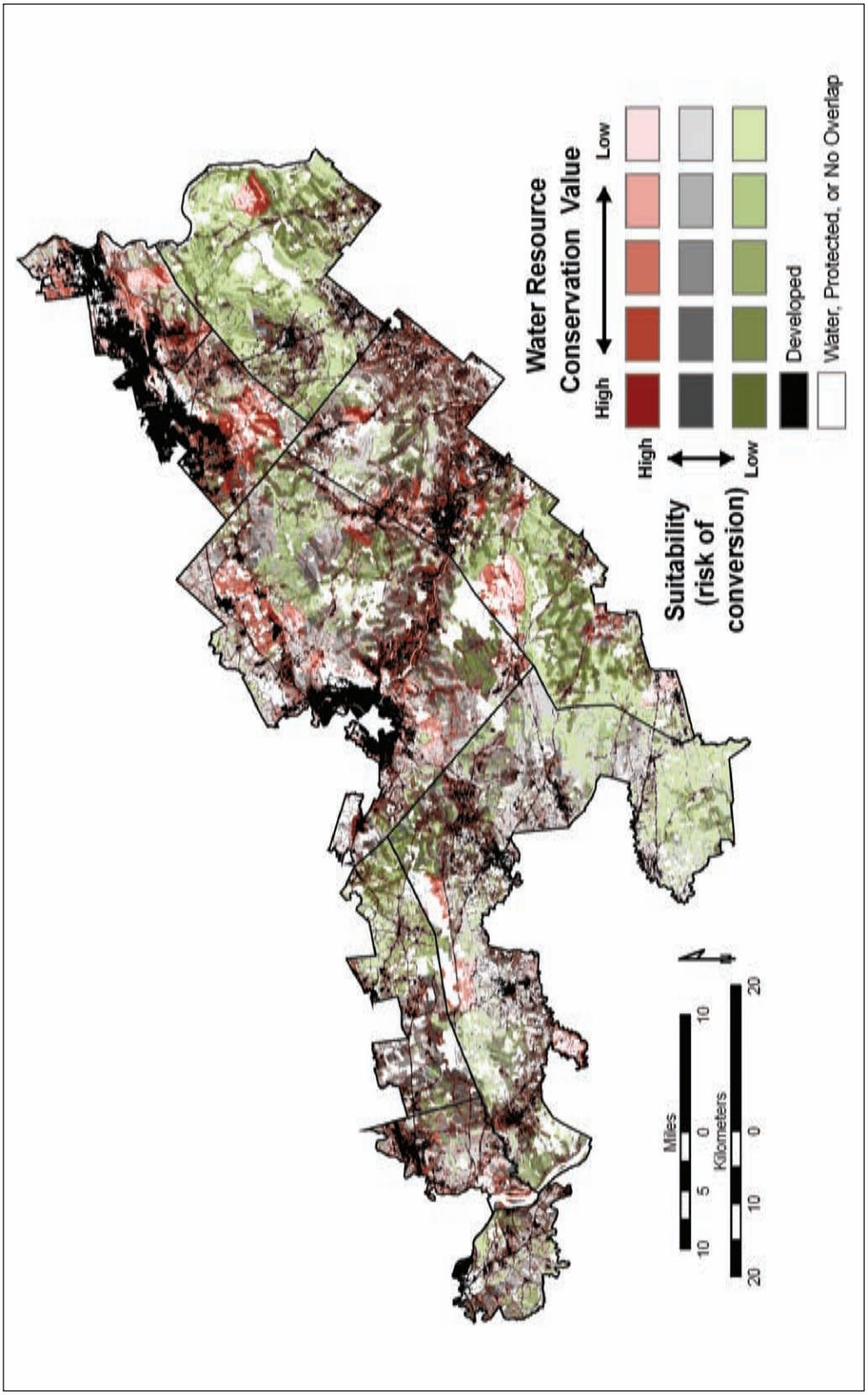


Figure 10-14. *Pennsylvania Highlands: Overlay of high to low water protection conservation values with high to low suitability (risk of conversion to development, stratified by county). Land that is already developed is shown in black and protected open space and water are shown in white.*

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APPENDIX 1: DEFINITIONS OF FRAGMENTATION CATEGORIES

Core forest – all the pixels in the surrounding window are forest.

Perforated forest – most of the pixels in the surrounding window are forested, but some appear to be part of the inside edge of a forest patch, such as would occur if a small clearing or house was built within a continuous tract of forest.

Edge forest – most of the pixels in the surrounding window are forested, but some appear to be part of the outside edge of forest, such as would occur along the boundary of a large urban area, or agricultural field.

Transitional forest – about half of the cells in the surrounding window are forested and these may appear to be part of a patch, edge, or perforation depending on the local forest pattern.

Patch forest – very few forest pixels are in the surrounding window and those that are contribute to a forest patch on a non-forest background, such as a small wooded lot within an urbanized region.

APPENDIX 2: TYPES OF ZONING BUILD-OUT ANALYSIS

The scale upon which a build-out analysis is based varies by project. For example, it can focus on the more general satellite-derived urban extent of a region, or it can examine very specific change on the level of sites within a tax parcel. The appropriateness of the scale of the build-out analysis is dictated by both the goals of the project and type of data available. It should be noted that build-out analyses do not predict *when* build-out will occur, but rather *how* it can occur under a given set of conditions.

The first build-out analyses were executed manually and relied heavily on mathematical formulas; the process was arduous and the potential for human error was high. However, today such analyses are done using computers equipped with GIS software, which greatly reduces the amount of time needed to conduct such a project. Mathematical formulas still form the basis of the quantitative measures of the build-out model, but the GIS can provide a strong visual representation and spatial specificity, as well as some of the quantitative measures. (Zirkle, 2003)

Developed/Undeveloped Build-out

This type of build-out analysis is the most basic and is generally of the coarsest scale. The developed/undeveloped build-out approach utilizes satellite imagery. Through the use of a remote sensing software package, the analyst can employ one of several techniques to classify pixels in the satellite image as either developed or undeveloped.

Zoning Build-out

The zoning build-out is of a finer resolution than the more general developed/undeveloped analysis. When time and data do not permit a parcel or site-level analysis, the zoning build-out may be used to determine and depict the maximum number of new residential, commercial and industrial buildings allowed in a zoning district based on current zoning regulations. However, the resolution upon which this type of build-out is based—the zoning district—is not normally specific enough to help a locality determine exactly where development can occur. (Zirkle, 2003)

Parcel-level Build-out

The parcel-level build-out overcomes some of the zoning build-out's limitations in specificity. This type of build-out requires specific parcels to be identified to ultimately determine development potential. In some cases, the amount of constrained land is subtracted from the total land in the parcel to determine which sections of that land are developable. A typical parcel-based build-out model might first determine the size of the specific parcel, taking into account any roads that may run through it. The parcel size is then reduced by the area the road occupies. The output from this calculation would next be divided by the zoning assigned to that location. Next, any other constraints on the parcel would be calculated, such as proximity to a wetland or nature reserve. A constraint value is then assigned to the parcel, which determines the number of units that can be constructed. (Amengual 2001)

Site-level Build-out

This type of analysis is the most detailed build-out model, and requires the creation of a site design for every parcel in the analysis area. Accordingly, it is also the most time consuming, but allows the analyst to generate a rough site plan for each parcel in order to account for physical constraints and parcel-level zoning requirements. The site-level build-out takes into account con-

straints and data from the other less detailed build-outs and produces the most accurate numbers from which to draw conclusions. (Zirkle, 2003)

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APPENDIX 3: MUNICIPALITY ZONING BUILD-OUT DATA

Average Residents per Housing Units by Municipality
CT Municipal Multiplier

TOWN CODE	FIPS CODE	MUNICIPALITY	COUNTY	STATE	TOTAL
5	2760	Barkhamsted	Litchfield	Connecticut	2.62
18	8980	Brookfield	Fairfield	Connecticut	2.80
20	10100	Burlington	Hartford	Connecticut	2.88
21	10940	Canaan	Litchfield	Connecticut	2.43
23	12270	Canton	Hartford	Connecticut	2.49
29	16050	Colebrook	Litchfield	Connecticut	2.60
31	17240	Cornwall	Litchfield	Connecticut	2.33
34	18500	Danbury	Fairfield	Connecticut	2.64
55	32290	Goshen	Litchfield	Connecticut	2.53
56	32640	Granby	Hartford	Connecticut	2.71
65	37140	Hartland	Hartford	Connecticut	2.83
66	37280	Harwinton	Litchfield	Connecticut	2.70
68	40290	Kent	Litchfield	Connecticut	2.43
74	43370	Litchfield	Litchfield	Connecticut	2.45
87	49460	Morris	Litchfield	Connecticut	2.52
91	50860	New Fairfield	Fairfield	Connecticut	3.01
92	51350	New Hartford	Litchfield	Connecticut	2.72
96	52630	New Milford	Litchfield	Connecticut	2.68
98	53470	Norfolk	Litchfield	Connecticut	2.44
100	54030	North Canaan	Litchfield	Connecticut	2.38
122	66420	Salisbury	Litchfield	Connecticut	2.19
125	67960	Sharon	Litchfield	Connecticut	2.26
127	68310	Sherman	Fairfield	Connecticut	2.67
128	68940	Simsbury	Hartford	Connecticut	2.70
143	76570	Torrington	Litchfield	Connecticut	2.33
149	79510	Warren	Litchfield	Connecticut	2.52
150	79720	Washington	Litchfield	Connecticut	2.42
162	86440	Winchester	Litchfield	Connecticut	2.42

Pennsylvania Municipal Multiplier

FIPS CODE	MUNICIPALITY	AVERAGE RESIDENTS PER HOUSING UNIT
364	Adamstown borough, Berks County, Pennsylvania	2.00
660	Alburtis borough, Lehigh County, Pennsylvania	2.74
2120	Alsace township, Berks County, Pennsylvania	2.57
2328	Amity township, Berks County, Pennsylvania	2.74
3384	Atglen borough, Chester County, Pennsylvania	2.95
4376	Bart township, Lancaster County, Pennsylvania	3.68
4976	Bedminster township, Bucks County, Pennsylvania	2.68
6088	Bethlehem city, Lehigh County, Pennsylvania	2.20
6096	Bethlehem township, Northampton County, Pennsylvania	2.69
8344	Brecknock township, Berks County, Pennsylvania	2.86
8352	Brecknock township, Lancaster County, Pennsylvania	3.17
8592	Bridgeton township, Bucks County, Pennsylvania	2.52
10704	Caernarvon township, Lancaster County, Pennsylvania	3.26
13512	Christiana borough, Lancaster County, Pennsylvania	2.55
13960	Clay township, Lancaster County, Pennsylvania	2.92
14984	Colebrookdale township, Berks County, Pennsylvania	2.64
15640	Conewago township, Dauphin County, Pennsylvania	2.79
15824	Conoy township, Lancaster County, Pennsylvania	2.78
16056	Coopersburg borough, Lehigh County, Pennsylvania	2.46
16256	Cornwall borough, Lebanon County, Pennsylvania	2.58
18888	Denver borough, Lancaster County, Pennsylvania	2.63
19664	Douglass township, Berks County, Pennsylvania	2.64
19672	Douglass township, Montgomery County, Pennsylvania	2.85
20480	Durham township, Bucks County, Pennsylvania	2.75
20680	Earl township, Berks County, Pennsylvania	2.63
20688	Earl township, Lancaster County, Pennsylvania	3.06
20984	East Cocalico township, Lancaster County, Pennsylvania	2.82
21008	East Coventry township, Chester County, Pennsylvania	2.63
21072	East Earl township, Lancaster County, Pennsylvania	3.28
21200	East Greenville borough, Montgomery County, Pennsylvania	2.76
21576	East Nantmeal township, Chester County, Pennsylvania	2.74
21648	Easton city, Northampton County, Pennsylvania	2.46
21760	East Rockhill township, Bucks County, Pennsylvania	2.82
22000	East Vincent township, Chester County, Pennsylvania	2.75
22336	Eden township, Lancaster County, Pennsylvania	3.21
23008	Elizabeth township, Lancaster County, Pennsylvania	2.96
23016	Elizabethtown borough, Lancaster County, Pennsylvania	2.31
23440	Elverson borough, Chester County, Pennsylvania	2.33
23584	Emmaus borough, Lehigh County, Pennsylvania	2.25
23832	Ephrata borough, Lancaster County, Pennsylvania	2.38
23840	Ephrata township, Lancaster County, Pennsylvania	2.92

24384	Exeter township, Berks County, Pennsylvania	2.65
26728	Forks township, Northampton County, Pennsylvania	2.76
27280	Franconia township, Montgomery County, Pennsylvania	2.70
27760	Freemansburg borough, Northampton County, Pennsylvania	2.64
29568	Glendon borough, Northampton County, Pennsylvania	2.64
30016	Goldsboro borough, York County, Pennsylvania	2.73
31088	Green Lane borough, Montgomery County, Pennsylvania	2.53
33224	Haycock township, Bucks County, Pennsylvania	2.71
33600	Heidelberg township, Berks County, Pennsylvania	2.63
33608	Heidelberg township, Lebanon County, Pennsylvania	2.85
33744	Hellertown borough, Northampton County, Pennsylvania	2.31
34016	Hereford township, Berks County, Pennsylvania	2.66
35528	Honey Brook borough, Chester County, Pennsylvania	2.71
35536	Honey Brook township, Chester County, Pennsylvania	2.90
40656	Kutztown borough, Berks County, Pennsylvania	2.48
43312	Limerick township, Montgomery County, Pennsylvania	2.63
44464	Londonderry township, Dauphin County, Pennsylvania	2.60
44584	Longswamp township, Berks County, Pennsylvania	2.61
44912	Lower Frederick township, Montgomery County, Pennsylvania	2.75
44992	Lower Milford township, Lehigh County, Pennsylvania	2.83
45072	Lower Pottsgrove township, Montgomery County, Pennsylvania	2.77
45096	Lower Salford township, Montgomery County, Pennsylvania	2.89
45104	Lower Saucon township, Northampton County, Pennsylvania	2.63
46888	Manheim borough, Lancaster County, Pennsylvania	2.40
47592	Marlborough township, Montgomery County, Pennsylvania	2.63
48128	Maxatawny township, Berks County, Pennsylvania	2.63
49384	Milford township, Bucks County, Pennsylvania	2.80
49560	Millcreek township, Lebanon County, Pennsylvania	2.79
50272	Mohnton borough, Berks County, Pennsylvania	2.44
51656	Mount Joy borough, Lancaster County, Pennsylvania	2.38
51664	Mount Joy township, Lancaster County, Pennsylvania	2.74
52200	Muhlenberg township, Berks County, Pennsylvania	2.39
53224	Newberry township, York County, Pennsylvania	2.65
53664	New Hanover township, Montgomery County, Pennsylvania	2.90
54576	Nockamixon township, Bucks County, Pennsylvania	2.63
54936	North Coventry township, Chester County, Pennsylvania	2.45
56672	Oley township, Berks County, Pennsylvania	2.58
56856	Ontelaunee township, Berks County, Pennsylvania	2.36
57672	Palmer township, Northampton County, Pennsylvania	2.46
57848	Paradise township, Lancaster County, Pennsylvania	2.99
58032	Parkesburg borough, Chester County, Pennsylvania	2.70
58840	Penn township, Lancaster County, Pennsylvania	2.74
59120	Pennsburg borough, Montgomery County, Pennsylvania	2.59
59384	Perkasie borough, Bucks County, Pennsylvania	2.68
59392	Perkiomen township, Montgomery County, Pennsylvania	2.87
60176	Pike township, Berks County, Pennsylvania	2.77

61616	Plumstead township, Bucks County, Pennsylvania	2.89
62416	Pottstown borough, Montgomery County, Pennsylvania	2.35
63048	Quakertown borough, Bucks County, Pennsylvania	2.52
63440	Rapho township, Lancaster County, Pennsylvania	2.76
63808	Red Hill borough, Montgomery County, Pennsylvania	2.44
64536	Richland township, Bucks County, Pennsylvania	2.62
64584	Richlandtown borough, Bucks County, Pennsylvania	2.70
64592	Richmond township, Berks County, Pennsylvania	2.48
64856	Riegelsville borough, Bucks County, Pennsylvania	2.23
65320	Robeson township, Berks County, Pennsylvania	2.76
65336	Robesonia borough, Berks County, Pennsylvania	2.43
65544	Rockland township, Berks County, Pennsylvania	2.83
66576	Royersford borough, Montgomery County, Pennsylvania	2.20
66728	Ruscombmanor township, Berks County, Pennsylvania	2.71
67080	Sadsbury township, Chester County, Pennsylvania	2.72
67096	Sadsbury township, Lancaster County, Pennsylvania	3.41
67528	Salford township, Montgomery County, Pennsylvania	2.92
67568	Salisbury township, Lancaster County, Pennsylvania	3.29
67576	Salisbury township, Lehigh County, Pennsylvania	2.54
68328	Schwenksville borough, Montgomery County, Pennsylvania	2.13
69248	Sellersville borough, Bucks County, Pennsylvania	2.56
71016	Skippack township, Montgomery County, Pennsylvania	2.74
71928	South Annville township, Lebanon County, Pennsylvania	2.61
72088	South Coventry township, Chester County, Pennsylvania	2.69
72208	South Heidelberg township, Berks County, Pennsylvania	2.64
72288	South Lebanon township, Lebanon County, Pennsylvania	2.54
72296	South Londonderry township, Lebanon County, Pennsylvania	2.61
72824	Spring township, Berks County, Pennsylvania	2.46
72920	Spring City borough, Chester County, Pennsylvania	2.27
73016	Springfield township, Bucks County, Pennsylvania	2.61
74712	Strasburg borough, Lancaster County, Pennsylvania	2.52
74720	Strasburg township, Lancaster County, Pennsylvania	3.15
76304	Telford borough, Bucks County, Pennsylvania	2.11
76400	Terre Hill borough, Lancaster County, Pennsylvania	2.81
76784	Tinicum township, Bucks County, Pennsylvania	2.49
77704	Trumbauersville borough, Bucks County, Pennsylvania	2.82
78280	Union township, Berks County, Pennsylvania	2.59
79040	Upper Frederick township, Montgomery County, Pennsylvania	2.79
79064	Upper Hanover township, Montgomery County, Pennsylvania	2.81
79160	Upper Milford township, Lehigh County, Pennsylvania	2.77
79240	Upper Pottsgrove township, Montgomery County, Pennsylvania	2.89
79280	Upper Salford township, Montgomery County, Pennsylvania	2.86
79288	Upper Saucon township, Lehigh County, Pennsylvania	2.78
79352	Upper Uwchlan township, Chester County, Pennsylvania	3.21
80616	Wallace township, Chester County, Pennsylvania	3.07
81160	Warwick township, Chester County, Pennsylvania	2.56

81184	Washington township, Berks County, Pennsylvania	2.78
82576	West Brandywine township, Chester County, Pennsylvania	2.77
82664	West Caln township, Chester County, Pennsylvania	2.92
82728	West Cocalico township, Lancaster County, Pennsylvania	2.99
82752	West Cornwall township, Lebanon County, Pennsylvania	2.29
82816	West Donegal township, Lancaster County, Pennsylvania	2.61
82832	West Easton borough, Northampton County, Pennsylvania	2.56
83664	West Nantmeal township, Chester County, Pennsylvania	2.84
83960	West Rockhill township, Bucks County, Pennsylvania	2.47
83968	West Sadsbury township, Chester County, Pennsylvania	3.04
84160	West Vincent township, Chester County, Pennsylvania	2.84
85256	Williams township, Northampton County, Pennsylvania	2.70
85592	Wilson borough, Northampton County, Pennsylvania	2.40
87080	York Haven borough, York County, Pennsylvania	3.01

State and Local Plans Consulted in Analysis

"A Comprehensive Plan for the County of Berks", Berks County Planning Commission, Reading, PA

"Bucks County Open Space Program", Bucks County Planning Commission, Doylestown, PA

"Conservation and Development Policies Plan for Connecticut 2005 – 2010", Office of Policy and Management Intergovernmental Policy Division, Hartford, CT

"Comprehensive Plan: The Lehigh Valley…2030", Lehigh Valley Planning Commission, Allentown. PA

"Lancaster County Comprehensive Plan: Long-Range Transportation Plan 2005-2030", Lancaster County Planning Commission, Lancaster, PA

Connecticut Municipal Zoning Data - Low Constraints

Name	Planning Region	Total Acres	Buildable Acreage (ROW)	Percentage Mun that is Buildable	2000 Dwelling Units	Dwelling Units under Zoning Build-out	Percent New Dwelling Units	2000 Residents	Additional ResidentsZoning Build-out
Barkhamsted	Litchfield Hills	24,775	6,586	27%	1,436	3,621	252%	3,494	9,507
Brookfield	Housatonic	13,037	4,453	34%	5,781	2,886	50%	15,664	8,125
Burlington	Central Connecticut	19,499	7,788	40%	2,901	3,135	108%	8,190	8,989
Canaan	Northwestern	21,212	5,358	25%	610	5,790	949%	1,081	14,039
Canton	Central Connecticut	16,014	8,326	52%	3,616	5,278	146%	8,840	13,068
Colebrook	Litchfield Hills	21,047	8,105	39%	656	4,388	669%	1,471	11,430
Cornwall	Northwestern	29,717	10,137	34%	873	2,587	296%	1,434	6,008
Danbury	Housatonic	28,118	5,872	21%	28,519	5,296	19%	74,848	14,098
Goshen	Litchfield Hills	28,934	14,080	49%	1,482	3,417	231%	2,697	8,684
Granby	Capitol Region	26,299	11,273	43%	3,887	7,832	201%	10,347	21,265
Harwinton	Litchfield Hills	19,907	10,307	52%	2,022	5,369	266%	5,283	14,514
Kent	Northwestern	31,808	10,248	32%	1,463	10,290	703%	2,858	24,941
Litchfield	Litchfield Hills	36,436	16,487	45%	3,629	9,001	248%	8,316	21,977
Morris	Litchfield Hills	11,963	5,082	42%	1,181	3,375	286%	2,301	8,541
New Fairfield	Housatonic	16,103	4,454	28%	5,148	2,762	54%	13,953	8,291
New Hartford	Litchfield Hills	24,363	9,892	41%	2,368	5,148	217%	6,088	14,026
New Milford	Housatonic	40,882	15,936	39%	10,710	12,887	120%	27,121	34,632
Norfolk	Litchfield Hills	29,663	10,988	37%	871	5,798	666%	1,660	14,110
North Canaan	Northwestern	12,495	4,600	37%	1,444	4,952	343%	3,350	11,763
Salisbury	Northwestern	38,514	15,252	40%	2,410	7,272	302%	3,977	15,891
Sharon	Northwestern	38,209	14,852	39%	1,617	7,656	473%	2,968	17,288
Sherman	Housatonic	14,971	6,118	41%	1,606	7,858	489%	3,827	21,018
Simsbury	Capitol Region	21,970	6,117	28%	8,739	5,962	68%	23,234	16,202
Torrington	Litchfield Hills	25,794	9,008	35%	16,147	11,693	72%	35,202	27,096
Warren	Northwestern	17,597	8,805	50%	650	4,371	672%	1,254	11,044
*N/A									
Hartland		21,935	5,191	24%	759			2012	
Washington		24,728	13,177	53%	1,764			3596	
Winchester		20,993	11,791	56%				10664	
Total CT Highlands			**260,283**		112,289	**148,624**		285,730	**376,547**

Connecticut Munical Zoning Data - High Constraints

Name	Planning Region	Total Acres	Buildable Acreage (ROW)	Percentage Mun that is Buildable	2000 Dwelling Units	Additional Dwelling Units under Zoning Build-out	Percent New Dwelling Units	2000 Residents	Additional ResidentsZoning Build-out
Barkhamsted	Litchfield Hills	24,775	4,502	18%	1,436	2,469	172%	3,494	6,510
Brookfield	Housatonic	13,037	3,448	26%	5,781	2,209	38%	15,664	6,247
Burlington	Central Connecticut	19,499	5,986	31%	2,901	2,368	82%	8,190	6,875
Canaan	Northwestern	21,212	3,314	16%	610	3,560	584%	1,081	8,604
Canton	Central Connecticut	16,014	5,526	35%	3,616	3,471	96%	8,840	8,514
Colebrook	Litchfield Hills	21,047	5,977	28%	656	3,218	491%	1,471	8,399
Cornwall	Northwestern	29,717	5,800	20%	873	1,459	167%	1,434	3,343
Danbury	Housatonic	28,118	3,822	14%	28,519	3,534	12%	74,848	9,472
Goshen	Litchfield Hills	28,934	11,020	38%	1,482	2,662	180%	2,697	6,803
Granby	Capitol Region	26,299	9,182	35%	3,887	6,569	169%	10,347	17,853
Harwinton	Litchfield Hills	19,907	8,351	42%	2,022	4,317	214%	5,283	11,674
Kent	Northwestern	31,808	6,256	20%	1,463	6,280	429%	2,858	15,169
Litchfield	Litchfield Hills	36,436	13,054	36%	3,629	7,114	196%	8,316	17,313
Morris	Litchfield Hills	11,963	4,233	35%	1,181	2,865	243%	2,301	7,266
New Fairfield	Housatonic	16,103	2,726	17%	5,148	1,662	32%	13,953	4,987
New Hartford	Litchfield Hills	24,363	7,271	30%	2,368	3,673	155%	6,088	10,021
New Milford	Housatonic	40,882	10,471	26%	10,710	8,597	80%	27,121	23,162
Norfolk	Litchfield Hills	29,663	7,637	26%	871	4,028	462%	1,660	9,765
North Canaan	Northwestern	12,495	3,467	28%	1,444	3,726	258%	3,350	8,843
Salisbury	Northwestern	38,514	10,772	28%	2,410	5,181	215%	3,977	11,273
Sharon	Northwestern	38,209	10,064	26%	1,617	5,151	319%	2,968	11,608
Sherman	Housatonic	14,971	3,631	24%	1,606	4,684	292%	3,827	12,547
Simsbury	Capitol Region	21,970	5,221	24%	8,739	5,228	60%	23,234	14,218
Torrington	Litchfield Hills	25,794	6,552	25%	16,147	8,620	53%	35,202	19,944
Warren	Northwestern	17,597	6,165	35%	650	3,040	468%	1,254	7,748
* N/A									
Hartland		21,935	17,100	78%	759			2,012	
Washington		24,728	15,036	61%	1,764			3,596	
Winchester		20,993	12,791	61%				10,664	
Total CT Highlands			**209,376**		112,289	**105,685**		285,730	**268,158**

Pennsylvania Low Constraints

Name	Type	Total Acres	Buildable Acreage (ROW)	Percentage Mun that is Buildable	2000 Dwelling Units	Additional Dwelling Units under Zoning Build-out	Percentage New Units	2000 Residents	Additional Residents Zoning Build-out
Adamstown	Boro	923	325	35%	532	1,186	223%	1,201	2,372
Alburtis	Boro	488	47	10%	806	388	48%	2,117	1,055
Allentown	City	11,578	0	0%	45,960	0	0%	106,632	0
Alsace	Twp	7,789	4,683	60%	1,503	1,788	119%	3,689	4,601
Amity	Twp	11,853	5,640	48%	3,353	3,061	91%	8,841	8,391
Atglen	Boro	554	304	55%	429	474	110%	1,217	1,400
Bart	Twp	10,497	7,502	71%	840	7,454	887%	3,064	27,431
Bedminster	Twp	20,077	12,731	63%	1,868	6,718	360%	4,804	18,010
Bethlehem	City	12,433	590	5%	29,631	3,459	12%	71,329	7,612
Bethlehem	Twp	9,326	478	5%	7,831	1,394	18%	21,171	3,759
Boyertown	Boro	503	34	7%	1,885	194	10%	3,940	420
Brecknock	Twp	11,412	7,424	65%	1,611	4,991	310%	4,459	14,276
Brecknock	Twp	15,828	9,623	61%	2,161	8,474	392%	6,699	26,857
Bridgeton	Twp	4,358	2,130	49%	612	837	137%	1,408	2,118
Caernarvon	Twp	5,714	22	0%	926	40	4%	2,312	114
Caernarvon	Twp	14,674	10,735	73%	1,303	7,896	606%	4,278	25,735
Christiana	Boro	333	3	1%	392	3	1%	1,122	9
Clay	Twp	14,563	5,517	38%	1,799	10,629	591%	5,139	31,046
Colebrookdale	Twp	5,377	2,470	46%	2,030	2,956	146%	5,270	7,818
Conewago	Twp	10,681	3,326	31%	1,069	4,825	451%	2,847	13,468
Conoy	Twp	11,622	2,409	21%	1,124	2,547	227%	3,072	7,085
Coopersburg	Boro	608	99	16%	1,050	382	36%	2,582	929
Cornwall	Boro	6,328	3,293	52%	1,261	1,928	153%	3,486	4,984
Denver	Boro	839	6	1%	1,298	3	0%	3,332	8
Douglass	Twp	8,078	5,057	63%	1,240	3,252	262%	3,311	8,597
Douglass	Twp	9,839	3,612	37%	3,275	3,869	118%	9,145	11,060
Durham	Twp	5,965	4,085	68%	525	1,441	274%	1,325	3,965
Earl	Twp	8,845	4,713	53%	1,201	2,549	212%	3,066	6,708
Earl	Twp	14,085	7	0%	2,126	2	0%	6,183	6
East Cocalico	Twp	13,163	6,850	52%	3,557	7,315	206%	9,954	20,644
East Coventry	Twp	7,018	4,166	59%	1,684	2,627	156%	4,566	6,916
East Earl	Twp	15,793	10,334	65%	1,791	8,650	483%	5,720	28,364
East Greenville	Boro	315	26	8%	1,173	115	10%	3,103	328
East Nantmeal	Twp	10,466	5,810	56%	587	5,586	952%	1,787	15,306
Easton	City	2,980	61	2%	10,545	385	4%	26,263	940
East Rockhill	Twp	8,380	4,769	57%	1,883	3,271	174%	5,199	9,232
East Vincent	Twp	8,718	5,112	59%	1,960	4,366	223%	5,500	12,023
Eden	Twp	7,994	5,996	75%	606	3,530	583%	1,856	11,326
Elizabeth	Twp	11,324	3,205	28%	1,336	2,025	152%	3,867	5,996
Elizabethtown	Boro	1,715	15	1%	4,473	37	1%	11,882	89
Elverson	Boro	641	3	1%	460	1	0%	959	2
Emmaus	Boro	1,813	163	9%	5,198	469	9%	11,242	1,047
Ephrata	Boro	2,273	31	1%	5,668	18	0%	13,194	40
Ephrata	Twp	10,405	5,104	49%	2,751	3,201	116%	8,045	9,361
Exeter	Twp	15,716	6,846	44%	8,178	5,231	64%	21,187	13,886
Forks	Twp	7,864	2	0%	3,159	9	0%	8,419	26
Franconia	Twp	8,838	1,961	22%	4,236	2,243	53%	11,523	6,071

Freemansburg	Boro	475	49	10%	721	196	27%	1,897	521
Glendon	Boro	399	1	0%	150	1	1%	369	3
Goldsboro	Boro	295	50	17%	376	119	32%	902	324
Green Lane	Boro	198	49	25%	233	97	42%	579	249
Haycock	Twp	13,337	5,175	39%	841	2,720	323%	2,191	7,370
Heidelberg	Twp	9,221	3,195	35%	613	1,554	254%	1,636	4,095
Heidelberg	Twp	15,781	9,621	61%	1,389	3,913	282%	3,832	11,155
Hellertown	Boro	854	4	1%	2,544	13	1%	5,615	27
Hereford	Twp	9,873	6,234	63%	1,277	6,786	531%	3,169	18,056
Honey Brook	Boro	305	133	44%	500	671	134%	1,287	1,822
Honey Brook	Twp	16,031	11,572	72%	2,134	16,582	777%	6,278	48,094
Kutztown	Boro	1,006	165	16%	1,940	619	32%	5,067	1,530
Limerick	Twp	14,523	4,870	34%	5,442	3,940	72%	13,534	10,410
Londonderry	Twp	17,218	7,334	43%	2,092	7,313	350%	5,223	19,028
Longswamp	Twp	14,658	8,348	57%	2,101	2,111	100%	5,612	5,514
Lower Alsace	Twp	3,054	749	25%	1,958	792	40%	4,469	1,877
Lower Frederick	Twp	5,182	2,870	55%	1,805	2,177	121%	4,756	5,996
Lower Macungie	Twp	14,471	1	0%	7,398	0	0%	19,220	0
Lower Milford	Twp	12,611	6,975	55%	1,308	3,714	284%	3,617	10,515
Lower Pottsgrove	Twp	5,132	1,705	33%	4,104	1,212	30%	11,301	3,375
Lower Salford	Twp	9,272	4,944	53%	4,531	4,438	98%	12,893	12,854
Lower Saucon	Twp	15,666	9,801	63%	3,915	7,415	189%	9,884	19,531
Manheim	Boro	890	2	0%	2,075	0	0%	4,784	0
Marlborough	Twp	7,940	3,361	42%	1,224	1,780	145%	3,109	4,683
Maxatawny	Twp	16,645	8,624	52%	1,412	8,607	610%	6,032	22,649
Milford	Twp	17,842	9,665	54%	3,161	6,356	201%	8,810	17,820
Millcreek	Twp	12,962	7,582	58%	1,090	6,280	576%	2,921	17,531
Mohnton	Boro	495	53	11%	1,259	141	11%	2,963	338
Mount Joy	Boro		4		2,957	13	0%	6,765	32
Mount Joy	Twp	17,909	9,249	52%	2,957	18,779	635%	7,949	51,407
Muhlenberg	Twp	7,698	1,664	22%	6,907	1,295	19%	16,285	3,085
Newberry	Twp	19,881	10,304	52%	5,677	7,294	128%	14,327	19,357
New Hanover	Twp	13,875	6,727	48%	2,633	6,005	228%	7,367	17,428
Nockamixon	Twp	14,299	7,133	50%	1,411	4,923	349%	3,517	12,959
North Coventry	Twp	8,843	5,117	58%	3,114	4,492	144%	7,381	10,987
Oley	Twp	15,400	5,506	36%	1,425	5,616	394%	3,583	14,509
Ontelaunee	Twp	5,971	1,953	33%	557	1,943	349%	1,221	4,579
Palmer	Twp	6,907	1,551	22%	6,865	3,005	44%	16,809	7,362
Paradise	Twp	11,917	7,952	67%	1,600	8,741	546%	4,698	26,137
Parkesburg	Boro	818	320	39%	1,321	510	39%	3,373	1,382
Penn	Twp	18,923	8	0%	2,671	1	0%	7,312	3
Pennsburg	Boro	511	87	17%	1,078	451	42%	2,732	1,178
Perkasie	Boro	1,636	416	25%	3,378	2,788	83%	8,828	7,468
Perkiomen	Twp	3,133	1,103	35%	2,556	1,275	50%	7,093	3,668
Pike	Twp	8,970	5,428	61%	627	2,636	420%	1,677	7,307
Plumstead	Twp	17,455	9,264	53%	4,103	6,844	167%	11,409	19,799
Pottstown	Boro	3,127	1	0%	9,996	0	0%	21,771	0
Quakertown	Boro	1,308	133	10%	3,631	731	20%	8,931	1,872
Rapho	Twp	30,749	18,353	60%	3,185	9,784	307%	8,578	27,018
Red Hill	Boro	432	78	18%	944	253	27%	2,196	610
Richland	Twp	13,263	5,154	39%	3,877	4,017	104%	9,920	10,560
Richlandtown	Boro	169	68	40%	451	429	95%	1,283	1,165

Richmond	Twp	15,090	3,774	25%	1,499	2,052	137%	3,554	5,078
Riegelsville	Boro	699	287	41%	403	232	58%	851	516
Robeson	Twp	21,884	12,510	57%	2,568	10,296	401%	6,869	28,437
Robesonia	Boro	567	130	23%	858	257	30%	2,036	623
Rockland	Twp	10,885	7,166	66%	1,368	3,755	274%	3,765	10,630
Royersford	Boro	509	21	4%	2,039	124	6%	4,246	270
Ruscombmanor	Twp	8,785	5,494	63%	1,421	4,288	302%	3,776	11,623
Sadsbury	Twp	4,001	1,724	43%	1,025	2,047	200%	2,582	5,570
Sadsbury	Twp	12,707	8,471	67%	894	9,702	1085%	2,966	33,077
St Lawrence	Boro	582	5	1%	781	4	1%	1,812	8
Salford	Twp	6,295	2,872	46%	821	1,094	133%	2,363	3,201
Salisbury	Twp	26,836	17,402	65%	3,112	4,547	146%	10,012	14,958
Salisbury	Twp	7,177	2,928	41%	5,281	1,561	30%	13,498	3,972
Schwenksville	Boro	260	64	25%	662	188	28%	1,693	398
Sellersville	Boro	744	143	19%	1,832	550	30%	4,595	1,426
Skippack	Twp	8,926	2,259	25%	2,493	1,944	78%	6,566	5,331
South Annville	Twp	12,433	6,656	54%	1,129	5,853	518%	2,946	15,280
South Coventry	Twp	5,017	3,506	70%	721	2,387	331%	1,895	6,423
South Heidelberg	Twp	8,802	4,221	48%	2,027	7,651	377%	5,491	20,233
South Lebanon	Twp	13,466	5,838	43%	3,030	5,827	192%	8,383	14,806
South Londonderry	Twp	15,558	8,680	56%	2,138	7,873	368%	5,458	20,553
Spring	Twp	11,764	4,998	42%	8,995	8,127	90%	21,805	19,979
Spring City	Boro	525	71	14%	1,531	362	24%	3,262	819
Springfield	Twp	19,685	14,110	72%	1,972	9,640	489%	4,963	25,170
Strasburg	Twp	610	7	1%	1,152	4	0%	2,802	11
Strasburg	Boro	12,861	7,732	60%	1,278	6,945	543%	4,019	21,871
Telford	Boro	657	61	9%	2,020	370	18%	4,360	777
Terre Hill	Boro	292	6	2%	458	6	1%	1,240	18
Tinicum	Twp	19,841	10,749	54%	1,834	5,381	293%	4,206	13,383
Topton	Boro	445	13	3%	838	56	7%	1,944	134
Trumbauersville	Boro	228	70	31%	382	168	44%	1,059	477
Union	Twp	14,959	5,495	37%	1,370	3,764	275%	3,453	9,760
Upper Frederick	Twp	6,437	3,265	51%	1,088	1,846	170%	3,141	5,158
Upper Hanover	Twp	13,545	5,614	41%	1,764	6,721	381%	4,885	18,910
Upper Milford	Twp	11,359	6,736	59%	2,564	5,733	224%	6,960	15,890
Upper Pottsgrove	Twp	3,176	1,493	47%	1,459	864	59%	4,102	2,503
Upper Salford	Twp	5,827	1,737	30%	1,074	1,043	97%	3,024	2,994
Upper Saucon	Twp	15,793	8,591	54%	4,117	8,281	201%	11,939	23,048
Upper Uwchlan	Twp	7,627	3,390	44%	2,167	3,106	143%	6,850	9,966
Wallace	Twp	7,638	5,413	71%	1,045	3,882	371%	3,240	11,917
Warwick	Twp	12,146	5,936	49%	1,033	3,243	314%	2,556	8,306
Washington	Twp	9,040	2,319	26%	1,246	2,340	188%	3,360	6,510
West Brandywine	Twp	8,517	5,933	70%	2,617	5,115	195%	7,162	14,174
West Caln	Twp	14,241	233	2%	2,458	584	24%	7,054	1,707
West Cocalico	Twp	17,601	6,236	35%	2,383	7,245	304%	6,967	21,671
West Cornwall	Twp	5,552	1,784	32%	942	1,675	178%	1,908	3,837
West Donegal	Twp	10,110	3,601	36%	2,560	3,166	124%	6,539	8,275
West Easton	Boro	217	1	0%	481	10	2%	1,151	25
West Nantmeal	Twp	8,572	5,167	60%	745	4,305	578%	2,031	12,232
West Pottsgrove	Twp	1,538	4	0%	1,606	2	0%	3,815	4
West Rockhill	Twp	10,530	5,571	53%	1,701	5,103	300%	4,233	12,576
West Sadsbury	Twp	6,708	2,253	34%	818	2,479	303%	2,444	7,535

West Vincent	Twp	11,190	8,186	73%	1,121	5,433	485%	3,170	15,432
Williams	Twp	11,893	7,255	61%	1,738	7,252	417%	4,468	19,583
Wilson	Boro	744	2	0%	3,346	3	0%	7,683	6
Bally	Boro	341	154	45%	426			1,062	
Bechtelsville	Boro	331	179	54%	364			930	
Birdsboro	Boro	857	190	22%	1927			5,064	
Cumru	Twp	13,488	8,583	64%	6132			13,822	
Derry	Twp	17,464	9,824	56%	9481			21,273	
District	Twp	7,379	5,432	74%	548			1,449	
Fairview	Twp	22,798	13,665	60%	5788			14,321	
Fleetwood	Boro	642	95	15%	1623			4,018	
Fountain Hill	Boro	484	129	27%	2029			4,614	
Kenhorst	Boro	360	32	9%	1265			2,662	
Laureldale	Boro	511	26	5%	1675			3,779	
Lewisberry	Boro	67	11	16%	150			388	
Lyons	Boro	227	88	39%	188			454	
Macungie	Boro	686	145	21%	1418			3,039	
Maidencreek	Twp	9,469	4,487	47%	2355			6,549	
Mount Gretna	Boro	94	65	69%	207			243	
Mt Penn	Boro	274	37	14%	1333			3,025	
New Holland	Boro	1,276	334	26%	2159			5,092	
New Morgan	Boro	3,670	2,852	78%	11			35	
Reading	City	6,503	495	8%	34309			81,201	
Shillington	Boro	647	42	6%	2321			5,059	
Sinking Spring	Boro	798	143	18%	1261			2,598	
York Haven	Boro	241	101	42%	323			848	
Total PA Highlands		**1,381,810**	**643,318**		**485,698**	**499,677**		**1,226,939**	**1,393,741**

Pennsylvania Municipalities High Constraints

Name	Type	Total Acres	Buildable Acreage (ROW)	Percentage Mun that is Buildable	2000 Dwelling Units	Additional Dwelling Units under Zoning Build-out	Percentage New Units	2000 Residents	Additional ResidentsZoning Build out
Adamstown	Boro	923	194	21%	532	807	152%	1,201	1,614
Alburtis	Boro	488	35	7%	806	292	36%	2,117	793
Allentown	City	11,578	0	0%	45,960	0	0%	106,632	0
Alsace	Twp	7,789	3,480	45%	1,503	1,334	89%	3,689	3,450
Amity	Twp	11,853	4,987	42%	3,353	2,699	80%	8,841	7,398
Atglen	Boro	554	230	42%	429	387	90%	1,217	1,144
Bart	Twp	10,497	7,028	67%	840	6,978	831%	3,064	25,682
Bedminster	Twp	20,077	11,618	58%	1,868	6,130	328%	4,804	16,436
Bethlehem	City	12,433	331	3%	29,631	1,651	6%	71,329	3,624
Bethlehem	Twp	9,326	468	5%	7,831	1,365	17%	21,171	3,682
Boyertown	Boro	503	20	4%	1,885	117	6%	3,940	254
Brecknock	Twp	11,412	5,240	46%	1,611	3,525	219%	4,459	10,104
Brecknock	Twp	15,828	8,569	54%	2,161	7,704	357%	6,699	24,412
Bridgeton	Twp	4,358	1,889	43%	612	732	120%	1,408	1,850
Caernarvon	Twp	5,714	20	0%	926	35	4%	2,312	100
Caernarvon	Twp	14,674	9,212	63%	1,303	6,773	520%	4,278	22,074
Christiana	Boro	333	1	0%	392	2	1%	1,122	6
Clay	Twp	14,563	4,673	32%	1,799	8,991	500%	5,139	26,271
Colebrookdale	Twp	5,377	1,657	31%	2,030	1,996	98%	5,270	5,300
Conewago	Twp	10,681	3,013	28%	1,069	4,377	409%	2,847	12,218
Conoy	Twp	11,622	1,684	14%	1,124	1,769	157%	3,072	4,926
Coopersburg	Boro	608	93	15%	1,050	358	34%	2,582	872
Cornwall	Boro	6,328	2,398	38%	1,261	1,481	117%	3,486	3,839
Denver	Boro	839	6	1%	1,298	3	0%	3,332	8
Douglass	Twp	8,078	4,067	50%	1,240	2,605	210%	3,311	6,896
Douglass	Twp	9,839	3,281	33%	3,275	3,534	108%	9,145	10,107
Durham	Twp	5,965	2,992	50%	525	1,053	201%	1,325	2,902
Earl	Twp	8,845	2,876	33%	1,201	1,535	128%	3,066	4,062
Earl	Twp	14,085	6	0%	2,126	2	0%	6,183	6
East Cocalico	Twp	13,163	5,989	45%	3,557	6,431	181%	9,954	18,152
East Coventry	Twp	7,018	3,739	53%	1,684	2,365	140%	4,566	6,232
East Earl	Twp	15,793	9,308	59%	1,791	7,977	445%	5,720	26,158
East Greenville	Boro	315	25	8%	1,173	111	9%	3,103	317
East Nantmeal	Twp	10,466	4,400	42%	587	4,238	722%	1,787	11,614
Easton	City	2,980	28	1%	10,545	208	2%	26,263	506
East Rockhill	Twp	8,380	4,328	52%	1,883	2,963	157%	5,199	8,366
East Vincent	Twp	8,718	4,492	52%	1,960	3,783	193%	5,500	10,418
Eden	Twp	7,994	5,204	65%	606	3,024	499%	1,856	9,696
Elizabeth	Twp	11,324	2,406	21%	1,336	1,527	114%	3,867	4,527
Elizabethtown	Boro	1,715	15	1%	4,473	37	1%	11,882	89
Elverson	Boro	641	3	1%	460	1	0%	959	2
Emmaus	Boro	1,813	147	8%	5,198	428	8%	11,242	956
Ephrata	Boro	2,273	27	1%	5,668	17	0%	13,194	38
Ephrata	Twp	10,405	4,503	43%	2,751	2,745	100%	8,045	8,030
Exeter	Twp	15,716	5,313	34%	8,178	3,862	47%	21,187	10,274
Forks	Twp	7,864	1	0%	3,159	5	0%	8,419	14

Franconia	Twp	8,838	1,846	21%	4,236	2,110	50%	11,523	5,714
Freemansburg	Boro	475	41	9%	721	177	25%	1,897	471
Glendon	Boro	399	0	0%	150	0	0%	369	0
Goldsboro	Boro	295	31	11%	376	71	19%	902	194
Green Lane	Boro	198	46	23%	233	91	39%	579	233
Haycock	Twp	13,337	4,837	36%	841	2,550	303%	2,191	6,909
Heidelberg	Twp	9,221	2,397	26%	613	1,127	184%	1,636	2,983
Heidelberg	Twp	15,781	7,950	50%	1,389	3,244	234%	3,832	9,261
Hellertown	Boro	854	2	0%	2,544	6	0%	5,615	13
Hereford	Twp	9,873	4,904	50%	1,277	5,383	422%	3,169	14,332
Honey Brook	Boro	305	130	43%	500	657	131%	1,287	1,785
Honey Brook	Twp	16,031	10,313	64%	2,134	14,313	671%	6,278	41,519
Kutztown	Boro	1,006	121	12%	1,940	473	24%	5,067	1,168
Limerick	Twp	14,523	4,600	32%	5,442	3,764	69%	13,534	9,950
Londonderry	Twp	17,218	6,226	36%	2,092	6,197	296%	5,223	16,138
Longswamp	Twp	14,658	6,742	46%	2,101	1,673	80%	5,612	4,381
Lower Alsace	Twp	3,054	410	13%	1,958	438	22%	4,469	1,035
Lower Frederick	Twp	5,182	2,427	47%	1,805	1,826	101%	4,756	5,038
Lower Macungie	Twp	14,471	1	0%	7,398	0	0%	19,220	0
Lower Milford	Twp	12,611	5,544	44%	1,308	2,940	225%	3,617	8,325
Lower Pottsgrove	Twp	5,132	1,487	29%	4,104	1,048	26%	11,301	2,923
Lower Salford	Twp	9,272	4,512	49%	4,531	4,049	89%	12,893	11,730
Lower Saucon	Twp	15,666	7,108	45%	3,915	5,604	143%	9,884	14,784
Manheim	Boro	890	1	0%	2,075	0	0%	4,784	0
Marlborough	Twp	7,940	2,909	37%	1,224	1,541	126%	3,109	4,063
Maxatawny	Twp	16,645	7,439	45%	1,412	7,415	525%	6,032	19,527
Milford	Twp	17,842	8,860	50%	3,161	5,709	181%	8,810	16,009
Millcreek	Twp	12,962	6,165	48%	1,090	5,277	484%	2,921	14,739
Mohnton	Boro	495	28	6%	1,259	66	5%	2,963	155
Mount Joy	Boro		3	#DIV/0!	2,957	11	0%	6,765	27
Mount Joy	Twp	17,909	8,474	47%	2,957	17,426	589%	7,949	47,700
Muhlenberg	Twp	7,698	1,147	15%	6,907	979	14%	16,285	2,327
Newberry	Twp	19,881	7,985	40%	5,677	5,522	97%	14,327	14,692
New Hanover	Twp	13,875	5,995	43%	2,633	5,454	207%	7,367	15,839
Nockamixon	Twp	14,299	6,191	43%	1,411	4,220	299%	3,517	11,122
North Coventry	Twp	8,843	4,043	46%	3,114	3,770	121%	7,381	9,214
Oley	Twp	15,400	4,604	30%	1,425	4,708	330%	3,583	12,171
Ontelaunee	Twp	5,971	1,689	28%	557	1,677	301%	1,221	3,953
Palmer	Twp	6,907	1,397	20%	6,865	2,736	40%	16,809	6,696
Paradise	Twp	11,917	6,843	57%	1,600	7,506	469%	4,698	22,448
Parkesburg	Boro	818	284	35%	1,321	453	34%	3,373	1,227
Penn	Twp	18,923	1	0%	2,671	0	0%	7,312	0
Pennsburg	Boro	511	87	17%	1,078	449	42%	2,732	1,173
Perkasie	Boro	1,636	324	20%	3,378	2,101	62%	8,828	5,625
Perkiomen	Twp	3,133	958	31%	2,556	1,108	43%	7,093	3,188
Pike	Twp	8,970	3,641	41%	627	1,796	286%	1,677	4,998
Plumstead	Twp	17,455	8,604	49%	4,103	6,363	155%	11,409	18,406
Pottstown	Boro	3,127	1	0%	9,996	0	0%	21,771	0
Quakertown	Boro	1,308	85	7%	3,631	453	12%	8,931	1,167
Rapho	Twp	30,749	16,455	54%	3,185	8,782	276%	8,578	24,266
Red Hill	Boro	432	78	18%	944	253	27%	2,196	610

Richland	Twp	13,263	4,648	35%	3,877	3,654	94%	9,920	9,607
Richlandtown	Boro	169	12	7%	451	28	6%	1,283	78
Richmond	Twp	15,090	2,764	18%	1,499	1,527	102%	3,554	3,761
Riegelsville	Boro	699	265	38%	403	210	52%	851	461
Robeson	Twp	21,884	8,442	39%	2,568	7,031	274%	6,869	19,476
Robesonia	Boro	567	94	16%	858	172	20%	2,036	417
Rockland	Twp	10,885	5,712	52%	1,368	3,112	227%	3,765	8,813
Royersford	Boro	509	19	4%	2,039	105	5%	4,246	227
Ruscombmanor	Twp	8,785	4,377	50%	1,421	3,430	241%	3,776	9,305
Sadsbury	Twp	4,001	1,439	36%	1,025	1,701	166%	2,582	4,630
Sadsbury	Twp	12,707	7,548	59%	894	8,711	974%	2,966	29,693
St Lawrence	Boro	582	2	0%	781	1	0%	1,812	2
Salford	Twp	6,295	2,529	40%	821	976	119%	2,363	2,858
Salisbury	Twp	26,836	15,496	58%	3,112	17,088	549%	10,012	56,214
Salisbury	Twp	7,177	2,058	29%	5,281	1,103	21%	13,498	2,820
Schwenksville	Boro	260	50	19%	662	146	22%	1,693	309
Sellersville	Boro	744	106	14%	1,832	346	19%	4,595	903
Skippack	Twp	8,926	2,091	23%	2,493	1,819	73%	6,566	4,992
South Annville	Twp	12,433	5,948	48%	1,129	5,375	476%	2,946	14,036
South Coventry	Twp	5,017	2,759	55%	721	1,926	267%	1,895	5,185
South Heidelberg	Twp	8,802	2,692	31%	2,027	4,827	238%	5,491	12,794
South Lebanon	Twp	13,466	5,461	41%	3,030	5,447	180%	8,383	13,850
South Londonderry	Twp	15,558	7,551	49%	2,138	6,883	322%	5,458	17,976
Spring	Twp	11,764	3,577	30%	8,995	6,086	68%	21,805	14,934
Spring City	Boro	525	69	13%	1,531	349	23%	3,262	789
Springfield	Twp	19,685	11,896	60%	1,972	8,129	412%	4,963	21,239
Strasburg	Twp	610	5	1%	1,152	3	0%	2,802	8
Strasburg	Boro	12,861	6,314	49%	1,278	5,709	447%	4,019	17,962
Telford	Boro	657	21	3%	2,020	95	5%	4,360	198
Terre Hill	Boro	292	2	1%	458	1	0%	1,240	3
Tinicum	Twp	19,841	8,219	41%	1,834	4,090	223%	4,206	10,145
Topton	Boro	445	12	3%	838	50	6%	1,944	120
Trumbauersville	Boro	228	2	1%	382	2	1%	1,059	6
Union	Twp	14,959	4,601	31%	1,370	3,188	233%	3,453	8,271
Upper Frederick	Twp	6,437	3,083	48%	1,088	1,752	161%	3,141	4,899
Upper Hanover	Twp	13,545	5,094	38%	1,764	6,158	349%	4,885	17,331
Upper Milford	Twp	11,359	5,343	47%	2,564	4,590	179%	6,960	12,733
Upper Pottsgrove	Twp	3,176	1,295	41%	1,459	754	52%	4,102	2,188
Upper Salford	Twp	5,827	1,558	27%	1,074	942	88%	3,024	2,704
Upper Saucon	Twp	15,793	7,079	45%	4,117	7,134	173%	11,939	19,866
Upper Uwchlan	Twp	7,627	2,708	36%	2,167	2,541	117%	6,850	8,150
Wallace	Twp	7,638	4,735	62%	1,045	3,395	325%	3,240	10,417
Warwick	Twp	12,146	4,720	39%	1,033	2,569	249%	2,556	6,590
Washington	Twp	9,040	1,921	21%	1,246	1,932	155%	3,360	5,384
West Brandywine	Twp	8,517	5,278	62%	2,617	4,594	176%	7,162	12,734
West Caln	Twp	14,241	169	1%	2,458	417	17%	7,054	1,219
West Cocalico	Twp	17,601	5,009	28%	2,383	5,987	251%	6,967	17,915
West Cornwall	Twp	5,552	1,230	22%	942	1,125	119%	1,908	2,576
West Donegal	Twp	10,110	3,350	33%	2,560	2,915	114%	6,539	7,623
West Easton	Boro	217	0	0%	481	4	1%	1,151	10
West Nantmeal	Twp	8,572	4,499	52%	745	3,746	503%	2,031	10,646

West Pottsgrove	Twp	1,538	4	0%	1,606	2	0%	3,815	4
West Rockhill	Twp	10,530	5,023	48%	1,701	4,538	267%	4,233	11,177
West Sadsbury	Twp	6,708	1,905	28%	818	2,206	270%	2,444	6,701
West Vincent	Twp	11,190	6,499	58%	1,121	4,371	390%	3,170	12,430
Williams	Twp	11,893	5,158	43%	1,738	5,155	297%	4,468	13,924
Wilson	Boro	744	1	0%	3,346	1	0%	7,683	2
Bally	Boro	341	145	43%	426			1,062	
Bechtelsville	Boro	331	115	35%	364			930	
Birdsboro	Boro	857	145	17%	1,927			5,064	
Cumru	Twp	13,488	12,645	94%	6,132			13,822	
Derry	Twp	17,464	8,200	47%	9,481			21,273	
District	Twp	7,379	4,172	57%	548			1,449	
Fairview	Twp	22,798	9,680	42%	5,788			14,321	
Fleetwood	Boro	642	87	14%	1,623			4,018	
Fountain Hill	Boro	484	54	11%	2,029			4,614	
Kenhorst	Boro	360	22	6%	1,265			2,662	
Laureldale	Boro	511	14	3%	1,675			3,779	
Lewisberry	Boro	67	11	16%	150			388	
Lyons	Boro	227	87	38%	188			454	
Macungie	Boro	686	140	20%	1,418			3,039	
Maidencreek	Twp	9,469	3,963	42%	2,355			6,549	
Mount Gretna	Boro	94	38	40%	207			243	
Mt Penn	Boro	274	17	6%	1,333			3,025	
New Holland	Boro	1,276	41	3%	2,159			5,092	
New Morgan	Boro	3,670	2,360	64%	11			35	
Reading	City	6,503	257	4%	34,309			81,201	
Shillington	Boro	647	32	5%	2,321			5,059	
Sinking Spring	Boro	798	566	71%	1,261			2,598	
York Haven	Boro	241	56	23%	323			848	
Total PA Highlands		**1,381,810**	**541,251**		**485,698**	**431,621**		**1,226,939**	**1,214,952**

APPENDIX 4: DESCRIPTION OF GEOMOD

GEOMOD was developed by researchers at the SUNY College of Environmental Science and Forestry (Hall, *et al.,* 1995a; 1995b; Pontius *et al.,* 2001) with funding from the US Department of Energy, Carbon Dioxide Research Program, Atmospheric and Climatic Change Division. The model simulates land use change using what we refer to as geographic modeling (Hall, M. *et al.,* 2000). It determines the rate of empirical land use conversion from forested to non-forest, extrapolates that rate into the future, and most importantly simulates the location of future land use change based on statistical analysis of the empirical pattern.

The rate of change is derived by comparing the area of forest found in a land cover/use map at one point in time to that found in another at a different (either earlier or later) point in time. The model can be run either forward or backward and simulated results can be tested against the actual landscape as derived from satellite or aerial photography imagery. Future rate trends can also be established from various independent variables that may influence deforestation such as population growth, economic activity, employment history, infrastructure establishment, etc., using regression analysis.

The spatially specific location of that estimated land use conversion, derives from a statistical deduction approach, which analyzes historical patterns of land use change against user-supplied map layers of bio-physical and cultural attributes. The change observed in any given landscape 'cell' is analyzed against a number of candidate drivers, which researchers (Hall *et al.,* 1995, Flint and Richards 1991, 1994; Dale 1994), have determined as potentially the most important factors influencing human settlement patterns. GEOMOD2 essentially uses non-linear multiple-regression to weight each driver according to its assessed importance in determining the pattern and location of changed cells over time. The underlying philosophy is based on the "maximum power principle" (Odum 1983). It is assumed that those conditions which are most likely to significantly impact an individual's energy return on investment (EROI) (Hall, Cleveland and Kaufmann 1986) as he/she develop and work new ground include such variables as: topographic position (elevation and steepness of slope), distance from rivers, roads and already established settlements, climate variables, etc. Each of these variables can affect the energy cost or the expected return from a development decision. In other words we assume that developers are knowledgeable to some degree about where development would be most profitable in energy and hence economic terms. Using the assigned weights GEOMOD can then develop or undevelop land going forward or backward in time. Starting from seeds of earliest development it extends human activity across the landscape, creating a pattern of development from undisturbed to disturbed that closely mimics reality. As it 'nibbles' away at the landscape the model adheres to the three following principles: (1) adjacency, which is the tendency to develop land next to land already developed; (2) dispersion, which is the phenomenon to 'jump' from one place to another relatively favorable location; and (3) regional heterogeneity, which accounts for significant differences in the pattern and rates of land use change among subregions or countries because of the population density, economic and political factors particular to those places.

The variation in accuracy of model predictions depends on the time scale used, the number of land classes modeled and the accuracy of the initializing data. We have found that the drivers of land use change pattern are both scale- and terrain-dependent: specifically, topographic features are more important than climate variables for largescale simulations where topography is rugged. We have achieved highest accuracy when predicting only two land use classes, forested and non-forested. Going to three classes, undisturbed, disturbed, and non-forest our accuracy declined

to 84%. Including all 12 land use categories delineated in Brown *et al.,* (1994) we achieved 78% accuracy. The amount of land use change is influenced greatly by population growth and land use policy in the region being modeled. The model, when linked with biomass estimates, can be used to estimate the magnitude of carbon released or sequestered in the vegetation (Brown *et al.,* 1994).

Data Requirements

The model is FORTRAN-based and requires as inputs a spatially-referenced set of equally-dimensioned digital grid (raster) maps. The following inputs, at a minimum, are required.

1. A digital elevation model, or better yet, a digital coverage of elevation contours and maximum/minimum elevation points from which a DEM can be prepared using ARC/INFO's (ESRI) Tin generator. Slope and aspect, potentially important drivers, are derived from this.

2. A digital hydrography coverage (streams, lakes) also used to generate the DEM.

3. A digital coverage of roads

4. A coverage of any other transportation routes (rail, air, boat) that give people access to the interior.

5. Classified and geo-referenced land use maps derived from either aerial photography or satellite imagery for preferably two points in time, and preferably at the same scale and no smaller than 1:24,000 with a grid cell resolution no larger than 30 x 30 meters. Existing settlements should be one of the identified land use classes. Also any land guaranteed as 'set aside' (*i.e.,* protected) should be indicated (see summary below).

6. Population data over the same period of time.

7. Climate data, particularly if there is a considerable elevation gradient. These would include both mean annual temperature, mean minimum and mean maximum and precipitation measurements from one or more nearby weather monitoring stations, if available. (The elevation and geographic coordinates of that station are required as well.)

Additional useful data:

1. Economic data such as crop production, investments, or exports, employment, average income, building permits, local government budgets for roads, bridges, sewage treatment, etc.

2. Social data such as average highest level of education, land use preference. (This needs Valerie Luzadis' input.)

3. A digital soil map and accompanying information on such soil characteristics as soil thickness, drainage characteristics, annual flooding, infiltration rate, % silt, clay, loam.

4. Any other climatic data, PET, daily insolation, cloud cover, etc. could be useful.

5. Biomass estimates for digitized vegetation polygons, or, if the land use map is classified at a level that supports biomass estimates, then an accompanying table would be useful.

Methods

- Reclassification of Land Use Types

  – Geomod can evaluate change in two land use types at a time. Therefore, each map of land use change must be reclassified similarly. The most common reclassification is to classify all undisturbed forest as type 1, and all other land use types, which can be characterized as having undergone some human intervention, such as urban and agricultural areas, as type 2. In addition, land that will not be evaluated, such as land that is unlikely to ever be used by humans for productive activity, *e.g.,* deserts, can be excluded from the analysis. Normally in the original land use map these areas are assigned a unique value. Furthermore, land that sits within the grid map, but lies outside the area being modeled, also must have a unique identifying number, indicating that it will not be included in the evaluation. This could include land in another country or region, oceans, or areas for which no data exists. A normal land use map, ready for input to GEOMOD, therefore, will usually consist of four possible values as follows:

    1. forested
    2. agriculture, cities, pasture, degraded land
    3. deserts, water (lakes, oceans, rivers)
    4. outside region of interest

- Rate Estimation

  – If two maps of land use from two points in time are available they must be reclassed as shown above. Using an area calculation we can determine how many cells of forest existed in each period. Subtraction of the second from the first tells us how many cells were deforested in the interim period. This number times the area per cell yields total area deforested. When we divide the area by the number of years we have our rate per year.

  – We can also calculate the rate of deforestation per year as a function of population or economic growth. Linear analysis of deforestation versus population, or multi-linear regression of deforestation versus population, gross regional product, exports, agricultural production, etc., allows us to project different rates of growth according to these indicators and hence simulate the land use change that can be expected as a function of changes in these independent variables. This gives us more flexibility to test different future scenarios.

Products

GEOMOD will produce a time series of land use maps, at a time interval to be selected, over the 40-year life of the project. Each digital map will be produced as a color print, and the area in each land-use type will be reported in an accompanying table. Additionally, the output and accompany-

ing predicted data, can be displayed in a timeseries display module called ECOPLOT (RPA 1997). ECOPLOT displays the changing landscape, over time, as a central image, and graphs important driving variables, and program output as graphs surrounding this image (*e.g.,* population growth, gdp, linear miles of roads built, biomass, carbon stored in the vegetation, etc.) (See http://nrmsc.usgs.gov/research/glacier_model.htm (Hall, M. 1995, Hall, M. and Fagre 2000) for a 'virtual' example of ECOPLOT displayed on the USGS web site – minus the graphs described above.) This tool is particularly intuitive for illustrating rapid and significant landscape change and is a useful informational aide when presenting land use alternatives and decision-making options, and their environmental consequences, to politicians, resource managers, developers, financial backers, and the general public.

Summary

We have been very successful in the past in predicting land use change, for example in Costa Rica in 1983 from a 1940 map (Hall *et al.,* 1995b; Pontius *et al.,* 2000). Comparison of our predicted results with an actual land use map of 1983 shows an 87% accuracy, with a Kappa factor of 40-50) (Pontius, 2000). Cornell (2000) has improved the accuracy to 92% by setting aside those lands with national park status, *i.e.,* protected areas. We feel, therefore, that given good data, GEOMOD should give highly accurate estimates of future potential land use change in the northeastern USA.

Comparison to the modeling methodology used in the New York – New Jersey Study

We attempt here to describe briefly the ways in which our methodology is similar and different from that employed in the NY/NJ study.

Although many techniques of land use change modeling have been developed over the past 20 years (Dale, 1994; Veldkamp and Fresco 1996; Lambin and Strahler, 1994; Hall *et al.,* 1995a, 1995b;Cornell and Hall 2001), many of the earlier ones, as well as some of the more recently developed "urban sprawl" models (*e.g.,* Clarke and Gaydos' GIGALOPOLIS 1998), are notably lacking in two very important features implicit to the modeling process, that of sensitivity analysis and model validation. With the exception of GEOMOD, these models fail to validate their projected landscapes against any real data. This leaves users with the misconception that they are producing believable results. While it is true that we can neither know the future, nor know if our projections of the future will bear any resemblance to reality, we can at least test model predictions against a set of data points not used in calibration of the model, in order to assess model performance and accuracy. GEOMOD explicitly employs the latter techniques. This consists of an iterative process of calibrating the model through factor analysis and weighting using development at time one, and validating projections of development against a time two reference map of "actual" lands developed (Figure 1). Once having determined which of the many landscape pattern and rate drivers tested produce the most accurate landscape upon validation, we can feel comfortable that our estimates of likely areas of impact, or projected areas of impact into the next decade(s) are based on the best knowledge we have at the current time and that they are more reliable than those that profess accuracy based only on calibration, rather than sensitivity analysis and validation.

The similarities and differences between the GEOMOD approach and that used in the New York/New Jersey Highlands study are summarized in Table 1. They are as follows:

1. Both models test a suite of potentially significant land characteristics that may explain the historical pattern of change and use these to derive a future likelihood of change map. To date we have tested 25 different factors in multiple towns, counties and watersheds. A complete list is in table 2.

2. Both models produce a "likelihood of change" map that represents each cell's likelihood of change with respect to all other cell's likelihood (see Connecticut example, Figure 2). The NY/NJ model derived a similar weight based on multilogit regression statistical fitting of explanatory variables to areas of change between time 1 and time 2. It then applies the statistically best fitting model to the time 2 land still available for development to show those areas most threatened. GEOMOD weights cells by assessing for every category of every potentially explanatory factor the percentage of all cells of that class already developed at time one.

3. This produces a "likelihood" map that is used to project the time 2 map that is validated. Once the final set of factors producing the most accurate time 2 map is derived, as measured by the Kappa for location and the Kappa for quantity statistic, this set of likelihood factors is applied to the current land available for development to show those areas most likely to be developed next. This validation procedure is the fundamental difference between the two approaches and is the only means we have to measure the future reliability of the model in an uncertain world.

4. The NY/NJ growth analysis used centroids of developed parcels as location of the independent variable (developed land), but gridded maps of independent explanatory factors to extract those bio-geo-socio-demographic characteristics most likely explanatory of, and spatially associated with, developed parcel centroids. GEOMOD uses developed land that has been identified from satellite image classification but is equally capable of gridding developed parcel centroids (and undeveloped) and using the same calibration/validation technique to produce the likelihood of change map. We will use this traditional approach, but also test it against the parcel-based approach, using parcel data generated by the build-out analysis. Parcel coverage for two points in time is seldom available, hence we shall randomly select a subset of parcels for calibration, and an independent set for validation, rather than use the two time period validation procedure that is possible with time-series data. This dual analysis will provide a second important step in any good modeling exercise and that is sensitivity analysis. How sensitive is our projection of areas of future change to the unit of measure, *i.e.,* the individual parcel, versus a land cover/use map grid cell? Because parcelization is the process that results in eventual visible land use change it is imperative to know if we can capture this process better through a parcel-based, versus satellite-based, analysis. The use of sensitivity analysis and validation combined will allow us to answer this question.

All projections of the future are based on assumptions that past patterns will continue. We, however, prefer to at least test this before selecting the final set of variables that yield the best predictive power. Normally, we use the suitability map, along with different rate scenarios, to predict landscape pattern 10 to 20 years into the future. We are then able to measure landscape fragmentation using metrics such as patch density, edge and interior habitat, etc., are calculated. Model output can also be evaluated with respect to water quality impacts. We are currently assessing land cover/use and water quality data from 75 monitoring stations in the Catskill-Delaware region of the New York City water supply system (Hall et al in progress). Once our analysis of the relation between

the two is finalized we can connect future water quality estimates to our land use change projections. For the Highlands project we will prepare the "likelihood of impact" map for other teams to use in their impact assessment. We will, however, go one step further and prepare a dynamic simulation of change 20 years into the future. This has proved to be a powerful tool for generating discussion and concern in the communities where we have presented similar results to date.

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APPENDIX 5: FARMLAND KEY INFORMANT SURVEY

Key Informant Survey for The Connecticut and Pennsylvania Updates to the Highlands Regional Study Agricultural Lands Analysis

PURPOSE

The purpose of this survey is to determine the perceived rate of conversion of agricultural land to other uses and the perceived drivers of that conversion among land conservation professionals and farmers in the Highlands regions of Connecticut and Pennsylvania.

SURVEY DESIGN

Informants will be knowledgeable about agriculture in the Highlands region. Targeted informants will be defined by profession and location. Informants will be selected from two profession domains: land conservation / land use planning professionals with experience in or knowledge about farmland conservation; and active farmers with the majority of their household income derived from the sale of farm products. Key informants may refer interviewers to other informants who are not clearly identifiable with either group but who have special knowledge about agricultural land use change. Informants will also be selected based on geographical linkage to a location within the area of interest at the county, census sub block or zip code scale. The geographical linkage will be determined by the area of the informant's primary sphere of activity or knowledge.

PROTOCOL

The majority of the interviews will be conducted over the telephone. The interviewers may elect to interview certain persons with deeper knowledge of agricultural land use in person and in greater detail.

Survey questions in blue pertain to farmers only and may be skipped when interviewing other informants.

The interview should not take more than ten or fifteen minutes unless the person being interviewed volunteers significant additional information. All comments concerning agricultural land use and land conservation should be recorded. If anecdotal evidence supporting a particular response is offered, the interviewer should make careful note of it. The interviewer will begin by identifying himself or herself.

The interviewer will explain that the call is about a study being conducted in the Highlands Region to explore land use and conservation issues, and that the interview is specifically intended to be about the agricultural uses of land in the region, and factors affecting agriculture.

Before beginning, the interviewer will make it clear that identifying information about the informant will never be made public. The interviewer must also read the Yale Human Subjects Committee's informant consent statement. Once the interviewer has read the statement to the informant, the interviewer will ask the informant if he or she has understood and accepted.

Informant's name _____

Telephone number _____

___ Informant understood and accepted the Yale Human Subjects Committee's informant consent statement

___ Informant understood and rejected the Yale Human Subjects Committee's informant consent statement

QUESTIONS

1. Please think for a moment about the area in which you have the most knowledge of agricultural land use. In order to make comparisons from one location to another, I would like to know which area you know the most about agricultural land use. This can be one or more counties or townships, or a combination of these.

2. Do you think that the use of land for agriculture has been

    a. on the decline
    b. on the increase
    c. about the same in your area over the last ten years?

3. Do you think this change has been

    a. very gradual
    b. gradual
    c. moderate
    d. rapid
    e. very rapid in your area over the last ten years?

4. Do you expect that the use of land for agriculture will

    a. increase
    b. decrease
    c. remain about the same in your area over the next ten years?

5. Do you expect this change will be

    a. very gradual
    b. gradual
    c. moderate
    d. rapid
    e. very rapid in your area over the next ten years?

6. How concerned are you about this change?

   a. very concerned
   b. concerned
   c. slightly concerned
   d. unconcerned

If concerned, please list reasons for your concern:

7. If you are concerned, is enough being done to prevent rapid conversion of land to uses other than agriculture? *Yes* *No*

8. In cases where it may be desirable to the landowner or the community, are there sufficient government and non-profit resources available to help protect agricultural lands from conversion to other uses? *Yes* *No*

9. Which organizations do you feel have been most effective at conserving agricultural land in your area?

   a. a private local or regional land conservation organization
   b. your county agricultural conservation board
   c. a private national land conservation organization such as the American Farmland Trust
      please specify (_____)

If you think that agricultural land has been and is being converted to other uses, the following questions apply:

10. To what other use do you feel most farmland in your area is being converted?

    a. residential development
    b. commercial development
    c. industrial development
    d. forest regrowth
    e. other (please specify _____)

11. Please rate the following statements according to whether you 1) strongly agree, 2) agree, 3) have no opinion, 4) disagree, or 5) strongly disagree as to whether each item is a factor in the conversion of farmland to other uses:

    High value of land for other purposes besides agriculture
    1 2 3 4 5

Retirement of active farmers

1 2 3 4 5

Lack of interest in farming as a career among young people

1 2 3 4 5

Increasing strictness of regulations

1 2 3 4 5

Poor prices for farm products

1 2 3 4 5

A lack of markets for farm products

1 2 3 4 5

High property taxes

1 2 3 4 5

Off-farm financial needs

1 2 3 4 5

Cost of material inputs including seed, animal feed, fertilizers, agrochemicals, pharmaceuticals

1 2 3 4 5

Cost of services including veterinary, machinery or building maintenance, contract field work

1 2 3 4 5

Cost of new equipment, technology, or buildings

1 2 3 4 5

Lack of adequate financing for new agricultural enterprises

1 2 3 4 5

Are there any other important reasons you think agricultural land is being converted to other uses?

12. If you perceive that a loss of agricultural land and farmland results mostly from conversion to residential use, please rate the following statements according to whether you 1) strongly agree, 2) agree, 3) have no opinion, 4) disagree, or 5) strongly disagree as to whether each item is a factor.

Local contractors are building new housing
1 2 3 4 5

Large developers are building new housing
1 2 3 4 5

Farmers are selling individual residential lots
1 2 3 4 5

Farmers are selling entire farms for residential development
1 2 3 4 5

New residents are coming from out-of-state
1 2 3 4 5

New residents come from in-state, but are moving from urban or suburban areas to rural areas
1 2 3 4 5

13. Do you know of any new agricultural enterprises being started in your area? *Yes* *No*

14. Do you know about any land that is being converted FROM some other use, such as fallow land or forest, TO an agricultural use?
Yes *No*

15. How many acres do you currently farm? (_____)

16. How often do you get offers to sell some or all of your land?

17. Have you sold off any lots while you owned your present farm? Yes No

18. In what year(s) did you sell off your lot(s)?

19. What would encourage you to sell (more of) your land?

20. Do you know of other people who are knowledgeable about agriculture or agricultural land conservation in the Highlands region and who may be willing to talk with me about these questions (Name and telephone number)?

Do you have any additional comments about agriculture, agricultural land conversion, or land conservation in your area?

APPENDIX 6: CONNECTICUT DATA

Land use land cover LULC classifications from Landsat Satellite Images 1985, 1990, 1995, and 2001 (Source: CLEAR)

LULC Class	Description
Developed	High-density built-up areas typically associated with commercial, industrial and residential activities and transportation routes. These areas can be expected to contain a significant amount of impervious surfaces, roofs, roads, and other concrete and asphalt surfaces.
Turf & Grass	A compound category of undifferentiated maintained grasses associated mostly with developed areas. This class contains cultivated lawns typical of residential neighborhoods, parks, cemeteries, golf courses, turf farms, and other maintained grassy areas. Also includes some agricultural fields due to similar spectral reflectance properties.
Other Grasses & Agriculture	Includes non-maintained grassy areas commonly found along transportation routes and other developed areas and also agricultural fields used for both crop production and pasture.
Deciduous Forest	Includes southern New England mixed hardwood forests. Also includes scrub areas characterized by patches of dense woody vegetation. May include isolated low density residential areas.
Coniferous Forest	Includes southern New England mixed softwood forests. May include isolated low density residential areas.
Water	Open water bodies and watercourses with relatively deep water.
Non-forested Wetland	Includes areas that predominately are wet throughout most of the year and that have a detectable vegetative cover (therefore not open water). Also includes some small water courses due to spectral characteristics of mixed pixels that include both water and vegetation.
Forested Wetland	Includes areas depicted as wetland, but with forested cover. Also includes some small water courses due to spectral characteristics of mixed pixels that include both water and vegetation.
Tidal Wetland	Emergent wetlands, wet throughout most of the year, with distinctive marsh vegetation and located in areas influenced by tidal change.
Barren	Mostly non-agricultural areas free from vegetation, such as sand, sand and gravel operations, bare exposed rock, mines, and quarries. Also includes some urban areas where the composition of construction materials spectrally resembles more natural materials. Also includes some bare soil agricultural fields.
Utility Rights-of-way	Includes utility rights-of-way. This category was manually digitized on-screen from rights-of-way visible in the Landsat satellite imagery. The class was digitized within the deciduous and coniferous categories only.

User's accuracy of 1985, 1990, 1995, and 2002
LULC data and overall accuracy at 3 levels of aggregation.
Data produced and accuracy assessment conducted by James Hurd of University of Connecticut, CLEARS Program.

	% User's Accuracy				
LULC Class	1985	1990	1995	2002	Average
Developed	90.0%	92.9%	93.0%	94.8%	92.7%
Turf & Grass	71.1%	71.4%	67.7%	55.6%	66.4%
Other Grasses &	75.0%	82.4%	82.4%	68.8%	77.1%
Deciduous Forest	79.2%	87.4%	85.3%	83.7%	83.9%
Coniferous Forest	91.3%	73.9%	93.2%	75.6%	83.5%
Water	96.1%	94.2%	100.0%	98.1%	97.1%
Non-forested Wetland	96.7%	87.9%	96.9%	93.3%	93.7%
Forested Wetland	97.1%	90.0%	87.5%	91.4%	91.5%
Tidal Wetland	97.3%	94.3%	97.0%	90.0%	94.6%
Barren Land	73.5%	51.4%	67.6%	56.3%	62.2%
Utility Row	85.3%	90.6%	96.8%	90.0%	90.7%
				Average	84.9%

	% Overall Accurac				
Level of Aggregation	**1985**	**1990**	**1995**	**2002**	**Average**
11 Categories	85.5%	84.9%	87.8%	82.4%	85.2%
3 Categories	89.2%	89.8%	90.2%	86.0%	88.8%
2 Categories	92.0%	92.9%	92.3%	91.7%	92.2%

Schema for aggregation of
CLEAR land use/cover classes to assess.

CLEAR Classification	Aggregate Class
Developed	Developed
Barren	Developed
Turf & Grass	Ag/turf/grass
Utility ROW	Ag/turf/grass
Other Grasses & Agriculture	Ag/turf/grass
Coniferous Forest	Forest/Wetlands
Deciduous Forest	Forest/Wetlands
Forested Wetland	Forest/Wetlands
Non-Forested Wetland	Forest/Wetlands
Water	Water

Towns in the CT Highlands Region.

Area of developed land by town (in acres and percent coverage of town) in 1985 and 2002 and change during the intervening time period in acres and as a percent of developed land

	1985		2002		1985 - 2002	
Town	**Acres**	**% of Town**	**Acres**	**% of Town**	**Acreage Change**	**Change as % of 1985 Developed Land**
Barkhamsted	1,595	6.4%	1,769	7.1%	174	10.9%
Brookfield	2,736	21.0%	3,262	25.1%	526	19.2%
Burlington	1,601	8.2%	2,076	10.7%	475	29.7%
Canaan	941	4.4%	993	4.7%	52	5.5%
Canton	1,642	10.3%	2,005	12.5%	362	22.1%
Colebrook	997	4.7%	1,069	5.1%	72	7.3%
Cornwall	1,566	5.3%	1,641	5.5%	75	4.8%
Danbury	7,977	28.4%	9,191	32.7%	1,213	15.2%
Goshen	1,570	5.4%	1,672	5.8%	103	6.5%
Granby	1,938	7.4%	2,446	9.3%	508	26.2%
Hartland	1,167	5.3%	1,241	5.7%	73	6.3%
Harwinton	1,502	7.6%	1,744	8.8%	242	16.1%
Kent	1,604	5.0%	1,759	5.5%	154	9.6%
Litchfield	3,177	8.7%	3,422	9.4%	244	7.7%
Morris	948	7.9%	992	8.3%	44	4.7%
New Fairfield	1,986	12.3%	2,279	14.2%	294	14.8%
New Hartford	1,906	7.8%	2,211	9.1%	304	16.0%
New Milford	4,730	11.6%	5,500	13.5%	770	16.3%
Norfolk	1,471	5.0%	1,540	5.2%	69	4.7%
North Canaan	1,093	8.8%	1,215	9.7%	122	11.1%
Salisbury	2,689	7.0%	2,794	7.3%	105	3.9%
Sharon	2,185	5.7%	2,275	6.0%	91	4.2%
Sherman	1,151	7.7%	1,336	8.9%	185	16.0%
Simsbury	3,761	17.1%	4,252	19.4%	490	13.0%
Torrington	5,002	19.4%	5,832	22.6%	830	16.6%
Warren	956	5.4%	1,009	5.7%	52	5.5%
Washington	1,990	8.1%	2,105	8.5%	115	5.8%
Winchester	2,315	10.7%	2,581	11.9%	265	11.5%
Total	62,198		70,210		8,012	12.9%

Area of forest by town (in acres and percent coverage of town) in 1985 and 2002 and change during the intervening time period in acres and as a percent of forested land in 1985.

	1985		2002		1985 - 2002	
Town	**Acres**	**% of Town**	**Acres**	**% of Town**	**Acreage Change**	**Change as % of 1985 Forest**
Barkhamsted	19,528	78.8%	19,233	77.6%	-295	-1.5%
Brookfield	7,164	55.0%	6,592	50.6%	-572	-8.0%
Burlington	14,922	76.6%	14,270	73.3%	-652	-4.4%
Canaan	15,344	72.3%	15,272	72.0%	-72	-0.5%
Canton	12,210	76.3%	11,791	73.7%	-419	-3.4%
Colebrook	17,140	81.4%	16,924	80.4%	-215	-1.3%
Cornwall	24,230	81.5%	23,984	80.7%	-246	-1.0%
Danbury	12,990	46.3%	12,063	43.0%	-927	-7.1%
Goshen	19,845	68.6%	19,668	68.0%	-177	-0.9%
Granby	19,347	73.6%	18,746	71.3%	-601	-3.1%
Hartland	18,603	84.8%	18,376	83.7%	-227	-1.2%
Harwinton	14,879	74.8%	14,511	73.0%	-368	-2.5%
Kent	24,407	76.7%	24,161	76.0%	-246	-1.0%
Litchfield	23,531	64.6%	23,134	63.5%	-397	-1.7%
Morris	6,571	55.1%	6,446	54.0%	-125	-1.9%
New Fairfield	9,225	57.3%	8,851	55.0%	-374	-4.1%
New Hartford	18,250	74.9%	17,803	73.1%	-447	-2.5%
New Milford	24,662	60.3%	23,647	57.9%	-1015	-4.1%
Norfolk	24,026	81.0%	23,802	80.2%	-225	-0.9%
North Canaan	6,861	54.9%	6,524	52.2%	-337	-4.9%
Salisbury	24,381	63.3%	24,182	62.8%	-200	-0.8%
Sharon	25,930	67.9%	25,702	67.3%	-228	-0.9%
Sherman	10,338	69.1%	10,108	67.5%	-231	-2.2%
Simsbury	12,083	55.1%	11,564	52.7%	-519	-4.3%
Torrington	15,989	62.0%	15,087	58.5%	-901	-5.6%
Warren	13,400	76.2%	13,248	75.3%	-152	-1.1%
Washington	16,376	66.3%	16,081	65.1%	-295	-1.8%
Winchester	15,742	72.6%	15,396	71.0%	-346	-2.2%
Total	467,971		457,163		-10,808	-2.3%

Area of all grasses and agriculture (turf&grass and other grasses and agriculture classes combined) by town (in acres and percent coverage of town) in 1985 and 2002 and change during the intervening time period in acres and as a percent of all grasses and agriculture in 1985.

	1985		2002		1985 - 2002	
Town	**Acres**	**% of Town**	**Acres**	**% of Town**	**Acreage Change**	**Change as % of 1985 Ag and Grass lands**
Barkhamsted	1,028	4.1%	1,069	4.3%	41	4.0%
Brookfield	2,112	16.2%	2,149	16.5%	37	1.7%
Burlington	1,615	8.3%	1,725	8.9%	111	6.9%
Canaan	2,465	11.6%	2,508	11.8%	43	1.8%
Canton	1,409	8.8%	1,461	9.1%	52	3.7%
Colebrook	977	4.6%	1,079	5.1%	102	10.5%
Cornwall	2,536	8.5%	2,753	9.3%	217	8.6%
Danbury	4,023	14.3%	3,906	13.9%	-117	-2.9%
Goshen	4,260	14.7%	4,374	15.1%	115	2.7%
Granby	3,941	15.0%	4,004	15.2%	62	1.6%
Hartland	522	2.4%	585	2.7%	63	12.1%
Harwinton	2,322	11.7%	2,426	12.2%	104	4.5%
Kent	3,905	12.3%	3,938	12.4%	33	0.8%
Litchfield	6,873	18.9%	7,021	19.3%	148	2.2%
Morris	2,810	23.5%	2,883	24.2%	73	2.6%
New Fairfield	1,374	8.5%	1,410	8.8%	36	2.6%
New Hartford	2,593	10.6%	2,660	10.9%	66	2.5%
New Milford	8,366	20.5%	8,347	20.4%	-19	-0.2%
Norfolk	1,812	6.1%	2,011	6.8%	199	11.0%
North Canaan	3,651	29.2%	3,685	29.5%	34	0.9%
Salisbury	8,167	21.2%	8,259	21.4%	92	1.1%
Sharon	7,861	20.6%	8,028	21.0%	166	2.1%
Sherman	1,968	13.2%	1,997	13.3%	29	1.5%
Simsbury	4,489	20.5%	4,642	21.2%	153	3.4%
Torrington	3,180	12.3%	3,186	12.4%	6	0.2%
Warren	1,629	9.3%	1,705	9.7%	76	4.7%
Washington	5,141	20.8%	5,298	21.4%	157	3.0%
Winchester	1,604	7.4%	1,674	7.7%	70	4.4%
Total	92,635		94,785		2,149	2.3%

Connecticut water and wetlands (forested and non-forested) by town in 1985 and 2002.

	Water						Non-forested Wetland						Forested Wetland					
	1985		2002		Change (1985-2002)		1985		2002		Change (1985-2002)		1985		2002		Change (1985-2002)	
	Acres	% of Town	Acres	% of Town	Acres	% from 1985	Acres	% of Town	Acres	% of Town	Acres	% from 1985	Acres	% of Town	Acres	% of Town	Acres	% from 1985
Barkhamsted	1,628	6.6%	1,815	7.3%	187	11.5%	55	0.2%	80	0.3%	25	45.2%	722	2.9%	662	2.7%	-60	-8.3%
Brookfield	496	3.8%	499	3.8%	3	0.6%	14	0.1%	45	0.3%	32	235.6%	267	2.0%	202	1.6%	-64	-24.1%
Burlington	567	2.9%	535	2.7%	-32	-5.6%	35	0.2%	132	0.7%	97	280.8%	482	2.5%	415	2.1%	-66	-13.8%
Canaan	409	1.9%	334	1.6%	-75	-18.4%	117	0.6%	208	1.0%	91	77.3%	1,823	8.6%	1,764	8.3%	-60	-3.3%
Canton	302	1.9%	309	1.9%	7	2.4%	6	0.0%	18	0.1%	12	196.2%	365	2.3%	322	2.0%	-43	-11.8%
Colebrook	860	4.1%	724	3.4%	-135	-15.7%	67	0.3%	143	0.7%	76	111.9%	716	3.4%	678	3.2%	-38	-5.3%
Cornwall	413	1.4%	360	1.2%	-53	-12.7%	34	0.1%	122	0.4%	88	258.8%	904	3.0%	790	2.7%	-114	-12.6%
Danbury	1,716	6.1%	1,622	5.8%	-93	-5.4%	47	0.2%	142	0.5%	95	201.0%	961	3.4%	884	3.1%	-77	-8.0%
Goshen	1,347	4.7%	1,179	4.1%	-168	-12.5%	83	0.3%	304	1.1%	221	266.0%	1,761	6.1%	1,630	5.6%	-130	-7.4%
Granby	133	0.5%	108	0.4%	-25	-18.7%	46	0.2%	76	0.3%	30	65.3%	695	2.6%	594	2.3%	-101	-14.5%
Hartland	875	4.0%	1,051	4.8%	175	20.0%	81	0.4%	67	0.3%	-14	-17.0%	540	2.5%	508	2.3%	-32	-5.9%
Harwinton	323	1.6%	286	1.4%	-37	-11.4%	32	0.2%	76	0.4%	45	139.6%	693	3.5%	641	3.2%	-52	-7.5%
Kent	1,010	3.2%	857	2.7%	-153	-15.2%	50	0.2%	189	0.6%	139	276.7%	803	2.5%	779	2.4%	-24	-3.0%
Litchfield	788	2.2%	676	1.9%	-112	-14.2%	67	0.2%	253	0.7%	186	276.1%	1,763	4.8%	1,647	4.5%	-116	-6.6%
Morris	1,080	9.0%	1,017	8.5%	-63	-5.8%	6	0.1%	54	0.5%	48	742.9%	489	4.1%	466	3.9%	-22	-4.5%
New Fairfield	3,140	19.5%	3,160	19.6%	20	0.6%	4	0.0%	9	0.1%	5	123.5%	337	2.1%	320	2.0%	-17	-5.0%
New Hartford	819	3.4%	888	3.6%	69	8.5%	91	0.4%	116	0.5%	25	27.2%	527	2.2%	461	1.9%	-66	-12.5%
New Milford	1,826	4.5%	1,696	4.1%	-130	-7.1%	21	0.1%	148	0.4%	127	608.8%	655	1.6%	615	1.5%	-41	-6.2%
Norfolk	1,077	3.6%	841	2.8%	-236	-21.9%	50	0.2%	272	0.9%	222	442.0%	1,229	4.1%	1,185	4.0%	-43	-3.5%
North Canaan	84	0.7%	73	0.6%	-11	-13.0%	7	0.1%	11	0.1%	4	56.3%	332	2.7%	300	2.4%	-32	-9.7%
Salisbury	2,250	5.8%	2,196	5.7%	-53	-2.4%	84	0.2%	171	0.4%	86	102.2%	849	2.2%	781	2.0%	-68	-8.0%
Sharon	1,068	2.8%	799	2.1%	-269	-25.2%	90	0.2%	377	1.0%	287	319.4%	1,064	2.8%	1,006	2.6%	-58	-5.5%
Sherman	1,129	7.5%	1,146	7.7%	16	1.4%	6	0.0%	8	0.1%	2	37.5%	359	2.4%	343	2.3%	-16	-4.3%
Simsbury	378	1.7%	279	1.3%	-99	-26.2%	34	0.2%	95	0.4%	61	182.2%	1,034	4.7%	907	4.1%	-127	-12.3%
Torrington	590	2.3%	399	1.5%	-191	-32.3%	49	0.2%	235	0.9%	186	376.7%	762	3.0%	691	2.7%	-71	-9.3%
Warren	944	5.4%	828	4.7%	-117	-12.4%	30	0.2%	164	0.9%	134	450.0%	627	3.6%	588	3.3%	-39	-6.2%
Washington	576	2.3%	558	2.3%	-18	-3.1%	5	0.0%	37	0.2%	33	676.2%	499	2.0%	460	1.9%	-39	-7.8%
Winchester	1,250	5.8%	1,159	5.3%	-91	-7.3%	22	0.1%	115	0.5%	94	434.0%	622	2.9%	588	2.7%	-34	-5.4%

[CT]. Regional-level impact metric values for years 1985 and 2002 using historic data and in 2022 using 9 development projection scenarios.

			Low Dev. Rate			Medium Dev. Rate			High Dev. Rate		
			BAU	Low	High	BAU	Low	High	BAU	Low	High
Indicator	1985	2002	2022	2022	2022	2022	2022	2022	2022	2022	2022
Perimeter:Area Ratio (ft/acres)	120.88	131.83	130.97	131.35	131.41	130.38	131.39	131.75	129.10	131.57	132.73
Interior Forest %	46.89	43.12	42.98	42.93	42.91	42.72	42.60	42.54	42.25	41.99	41.83
Largest Forest Patch %	3.34	3.31	3.31	3.31	3.31	3.01	3.00	3.30	3.00	3.00	3.30
Impervious Surface %	7.48	7.83	8.00	8.00	8.00	8.22	8.22	8.22	8.62	8.62	8.62
Altered Land %	24.49	26.23	26.64	26.64	26.61	27.20	27.20	27.14	28.24	28.25	28.15
Developed Prime Farmland %	14.84	16.29	17.21	17.32	17.40	18.36	18.50	18.72	20.50	20.70	21.09
Altered Riparian Area % (295 ft)	27.34	28.62	29.32	28.92	28.88	30.12	29.25	29.16	31.53	29.88	29.67
Altered Riparian Area % (100 ft)	25.98	27.08	27.80	27.24	27.15	28.62	27.43	27.21	30.06	27.81	27.33

[CT] Acreage and percent composition by forest type for 1985, 2002, and 3 projection scenarios using medium development rate but differing constraint-level.

					Constraints					
					BAU		Low		High	
	1985		2002		2022		2022		2022	
Forest Type	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres
Core	46.66	221318.90	42.62	197015.4	42.23	192762.73	42.10	192191.62	41.97	191741.3
Patch	2.44	11557.42	2.72	12560.64	2.62	11963.29	2.69	12286.43	2.70	12314.22
Transition	6.04	28627.33	6.63	30643.12	6.73	30714.06	6.79	31002.51	6.85	31298.74
Edge	24.94	118299.60	24.91	115131.6	27.08	123609.94	27.13	123839.90	27.14	123997.1
Perforated	19.93	94521.81	23.12	106890.5	21.29	97196.78	21.23	96927.46	21.29	97247.48

Table IMPa-3.[CT] Town most and least impacted in 1985.

Town	Perimeter:Area Ratio (ft/acres)	Interior Forest %	Largest Forest Patch %	Impervious Surface %	Altered Land %	Developed Prime Farmland %	Altered Riparian Area % (295 ft)	Altered Riparian Area % (100 ft)
Least Impact	Colebrook 75.25	Hartland 65.69	New Fairfield 52.95	Canaan 6.04	Hartland 8.77	Goshen 10.88	Goshen 12.78	Goshen 11.36
Most Impact	Brookfield 263.44	Danbury 19.80	Brookfield 4.67	Danbury 13.39	Danbury 46.89	New Fairfield 24.73	North Canaan 52.96	North Canaan 54.19

[CT]. Town most and least impacted in 2002.

Town	Perimeter:Area Ratio (ft/acres)	Interior Forest %	Largest Forest Patch %	Impervious Surface %	Altered Land %	Developed Prime Farmland %	Altered Riparian Area % (295 ft)	Altered Riparian Area % (100 ft)
Least Impact	Colebrook 81.27	Hartland 63.19	New Fairfield 47.90	Canaan 6.11	Hartland 9.31	Goshen 11.26	Goshen 13.69	Goshen 12.28
Most Impact	Brookfield 311.95	Brookfield 13.24	Brookfield 3.70	Danbury 14.66	Danbury 50.51	Danbury 29.77	North Canaan 54.62	North Canaan 56.00

Table IMPa-5.[CT]. Town-level impact metric values for year 1985.

	1985							
Town	Perimeter:Area Ratio (ft/acres)	Interior Forest %	Largest Forest Patch %	Impervious Surface %	Altered Land %	Developed Prime Farmland %	Altered Riparian Area % (295 ft)	Altered Riparian Area % (100 ft)
Salisbury	119.42	45.06	26.49	6.87	30.19	12.38	30.04	30.12
North Canaan	154.90	33.78	16.66	7.27	41.97	12.19	52.96	54.19
Norfolk	79.02	64.35	21.93	6.22	11.49	12.67	14.49	13.49
Colebrook	75.25	65.43	19.99	6.16	11.22	15.93	20.12	19.69
Hartland	77.02	65.69	20.38	6.33	8.77	12.58	15.55	15.94

Granby	121.33	48.93	24.35	6.87	23.20	13.65	26.24	26.37
Canaan	81.44	61.02	32.71	6.04	16.91	11.50	27.59	28.14
Barkhamsted	92.62	60.67	16.26	6.72	12.29	16.85	26.12	24.95
Winchester	121.88	50.69	21.99	7.99	19.77	23.91	24.62	21.72
Sharon	94.87	50.26	27.88	6.43	27.09	11.51	32.36	30.62
Canton	132.23	48.03	9.66	7.74	19.86	18.64	32.82	33.10
Simsbury	253.43	21.48	10.57	9.73	39.01	18.68	34.63	33.46
Cornwall	77.34	63.18	41.16	6.28	14.10	13.10	21.82	22.18
Goshen	103.52	51.94	19.36	6.37	21.38	10.88	12.78	11.36
New Hartford	123.04	48.56	18.18	7.06	19.86	13.72	27.21	27.80
Torrington	165.70	35.69	5.68	10.42	33.35	23.68	35.75	29.92
Burlington	114.61	51.11	30.53	7.17	18.36	13.99	18.66	17.10
Harwinton	123.76	47.83	26.54	6.94	20.25	12.61	18.65	16.86
Litchfield	148.93	38.46	10.00	7.30	28.83	14.17	18.79	16.88
Kent	85.35	59.18	23.47	6.24	17.98	12.77	26.98	27.73
Warren	86.73	59.57	20.34	6.39	15.59	14.09	24.12	18.32
Morris	174.77	32.04	8.22	7.25	34.91	11.92	27.07	23.32
Washington	150.14	36.87	6.86	7.10	30.04	11.46	29.15	25.94
New Milford	180.43	32.71	5.51	8.21	35.10	15.90	40.35	39.32
Sherman	142.59	43.29	24.89	7.13	22.65	11.89	24.59	22.59
New Fairfield	161.19	41.06	52.95	9.12	26.21	24.73	23.11	20.37
Brookfield	263.44	19.81	4.67	10.99	40.54	20.80	31.05	27.59
Danbury	263.31	19.80	17.36	13.39	46.89	24.60	45.30	39.06
Average	134.58	46.30	20.16	7.56	24.56	15.39	27.25	25.65
Minimum	75.25	19.80	4.67	6.04	8.77	10.88	12.78	11.36
Maximum	263.44	65.69	52.95	13.39	46.89	24.73	52.96	54.19

[CT] Town-level impact metric values for year 2002.

	2002							
Town	Perimeter:Area Ratio (ft/acres)	Interior Forest %	Largest Forest Patch %	Impervious Surface %	Altered Land %	Developed Prime Farmland %	Altered Riparian Area % (295 ft)	Altered Riparian Area % (100 ft)
Salisbury	123.14	43.61	26.36	6.95	30.79	12.72	30.45	30.57
North Canaan	162.13	30.89	16.17	7.54	44.96	13.18	54.62	56.00
Norfolk	85.00	60.96	21.56	6.28	12.37	13.48	15.09	14.15
Colebrook	81.27	62.27	19.77	6.25	12.68	17.10	23.47	23.62
Hartland	82.37	63.19	24.23	6.45	9.31	13.94	14.68	14.01
Granby	136.56	43.83	23.68	7.42	25.84	16.04	27.38	27.41
Canaan	83.31	59.62	32.39	6.11	17.40	12.05	27.91	28.40
Barkhamsted	99.78	57.93	15.61	6.95	13.01	18.14	24.95	22.27
Winchester	129.42	47.33	21.64	8.34	21.52	25.50	26.83	23.70
Sharon	101.69	47.51	27.26	6.49	27.61	11.93	31.64	29.53
Canton	152.12	41.40	9.14	8.40	22.70	21.37	35.12	35.01
Simsbury	274.26	18.19	10.29	10.35	41.98	20.59	36.84	35.21
Cornwall	84.69	59.68	40.55	6.35	15.18	13.79	23.12	23.57
Goshen	110.73	48.83	18.92	6.47	22.16	11.26	13.69	12.28
New Hartford	137.33	43.79	17.85	7.44	21.71	15.28	28.84	28.97
Torrington	187.65	30.12	5.58	11.31	36.95	26.92	38.07	32.61
Burlington	139.94	43.25	29.08	7.88	21.78	15.77	20.13	18.37
Harwinton	138.93	42.70	25.53	7.29	22.31	14.05	21.16	19.10
Litchfield	157.70	35.56	9.90	7.49	29.97	14.80	19.84	17.79
Kent	93.52	55.26	22.87	6.37	18.81	13.33	27.05	27.40
Warren	95.07	55.28	19.72	6.47	16.51	14.61	25.39	19.25
Morris	180.83	30.01	7.42	7.35	36.20	12.32	28.67	24.56
Washington	161.20	33.29	6.56	7.24	31.34	11.99	30.49	26.98
New Milford	200.18	28.18	5.40	8.76	37.69	18.19	41.97	40.75

Sherman	157.41	39.09	21.23	7.51	24.33	13.77	25.36	23.04
New Fairfield	188.93	34.21	47.90	9.78	29.08	27.22	25.57	22.54
Brookfield	311.95	13.24	3.70	12.19	45.37	24.47	34.08	30.77
Danbury	283.16	16.94	15.60	14.66	50.51	29.77	48.23	41.76
Average	147.87	42.36	19.50	7.93	26.43	16.91	28.59	26.77
Minimum	81.27	13.24	3.70	6.11	9.31	11.26	13.69	12.28
Maximum	311.95	63.19	47.90	14.66	50.51	29.77	54.62	56.00

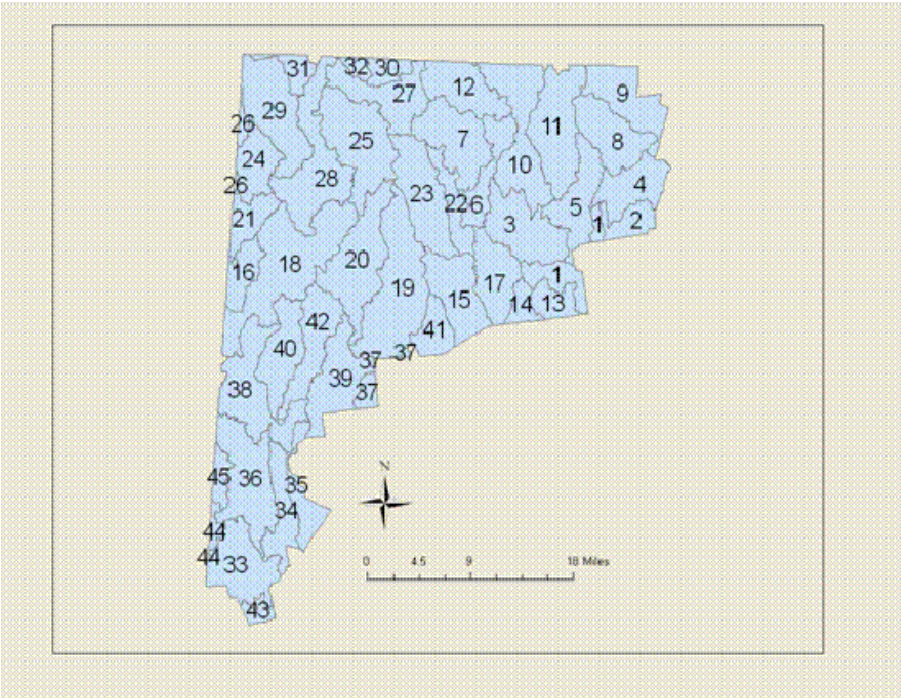
Town-level impact metric values measured after projecting development to year 2022 using medium development rate and "business as usual" development constraints..

	"Business As Usual" Constraints							
Town	Perimeter:Area Ratio (ft/acres)	Interior Forest %	Largest Forest Patch %	Impervious Surface %	Altered Land %	Developed Prime Farmland %	Altered Riparian Area % (295 ft)	Altered Riparian Area % (100 ft)
Salisbury	122.09	43.58	26.32	7.03	31.02	13.22	30.99	31.12
North Canaan	158.67	30.79	16.13	7.87	45.60	14.81	56.46	57.97
Norfolk	84.36	60.90	21.56	6.36	12.61	14.73	15.62	14.41
Colebrook	81.18	62.09	19.64	6.36	13.03	19.98	24.21	24.31
Hartland	82.40	63.05	24.23	6.55	9.65	15.47	14.81	14.15
Granby	137.19	42.77	23.09	8.02	27.71	19.73	29.18	29.47
Canaan	82.19	59.60	32.39	6.18	17.62	12.77	28.06	28.57
Barkhamsted	99.19	57.57	15.37	7.18	13.77	20.26	26.61	23.66
Winchester	133.51	45.97	21.63	8.76	22.84	25.86	27.94	24.99
Sharon	100.89	47.51	27.26	6.56	27.74	12.69	31.72	29.58
Canton	147.92	40.95	9.14	9.12	24.55	26.91	38.37	38.99

Simsbury	272.18	17.83	10.29	11.03	43.93	23.36	38.60	36.45
Cornwall	84.00	59.62	40.47	6.41	15.37	14.29	23.85	24.16
Goshen	110.51	48.74	18.91	6.58	22.53	11.57	14.23	12.86
New Hartford	136.93	43.21	17.60	7.83	22.87	17.20	31.46	31.80
Torrington	180.10	29.52	5.58	12.39	39.61	31.39	42.75	37.64
Burlington	146.98	41.20	28.91	8.67	24.38	18.13	20.90	18.92
Harwinton	142.33	41.52	25.53	7.68	23.49	15.76	22.33	20.39
Litchfield	155.51	35.46	9.88	7.70	30.50	15.90	20.67	18.59
Kent	92.76	55.20	22.79	6.52	19.00	14.91	27.20	27.59
Warren	94.93	55.14	19.72	6.57	16.83	15.73	26.21	19.89
Morris	180.17	29.85	7.42	7.48	36.49	12.74	29.16	24.94
Washington	160.93	33.04	6.51	7.39	31.77	12.55	31.84	28.09
New Milford	194.82	28.06	5.40	9.42	38.71	21.99	44.16	43.30
Sherman	155.52	38.77	21.23	7.94	25.41	16.43	27.18	24.58
New Fairfield	195.01	32.41	47.54	10.56	30.93	32.71	26.87	23.45
Brookfield	310.69	12.32	3.70	13.59	48.41	28.36	41.50	40.36
Danbury	275.11	16.22	15.29	16.15	53.60	35.76	53.01	46.87
Average	147.07	41.89	19.41	8.35	27.50	19.11	30.21	28.47
Minimum	81.18	12.32	3.70	6.18	9.65	11.57	14.23	12.86
Maximum	310.69	63.05	47.54	16.15	53.60	35.76	56.46	57.97

[CT] Towns least and most impacted after projecting development to year 2022 using medium development rate and "business as usual" development constraints.

	"Business As Usual" Constraints							
Town	Perimeter:Area Ratio (ft/acres)	Interior Forest %	Largest Forest Patch %	Impervious Surface %	Altered Land %	Developed Prime Farmland %	Altered Riparian Area % (295 ft)	Altered Riparian Area % (100 ft)
Least Impact	Colebrook 81.18	Hartland 63.05	New Fairfield 47.54	Canaan 6.18	Hartland 9.65	Goshen 11.57	Goshen 14.23	Goshen 12.86
Most Impact	Brookfield 310.69	Brookfield 12.32	Brookfield 3.70	Danbury 16.15	Danbury 53.60	Danbury 35.76	North Canaan 56.46	North Canaan 57.97



HUC 12 watersheds intersecting the CT Highlands Region. Names for each numeric code in the map are in the following table.

Code	HUC 12 Watershed	Code	HUC 12 Watershed
1	Farmington River-Burlington Brook to Thompson Brook	24	Mudge Pond Brook
2	Farmington River-Thompson Brook to Hop Brook	25	Hollenbeck River
3	Nepaug River	26	Webatuck Creek-headwaters to Wassaic Creek
4	Farmington River-Hop Brook to mouth	27	Blackberry River
5	Farmington River-headwaters to Burlington Brook	28	Housatonic mainstem-Konkapot River to Furnace Brook
6	Still River mainstem	29	Salmon Creek
7	Mad River	30	Whiting River
8	West Branch Salmon Brook	31	Hubbard Brook
9	Salmon Brook	32	Konkapot River
10	West Branch Farmington River-Clam River to mouth	33	Still River-headwaters to Limekiln Brook
11	East Branch Farmington mainstem	34	Still River-Limekiln Brook to mouth
12	Sandy Brook	35	Housatonic mainstem-Still River to Pootatuck River
13	Mine Brook	36	Candlewood Lake
14	Pequabuck River	37	Weekeepeemee River
15	Naugatuck mainstem-East Branch to Hancock Brook	38	Housatonic mainstem-Tenmile River to Still River
16	Macedonia Brook	39	Shepaug River-Bantam River to mouth
17	Leadmine Brook	40	West Aspetuck River
18	Housatonic mainstem-Furnace Brook to Tenmile River	41	Branch Brook
19	Bantam River	42	East Aspetuck River
20	Shepaug River-headwaters to Bantam River	43	Saugatuck River-headwaters to Aspetuck River
21	Webatuck Creek	44	East Branch Croton River-headwaters to Haviland Hollow Brook
22	East Branch Naugatuck River	45	Haviland Hollow Brook
23	West Branch Naugatuck River		

Area of developed land by HUC 12 watersheds (in acres and percent coverage of town) in 1985 and 2002 and change during the intervening time period in acres and as a percent of developed land in 1985.

	1985		2002		1985 - 2002	
Watershed	**Acres**	**% of Watershed**	**Acres**	**% of Watershed**	**Acreage Change**	**Change as % of 1985 Developed Land**
Bantam River	2,912	8.3%	3,137	9.0%	225	7.7%
Blackberry River	1,350	7.8%	1,492	8.7%	142	10.5%
Branch Brook	626	7.7%	663	8.1%	37	5.9%
Candlewood Lake	3,287	13.2%	3,626	14.5%	339	10.3%
East Aspetuck River	1,578	9.8%	1,718	10.6%	140	8.9%
East Branch Croton River-headwaters to Haviland Hollow Brook	489	21.1%	540	23.3%	51	10.4%
East Branch Farmington mainstem	1,227	5.0%	1,282	5.3%	55	4.5%
East Branch Naugatuck River	1,863	20.6%	2,012	22.2%	149	8.0%
Farmington River-Burlington Brook to Thompson Brook	1,095	11.1%	1,410	14.3%	315	28.8%
Farmington River-headwaters to Burlington Brook	1,526	9.5%	1,847	11.5%	322	21.1%
Farmington River-Hop Brook to mouth	2,384	16.7%	2,699	18.9%	315	13.2%
Farmington River-Thompson Brook to Hop Brook	1,362	19.6%	1,562	22.5%	200	14.7%
Haviland Hollow Brook	236	5.8%	270	6.6%	34	14.3%
Hollenbeck River	928	3.4%	973	3.5%	45	4.9%
Housatonic mainstem-Furnace Brook to Tenmile River	1,989	5.1%	2,140	5.5%	151	7.6%
Housatonic mainstem-Konkapot River to Furnace Brook	1,733	6.4%	1,797	6.6%	63	3.7%
Housatonic mainstem-Still River to Pootatuck River	1,213	13.7%	1,538	17.4%	325	26.8%
Housatonic mainstem-Tenmile River to Still River	2,409	9.7%	2,860	11.5%	451	18.7%
Hubbard Brook	464	8.9%	482	9.2%	18	3.9%
Konkapot River	122	5.1%	138	5.8%	15	12.6%
Leadmine Brook	1,475	9.8%	1,757	11.7%	282	19.1%
Macedonia Brook	371	4.5%	384	4.7%	13	3.6%
Mad River	1,702	8.4%	1,795	8.8%	93	5.4%
Mine Brook	459	6.8%	626	9.4%	168	36.5%
Mudge Pond Brook	995	8.5%	1,048	9.0%	53	5.3%
Naugatuck mainstem-East Branch to Hancock Brook	2,180	12.2%	2,411	13.5%	231	10.6%
Nepaug River	1,397	6.8%	1,687	8.2%	290	20.7%
Pequabuck River	134	3.1%	176	4.0%	42	31.2%
Salmon Brook	1,447	8.6%	1,800	10.7%	352	24.3%
Salmon Creek	1,545	6.4%	1,606	6.7%	61	4.0%
Sandy Brook	906	5.6%	961	6.0%	55	6.0%
Saugatuck River-headwaters to Aspetuck River	197	6.9%	222	7.8%	25	12.6%
Shepaug River-Bantam River to mouth	1,502	7.9%	1,658	8.8%	156	10.4%
Shepaug River-headwaters to Bantam River	1,537	5.9%	1,618	6.2%	81	5.3%
Still River mainstem	1,576	13.8%	2,042	17.8%	466	29.6%
Still River-headwaters to Limekiln Brook	6,196	32.0%	7,035	36.3%	839	13.5%
Still River-Limekiln Brook to mouth	3,132	25.8%	3,845	31.7%	713	22.8%
Webatuck Creek	431	5.0%	447	5.2%	16	3.6%
Webatuck Creek-headwaters to Wassaic Creek	143	7.1%	153	7.5%	10	7.1%
Weekeepeemee River	217	5.9%	225	6.1%	8	3.8%
West Aspetuck River	1,079	6.6%	1,183	7.3%	104	9.7%
West Branch Farmington River-Clam River to mouth	1,672	6.5%	1,894	7.4%	222	13.3%
West Branch Naugatuck River	1,716	7.9%	1,837	8.4%	121	7.1%
West Branch Salmon Brook	1,068	6.3%	1,272	7.5%	205	19.2%
Whiting River	272	5.7%	283	5.9%	11	4.1%
Total	62,142		70,153		8,011	12.9%

Area of all grasses and agriculture (turf grass and other grasses and agriculture classes combined) by HUC 12 watersheds (in acres and percent coverage of town) in 1985 and 2002 and change during the intervening time period in acres and as a percent of grasses/agriculture in 1985.

	1985		2002		1985 - 2002	
Watershed	**Acres**	**% of Watershed**	**Acres**	**% of Watershed**	**Acreage Change**	**Change as % of 1985 Grasses/Agriculture**
Bantam River	7,174	20.5%	7,348	21.0%	174	2.4%
Blackberry River	2,417	14.0%	2,519	14.6%	102	4.2%
Branch Brook	2,264	27.7%	2,301	28.1%	38	1.7%
Candlewood Lake	1,541	6.2%	1,588	6.4%	47	3.1%
East Aspetuck River	3,116	19.3%	3,176	19.6%	60	1.9%
East Branch Croton River-headwaters to Haviland Hollow Brook	353	15.2%	358	15.4%	5	1.4%
East Branch Farmington mainstem	472	1.9%	508	2.1%	36	7.5%
East Branch Naugatuck River	947	10.5%	965	10.7%	18	1.9%
Farmington River-Burlington Brook to Thompson Brook	912	9.2%	973	9.8%	60	6.6%
Farmington River-headwaters to Burlington Brook	1,417	8.8%	1,484	9.3%	67	4.7%
Farmington River-Hop Brook to mouth	3,011	21.1%	3,148	22.1%	137	4.6%
Farmington River-Thompson Brook to Hop Brook	1,330	19.1%	1,341	19.3%	11	0.8%
Haviland Hollow Brook	331	8.1%	340	8.3%	9	2.7%
Hollenbeck River	2,530	9.2%	2,571	9.4%	41	1.6%
Housatonic mainstem-Furnace Brook to Tenmile River	3,978	10.2%	4,233	10.8%	255	6.4%
Housatonic mainstem-Konkapot River to Furnace Brook	3,149	11.6%	3,224	11.9%	75	2.4%
Housatonic mainstem-Still River to Pootatuck River	1,692	19.2%	1,743	19.7%	51	3.0%
Housatonic mainstem-Tenmile River to Still River	4,747	19.2%	4,722	19.1%	-25	-0.5%
Hubbard Brook	840	16.1%	854	16.4%	14	1.7%
Konkapot River	833	34.9%	857	35.9%	24	2.9%
Leadmine Brook	2,428	16.1%	2,494	16.6%	66	2.7%
Macedonia Brook	582	7.1%	609	7.4%	28	4.7%
Mad River	1,050	5.2%	1,156	5.7%	106	10.1%
Mine Brook	518	7.7%	555	8.3%	38	7.3%
Mudge Pond Brook	4,692	40.1%	4,734	40.5%	42	0.9%
Naugatuck mainstem-East Branch to Hancock Brook	2,425	13.5%	2,460	13.7%	35	1.4%
Nepaug River	2,222	10.9%	2,267	11.1%	45	2.0%
Pequabuck River	240	5.5%	253	5.8%	12	5.2%
Salmon Brook	2,823	16.7%	2,871	17.0%	48	1.7%
Salmon Creek	4,392	18.3%	4,433	18.5%	41	0.9%
Sandy Brook	896	5.6%	973	6.1%	77	8.6%
Saugatuck River-headwaters to Aspetuck River	178	6.2%	187	6.5%	8	4.6%
Shepaug River-Bantam River to mouth	4,880	25.8%	4,984	26.3%	104	2.1%
Shepaug River-headwaters to Bantam River	2,743	10.5%	2,865	11.0%	122	4.4%
Still River mainstem	1,002	8.7%	1,013	8.8%	11	1.1%
Still River-headwaters to Limekiln Brook	3,205	16.5%	3,112	16.1%	-93	-2.9%
Still River-Limekiln Brook to mouth	2,411	19.9%	2,347	19.4%	-64	-2.6%
Webatuck Creek	2,668	30.8%	2,679	30.9%	11	0.4%
Webatuck Creek-headwaters to Wassaic Creek	739	36.5%	744	36.7%	4	0.6%
Weekeepeemee River	778	21.2%	801	21.8%	22	2.9%
West Aspetuck River	2,532	15.5%	2,595	15.9%	63	2.5%
West Branch Farmington River-Clam River to mouth	1,003	3.9%	1,079	4.2%	76	7.6%
West Branch Naugatuck River	1,938	8.9%	2,011	9.3%	73	3.8%
West Branch Salmon Brook	1,636	9.6%	1,672	9.8%	36	2.2%
Whiting River	1,222	25.6%	1,246	26.1%	24	2.0%
Total	92,256		94,390		2,134	2.3%

Area of forest by HUC 12 watersheds (in acres and percent coverage of town) in 1985 and 2002 and change during the intervening time period in acres and as a percent of forest in 1985.

	1985		2002		1985 - 2002	
Watershed	**Acres**	**% of Watershed**	**Acres**	**% of Watershed**	**Acreage Change**	**Change as % of 1985 Forest**
Bantam River	20,587	58.9%	20,191	57.8%	-396	-1.9%
Blackberry River	12,430	72.1%	12,125	70.3%	-305	-2.5%
Branch Brook	4,760	58.2%	4,675	57.1%	-85	-1.8%
Candlewood Lake	13,770	55.2%	13,317	53.4%	-452	-3.3%
East Aspetuck River	10,251	63.4%	10,045	62.1%	-206	-2.0%
East Branch Croton River-headwaters to Haviland Hollow Brook	1,319	56.8%	1,264	54.4%	-55	-4.2%
East Branch Farmington mainstem	19,613	80.4%	19,353	79.3%	-261	-1.3%
East Branch Naugatuck River	5,556	61.4%	5,361	59.3%	-195	-3.5%
Farmington River-Burlington Brook to Thompson Brook	7,195	72.8%	6,807	68.9%	-388	-5.4%
Farmington River-headwaters to Burlington Brook	12,564	78.4%	12,146	75.8%	-418	-3.3%
Farmington River-Hop Brook to mouth	7,659	53.7%	7,286	51.1%	-373	-4.9%
Farmington River-Thompson Brook to Hop Brook	3,882	55.9%	3,719	53.5%	-163	-4.2%
Haviland Hollow Brook	3,409	83.2%	3,366	82.2%	-43	-1.3%
Hollenbeck River	21,012	76.5%	20,966	76.4%	-45	-0.2%
Housatonic mainstem-Furnace Brook to Tenmile River	31,314	80.3%	30,827	79.0%	-486	-1.6%
Housatonic mainstem-Konkapot River to Furnace Brook	20,799	76.6%	20,669	76.1%	-131	-0.6%
Housatonic mainstem-Still River to Pootatuck River	5,230	59.2%	4,895	55.4%	-335	-6.4%
Housatonic mainstem-Tenmile River to Still River	16,036	64.7%	15,349	61.9%	-687	-4.3%
Hubbard Brook	2,774	53.1%	2,739	52.5%	-35	-1.3%
Konkapot River	1,079	45.2%	955	40.0%	-124	-11.5%
Leadmine Brook	10,264	68.2%	9,917	65.9%	-347	-3.4%
Macedonia Brook	6,902	83.9%	6,874	83.6%	-28	-0.4%
Mad River	15,727	77.4%	15,530	76.4%	-197	-1.3%
Mine Brook	5,447	81.3%	5,216	77.9%	-230	-4.2%
Mudge Pond Brook	4,876	41.7%	4,796	41.0%	-80	-1.6%
Naugatuck mainstem-East Branch to Hancock Brook	12,520	69.9%	12,228	68.3%	-292	-2.3%
Nepaug River	15,197	74.3%	14,785	72.2%	-412	-2.7%
Pequabuck River	3,672	83.8%	3,601	82.1%	-70	-1.9%
Salmon Brook	11,834	70.0%	11,409	67.5%	-425	-3.6%
Salmon Creek	16,662	69.4%	16,556	69.0%	-105	-0.6%
Sandy Brook	12,978	80.9%	12,867	80.2%	-112	-0.9%
Saugatuck River-headwaters to Aspetuck River	2,200	77.0%	2,177	76.2%	-24	-1.1%
Shepaug River-Bantam River to mouth	11,902	62.9%	11,625	61.4%	-278	-2.3%
Shepaug River-headwaters to Bantam River	18,972	72.8%	18,743	72.0%	-229	-1.2%
Still River mainstem	8,124	70.9%	7,636	66.6%	-487	-6.0%
Still River-headwaters to Limekiln Brook	8,118	41.9%	7,518	38.8%	-600	-7.4%
Still River-Limekiln Brook to mouth	5,740	47.3%	5,062	41.8%	-679	-11.8%
Webatuck Creek	5,173	59.7%	5,158	59.5%	-15	-0.3%
Webatuck Creek-headwaters to Wassaic Creek	1,049	51.8%	1,038	51.3%	-11	-1.1%
Weekeepeemee River	2,535	69.1%	2,509	68.4%	-26	-1.0%
West Aspetuck River	11,395	69.9%	11,236	68.9%	-159	-1.4%
West Branch Farmington River-Clam River to mouth	20,715	80.9%	20,348	79.4%	-366	-1.8%
West Branch Naugatuck River	16,626	76.5%	16,452	75.7%	-174	-1.0%
West Branch Salmon Brook	13,656	80.2%	13,415	78.8%	-241	-1.8%
Whiting River	3,079	64.4%	3,044	63.7%	-35	-1.1%
Total	466,605		455,800		-10,806	-2.3%

Connecticut water and wetlands (forested and non-forested) by HUC 12 watershed in 1985 and 2002.

	Water						Non-forested Wetland						Forested Wetland					
	1985		2002		Change (1985-2002)		1985		2002		Change (1985-2002)		1985		2002		Change (1985-2002)	
HUC 12 Watershed	Acres	% of HUC 12	Acres	% of HUC 12	Acres	% from 1985	Acres	% of HUC 12	Acres	% of HUC 12	Acres	% from 1985	Acres	% of HUC 12	Acres	% of HUC 12	Acres	% from 1985
Bantam River	1,560	4.5%	1,367	3.9%	-193	-12.4%	84	0.2%	333	1.0%	250	298.9%	2,412	6.9%	2,278	6.5%	-134	-5.5%
Blackberry River	440	2.6%	369	2.1%	-70	-16.0%	17	0.1%	68	0.4%	51	292.1%	424	2.5%	397	2.3%	-27	-6.4%
Branch Brook	345	4.2%	320	3.9%	-25	-7.1%	3	0.0%	31	0.4%	28	864.3%	172	2.1%	164	2.0%	-8	-4.5%
Candlewood Lake	5,897	23.6%	5,924	23.7%	28	0.5%	6	0.0%	10	0.0%	5	87.5%	407	1.6%	386	1.5%	-22	-5.3%
East Aspetuck River	787	4.9%	732	4.5%	-55	-6.9%	6	0.0%	67	0.4%	62	1120.8%	400	2.5%	380	2.4%	-20	-4.9%
East Branch Croton River-headwaters to Haviland Hollow Brook	8	0.4%	8	0.3%	0	-2.8%	2	0.1%	3	0.1%	1	33.3%	147	6.3%	146	6.3%	-1	-0.8%
East Branch Farmington mainstem	2,312	9.5%	2,657	10.9%	346	15.0%	90	0.4%	77	0.3%	-12	-13.6%	435	1.8%	402	1.6%	-33	-7.6%
East Branch Naugatuck River	424	4.7%	392	4.3%	-31	-7.4%	6	0.1%	42	0.5%	36	560.7%	212	2.3%	205	2.3%	-8	-3.6%
Farmington River-Burlington Brook to	124	1.3%	119	1.2%	-5	-3.7%	7	0.1%	15	0.2%	8	109.4%	326	3.3%	291	2.9%	-35	-10.8%
Farmington River-headwaters to Burlington	204	1.3%	196	1.2%	-8	-3.9%	3	0.0%	17	0.1%	14	400.0%	271	1.7%	234	1.5%	-37	-13.6%
Farmington River-Hop Brook to mouth	282	2.0%	200	1.4%	-81	-28.9%	30	0.2%	86	0.6%	56	188.5%	758	5.3%	678	4.8%	-81	-10.7%
Farmington River-Thompson Brook to Hop	113	1.6%	85	1.2%	-28	-24.4%	3	0.0%	13	0.2%	10	280.0%	218	3.1%	174	2.5%	-43	-19.9%
Haviland Hollow Brook	42	1.0%	41	1.0%	-2	-3.8%	1	0.0%	2	0.1%	2	233.3%	67	1.6%	62	1.5%	-6	-8.2%
Hollenbeck River	446	1.6%	340	1.2%	-106	-23.7%	122	0.4%	250	0.9%	128	104.9%	2,302	8.4%	2,218	8.1%	-84	-3.6%
Housatonic mainstem-Furnace Brook to Tenmile	710	1.8%	672	1.7%	-38	-5.4%	42	0.1%	128	0.3%	86	205.5%	940	2.4%	853	2.2%	-87	-9.3%
Housatonic mainstem-Konkapot River to Furnace	760	2.8%	694	2.6%	-66	-8.7%	22	0.1%	114	0.4%	92	412.4%	614	2.3%	542	2.0%	-72	-11.7%
Housatonic mainstem-Still River to Pootatuck	455	5.2%	438	5.0%	-17	-3.7%	10	0.1%	39	0.4%	29	284.1%	165	1.9%	124	1.4%	-40	-24.4%
Housatonic mainstem-Tenmile River to Still	833	3.4%	673	2.7%	-160	-19.2%	19	0.1%	170	0.7%	151	803.7%	460	1.9%	441	1.8%	-19	-4.1%
Hubbard Brook	922	17.7%	915	17.5%	-7	-0.8%	17	0.3%	36	0.7%	19	110.7%	188	3.6%	172	3.3%	-16	-8.5%
Konkapot River	25	1.0%	21	0.9%	-4	-16.7%	0	0.0%	3	0.1%	3	1300.0%	109	4.6%	101	4.2%	-8	-7.0%
Leadmine Brook	191	1.3%	148	1.0%	-43	-22.4%	28	0.2%	67	0.4%	39	137.4%	597	4.0%	557	3.7%	-40	-6.7%
Macedonia Brook	179	2.2%	120	1.5%	-59	-33.2%	3	0.0%	53	0.6%	50	1990.9%	186	2.3%	181	2.2%	-5	-2.6%
Mad River	974	4.8%	857	4.2%	-117	-12.0%	25	0.1%	151	0.7%	126	501.8%	773	3.8%	733	3.6%	-40	-5.2%
Mine Brook	73	1.1%	31	0.5%	-42	-57.3%	11	0.2%	59	0.9%	48	426.5%	174	2.6%	166	2.5%	-8	-4.4%
Mudge Pond Brook	685	5.9%	600	5.1%	-85	-12.4%	53	0.5%	143	1.2%	90	168.1%	357	3.1%	335	2.9%	-22	-6.1%
Naugatuck mainstem-East Branch to Hancock	181	1.0%	157	0.9%	-25	-13.7%	11	0.1%	44	0.2%	33	295.8%	330	1.8%	287	1.6%	-43	-13.0%
Nepaug River	807	3.9%	879	4.3%	72	8.9%	101	0.5%	143	0.7%	41	40.7%	566	2.8%	509	2.5%	-57	-10.1%
Pequabuck River	163	3.7%	160	3.6%	-3	-1.8%	13	0.3%	43	1.0%	30	229.8%	161	3.7%	128	2.9%	-33	-20.5%
Salmon Brook	109	0.6%	88	0.5%	-20	-18.8%	41	0.2%	61	0.4%	21	50.8%	457	2.7%	378	2.2%	-79	-17.2%
Salmon Creek	893	3.7%	846	3.5%	-47	-5.3%	32	0.1%	93	0.4%	61	189.3%	446	1.9%	410	1.7%	-36	-8.1%
Sandy Brook	503	3.1%	399	2.5%	-103	-20.5%	76	0.5%	178	1.1%	102	135.3%	677	4.2%	644	4.0%	-33	-4.9%
Saugatuck River-headwaters to Aspetuck River	61	2.1%	44	1.5%	-17	-27.9%	10	0.4%	31	1.1%	21	204.5%	201	7.0%	189	6.6%	-12	-6.1%
Shepaug River-Bantam River to mouth	209	1.1%	189	1.0%	-20	-9.6%	4	0.0%	35	0.2%	31	856.3%	329	1.7%	302	1.6%	-27	-8.1%
Shepaug River-headwaters to Bantam River	1,419	5.4%	1,241	4.8%	-179	-12.6%	101	0.4%	315	1.2%	214	212.8%	1,248	4.8%	1,167	4.5%	-81	-6.5%
Still River mainstem	266	2.3%	204	1.8%	-62	-23.5%	24	0.2%	79	0.7%	56	235.9%	338	3.0%	284	2.5%	-54	-15.9%
Still River-headwaters to Limekiln Brook	1,010	5.2%	947	4.9%	-63	-6.2%	33	0.2%	104	0.5%	71	216.8%	563	2.9%	508	2.6%	-55	-9.8%
Still River-Limekiln Brook to mouth	62	0.5%	73	0.6%	10	16.5%	8	0.1%	16	0.1%	8	91.9%	280	2.3%	238	2.0%	-42	-14.9%
Webatuck Creek	139	1.6%	105	1.2%	-34	-24.2%	21	0.2%	52	0.6%	31	147.8%	233	2.7%	222	2.6%	-11	-4.5%
Webatuck Creek-headwaters to Wassaic Creek	15	0.7%	7	0.3%	-8	-54.5%	0	0.0%	8	0.4%	8	N/A	69	3.4%	67	3.3%	-2	-3.3%
Weekeepeemee River	9	0.3%	3	0.1%	-6	-67.5%	0	0.0%	4	0.1%	4	N/A	129	3.5%	124	3.4%	-6	-4.6%
West Aspetuck River	410	2.5%	313	1.9%	-97	-23.6%	50	0.3%	163	1.0%	113	226.3%	773	4.7%	743	4.6%	-30	-3.9%
West Branch Farmington River-Clam River to	1,189	4.6%	1,159	4.5%	-31	-2.6%	45	0.2%	84	0.3%	39	85.9%	550	2.1%	485	1.9%	-66	-11.9%
West Branch Naugatuck River	762	3.5%	600	2.8%	-162	-21.3%	34	0.2%	196	0.9%	163	481.6%	637	2.9%	594	2.7%	-43	-6.8%
West Branch Salmon Brook	25	0.1%	29	0.2%	4	15.7%	9	0.1%	18	0.1%	9	97.5%	618	3.6%	580	3.4%	-38	-6.2%
Whiting River	37	0.8%	19	0.4%	-18	-49.7%	8	0.2%	15	0.3%	6	77.8%	109	2.3%	112	2.3%	3	3.0%

[CT] HUC 12 watershed-level impact metric values for year 1985.

	1985							
HUC 12 Name	Perimeter:Area Ratio (ft/acres)	Interior Forest %	Largest Forest Patch %	Impervious Surface %	Altered Land %	Developed Prime Farmland %	Altered Riparian Area % (295 ft)	Altered Riparian Area % (100 ft)
Farmington River-Burlington Brook to Thompson Brook	156.50	43.25	12.14	7.95	22.85	17.87	20.05	19.44
Farmington River-Thompson Brook to Hop Brook	287.02	20.47	13.27	10.44	39.96	20.83	42.49	42.21
Nepaug River	121.01	49.45	13.28	6.78	19.30	12.19	23.92	24.80
Farmington River-Hop Brook to mouth	265.48	19.13	6.14	9.62	39.55	18.21	30.26	27.81
Farmington River-headwaters to Burlington Brook	131.27	51.40	15.45	7.50	18.86	17.22	35.44	33.66
Still River mainstem	166.63	42.39	7.26	8.77	24.18	23.52	38.06	33.01
Mad River	100.92	58.97	26.26	7.26	14.57	22.76	17.73	15.63
West Branch Salmon Brook	94.11	59.22	50.64	6.54	15.95	12.17	20.07	21.72
Salmon Brook	146.63	42.36	19.85	7.21	26.55	14.56	27.50	26.79
West Branch Farmington River-Clam River to mouth	96.63	61.68	13.52	6.71	12.75	19.69	29.18	28.57
East Branch Farmington mainstem	79.78	66.58	18.21	6.34	8.79	14.22	21.35	23.80
Sandy Brook	91.14	61.27	20.38	6.42	11.62	15.62	13.95	12.15
Mine Brook	108.04	56.88	36.66	6.73	14.99	12.20	16.26	15.25
Pequabuck River	73.00	69.66	60.99	5.66	8.89	8.97	13.51	11.26
Naugatuck mainstem-East Branch to Hancock Brook	156.62	39.04	18.82	8.26	27.43	17.75	27.71	24.78
Macedonia Brook	75.51	67.24	70.57	6.07	11.84	15.77	23.67	19.84
Leadmine Brook	154.11	39.69	26.17	7.58	26.76	13.70	19.73	19.05
Housatonic mainstem-Furnace Brook to Tenmile River	85.09	61.98	23.01	6.23	15.69	12.20	23.32	23.00

Bantam River	163.91	34.70	7.17	7.24	30.82	13.36	19.06	16.34
Shepaug River-headwaters to Bantam River	104.13	55.35	22.78	6.53	17.48	11.94	14.57	11.91
Webatuck Creek	112.29	43.63	46.63	6.19	36.36	8.69	39.07	40.08
East Branch Naugatuck River	166.11	37.65	12.95	10.92	33.01	29.17	34.81	25.40
West Branch Naugatuck River	89.03	57.87	32.46	7.09	17.54	15.75	20.73	18.39
Mudge Pond Brook	197.60	23.83	14.11	7.33	51.95	12.04	44.03	41.29
Hollenbeck River	69.86	67.17	38.83	5.73	13.22	10.50	21.68	21.89
Webatuck Creek-headwaters to Wassaic Creek	217.62	26.82	22.12	6.78	44.36	10.55	47.44	47.85
Blackberry River	117.30	52.82	27.15	7.04	23.38	14.55	37.57	41.01
Housatonic mainstem-Konkapot River to Furnace Brook	106.08	56.33	24.72	6.63	18.77	14.14	32.61	34.84
Salmon Creek	108.10	51.38	37.45	6.66	25.85	12.32	24.30	24.69
Whiting River	133.12	39.96	28.37	6.39	32.60	9.00	40.13	40.73
Hubbard Brook	177.94	36.04	9.13	7.83	30.67	15.61	23.14	18.37
Konkapot River	180.67	27.15	29.47	6.23	49.67	8.56	44.09	49.86
Still River-headwaters to Limekiln Brook	309.11	14.79	11.82	14.38	52.56	27.12	50.97	46.06
Still River-Limekiln Brook to mouth	301.03	15.27	5.25	12.17	50.02	19.31	46.09	39.58
Housatonic mainstem-Still River to Pootatuck River	227.76	23.53	6.68	8.89	35.50	17.84	22.95	22.92
Candlewood Lake	189.97	38.34	22.37	9.67	25.61	20.54	21.63	19.73
Weekeepeemee River	145.45	38.98	22.86	6.44	27.20	8.31	38.13	22.10
Housatonic mainstem-Tenmile River to Still River	157.93	39.46	7.55	7.62	31.04	14.31	40.78	40.96
Shepaug River-Bantam River to mouth	165.34	32.46	8.15	7.04	34.62	10.88	27.26	25.73
West Aspetuck River	126.87	48.03	25.46	6.69	23.13	14.01	26.52	24.64
Branch Brook	161.36	32.83	8.82	7.03	37.04	11.57	21.81	22.52
East Aspetuck River	162.39	39.27	17.37	7.68	30.72	16.98	46.94	36.67
Saugatuck River-headwaters to Aspetuck River	145.58	49.08	84.86	6.76	13.76	14.01	17.84	15.21
East Branch Croton River-headwaters to Haviland Hollow Brook	247.98	24.49	33.24	10.79	36.53	29.13	18.11	17.26
Haviland Hollow Brook	107.64	58.07	43.27	6.41	14.21	12.00	25.47	20.42
Average	150.70	43.91	24.53	7.61	26.63	15.37	28.71	26.87
Minimum	69.86	14.79	5.25	5.66	8.79	8.31	13.51	11.26
Maximum	309.11	69.66	84.86	14.38	52.56	29.17	50.97	49.86

[CT]. HUC 12 watershed-level impact metric values for year 2002.

	2002							
HUC 12 Name	Perimeter:Area Ratio (ft/acres)	Interior Forest %	Largest Forest Patch %	Impervious Surface %	Altered Land %	Developed Prime Farmland %	Altered Riparian Area % (295 ft)	Altered Riparian Area % (100 ft)
Farmington River-Burlington Brook to Thompson Brook	185.11	35.30	11.23	8.88	27.14	19.98	21.86	20.85
Farmington River-Thompson Brook to Hop Brook	310.04	16.77	7.72	11.25	43.06	23.06	44.75	44.01
Nepaug River	135.64	44.33	12.97	7.21	21.19	13.81	25.16	25.87
Farmington River-Hop Brook to mouth	290.84	15.37	6.01	10.23	42.73	20.08	32.54	29.62
Farmington River-headwaters to Burlington Brook	151.05	44.57	15.14	8.08	21.69	19.73	38.59	36.39
Still River mainstem	191.63	35.36	6.99	9.93	28.91	29.06	43.99	38.87
Mad River	107.48	55.15	25.88	7.38	15.65	23.45	18.71	16.68
West Branch Salmon Brook	104.78	54.97	49.91	6.89	17.52	13.63	20.84	22.55
Salmon Brook	161.70	37.68	19.33	7.81	29.51	17.35	28.87	27.92
West Branch Farmington River-Clam River to mouth	104.05	58.03	13.40	6.96	14.46	21.46	32.97	32.53
East Branch Farmington mainstem	83.49	64.97	19.13	6.43	8.75	14.80	18.33	18.46
Sandy Brook	96.53	58.59	20.18	6.50	12.48	16.97	14.57	12.72
Mine Brook	133.43	48.73	35.51	7.43	18.36	14.26	17.80	16.73
Pequabuck River	86.07	62.87	59.12	5.94	10.68	10.11	17.77	15.72
Naugatuck mainstem-East Branch to Hancock Brook	165.94	35.86	18.70	8.63	29.23	19.10	29.60	26.55
Macedonia Brook	79.52	64.41	69.66	6.10	12.28	16.43	23.61	19.65
Leadmine Brook	171.70	35.03	25.00	8.11	29.31	15.55	22.15	21.16
Housatonic mainstem-Furnace Brook to Tenmile River	94.53	57.57	22.84	6.34	17.05	12.78	24.74	24.40
Bantam River	176.01	31.08	7.01	7.42	32.05	13.87	20.35	17.52
Shepaug River-headwaters to Bantam River	112.37	51.65	22.22	6.61	18.46	12.39	16.12	13.39
Webatuck Creek	116.58	41.70	46.22	6.24	36.54	8.96	37.67	38.19
East Branch Naugatuck River	178.01	34.33	12.79	11.39	35.18	30.55	36.56	27.13
West Branch Naugatuck River	94.68	55.08	26.92	7.23	18.43	16.95	21.30	18.85
Mudge Pond Brook	207.89	22.18	13.97	7.45	52.43	12.50	43.29	40.28
Hollenbeck River	72.09	65.46	38.44	5.77	13.57	10.96	21.90	22.14

Webatuck Creek-headwaters to Wassaic Creek	218.43	26.23	21.96	6.91	44.85	11.30	48.84	49.17
Blackberry River	123.78	49.70	26.22	7.28	25.37	15.96	38.68	42.10
Housatonic mainstem-Konkapot River to Furnace Brook	111.02	54.08	24.60	6.69	19.40	14.61	32.74	34.73
Salmon Creek	110.38	50.17	37.23	6.73	26.35	12.73	24.69	25.09
Whiting River	140.04	38.34	27.94	6.45	33.39	9.43	41.56	42.57
Hubbard Brook	187.59	33.90	9.13	7.95	31.53	15.79	23.82	19.30
Konkapot River	193.52	21.74	25.94	6.41	55.19	9.13	45.29	51.39
Still River-headwaters to Limekiln Brook	329.31	12.44	9.52	15.65	55.89	31.86	53.61	48.53
Still River-Limekiln Brook to mouth	341.26	11.08	5.06	13.86	55.88	23.76	50.15	43.73
Housatonic mainstem-Still River to Pootatuck River	283.19	14.80	8.71	9.98	39.76	22.03	25.36	25.10
Candlewood Lake	210.34	33.11	21.86	10.19	27.97	22.38	23.81	21.76
Weekeepeemee River	156.10	35.19	22.34	6.50	28.08	8.59	38.76	22.08
Housatonic mainstem-Tenmile River to Still River	177.69	33.67	6.88	8.14	33.79	16.61	41.35	40.48
Shepaug River-Bantam River to mouth	180.57	28.27	7.76	7.28	36.15	11.81	28.37	26.54
West Aspetuck River	135.80	44.61	25.11	6.86	24.07	14.74	26.78	24.94
Branch Brook	163.67	31.59	8.72	7.16	38.06	12.07	23.08	23.72
East Aspetuck River	174.62	35.30	16.97	7.93	32.03	18.17	47.43	36.46
Saugatuck River-headwaters to Aspetuck River	153.71	46.72	83.16	7.00	14.83	14.95	19.34	16.62
East Branch Croton River-headwaters to Haviland Hollow Brook	279.90	19.07	32.33	11.42	38.95	31.56	18.55	17.97
Haviland Hollow Brook	118.56	54.28	41.32	6.65	15.40	13.01	25.90	20.86
Average	164.46	40.03	23.76	7.98	28.52	16.85	30.05	28.03
Minimum	72.09	11.08	5.06	5.77	8.75	8.59	14.57	12.72
Maximum	341.26	65.46	83.16	15.65	55.89	31.86	53.61	51.39

[CT] HUC 12 watersheds most and least impacted in 1985.

HUC 12 Name	Perimeter:Area Ratio (ft/acre)	Interior Forest %	Largest Forest Patch %	Impervious Surface %	Altered Land %	Developed Prime Farmland %	Altered Riparian Area % (295 ft)	Altered Riparian Area % (100 ft)
	Hollenbeck River	Pequabuck River	Saugatuck River-headwaters to Aspetuck River	Pequabuck River	East Branch Farmington mainstem	Weekeepeemee River	Pequabuck River	Pequabuck River
Least Impact	69.86	69.66	84.86	5.66	8.79	8.31	13.51	11.26
	Still River-headwaters to Limekiln Brook	Still River-headwaters to Limekiln Brook	Still River-Limekiln Brook to mouth	Still River-headwaters to Limekiln Brook	Still River-headwaters to Limekiln Brook	East Branch Naugatuck River	Still River-headwaters to Limekiln Brook	Konkapot River
Most Impact	309.11	14.79	5.25	14.38	52.56	29.17	50.97	49.86

[CT]. HUC 12 watersheds most and least impacted in 2002.

HUC 12 Name	Perimeter:Area Ratio (ft/acre)	Interior Forest %	Largest Forest Patch %	Impervious Surface %	Altered Land %	Developed Prime Farmland %	Altered Riparian Area % (295 ft)	Altered Riparian Area % (100 ft)
	Hollenbeck River	Hollenbeck River	Saugatuck River-headwaters to Aspetuck River	Hollenbeck River	East Branch Farmington mainstem	Weekeepeemee River	Sandy Brook	Sandy Brook
Least Impact	72.09	65.46	83.16	5.77	8.75	8.59	14.57	12.72
	Still River-Limekiln Brook to mouth	Still River-Limekiln Brook to mouth	Still River-Limekiln Brook to mouth	Still River-headwaters to Limekiln Brook	Still River-headwaters to Limekiln Brook	Still River-headwaters to Limekiln Brook	Still River-headwaters to Limekiln Brook	Konkapot River
Most Impact	341.26	11.08	5.06	15.65	55.89	31.86	53.61	51.39

[CT] HUC 12 watershed-level impact metric values measured after projecting development to year 2022 using medium development rate and "business as usual" development constraints..

	"Business As Usual" Constraints							
HUC 12 Name	Perimeter:Area Ratio (ft/acres)	Interior Forest %	Largest Forest Patch %	Impervious Surface %	Altered Land %	Developed Prime Farmland %	Altered Riparian Area % (295 ft)	Altered Riparian Area % (100 ft)
Farmington River-Burlington Brook to Thompson Brook	195.40	32.21	11.20	10.00	30.73	24.28	23.63	22.18
Farmington River-Thompson Brook to Hop Brook	309.73	15.82	7.66	12.67	47.19	29.50	47.79	46.00
Nepaug River	137.22	43.48	12.81	7.49	22.11	15.12	25.95	26.83
Farmington River-Hop Brook to mouth	289.39	15.33	5.98	10.64	43.90	21.71	33.91	30.76
Farmington River-headwaters to Burlington Brook	147.62	43.98	15.14	8.94	24.06	24.73	43.10	41.97
Still River mainstem	198.12	32.69	6.03	11.53	33.59	34.28	52.17	48.63
Mad River	107.92	54.72	25.83	7.51	16.06	23.69	19.16	17.16
West Branch Salmon Brook	104.62	54.17	49.31	7.24	18.62	16.28	21.16	22.92
Salmon Brook	163.13	36.63	18.98	8.48	31.59	21.04	31.09	30.52
West Branch Farmington River-Clam River to mouth	102.14	57.58	13.40	7.38	15.72	26.82	36.00	35.06
East Branch Farmington mainstem	83.62	64.94	19.13	6.45	8.79	14.99	18.34	18.53
Sandy Brook	96.50	58.43	20.03	6.60	12.78	20.45	15.29	13.35
Mine Brook	133.54	48.73	35.50	7.45	18.40	14.26	17.85	16.75
Pequabuck River	85.89	62.83	59.08	5.97	10.78	10.34	17.77	15.82
Naugatuck mainstem-East Branch to Hancock Brook	163.57	35.32	18.65	9.19	30.76	21.49	33.24	30.18
Macedonia Brook	79.06	64.41	69.63	6.13	12.33	16.49	23.74	19.77
Leadmine Brook	173.81	33.76	25.00	8.76	31.08	18.85	24.50	23.65
Housatonic mainstem-Furnace Brook to Tenmile River	93.62	57.52	22.79	6.49	17.28	14.32	25.24	24.86
Bantam River	174.46	30.97	7.01	7.64	32.59	14.93	21.15	18.24
Shepaug River-headwaters to Bantam River	111.83	51.60	22.22	6.69	18.72	12.70	16.52	13.74
Webatuck Creek	116.58	41.70	46.22	6.24	36.54	8.96	37.67	38.19
East Branch Naugatuck River	167.94	34.07	12.79	12.11	36.65	32.29	37.93	27.85
West Branch Naugatuck River	94.66	55.01	26.92	7.28	18.55	17.03	21.59	19.19

Mudge Pond Brook	204.57	22.16	13.97	7.72	52.91	13.74	43.55	40.44
Hollenbeck River	71.79	65.45	38.44	5.79	13.62	11.16	22.01	22.27
Webatuck Creek-headwaters to Wassaic Creek	218.43	26.23	21.96	6.91	44.85	11.30	48.84	49.17
Blackberry River	120.70	49.52	26.04	7.64	26.22	18.99	40.80	44.13
Housatonic mainstem-Konkapot River to Furnace Brook	110.18	54.02	24.60	6.76	19.62	15.24	33.09	35.09
Salmon Creek	108.83	50.12	37.17	6.86	26.70	13.58	25.44	25.89
Whiting River	140.04	38.34	27.94	6.45	33.39	9.43	41.56	42.57
Hubbard Brook	187.59	33.90	9.13	7.95	31.53	15.79	23.82	19.30
Konkapot River	193.52	21.74	25.94	6.41	55.19	9.13	45.29	51.39
Still River-headwaters to Limekiln Brook	325.59	11.43	9.09	17.34	59.44	38.57	58.85	54.33
Still River-Limekiln Brook to mouth	337.74	9.64	4.96	16.55	61.27	32.07	59.23	54.63
Housatonic mainstem-Still River to Pootatuck River	283.30	14.77	8.71	10.08	40.02	22.43	25.45	25.15
Candlewood Lake	212.80	32.24	21.62	10.50	28.79	23.06	24.72	22.34
Weekeepeemee River	156.10	35.19	22.34	6.50	28.08	8.59	38.76	22.08
Housatonic mainstem-Tenmile River to Still River	169.92	33.45	6.78	9.01	35.32	22.20	44.72	44.20
Shepaug River-Bantam River to mouth	181.11	28.06	7.69	7.36	36.42	12.14	29.20	27.42
West Aspetuck River	135.64	44.60	25.11	6.93	24.22	15.48	27.12	25.34
Branch Brook	163.71	31.58	8.72	7.18	38.09	12.07	23.10	23.75
East Aspetuck River	172.96	35.03	16.97	8.31	32.96	20.38	50.03	38.47
Saugatuck River-headwaters to Aspetuck River	154.46	46.51	83.03	7.04	14.96	14.95	19.48	16.76
East Branch Croton River-headwaters to Haviland Hollow Brook	291.58	17.73	27.57	12.76	41.48	43.50	19.94	19.19
Haviland Hollow Brook	118.56	54.28	41.32	6.65	15.40	13.01	25.90	20.86
Average	164.21	39.60	23.56	8.39	29.54	18.92	31.46	29.49
Minimum	71.79	9.64	4.96	5.79	8.79	8.59	15.29	13.35
Maximum	337.74	65.45	83.03	17.34	61.27	43.50	59.23	54.63

[CT] HUC 12 watersheds most and least impacted after projecting development to year 2022 using medium development rate and "business as usual" development constraints

	"Business As Usual" Constraints							
HUC 12 Name	Perimeter:Area Ratio (ft/acre)	Interior Forest %	Largest Forest Patch %	Impervious Surface %	Altered Land %	Developed Prime Farmland %	Altered Riparian Area % (295 ft)	Altered Riparian Area % (100 ft)
	Hollenbeck River	Hollenbeck River	Saugatuck River-headwaters to Aspetuck River	Hollenbeck River	East Branch Farmington mainstem	Weekeepeemee River	Sandy Brook	Sandy Brook
Least Impact	71.79	65.45	83.03	5.79	8.79	8.59	15.29	13.35
	Still River-Limekiln Brook to mouth	Still River-Limekiln Brook to mouth	Still River-Limekiln Brook to mouth	Still River-headwaters to Limekiln Brook	Still River-Limekiln Brook to mouth	East Branch Croton River-headwaters to Haviland Hollow Brook	Still River-Limekiln Brook to mouth	Still River-Limekiln Brook to mouth
Most Impact	337.74	9.64	4.96	17.34	61.27	43.5	59.23	54.63

[Connecticut] Potential drivers tested with stratification by town ranked in decreasing order of receiver operating characteristic statistic (ROC). An ROC of 1 indicates a perfect fit to the validation data while a 0.5 indicates a random fit. Number of quantiles indicates the grouping scheme that gave the best ROC for each driver (10, 20, 30, 50, or 100 quantile classes). N/A indicates categorical data not grouped.

Driver name (stratified by town)	Number of quantiles	ROC
Distance from major roads	10	0.758210
Percent of population over age 65	30	0.758030
Population density ages 18 to 29	50	0.757857
Percent of population under age of 18	100	0.756752
Population density	10	0.755746
Percent in poverty	30	0.755376
Distance from utility right-of-ways (1995)	10	0.755311
Density of 1995 development in a 4,200 ft radius	10	0.755055
Density of 1995 development in a 5,100 ft radius	10	0.754963
Density of people working in service occupations	10	0.754929
Distance from densely developed areas (50% developed within 600 ft radius in 1995)	10	0.754371
Drainage class of major soil component	N/A	0.754060
Distance from lakes of size 4263.87 to 852.34 acres	10	0.753966
Density of 1995 development in a 3,900 ft radius	20	0.753963
Distance from primary routes	10	0.753952
Density of 1995 development in a 2,700 ft radius	10	0.753804
Density of 1995 development in a 2,400 ft radius	10	0.753787
Distance from box stores	10	0.753565
Density of 1995 development in a 4,500 ft radius	10	0.753543

Density of 1995 development in a 4,800 ft radius	10	0.753409
Population density ages 30 to 44	20	0.753367
Percentage of the civilian labor force that is unemployed	20	0.753059
Density of 1995 development in a 3,300 ft radius	10	0.752992
Median rent paid	20	0.752633
Runoff potential class for soils	N/A	0.752603
Population density ages under 18	10	0.752258
Median household income	10	0.751851
Density of 1995 development in a 3,000 ft radius	10	0.751547
Density of 1995 development in a 2,100 ft radius	10	0.751452
Distance from other grasses & agriculture (1995)	20	0.751353
Population density ages 45 to 64	10	0.751042
Density of people 16 and over in the labor force	10	0.751020
Density of 1995 development in a 3,600 ft radius	10	0.750902
Distance from lakes of size 4263.87 to 29.87 acres	50	0.750871
Distance from lakes of size 4263.87 to 13.29 acres	10	0.750582
Percent of people 18 and older who have had one or more years of college	10	0.749422
Percentage of houses that use a public sewer system	50	0.749254
Distance from lakes of size 4263.87 to 121.29 acres	10	0.749073
Topographic slope	10	0.749011
Populations ages 30 to 44	10	0.748969
Presence/absence of wetland soils	N/A	0.748661
Distance from turf & grass or other grasses & agriculture (1995)	20	0.748582
Connecticut wetland classification	N/A	0.748247
Number of people working in service occupations	50	0.748170
Populations ages 65 and over	10	0.748154

Distance from forested wetland (1995)	10	0.748036
Distance from lakes of size 4263.87 to 214.54 acres	10	0.747891
Density of 1995 development in a 1,800 ft radius	10	0.746431
Per capita income	20	0.745542
Hydric rating for soils	N/A	0.745500
Populations ages 45 to 64	50	0.745425
Distance from lakes of size 4263.87 to 357.62 acres	10	0.745267
Bedrock type	N/A	0.745133
Distance from non-forested wetland or forested wetland (1995)	10	0.744836
Farmland soil classification	N/A	0.744805
Distance from lakes of size 4263.87 to 0 acres	10	0.744433
Median value non-condo housing unit	100	0.744368
Population under age of 18	100	0.744278
Distance from reservoirs, lakes, or ponds	10	0.744271
Percentage of houses that have 4+ bedrooms	20	0.744122
Housing units	10	0.744117
Populations ages 18 to 29	100	0.744017
Percentage of houses that get their water from a public system or private company	20	0.743770
Distance from reservoirs, lakes, or ponds larger than 25 acres	10	0.743333
Number of people in construction	100	0.742910
Distance from non-standard roads	20	0.742560
Distance from turf & grass	10	0.742518
Population density ages over 65	30	0.742209
Topographic aspect	10	0.742095
Construction labor force density	10	0.741842
Number of people 16 and over in the labor force	50	0.741761

Distance from densely developed areas (50% developed within 1,200 ft radius in 1995)	10	0.741537
Distance from lakes of size 4263.87 to 565.30 acres	30	0.741333
Total population	100	0.740695
Distance from primary or secondary routes	10	0.740537
Distance from major rivers	10	0.740157
Distance from named rivers and streams	10	0.740125
Density of 1995 development in a 900 ft radius	10	0.740000
Density of 1995 development in a 1,500 ft radius	10	0.739768
Commuting distance from employment base	100	0.739754
Housing density	100	0.739663
Distance from protected lands	10	0.739452
Distance from lakes of size 4263.87 to 56.11 acres	10	0.739424
Distance from secondary route	10	0.739279
Distance from edge of patch of contiguous land use/cover (1995)	10	0.738702
Distance from unimproved road	10	0.738036
Distance from golf course	20	0.737639
Distance from interstate exits	20	0.737410
Land use/cover (1995)	N/A	0.737339
Density of 1995 development in a 1,200 ft radius	10	0.737329
Elevation	10	0.736658
Size of patch of contiguous land use/cover (1995)	10	0.736530
Distance from primary route, secondary route, or local round	10	0.735684
Density of 1995 development in a 600 ft radius	10	0.735036
Distance from water (1995)	10	0.734424
Distance from city centers	10	0.734177
Distance from private schools	10	0.733670

Density of 1995 development in a 300 ft radius	30	0.733586
Distance from rivers or streams	10	0.732448
Size of viewshed as determined by viewshed index	10	0.731439
Distance from developed areas (1995)	10	0.731197
Distance from named reservoirs, lakes, or ponds	10	0.730716
Distance from deciduous or coniferous forest (1995)	10	0.730070
Distance from deciduous, coniferous, or forested wetland (1995)	10	0.729913
Distance from non-forested wetland (1995)	10	0.729827
Distance from facilities reporting toxic releases	20	0.729083
Distance from any type of road	10	0.725710
Distance from barren land (1995)	50	0.725162
Distance from local roads	10	0.720879
Annual probability of flood event (dominant condition)	N/A	0.501418
Annual probability of flood event (maximum condition)	N/A	0.501418
Available soil water storage to 100 cm	N/A	0.501418
Available soil water storage to 150 cm	N/A	0.501418
Available soil water storage to 50 cm	N/A	0.501418
Dominant soil drainage class	N/A	0.501418
Dominant soil hydrological group	N/A	0.501418
Dominant soil rating class for suitability as site for dwellings with basements	N/A	0.501418
Dominant soil rating class for suitability as site for dwellings without basements	N/A	0.501418
Dominant soil rating class for suitability as site for roads	N/A	0.501418
Least limiting soil rating class for suitability as site for dwellings with basements	N/A	0.501418
Least limiting soil rating class for suitability as site for septic tank	N/A	0.501418
Most limiting soil rating class for suitability as site for dwellings with basements	N/A	0.501418
Most limiting soil rating class for suitability as site for septic tank	N/A	0.501418

Proportion of hydric soils	N/A	0.501418
Wettest soil drainage class	N/A	0.501418
Dominant soil rating class for suitability as site for septic tank	N/A	0.501416
Available soil water storage to 25 cm	N/A	0.501408
Surficial materials	N/A	0.497089
Most limiting soil rating class for suitability as site for dwellings with basements	N/A	0.500549
Distance from deciduous or coniferous forest (1995)	100	0.500535

[Connecticut] Potential drivers tested without stratification by town ranked in decreasing order of receiver operating characteristic statistic (ROC). An ROC of 1 indicates a perfect fit to the validation data while a 0.5 indicates a random fit. Number of quantiles indicates the grouping scheme that gave the best ROC for each driver (10, 20, 30, 50, or 100 quantile classes). N/A indicates categorical data not grouped.

Driver name (non-stratified by town)	Number of quantiles	ROC
Percent in poverty	100	0.739442
Percent of population over age 65	100	0.736336
Median household income	100	0.736080
Population density ages 30 to 44	100	0.735221
Percentage of the civilian labor force that is unemployed	50	0.734556
Median rent paid	50	0.734261
Population density	100	0.734206
Population density ages 45 to 64	100	0.731999
Percentage of houses that get their water from a public system or private company	100	0.731891
Percent of population under age of 18	100	0.730644
Density of people 16 and over in the labor force	100	0.730568
Population density ages under 18	100	0.728147
Commuting distance from employment base	100	0.727923
Percentage of houses that use a public sewer system	100	0.723685
Construction labor force density	50	0.717462
CT magazine town rankings by crime (2007)	20	0.716234
Median value non-condo housing unit	50	0.713650
Populations ages 30 to 44	50	0.713198
Percentage of houses that have 4+ bedrooms	100	0.712137
Population density ages 18 to 29	100	0.710364
Density of people working in service occupations	100	0.710207

Housing density	100	0.709583
CT magazine town population classes (2007)	20	0.709524
Percent of people 18 and older who have had one or more years of college	100	0.708006
Number of people 16 and over in the labor force	100	0.707785
Populations ages 45 to 64	30	0.707671
CT magazine town rankings by leisure/culture (2007)	20	0.704733
Density of 1995 development in a 5,100 ft radius	20	0.701467
Housing units	100	0.701252
Density of 1995 development in a 4,800 ft radius	30	0.698411
Density of 1995 development in a 4,500 ft radius	20	0.697090
Number of people working in service occupations	100	0.696921
Distance from interstate exits	20	0.696092
Population under age of 18	100	0.695839
Total population	100	0.692453
Density of 1995 development in a 4,200 ft radius	20	0.691706
Density of 1995 development in a 3,900 ft radius	30	0.690304
Distance from densely developed areas (50% developed within 600 ft radius in 1995)	50	0.689013
Density of 1995 development in a 3,600 ft radius	30	0.686489
Per capita income	50	0.685500
Population density ages over 65	100	0.683670
Populations ages 18 to 29	100	0.683597
CT magazine town rankings by cost of living (2007)	20	0.677165
Density of 1995 development in a 3,300 ft radius	20	0.677142
Distance from box stores	10	0.674088
Density of 1995 development in a 3,000 ft radius	50	0.673994
Distance from densely developed areas (50% developed within 1,200 ft radius in 1995)	30	0.671627

Elevation	20	0.669296
Density of 1995 development in a 2,700 ft radius	30	0.668627
Distance from facilities reporting toxic releases	30	0.668285
Distance from barren land (1995)	30	0.668092
CT magazine town total scores (2007)	20	0.666851
Density of 1995 development in a 2,400 ft radius	30	0.662723
Bedrock type	N/A	0.661788
Populations ages 65 and over	100	0.661406
Density of 1995 development in a 2,100 ft radius	20	0.655473
CT magazine town rankings by economy (2007)	20	0.642956
Density of 1995 development in a 1,800 ft radius	30	0.642342
CT magazine town rankings by education (2007)	20	0.631921
Distance from turf & grass	50	0.629064
Density of 1995 development in a 1,500 ft radius	100	0.625195
Number of people in construction	50	0.624748
CT magazine overall town rankings (2007)	10	0.618139
Density of 1995 development in a 1,200 ft radius	30	0.610702
Distance from turf & grass or other grasses & agriculture (1995)	50	0.610693
Least limiting soil rating class for suitability as site for dwellings with basements	N/A	0.602690
Distance from non-standard roads	30	0.602485
Distance from primary routes	10	0.600763
Distance from utility right-of-ways (1995)	30	0.600170
Distance from private schools	10	0.597246
Density of 1995 development in a 900 ft radius	30	0.595971
Distance from major roads	50	0.594451
Distance from other grasses & agriculture (1995)	30	0.592825

Distance from golf course	10	0.592254
Surficial materials	N/A	0.590199
Distance from lakes of size 4263.87 to 852.34 acres	20	0.587852
Distance from major rivers	10	0.584816
Available soil water storage to 150 cm	N/A	0.580391
Distance from primary route, secondary route, or local round	10	0.579547
Distance from edge of patch of contiguous land use/cover (1995)	20	0.579124
Topographic slope	20	0.578645
Distance from city centers	20	0.578474
Distance from lakes of size 4263.87 to 565.30 acres	30	0.577568
Distance from local roads	10	0.575985
Size of patch of contiguous land use/cover (1995)	100	0.572988
Distance from developed areas (1995)	10	0.571043
Density of 1995 development in a 600 ft radius	30	0.569709
Distance from primary or secondary routes	50	0.569410
Wettest soil drainage class	N/A	0.563546
Dominant soil drainage class	N/A	0.557437
Available soil water storage to 100 cm	N/A	0.556982
Drainage class of major soil component	N/A	0.556685
Distance from lakes of size 4263.87 to 13.29 acres	50	0.555660
Distance from secondary route	20	0.553404
Distance from protected lands	30	0.550240
Distance from any type of road	10	0.549549
Dominant soil hydrological group	N/A	0.548453
Distance from lakes of size 4263.87 to 357.62 acres	10	0.548163
Distance from reservoirs, lakes, or ponds	30	0.545229

Distance from lakes of size 4263.87 to 0 acres	30	0.545229
Distance from non-forested wetlands (1995)	10	0.543094
Farmland soil classification	N/A	0.541291
Available soil water storage to 50 cm	N/A	0.540815
Topographic aspect	30	0.539444
Distance from forested wetland (1995)	30	0.538950
Distance from non-forested wetland or forested wetland (1995)	50	0.538923
Available soil water storage to 25 cm	N/A	0.538671
Distance from named reservoirs, lakes, or ponds	30	0.536672
Density of 1995 development in a 300 ft radius	10	0.535839
Runoff potential class for soils	N/A	0.535677
Connecticut wetland classification	N/A	0.532734
Presence/absence of wetland soils	N/A	0.532417
Hydric rating for soils	N/A	0.528741
Distance from lakes of size 4263.87 to 121.29 acres	10	0.527825
Distance from lakes of size 4263.87 to 56.11 acres	20	0.525832
Land use/cover (1995)	N/A	0.525321
Distance from lakes of size 4263.87 to 29.87 acres	50	0.520360
Distance from unimproved road	10	0.516892
Distance from reservoirs, lakes, or ponds larger than 25 acres	20	0.516787
Proportion of hydric soils	N/A	0.516200
Dominant soil rating class for suitability as site for dwellings with basements	N/A	0.511593
Annual probability of flood event (maximum condition)	N/A	0.510075
Annual probability of flood event (dominant condition)	N/A	0.510075
Least limiting soil rating class for suitability as site for septic tank	N/A	0.507451
Distance from lakes of size 4263.87 to 214.54 acres	10	0.501607

Most limiting soil rating class for suitability as site for dwellings with basements	N/A	0.500549
Distance from deciduous or coniferous forest (1995)	100	0.500535
Most limiting soil rating class for suitability as site for septic tank	N/A	0.497090
Dominant soil rating class for suitability as site for septic tank	N/A	0.496554
Distance from named rivers and streams	10	0.494568
Distance from rivers or streams	30	0.493965
Distance from deciduous, coniferous, or forested wetland (1995)	50	0.493842
Distance from water (1995)	30	0.487624
Size of viewshed as determined by viewshed index	100	0.485176
Dominant soil rating class for suitability as site for dwellings without basements	N/A	0.479257
Dominant soil rating class for suitability as site for roads	N/A	0.465230

[Connecticut] Six sets of twelve drivers each entered into optimization procedure to find driver weights that maximize ROC of final suitability map. If the weight is 0 the driver was dropped from the final composite suitability map. Sets are listed in descending order of ROC success.

1) Top 12 Physio-economic Drivers by ROC (Stratified)	**Quantile Number**	**ROC**	**Weight**
Distance from major roads	10	0.75821	3.1905
Distance from utility right-of-ways (1995)	10	0.755311	1.8571
Density of 1995 development in a 4,200 ft radius	10	0.755055	2.0476
Distance from densely developed areas (50% developed within 600 ft radius in 1995)	10	0.754371	1.2857
Drainage class of major soil component	N/A	0.75406	1.381
Distance from lakes of size 4263.87 to 852.34 acres	10	0.753966	1.2381
Distance from primary routes	10	0.753952	2.1905
Runoff potential class for soils	N/A	0.752603	1.619
Distance from other grasses & agriculture (1995)	20	0.751353	2.381
Topographic slope	10	0.749011	1
Distance from interstate exits	20	0.73741	0
Land use/cover (1995)	N/A	0.737339	0
Composite Suitability Map		0.787505	

2) Top 12 Either Physio-economic or Demographic Drivers (Also Top 6 Physio-economic Drivers and Top 6 Demographic Drivers by ROC) (Stratified)			
Percent of population over age 65	10	0.75821	1
Distance from major roads	30	0.75803	1.0789
Population density ages 18 to 29	50	0.757857	1.0526
Percent of population under age of 18	100	0.756752	0
Population density	10	0.755746	0
Percent in poverty	30	0.755376	0
Distance from utility right-of-ways (1995)	10	0.755311	0
Density of 1995 development in a 4,200 ft radius	10	0.755055	0
Density of people working in service occupations	10	0.754929	0
Distance from densely developed areas (50% developed within 600 ft radius in 1995)	10	0.754371	0
Distance from lakes of size 4263.87 to 852.34 acres	10	0.753966	0
Runoff potential class for soils	N/A	0.752603	0
Composite Suitability Map		0.781569	

3) Top 6 Physio-economic Drivers and Top 6 demographic Drivers by ROC (Non-Stratified)			
Percent in poverty	100	0.739442	1.963
Percent of population over age 65	100	0.736336	1.4444
Median household income	100	0.73608	1.4444
Population density ages 30 to 44	100	0.735221	0
Percentage of the civilian labor force that is unemployed	50	0.734556	1.8889
Median rent paid	50	0.734261	0
Density of 1995 development in a 5,100 ft radius	20	0.701467	1

Distance from interstate exits	20	0.696092	0
Distance from densely developed areas (50% developed within 600 ft radius in 1995)	50	0.689013	1.1481
Elevation	20	0.669296	1.5556
Distance from barren land (1995)	30	0.668092	1.037
Bedrock type	N/A	0.661788	0
Composite Suitability Map		0.77695	

4) Top 12 Demographic Drivers by ROC (Stratified)			
Percent of population over age 65	30	0.75803	1.1351
Population density ages 18 to 29	50	0.757857	1.2162
Percent of population under age of 18	100	0.756752	1.0541
Population density	10	0.755746	1.0811
Percent in poverty	30	0.755376	1.1351
Density of people working in service occupations	10	0.754929	1
Population density ages 30 to 44	20	0.753367	0
Percentage of the civilian labor force that is unemployed	20	0.753059	0
Median rent paid	20	0.752633	0
Population density ages under 18	10	0.752258	0
Median household income	10	0.751851	0
Population density ages 45 to 64	10	0.751042	0
Composite Suitability Map		0.767637	

5) Top 12 Demographic Drivers by ROC (Also Top 12 Either Physio-economic or Demographic) (Non-Stratified)			
Percent in poverty	100	0.739442	1.2903
Percent of population over age 65	100	0.736336	0
Median household income	100	0.73608	1.2903
Population density ages 30 to 44	100	0.735221	1.2903
Percentage of the civilian labor force that is unemployed	50	0.734556	1.2581
Median rent paid	50	0.734261	1
Population density	100	0.734206	1.2903
Population density ages 45 to 64	100	0.731999	1.4516
Percentage of houses that get their water from a public system or private company	100	0.731891	1.2903
Percent of population under age of 18	100	0.730644	1.3226
Population density ages under 18	100	0.730568	1.2903
Composite Suitability Map		0.764867	

6) Top 12 Physio-economic Drivers by ROC (Non-Stratified)			
Density of 1995 development in a 5,100 ft radius	20	0.701467	8
Distance from interstate exits	20	0.696092	18.5
Distance from densely developed areas (50% developed within 600 ft radius in 1995)	50	0.689013	2
Elevation	20	0.669296	11.5
Distance from barren land (1995)	30	0.668092	7
Bedrock type	N/A	0.661788	13.25
Distance from turf & grass	50	0.629064	1
Distance from turf & grass or other grasses & agriculture (1995)	50	0.610693	11

Least limiting soil rating class for suitability as site for dwellings with basements	N/A	0.60269	5
Distance from non-standard roads	30	0.602485	5
Distance from primary routes	10	0.600763	2.75
Distance from utility right-of-ways (1995)	30	0.60017	0
Composite Suitability Map		0.74944	

[Connecticut] All possible permutations of suitability images, extrapolation techniques, projection methods, and neighborhood constraints with associated percent correct and kappa statistic. (Note: Best fit indicates a least squares line through the three years prior to 2002. LE indicates a simple linear extrapolation to 2002 based upon rate-of-change between two years indicated.

Suitability map origin	Extrapolation technique	Projection method	Neighborhood constraints	Overall Accuracy	Kappa	User's Accuracy Dev	User's Accuracy Undev	Producer's Accuracy Dev	Producer's Accuracy Undev
GEOMOD,non-stratified	LE 85&90	Stratified	3 X 3	99.2502	98.5005	8.6422	99.5412	5.7030	99.7062
GEOMOD,non-stratified	LE 85&90	Stratified	None	99.2481	98.4961	7.6910	99.5403	5.0684	99.7049
GEOMOD, stratified	LE 85&90	Stratified	3 X 3	99.2468	98.4936	7.4917	99.5396	4.9371	99.7043
GEOMOD, stratified	LE 85&90	Stratified	None	99.2467	98.4935	8.0937	99.5394	5.3411	99.7044
Logistic regression, stratified	LE 85&90	Stratified	3 X 3	99.2463	98.4926	7.4086	99.5394	4.8823	99.7040
Logistic regression, stratified	LE 85&90	Stratified	None	99.2432	98.4864	7.5453	99.5377	4.9792	99.7026
Logistic regression, non-stratified	LE 85&90	Stratified	3 X 3	99.2416	98.4833	7.2960	99.5369	4.8147	99.7018
Logistic regression, non-stratified	LE 85&90	Stratified	None	99.2321	98.4642	5.1827	99.5323	3.4154	99.6969
GEOMOD,non-stratified	Best fit 85-95	Stratified	3 X 3	99.2320	98.4640	5.1661	99.5322	3.4045	99.6968
GEOMOD,non-stratified	Best fit 85-95	Stratified	None	99.2313	98.4625	5.0498	99.5318	3.3279	99.6965
GEOMOD,non-stratified	LE 85&95	Stratified	3 X 3	99.2297	98.4594	5.4346	99.5309	3.5863	99.6959
GEOMOD,non-stratified	LE 85&95	Stratified	None	99.2276	98.4552	5.1022	99.5298	3.3670	99.6948
GEOMOD, stratified	Best fit 85-95	Stratified	3 X 3	99.2256	98.4512	4.2144	99.5292	2.7805	99.6934
GEOMOD, stratified	Best fit 85-95	Stratified	None	99.2248	98.4495	4.0816	99.5288	2.6929	99.6930
GEOMOD,non-stratified	LE 85&90	Stratified	5 X 5	99.2246	98.4491	4.0484	99.5287	2.6710	99.6929
GEOMOD, stratified	LE 85&95	Stratified	3 X 3	99.2244	98.4488	3.9701	99.5284	2.6163	99.6930
GEOMOD, stratified	LE 85&95	Stratified	None	99.2244	98.4488	3.9701	99.5284	2.6163	99.6930
Logistic regression, stratified	Best fit 85-95	Stratified	3 X 3	99.2243	98.4486	4.5870	99.5282	3.0270	99.6931
Logistic regression, stratified	Best fit 85-95	Stratified	None	99.2229	98.4458	3.7375	99.5277	2.4631	99.6923
Logistic regression, non-stratified	Best fit 85-95	Stratified	3 X 3	99.2221	98.4441	4.2380	99.5270	2.7967	99.6920
Logistic regression, non-stratified	Best fit 85-95	Stratified	None	99.2217	98.4435	4.1881	99.5269	2.7638	99.6918
Logistic regression, non-stratified	LE 85&95	Stratified	3 X 3	99.2210	98.4420	4.0718	99.5265	2.6870	99.6915
Logistic regression, non-stratified	LE 85&95	Stratified	None	99.2207	98.4413	4.0219	99.5263	2.6541	99.6913
Logistic regression, stratified	LE 85&95	Stratified	3 X 3	99.2206	98.4411	4.0053	99.5263	2.6431	99.6913
Logistic regression, stratified	LE 85&95	Stratified	None	99.2200	98.4401	3.9222	99.5260	2.5883	99.6910

GEOMOD, stratified	LE 85&90	Stratified	5 X 5	99.2197	98.4394	3.2852	99.5262	2.1675	99.6905
GEOMOD,non-stratified	LE 90&95	Stratified	3 X 3	99.2195	98.4390	3.8391	99.5258	2.5335	99.6907
GEOMOD,non-stratified	LE 90&95	Stratified	None	99.2193	98.4387	3.1728	99.5258	2.0909	99.6905
GEOMOD, stratified	LE 90&95	Stratified	3 X 3	99.2193	98.4385	3.2188	99.5260	2.1237	99.6903
GEOMOD, stratified	LE 90&95	Stratified	None	99.2190	98.4380	3.1229	99.5257	2.0580	99.6903
Logistic regression, non-stratified	LE 90&95	Stratified	3 X 3	99.2190	98.4379	3.1691	99.5258	2.0909	99.6901
Logistic regression, non-stratified	LE 90&95	Stratified	None	99.2183	98.4367	3.6563	99.5252	2.4128	99.6901
Logistic regression, stratified	LE 90&95	Stratified	3 X 3	99.2181	98.4362	3.6231	99.5251	2.3909	99.6900
Logistic regression, stratified	LE 90&95	Stratified	None	99.2180	98.4359	2.9568	99.5252	1.9485	99.6898
GEOMOD,non-stratified	LE 85&90	Stratified	7 X 7	99.2156	98.4311	3.2242	99.5238	2.1277	99.6887
Logistic regression, stratified	LE 85&90	Stratified	5 X 5	99.2154	98.4307	3.1910	99.5237	2.1057	99.6886
Logistic regression, non-stratified	LE 85&90	Stratified	5 X 5	99.2154	98.4307	3.1910	99.5237	2.1057	99.6886
GEOMOD,non-stratified	Best fit 85-95	Stratified	5 X 5	99.2150	98.4301	3.1411	99.5235	2.0728	99.6885
GEOMOD,non-stratified	LE 85&95	Stratified	5 X 5	99.2145	98.4290	3.0580	99.5232	2.0180	99.6882
GEOMOD, stratified	Best fit 85-95	Stratified	5 X 5	99.2143	98.4286	3.0248	99.5231	1.9961	99.6881
GEOMOD, stratified	LE 85&90	Stratified	7 X 7	99.2139	98.4277	2.9583	99.5229	1.9522	99.6879
GEOMOD, stratified	LE 85&95	Stratified	5 X 5	99.2125	98.4250	2.7422	99.5222	1.8096	99.6872
Logistic regression, non-stratified	Best fit 85-95	Stratified	5 X 5	99.2121	98.4242	2.0906	99.5224	1.3793	99.6867
Logistic regression, stratified	Best fit 85-95	Stratified	5 X 5	99.2119	98.4237	2.0574	99.5223	1.3574	99.6865
Logistic regression, non-stratified	LE 85&95	Stratified	5 X 5	99.2118	98.4235	2.0408	99.5222	1.3465	99.6865
Logistic regression, stratified	LE 85&95	Stratified	5 X 5	99.2088	98.4175	2.1605	99.5204	1.4258	99.6853
Logistic regression, stratified	LE 85&90	Stratified	7 X 7	99.2084	98.4169	2.1107	99.5202	1.3928	99.6852
GEOMOD,non-stratified	LE 90&95	Stratified	5 X 5	99.2082	98.4164	2.0774	99.5201	1.3709	99.6851
GEOMOD, stratified	LE 90&95	Stratified	5 X 5	99.2082	98.4164	2.0774	99.5201	1.3709	99.6851
GEOMOD,non-stratified	Best fit 85-95	Stratified	7 X 7	99.2076	98.4153	1.3937	99.5202	0.9195	99.6844
Logistic regression, non-stratified	LE 85&90	Stratified	7 X 7	99.2074	98.4149	1.3605	99.5201	0.8976	99.6843
Logistic regression, non-stratified	LE 90&95	Stratified	5 X 5	99.2074	98.4149	1.3605	99.5201	0.8976	99.6843
Logistic regression, stratified	LE 90&95	Stratified	5 X 5	99.2057	98.4113	1.6786	99.5188	1.1077	99.6838
GEOMOD,non-stratified	LE 85&95	Stratified	7 X 7	99.2040	98.4079	1.4127	99.5180	0.9322	99.6829
GEOMOD, stratified	Best fit 85-95	Stratified	7 X 7	99.2036	98.4073	1.3628	99.5178	0.8993	99.6828
GEOMOD, stratified	LE 85&95	Stratified	7 X 7	99.2036	98.4073	1.3628	99.5178	0.8993	99.6828
Logistic regression, non-stratified	Best fit 85-95	Stratified	7 X 7	98.7488	97.4977	6.9207	99.5752	12.7860	99.1658
Logistic regression, non-stratified	LE 85&95	Stratified	7 X 7	98.7487	97.4975	6.9147	99.5751	12.7750	99.1658

Logistic regression, stratified	Best fit 85-95	Stratified	7 X 7	98.7447	97.4895	6.6896	99.5731	12.3591	99.1638
Logistic regression, stratified	LE 85&95	Stratified	7 X 7	98.7410	97.4821	6.8966	99.5731	12.7660	99.1601
GEOMOD,non-stratified	LE 90&95	Stratified	7 X 7	98.7241	97.4482	5.9545	99.5645	11.0222	99.1516
GEOMOD, stratified	LE 90&95	Stratified	7 X 7	98.7140	97.4280	5.3916	99.5594	9.9803	99.1465
Logistic regression, non-stratified	LE 90&95	Stratified	7 X 7	98.7028	97.4055	4.3751	99.5523	8.0898	99.1423
GEOMOD,non-stratified	LE 90&95	Non-stratified	5 X 5	98.7025	97.4049	4.3574	99.5522	8.0569	99.1422
GEOMOD,non-stratified	LE 90&95	Non-stratified	7 X 7	98.6982	97.3964	4.1205	99.5500	7.6190	99.1400
GEOMOD,non-stratified	LE 90&95	Non-stratified	None	98.6981	97.3962	4.0766	99.5496	7.5315	99.1403
Logistic regression, stratified	LE 90&95	Stratified	7 X 7	98.6978	97.3956	4.0588	99.5494	7.4986	99.1402
GEOMOD,non-stratified	LE 90&95	Non-stratified	3 X 3	98.6965	97.3929	4.4194	99.5506	8.1816	99.1376
GEOMOD, stratified	LE 90&95	Non-stratified	None	98.6960	97.3920	3.9580	99.5485	7.3125	99.1393
GEOMOD, stratified	LE 90&95	Non-stratified	7 X 7	98.6930	97.3861	3.7921	99.5470	7.0060	99.1378
GEOMOD, stratified	LE 90&95	Non-stratified	5 X 5	98.6928	97.3857	3.7803	99.5469	6.9841	99.1377
Logistic regression, non-stratified	LE 90&95	Non-stratified	7 X 7	98.6926	97.3853	4.2007	99.5486	7.7758	99.1357
Logistic regression, non-stratified	LE 90&95	Non-stratified	None	98.6926	97.3852	3.7684	99.5468	6.9622	99.1376
GEOMOD, stratified	LE 90&95	Non-stratified	3 X 3	98.6921	97.3842	3.7388	99.5466	6.9075	99.1373
Logistic regression, non-stratified	LE 90&95	Non-stratified	5 X 5	98.6901	97.3802	3.6262	99.5456	6.6995	99.1363
Logistic regression, stratified	LE 90&95	Non-stratified	None	98.6887	97.3774	3.5492	99.5449	6.5572	99.1356
Logistic regression, stratified	LE 90&95	Non-stratified	7 X 7	98.6878	97.3757	3.9396	99.5463	7.2933	99.1333
Logistic regression, non-stratified	LE 90&95	Non-stratified	3 X 3	98.6873	97.3746	3.9045	99.5460	7.2275	99.1331
Logistic regression, stratified	LE 90&95	Non-stratified	5 X 5	98.6862	97.3725	3.8452	99.5454	7.1178	99.1325
Logistic regression, stratified	LE 90&95	Non-stratified	3 X 3	98.6860	97.3719	3.4338	99.5438	6.3492	99.1339
GEOMOD,non-stratified	LE 85&95	Non-stratified	None	98.6859	97.3717	3.4279	99.5438	6.3383	99.1338
GEOMOD,non-stratified	LE 85&95	Non-stratified	7 X 7	98.6849	97.3698	3.3746	99.5433	6.2397	99.1333
GEOMOD,non-stratified	LE 85&95	Non-stratified	5 X 5	98.6849	97.3697	3.7682	99.5447	6.9752	99.1318
GEOMOD, stratified	LE 85&95	Non-stratified	None	98.6837	97.3674	3.7030	99.5441	6.8546	99.1312
GEOMOD,non-stratified	LE 85&95	Non-stratified	3 X 3	98.6823	97.3646	3.6315	99.5435	6.7230	99.1305
Logistic regression, non-stratified	LE 85&95	Non-stratified	None	98.6807	97.3614	3.5371	99.5426	6.5475	99.1297
GEOMOD, stratified	LE 85&95	Non-stratified	7 X 7	98.6794	97.3589	3.4716	99.5420	6.4268	99.1291
Logistic regression, stratified	LE 85&95	Non-stratified	7 X 7	98.6788	97.3576	3.4360	99.5417	6.3610	99.1287
GEOMOD, stratified	LE 85&95	Non-stratified	5 X 5	98.6784	97.3567	3.4068	99.5415	6.3062	99.1286
Logistic regression, stratified	LE 85&95	Non-stratified	5 X 5	98.6767	97.3533	3.3120	99.5406	6.1307	99.1277
Logistic regression, non-stratified	LE 85&95	Non-stratified	7 X 7	98.6753	97.3506	3.2350	99.5399	5.9882	99.1270

GEOMOD, stratified	LE 85&95	Non-stratified	3 X 3	98.6748	97.3495	3.2109	99.5397	5.9443	99.1267
Logistic regression, non-stratified	LE 85&95	Non-stratified	5 X 5	98.6733	97.3465	3.1280	99.5389	5.7907	99.1260
Logistic regression, stratified	LE 85&95	Non-stratified	3 X 3	98.6706	97.3412	2.9799	99.5376	5.5166	99.1246
Logistic regression, non-stratified	LE 85&95	Non-stratified	3 X 3	98.6704	97.3408	2.9624	99.5374	5.4837	99.1246
GEOMOD,non-stratified	Best fit 85-95	Non-stratified	None	98.6691	97.3382	2.8913	99.5368	5.3521	99.1239
GEOMOD,non-stratified	Best fit 85-95	Non-stratified	7 X 7	98.6684	97.3367	2.8499	99.5364	5.2753	99.1235
GEOMOD,non-stratified	Best fit 85-95	Non-stratified	5 X 5	98.6652	97.3304	2.6721	99.5348	4.9463	99.1219
GEOMOD, stratified	Best fit 85-95	Non-stratified	None	98.6592	97.3184	1.9359	99.5304	3.5796	99.1204
Logistic regression, stratified	LE 85&95	Non-stratified	None	98.6567	97.3134	1.7939	99.5291	3.3169	99.1192
Logistic regression, stratified	Best fit 85-95	Non-stratified	None	98.6553	97.3106	1.7169	99.5284	3.1746	99.1185
GEOMOD,non-stratified	Best fit 85-95	Non-stratified	3 X 3	98.6536	97.3072	1.6222	99.5275	2.9995	99.1176
GEOMOD, stratified	Best fit 85-95	Non-stratified	7 X 7	98.6530	97.3060	1.5866	99.5272	2.9338	99.1173
Logistic regression, stratified	Best fit 85-95	Non-stratified	7 X 7	98.6526	97.3051	1.5630	99.5270	2.8900	99.1171
Logistic regression, non-stratified	Best fit 85-95	Non-stratified	None	98.6516	97.3031	1.9194	99.5280	3.5534	99.1150
GEOMOD, stratified	Best fit 85-95	Non-stratified	5 X 5	98.6508	97.3016	1.8780	99.5276	3.4766	99.1147
Logistic regression, stratified	Best fit 85-95	Non-stratified	5 X 5	98.6500	97.2999	1.8306	99.5272	3.3889	99.1142
Logistic regression, non-stratified	Best fit 85-95	Non-stratified	7 X 7	98.6496	97.2993	1.8128	99.5270	3.3560	99.1141
Logistic regression, non-stratified	Best fit 85-95	Non-stratified	5 X 5	98.6490	97.2980	1.7773	99.5267	3.2902	99.1138
GEOMOD, stratified	Best fit 85-95	Non-stratified	3 X 3	98.6487	97.2974	1.7595	99.5265	3.2573	99.1136
Logistic regression, stratified	Best fit 85-95	Non-stratified	3 X 3	98.6484	97.2967	1.7417	99.5264	3.2244	99.1134
Logistic regression, non-stratified	Best fit 85-95	Non-stratified	3 X 3	98.6452	97.2904	1.5640	99.5248	2.8954	99.1118
GEOMOD,non-stratified	LE 85&90	Non-stratified	None	98.6178	97.2356	6.2824	99.5775	13.3881	99.0312
GEOMOD,non-stratified	LE 85&90	Non-stratified	7 X 7	98.6171	97.2341	6.2465	99.5772	13.3114	99.0309
GEOMOD, stratified	LE 85&90	Non-stratified	None	98.6166	97.2333	6.2259	99.5770	13.2677	99.0306
Logistic regression, stratified	LE 85&90	Non-stratified	None	98.6132	97.2263	6.4478	99.5774	13.7640	99.0267
GEOMOD,non-stratified	LE 85&90	Non-stratified	5 X 5	98.5998	97.1995	5.8005	99.5706	12.3821	99.0200
Logistic regression, non-stratified	LE 85&90	Non-stratified	None	98.5808	97.1616	4.8859	99.5610	10.4299	99.0104
GEOMOD, stratified	LE 85&90	Non-stratified	7 X 7	98.5745	97.1490	4.1953	99.5559	8.9436	99.0093
Logistic regression, stratified	LE 85&90	Non-stratified	7 X 7	98.5739	97.1478	4.1645	99.5555	8.8779	99.0090
Logistic regression, non-stratified	LE 85&90	Non-stratified	7 X 7	98.5695	97.1391	3.9540	99.5534	8.4291	99.0068
GEOMOD, stratified	LE 85&90	Non-stratified	5 X 5	98.5695	97.1390	3.9349	99.5531	8.3853	99.0070
Logistic regression, stratified	LE 85&90	Non-stratified	5 X 5	98.5688	97.1375	3.8989	99.5528	8.3087	99.0066
Logistic regression, non-stratified	LE 85&90	Non-stratified	5 X 5	98.5663	97.1326	4.1823	99.5537	8.9274	99.0032

GEOMOD,non-stratified	LE 85&90	Non-stratified	3 X 3	98.5659	97.1318	3.7602	99.5513	8.0131	99.0052
Logistic regression, stratified	LE 85&90	Non-stratified	3 X 3	98.5659	97.1318	3.7602	99.5513	8.0131	99.0052
Logistic regression, non-stratified	LE 85&90	Non-stratified	3 X 3	98.5645	97.1291	3.6934	99.5506	7.8708	99.0045
GEOMOD, stratified	LE 85&90	Non-stratified	3 X 3	98.5633	97.1265	4.0382	99.5522	8.6203	99.0016

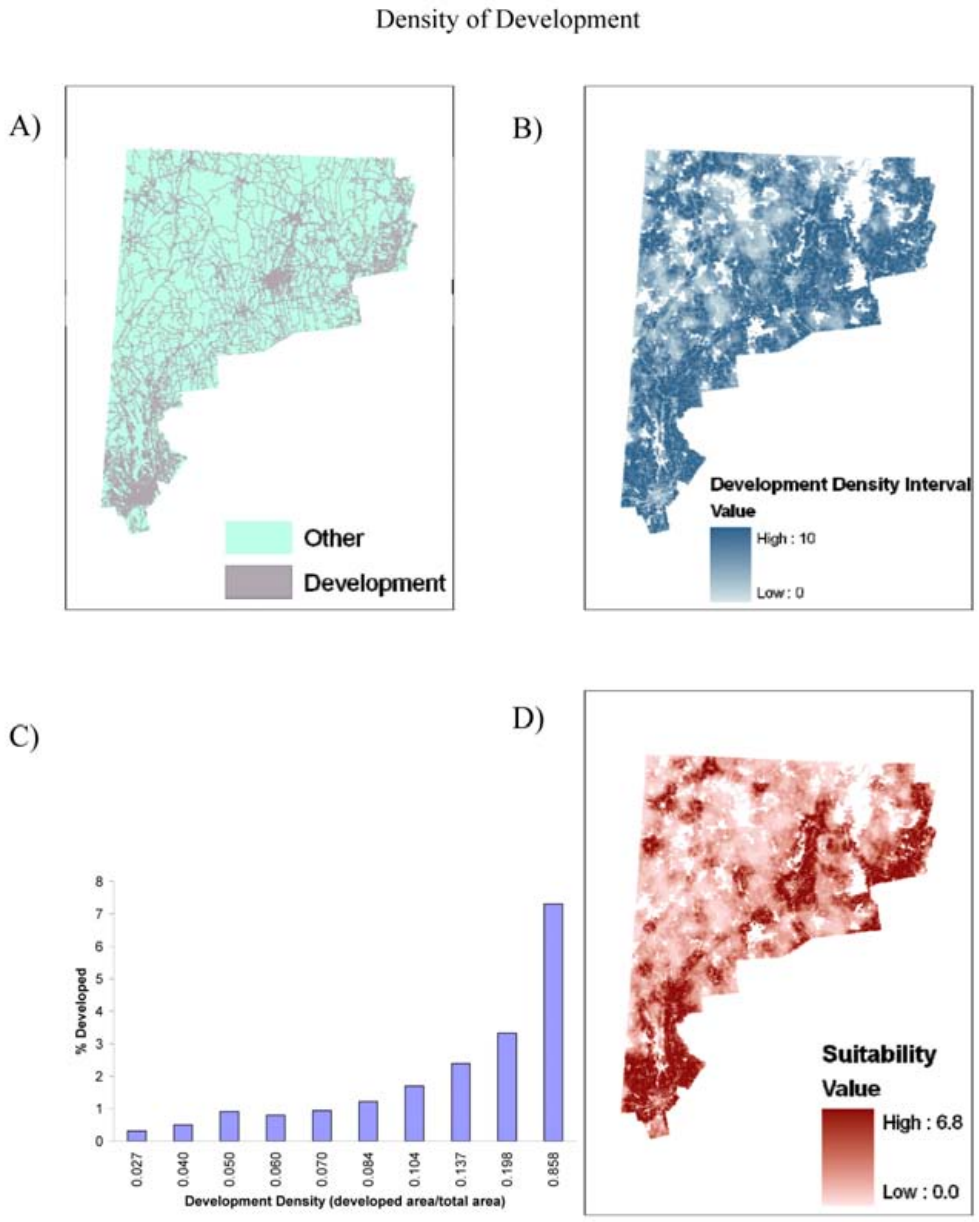


Illustration of operations involved in creation of individual suitability map based on density of development in a 4,200 ft radius. A) Map of development (data from 2002) B) Map of density of development classified into intervals (data from 2002). C) Histogram showing percent of cells available for development in each density interval (development data from 1985) that were developed between 1985 and 2002. D) Suitability map created by assigning percent developed values in histogram to density interval map.

Soil Runoff Class

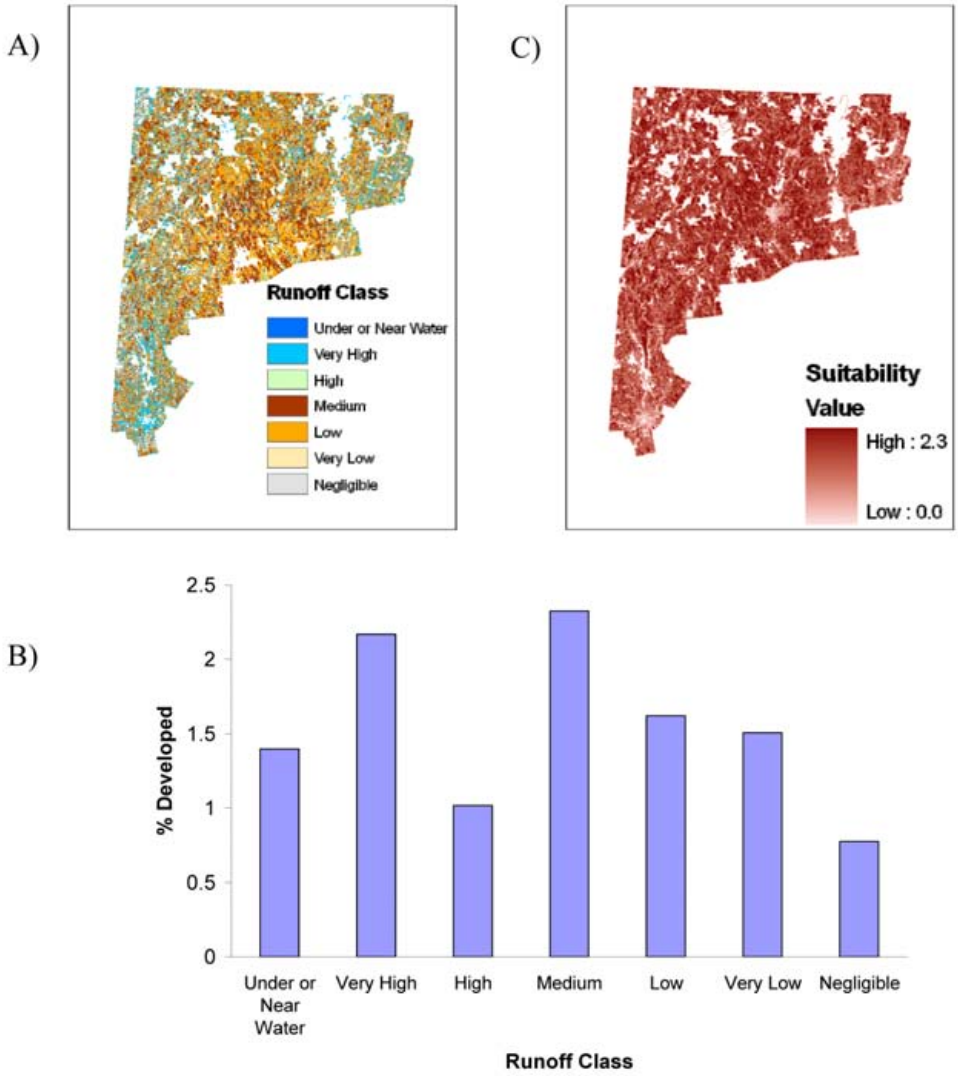
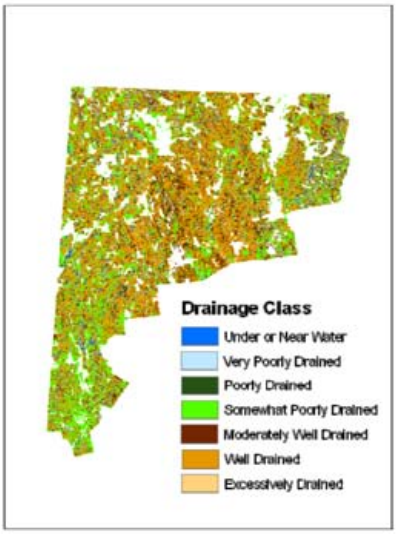


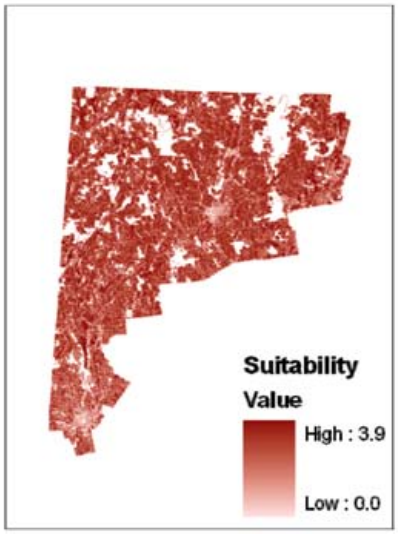
Illustration of operations involved in creation of individual suitability map based on soil runoff class. A) Map of soil runoff classes. B) Histogram showing percent of cells available for development in each runoff class that became developed between 1985 and 2002. D) Suitability map created by assigning percent developed values in histogram to the soil runoff class map.

Soil Drainage Class

A)



C)



B)

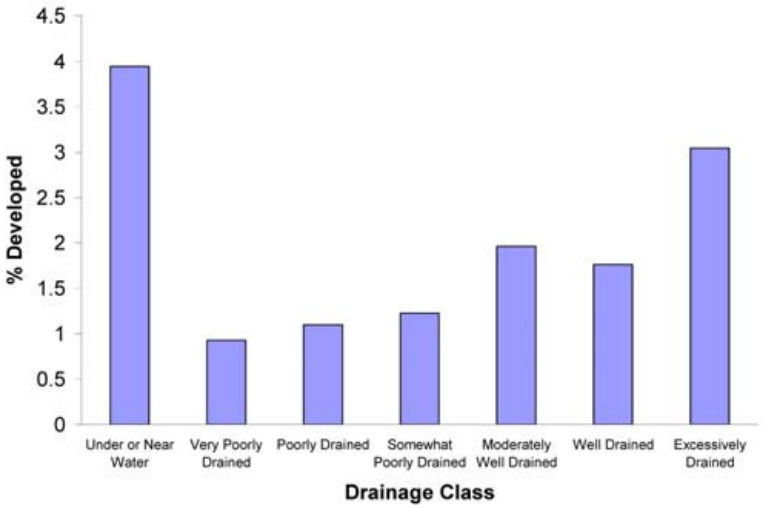


Illustration of operations involved in creation of individual suitability map based on drainage class of soils. A) Map of soil drainage class. B) Histogram showing percent of cells available for development in each drainage class that became developed between 1985 and 2002. C) Suitability map created by assigning percent developed values in histogram to drainage class map.

Distance from Utility Right-of-Way (ROW)

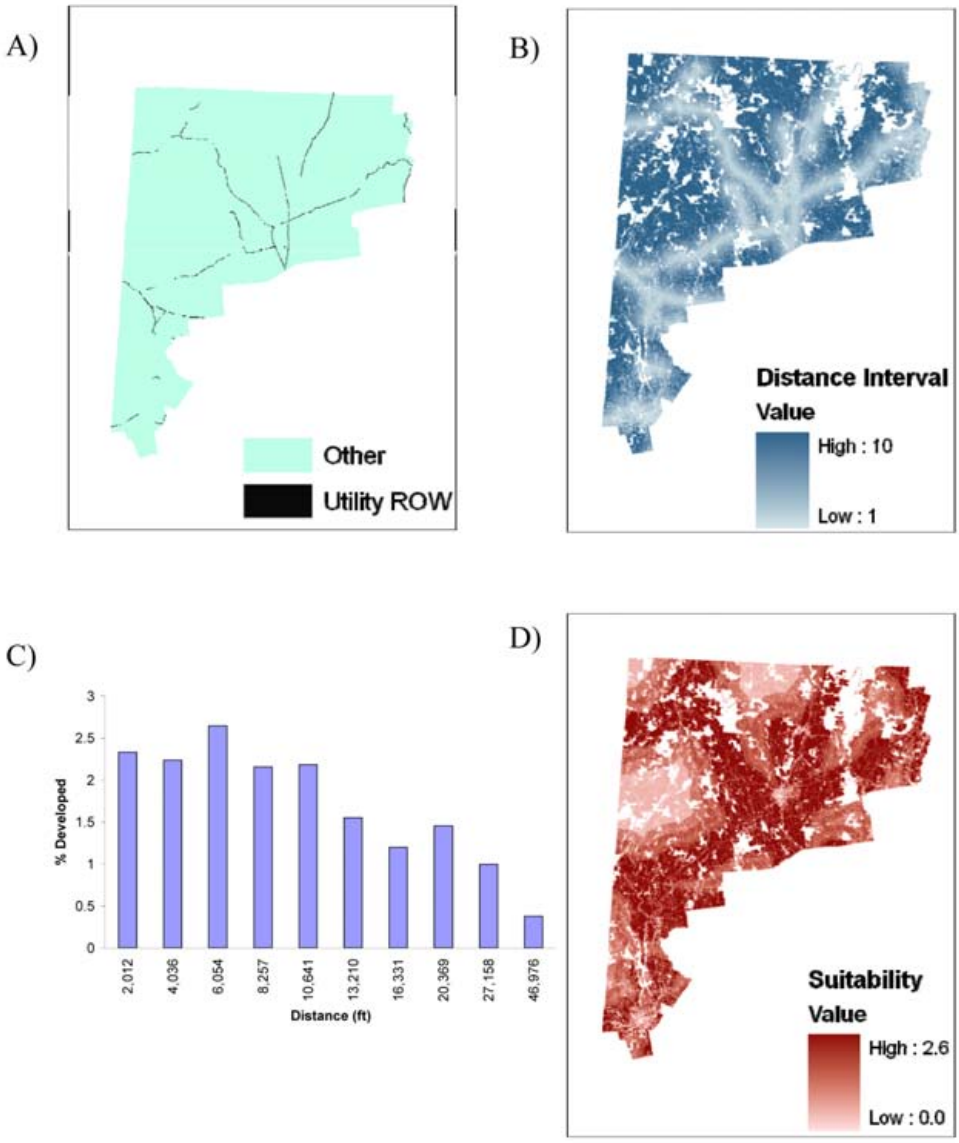


Illustration of operations involved in creation of individual suitability map based on distance from utility ROW. A) Map of utility ROW (data from 2002) B) Map of Euclidean distance from utility ROW roads classified into intervals (data from 2002). C) Histogram showing percent of cells available for development in each distance interval (LULC data from 1985) that were developed between 1985 and 2002. D) Suitability map created by assigning percent developed values in histogram to distance interval map.

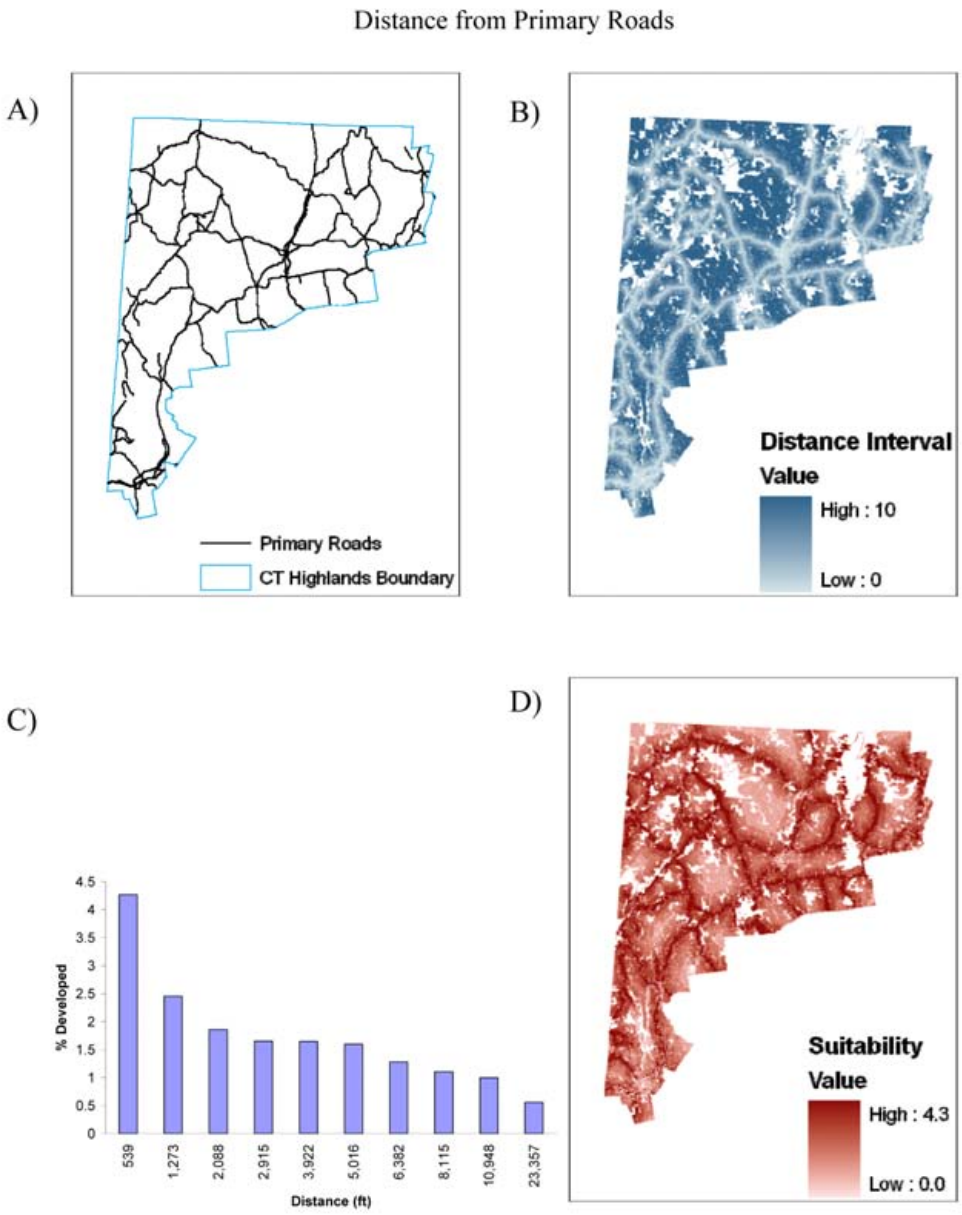


Illustration of operations involved in creation of individual suitability map based on distance from primary roads. A) Map of primary roads. B) Map of Euclidean distance from primary roads classified into intervals. C) Histogram showing percent of cells available for development in each distance interval that were developed between 1985 and 2002. D) Suitability map created by assigning percent developed values in histogram to distance interval map.

Distance from Major Roads

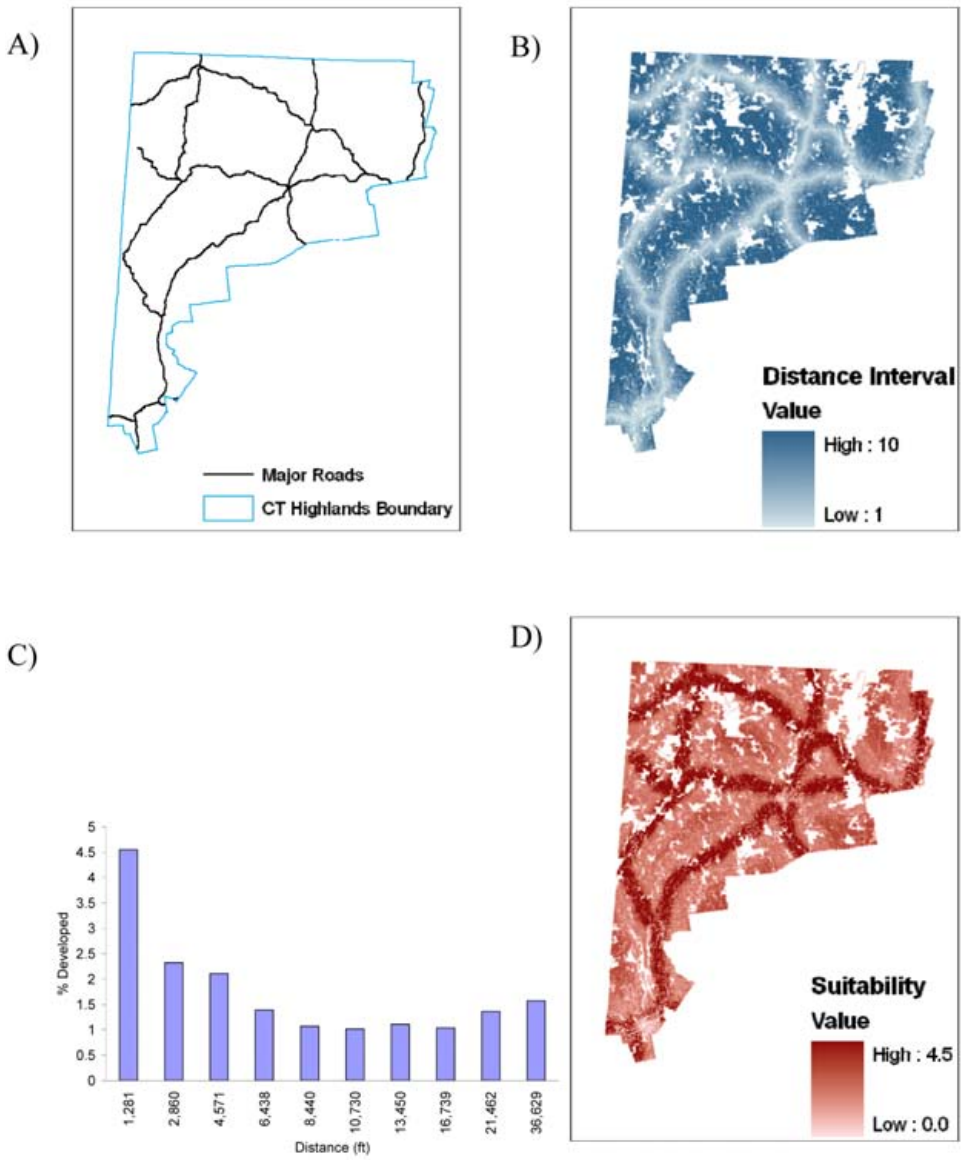


Illustration of operations involved in creation of individual suitability map based on distance from major roads. A) Map of major roads. B) Map of Euclidean distance from major roads classified into intervals. C) Histogram showing percent of cells available for development in each distance interval that were developed between 1985 and 2002. D) Suitability map created by assigning percent developed values in histogram to distance interval map.

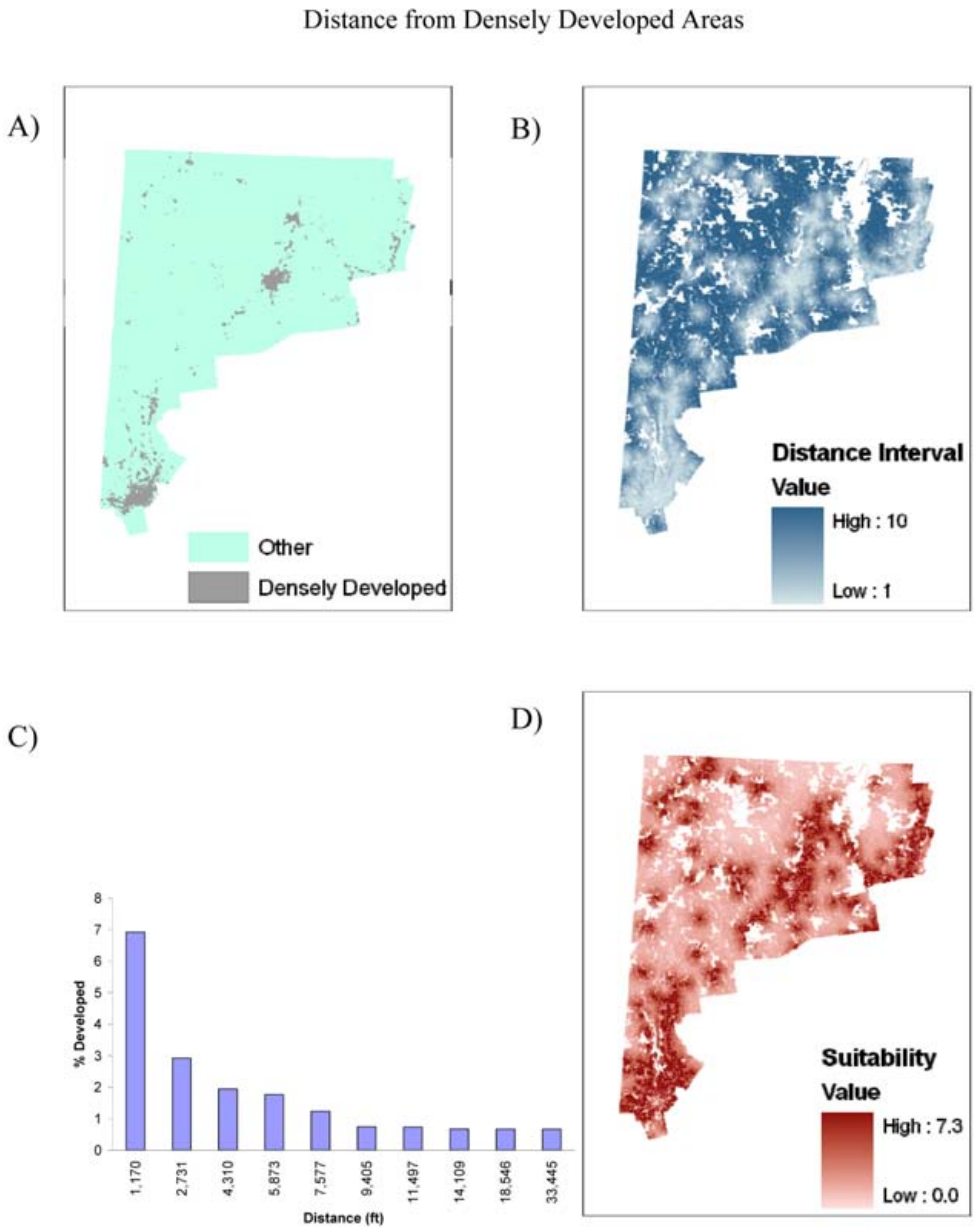


Illustration of operations involved in creation of individual suitability map based on distance from densely developed areas (50% developed within 600 ft radius in 1985). A) Map of densely developed areas (LULC data from 2002) B) Map of Euclidean distance from densely developed areas classified into intervals. C) Histogram showing percent of cells available for development in each distance interval (development data from 1985) that were developed between 1985 and 2002. D) Suitability map created by assigning percent developed values in histogram to distance interval map.

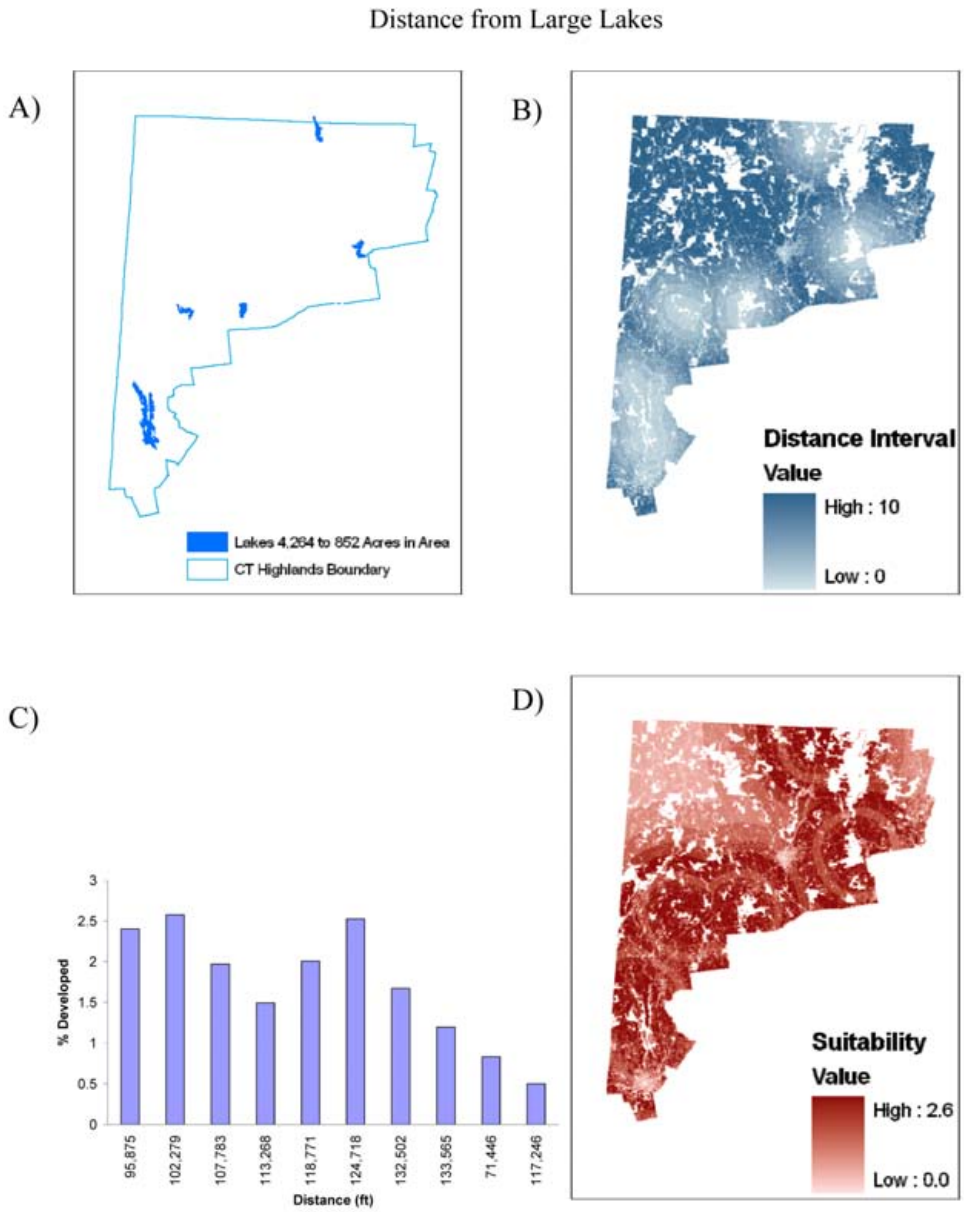


Illustration of operations involved in creation of individual suitability map based on distance from lakes 4,264 to 852 acres in area. A) Map of lakes between 4,264 and 852 acres. B) Map of Euclidean distance from lakes classified into intervals. C) Histogram showing percent of cells available for development in each distance interval that were developed between 1985 and 2002. D) Suitability map created by assigning percent developed values in histogram to distance interval map.

Distance from Other Grasses and Agricultural Lands

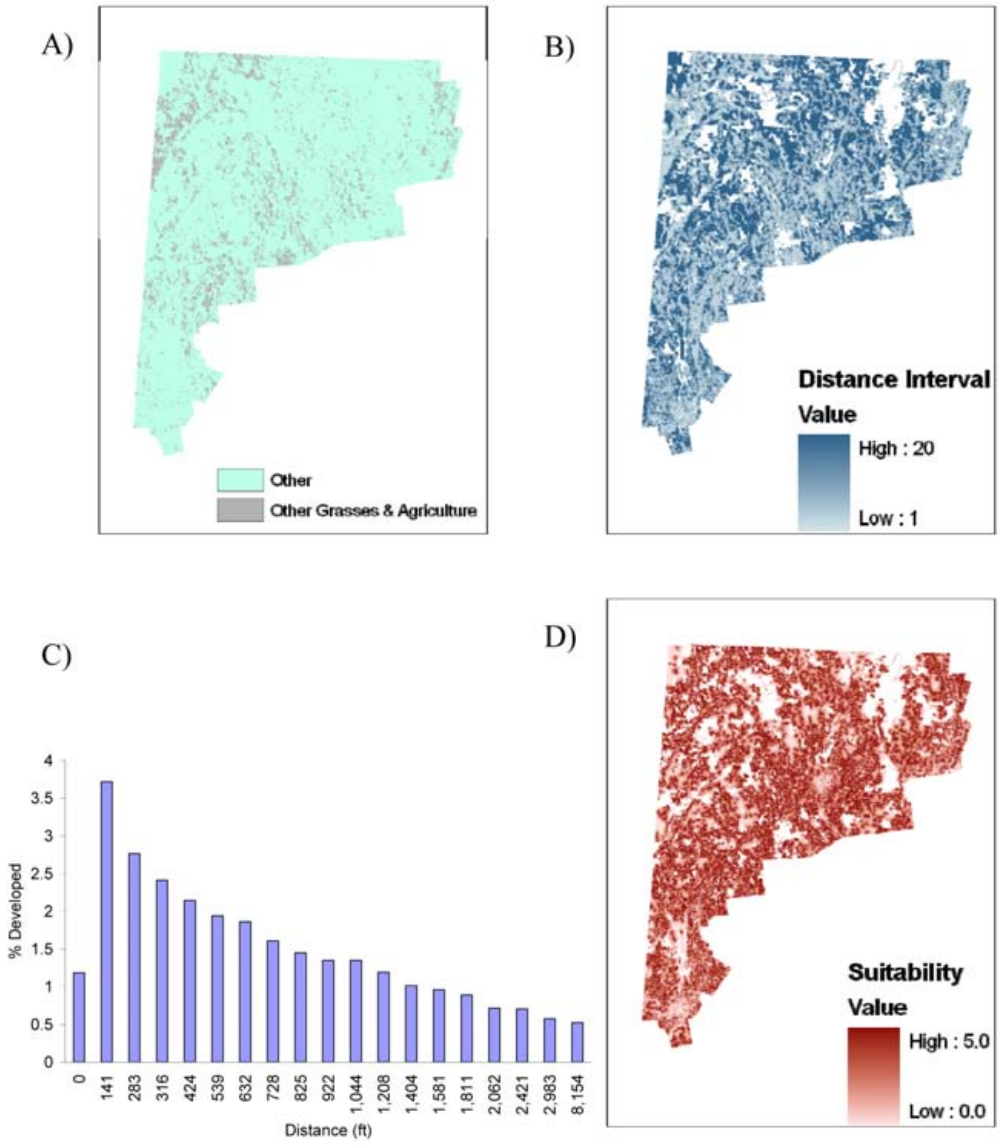


Illustration of operations involved in creation of individual suitability map based on distance from other grasses and agriculture LULC. A) Map of other grasses and agriculture (data from 2002). B) Map of Euclidean distance from other grasses and agriculture classified into intervals. C) Histogram showing percent of cells available for development in each distance interval (LULC data from 1985) that were developed between 1985 and 2002. D) Suitability map created by assigning percent developed values in histogram to distance interval map.

Topographic Slope

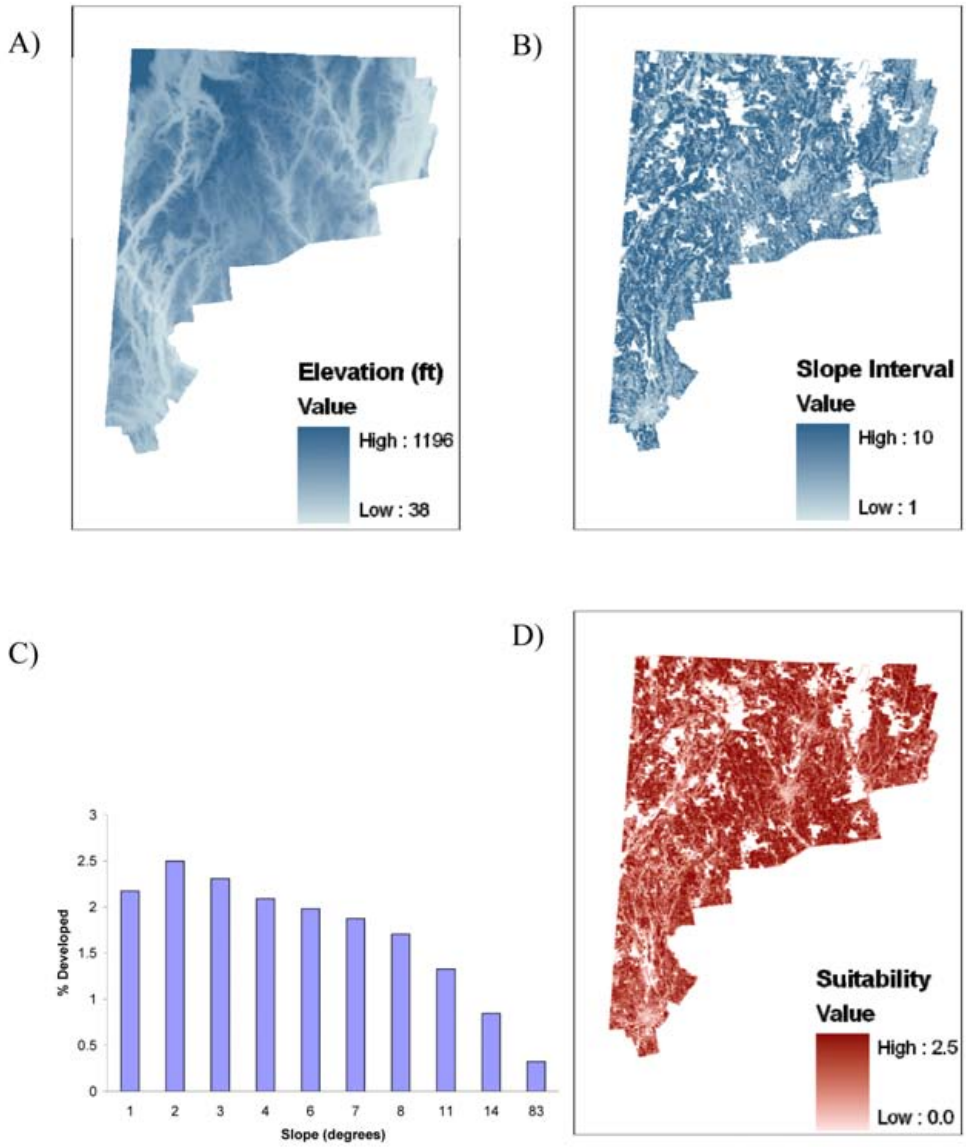
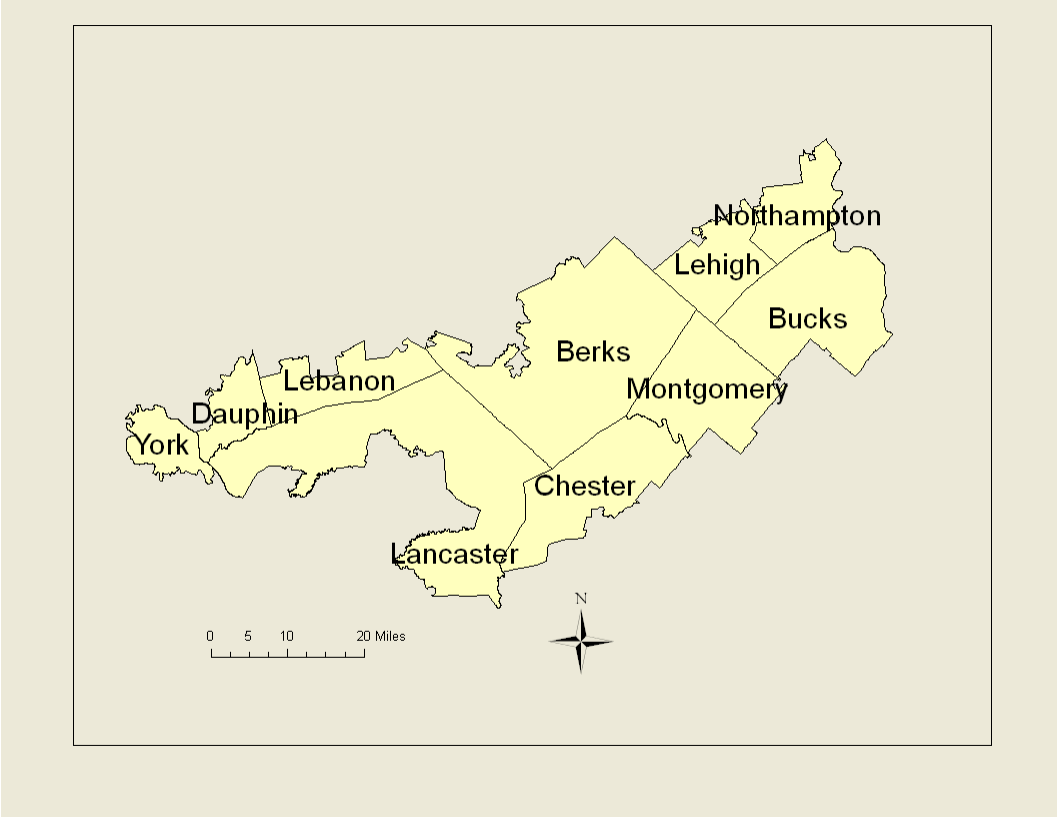


Illustration of operations involved in creation of individual suitability map based on topographic slope. A) Map of elevation. B) Map of slope derived from the elevation map classified into intervals. C) Histogram showing percent of cells available for development in each slope interval that were developed between 1985 and 2002. D) Suitability map created by assigning percent developed values in histogram to slope interval map.

APPENDIX 7: PENNSYLVANIA DATA



Counties in the PA Highlands Region.

Acreage and percent composition of land use/cover types by county in 1992.

	Water		Urban		Barren		Forest		Rangeland		Agriculture		Wetland		Total
County	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**
Berks	2,302	0.7%	43,524	13.7%	2,256	0.7%	127,732	40.3%	0	0.0%	136,224	43.0%	4,767	1.5%	316,805
Bucks	2,099	1.2%	13,678	8.0%	1,964	1.2%	74,829	43.9%	0	0.0%	74,236	43.6%	3,482	2.0%	170,288
Chester	975	0.7%	9,482	6.8%	1,075	0.8%	49,097	35.2%	0	0.0%	76,437	54.7%	2,605	1.9%	139,672
Dauphin	2,675	5.9%	8,597	18.9%	676	1.5%	9,993	22.0%	0	0.0%	22,559	49.7%	875	1.9%	45,374
Lancaster	2,456	0.8%	36,105	11.7%	3,048	1.0%	56,615	18.3%	0	0.0%	206,061	66.7%	4,574	1.5%	308,859
Lebanon	280	0.3%	9,633	11.7%	317	0.4%	27,500	33.5%	0	0.0%	43,990	53.5%	491	0.6%	82,211
Lehigh	257	0.3%	25,969	32.5%	545	0.7%	22,177	27.7%	3	0.0%	29,387	36.8%	1,617	2.0%	79,957
Montgomery	880	0.7%	24,086	18.6%	1,317	1.0%	38,478	29.8%	0	0.0%	62,783	48.6%	1,695	1.3%	129,238
Northampton	522	0.8%	23,059	34.4%	570	0.9%	16,152	24.1%	41	0.1%	25,102	37.5%	1,553	2.3%	66,998
York	665	1.5%	8,254	19.1%	106	0.2%	20,136	46.5%	0	0.0%	13,963	32.3%	167	0.4%	43,290
Total	13,112		202,387		11,874		442,708		44		690,742		21,825		1,382,693

Acreage and percent composition of land use/cover types by county in 2001.

	Water		Urban		Barren		Forest		Rangeland		Agriculture		Wetland		Total
County	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**
Berks	2,554	0.8%	47,929	15.1%	2,404	0.8%	128,681	40.6%	0	0.0%	129,385	40.8%	5,853	1.8%	316,805
Bucks	2,213	1.3%	14,267	8.4%	2,067	1.2%	75,455	44.3%	0	0.0%	71,689	42.1%	4,598	2.7%	170,288
Chester	1,153	0.8%	10,244	7.3%	1,214	0.9%	49,236	35.3%	0	0.0%	74,358	53.2%	3,467	2.5%	139,672
Dauphin	2,887	6.4%	9,361	20.6%	722	1.6%	9,876	21.8%	0	0.0%	21,458	47.3%	1,070	2.4%	45,374
Lancaster	2,742	0.9%	38,365	12.4%	3,292	1.1%	56,545	18.3%	0	0.0%	202,265	65.5%	5,651	1.8%	308,859
Lebanon	324	0.4%	10,411	12.7%	271	0.3%	26,940	32.8%	0	0.0%	43,716	53.2%	549	0.7%	82,211
Lehigh	278	0.3%	27,442	34.3%	575	0.7%	22,510	28.2%	4	0.0%	27,258	34.1%	1,890	2.4%	79,957
Montgomery	958	0.7%	26,147	20.2%	1,383	1.1%	40,620	31.4%	0	0.0%	57,824	44.7%	2,306	1.8%	129,238
Northampton	563	0.8%	24,343	36.3%	609	0.9%	15,750	23.5%	45	0.1%	24,059	35.9%	1,629	2.4%	66,998
York	742	1.7%	8,828	20.4%	57	0.1%	19,112	44.1%	0	0.0%	14,362	33.2%	188	0.4%	43,290
Total	14,413		217,336		12,594		444,725		48		666,375		27,202		1,382,693

Area of urban land by county (in acres and percent coverage of county) in 1992 and 2001 and change during the intervening time period in acres and as a percent of urban land in 1992.

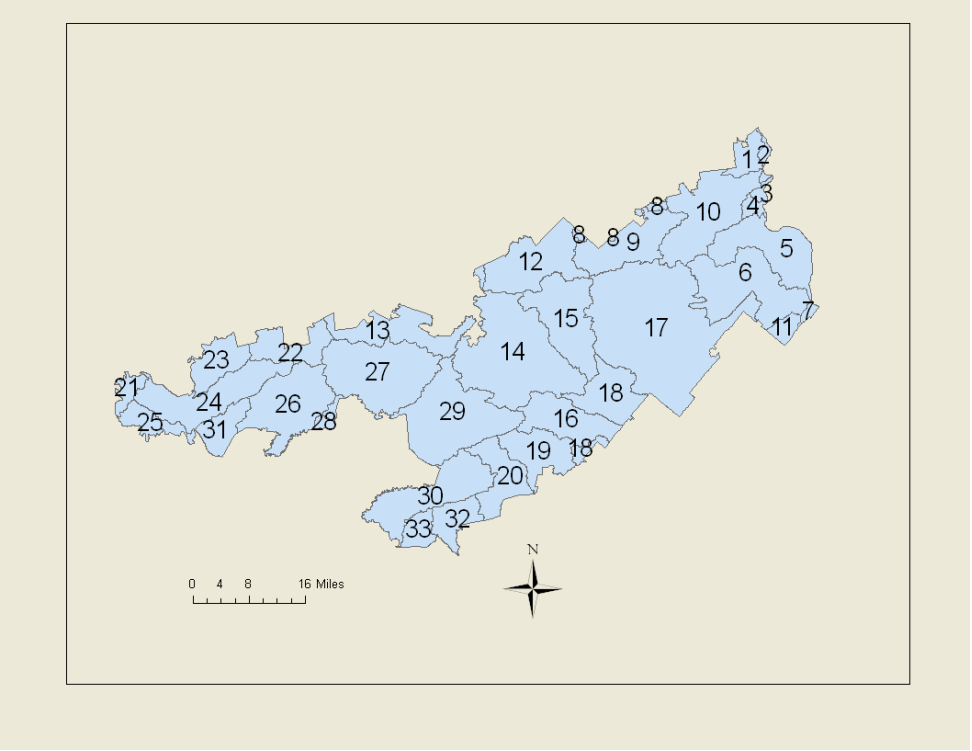
	1992		2001		1992-2001	
County	**Acres**	**% of County**	**Acres**	**% of County**	**Acreage Change**	**Change as % of 1992 Urban**
Berks	43,524	13.7%	47,929	15.1%	4,405	10.1%
Bucks	13,678	8.0%	14,267	8.4%	588	4.3%
Chester	9,482	6.8%	10,244	7.3%	762	8.0%
Dauphin	8,597	18.9%	9,361	20.6%	764	8.9%
Lancaster	36,105	11.7%	38,365	12.4%	2,260	6.3%
Lebanon	9,633	11.7%	10,411	12.7%	777	8.1%
Lehigh	25,969	32.5%	27,442	34.3%	1,472	5.7%
Montgome	24,086	18.6%	26,147	20.2%	2,061	8.6%
Northampt	23,059	34.4%	24,343	36.3%	1,284	5.6%
York	8,254	19.1%	8,828	20.4%	573	6.9%
Total	202,387		217,336		14,948	7.4%

Area of forest by county (in acres and percent coverage of county) in 1992 and 2001 and change during the intervening time period in acres and as a percent of forest in 1992.

	1992		2001		1992-2001	
County	**Acres**	**% of County**	**Acres**	**% of County**	**Acreage Change**	**Change as % of 1992 Forest**
Berks	127,732	40.32%	128,681	40.62%	949	0.7%
Bucks	74,829	43.94%	75,455	44.31%	626	0.8%
Chester	49,097	35.15%	49,236	35.25%	139	0.3%
Dauphin	9,993	22.02%	9,876	21.77%	-117	-1.2%
Lancaster	56,615	18.33%	56,545	18.31%	-70	-0.1%
Lebanon	27,500	33.45%	26,940	32.77%	-560	-2.0%
Lehigh	22,177	27.74%	22,510	28.15%	333	1.5%
Montgome	38,478	29.77%	40,620	31.43%	2,142	5.6%
Northampt	16,152	24.11%	15,750	23.51%	-401	-2.5%
York	20,136	46.51%	19,112	44.15%	-1,023	-5.1%
Total	442,708		444,725		2,017	0.5%

Area of agriculture by county (in acres and percent coverage of county) in 1992 and 2001 and change during the intervening time period in acres and as a percent of agriculture in 1992.

	1992		2001		1992-2001	
County	**Acres**	**% of County**	**Acres**	**% of County**	**Acreage Change**	**Change as % of 1992 Agriculture**
Berks	136,224	43.0%	129,385	40.8%	-6,839	-5.0%
Bucks	74,236	43.6%	71,689	42.1%	-2,548	-3.4%
Chester	76,437	54.7%	74,358	53.2%	-2,079	-2.7%
Dauphin	22,559	49.7%	21,458	47.3%	-1,101	-4.9%
Lancaster	206,061	66.7%	202,265	65.5%	-3,797	-1.8%
Lebanon	43,990	53.5%	43,716	53.2%	-274	-0.6%
Lehigh	29,387	36.8%	27,258	34.1%	-2,129	-7.2%
Montgome	62,783	48.6%	57,824	44.7%	-4,959	-7.9%
Northampt	25,102	37.5%	24,059	35.9%	-1,043	-4.2%
York	13,963	32.3%	14,362	33.2%	399	2.9%
Total	690,742		666,375		-24,367	-3.5%



IUC 11 watersheds intersecting the PA Highlands Region. Names for each numeric ode in the map are in the following table.

Code	HUC 11 Watershed	Code	HUC 11 Watershed
1	Bushkill	18	Lower Schuylkill River
2	Mud Run	19	West Branch Brandywine Creek
3	Delaware River Tributaries	20	East Branch Brandywine Creek
4	Frya Run	21	Yellow Breeches Creek
5	Tinicum and Cooks Creeks	22	Quittapahilla Creek
6	Tohickon Creek	23	Swatara Creek
7	Paunnacussing Creek	24	Conewago Creek, East Bank Susquehanna River
8	Jordan Creek	25	Conewago Creek, West Bank Susquehanna River
9	Little Lehigh Creek	26	Chickies Creek
10	Lower Lehigh River	27	Cocalico Creek
11	North Branch Neshaminy Creek	28	Little Conestoga Creek
12	Maiden Creek	29	Conestoga River
13	Tulpehocken Creek	30	Pequea Creek
14	Middle Schuylkill River	31	Susquehanna River Tributaries
15	Manatawny Creek	32	East Branch Octoraro Creek
16	French Creek	33	West Branch Octoraro Creek
17	Perkiomen Creek		

Acreage and percent composition of land use/cover types by HUC 11 watershed in 1992.

	Water		Urban		Barren		Forest		Rangeland		Agriculture		Wetland		Total
Watershed	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**
Bushkill	11	0.1%	5,670	42.4%	13	0.1%	864	6.5%	10	0.1%	6,620	49.5%	186	1.4%	13,375
Mud Run	124	3.3%	1,290	34.1%	26	0.7%	711	18.8%	3	0.1%	1,486	39.3%	142	3.8%	3,782
Delaware River Tributaries	75	2.4%	151	4.8%	25	0.8%	1,539	49.4%	0	0.0%	1,250	40.1%	75	2.4%	3,114
Frya Run	35	0.7%	121	2.4%	33	0.7%	2,115	42.9%	0	0.0%	2,583	52.3%	48	1.0%	4,936
Tinicum and Cooks Creeks	589	1.1%	1,180	2.2%	765	1.4%	26,858	49.8%	0	0.0%	23,126	42.9%	1,381	2.6%	53,898
Tohickon Creek	1,359	1.9%	5,632	7.9%	786	1.1%	32,854	46.1%	0	0.0%	29,368	41.2%	1,289	1.8%	71,288
Paunnacussing Creek	23	0.9%	28	1.1%	22	0.9%	1,200	47.3%	0	0.0%	1,193	47.0%	73	2.9%	2,539
Jordan Creek	6	0.2%	2,305	60.1%	4	0.1%	125	3.3%	0	0.0%	1,393	36.3%	0	0.0%	3,834
Little Lehigh Creek	96	0.2%	16,293	35.0%	130	0.3%	13,883	29.8%	0	0.0%	15,740	33.8%	385	0.8%	46,527
Lower Lehigh River	454	0.7%	24,372	35.6%	768	1.1%	17,376	25.4%	31	0.0%	23,367	34.1%	2,142	3.1%	68,511
North Branch Neshaminy Creek	2	0.0%	1,152	15.1%	76	1.0%	1,595	20.9%	0	0.0%	4,756	62.3%	48	0.6%	7,629
Maiden Creek	1,319	2.4%	8,021	14.5%	198	0.4%	14,693	26.5%	0	0.0%	31,008	55.9%	223	0.4%	55,462
Tulpehocken Creek	99	0.2%	7,507	17.5%	97	0.2%	12,599	29.3%	0	0.0%	22,547	52.4%	167	0.4%	43,016
Middle Schuylkill River	803	0.7%	23,989	19.8%	883	0.7%	52,368	43.3%	0	0.0%	40,534	33.5%	2,377	2.0%	120,954
Manatawny Creek	61	0.1%	3,149	5.4%	576	1.0%	24,279	41.4%	0	0.0%	29,448	50.3%	1,067	1.8%	58,581
French Creek	73	0.2%	1,062	2.6%	239	0.6%	19,558	48.7%	0	0.0%	18,519	46.1%	702	1.7%	40,153
Perkiomen Creek	767	0.4%	23,779	12.7%	2,072	1.1%	64,911	34.8%	0	0.0%	92,557	49.6%	2,689	1.4%	186,776
Lower Schuylkill River	357	0.9%	9,579	23.2%	101	0.2%	10,825	26.2%	0	0.0%	19,854	48.1%	534	1.3%	41,250
West Branch Brandywine Creek	621	1.8%	1,632	4.8%	234	0.7%	11,365	33.4%	0	0.0%	19,462	57.2%	691	2.0%	34,006
East Branch Brandywine Creek	50	0.2%	2,089	6.4%	431	1.3%	9,735	29.7%	0	0.0%	19,762	60.3%	699	2.1%	32,766
Yellow Breeches Creek	29	0.3%	2,230	24.6%	19	0.2%	3,760	41.6%	0	0.0%	2,980	32.9%	29	0.3%	9,046
Quittapahilla Creek	134	0.5%	4,708	17.0%	71	0.3%	5,311	19.1%	0	0.0%	17,497	63.1%	16	0.1%	27,737
Swatara Creek	148	0.6%	6,885	26.3%	274	1.0%	6,388	24.4%	0	0.0%	12,115	46.3%	374	1.4%	26,184

Conewago Creek, East Bank Susquehanna River	3,087	5.3%	7,844	13.6%	662	1.1%	21,580	37.3%	0	0.0%	23,724	41.0%	906	1.6%	57,803
Conewago Creek, West Bank Susquehanna River	150	0.9%	2,066	12.5%	42	0.3%	8,365	50.7%	0	0.0%	5,753	34.9%	109	0.7%	16,485
Chickies Creek	12	0.0%	7,143	11.4%	340	0.5%	10,254	16.3%	0	0.0%	44,595	71.1%	396	0.6%	62,739
Cocalico Creek	529	0.6%	12,523	15.0%	545	0.7%	28,193	33.9%	0	0.0%	40,340	48.5%	1,129	1.4%	83,259
Little Conestoga Creek	1	0.0%	768	27.6%	0	0.0%	16	0.6%	0	0.0%	1,995	71.7%	2	0.1%	2,782
Conestoga River	71	0.1%	10,653	11.9%	1,353	1.5%	22,300	24.9%	0	0.0%	53,249	59.5%	1,903	2.1%	89,529
Pequea Creek	23	0.0%	4,029	6.9%	759	1.3%	9,519	16.4%	0	0.0%	42,584	73.2%	1,238	2.1%	58,152
Susquehanna River Tributaries	1,819	9.2%	2,905	14.7%	87	0.4%	2,205	11.2%	0	0.0%	12,492	63.2%	259	1.3%	19,768
East Branch Octoraro Creek	3	0.0%	1,075	5.3%	153	0.8%	3,213	15.8%	0	0.0%	15,469	76.2%	377	1.9%	20,291
West Branch Octoraro Creek	1	0.0%	195	1.5%	76	0.6%	1,442	11.4%	0	0.0%	10,846	85.4%	137	1.1%	12,695
Total	12,931		202,023		11,860		442,002		44		688,211		21,795		1,378,867

	Water		Urban		Barren		Forest		Rangeland		Agriculture		Wetland		Total
Watershed	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**
Bushkill	18	0.1%	5,849	43.7%	4	0.0%	680	5.1%	11	0.1%	6,765	50.6%	49	0.4%	13,375
Mud Run	141	3.7%	1,328	35.1%	17	0.4%	649	17.1%	3	0.1%	1,552	41.0%	93	2.5%	3,782
Delaware River Tributaries	88	2.8%	149	4.8%	26	0.8%	1,515	48.6%	0	0.0%	1,195	38.4%	141	4.5%	3,114
Frya Run	41	0.8%	121	2.5%	35	0.7%	2,049	41.5%	0	0.0%	2,619	53.1%	70	1.4%	4,936
Tinicum and Cooks Creeks	652	1.2%	1,095	2.0%	808	1.5%	26,763	49.7%	0	0.0%	22,737	42.2%	1,843	3.4%	53,898
Tohickon Creek	1,398	2.0%	5,831	8.2%	844	1.2%	33,090	46.4%	0	0.0%	28,326	39.7%	1,799	2.5%	71,288
Paunnacussing Creek	26	1.0%	28	1.1%	24	0.9%	1,206	47.5%	0	0.0%	1,158	45.6%	96	3.8%	2,539
Jordan Creek	8	0.2%	2,348	61.2%	0	0.0%	101	2.6%	0	0.0%	1,377	35.9%	0	0.0%	3,834
Little Lehigh Creek	108	0.2%	17,389	37.4%	127	0.3%	13,635	29.3%	0	0.0%	14,829	31.9%	439	0.9%	46,527
Lower Lehigh River	465	0.7%	25,844	37.7%	837	1.2%	17,483	25.5%	34	0.0%	21,359	31.2%	2,488	3.6%	68,511
North Branch Neshaminy Creek	1	0.0%	1,338	17.5%	48	0.6%	1,552	20.3%	0	0.0%	4,641	60.8%	49	0.6%	7,629
Maiden Creek	1,408	2.5%	8,716	15.7%	126	0.2%	14,458	26.1%	0	0.0%	30,506	55.0%	248	0.4%	55,462
Tulpehocken Creek	134	0.3%	8,258	19.2%	60	0.1%	12,102	28.1%	0	0.0%	22,278	51.8%	185	0.4%	43,016
Middle Schuylkill River	904	0.7%	26,390	21.8%	980	0.8%	52,838	43.7%	0	0.0%	36,815	30.4%	3,026	2.5%	120,954
Manatawny Creek	64	0.1%	3,532	6.0%	673	1.1%	24,832	42.4%	0	0.0%	28,157	48.1%	1,323	2.3%	58,581
French Creek	98	0.2%	1,090	2.7%	272	0.7%	19,645	48.9%	0	0.0%	18,186	45.3%	862	2.1%	40,153
Perkiomen Creek	873	0.5%	25,410	13.6%	2,209	1.2%	68,078	36.4%	0	0.0%	86,842	46.5%	3,363	1.8%	186,776
Lower Schuylkill River	397	1.0%	10,606	25.7%	116	0.3%	10,995	26.7%	0	0.0%	18,263	44.3%	873	2.1%	41,250
West Branch Brandywine Creek	646	1.9%	1,749	5.1%	269	0.8%	11,581	34.1%	0	0.0%	18,747	55.1%	1,015	3.0%	34,006

East Branch Brandywine Creek	132	0.4%	2,230	6.8%	474	1.4%	9,742	29.7%	0	0.0%	19,353	59.1%	834	2.5%	32,766
Yellow Breeches Creek	35	0.4%	2,356	26.1%	4	0.0%	3,504	38.7%	0	0.0%	3,112	34.4%	34	0.4%	9,046
Quittapahilla Creek	147	0.5%	5,127	18.5%	39	0.1%	4,810	17.3%	0	0.0%	17,597	63.4%	17	0.1%	27,737
Swatara Creek	185	0.7%	7,626	29.1%	292	1.1%	6,153	23.5%	0	0.0%	11,492	43.9%	436	1.7%	26,184
Conewago Creek, East Bank Susquehanna River	3,378	5.8%	8,353	14.5%	678	1.2%	21,660	37.5%	0	0.0%	22,625	39.1%	1,109	1.9%	57,803
Conewago Creek, West Bank Susquehanna River	185	1.1%	2,199	13.3%	42	0.3%	8,015	48.6%	0	0.0%	5,921	35.9%	122	0.7%	16,485
Chickies Creek	17	0.0%	7,601	12.1%	358	0.6%	10,437	16.6%	0	0.0%	43,827	69.9%	499	0.8%	62,739
Cocalico Creek	594	0.7%	13,305	16.0%	577	0.7%	28,246	33.9%	0	0.0%	39,212	47.1%	1,325	1.6%	83,259
Little Conestoga Creek	12	0.4%	856	30.8%	0	0.0%	9	0.3%	0	0.0%	1,903	68.4%	2	0.1%	2,782
Conestoga River	98	0.1%	11,605	13.0%	1,467	1.6%	22,285	24.9%	0	0.0%	51,838	57.9%	2,236	2.5%	89,529
Pequea Creek	25	0.0%	4,192	7.2%	831	1.4%	9,199	15.8%	0	0.0%	42,334	72.8%	1,572	2.7%	58,152
Susquehanna River Tributaries	1,940	9.8%	3,059	15.5%	94	0.5%	2,186	11.1%	0	0.0%	12,097	61.2%	393	2.0%	19,768
East Branch Octoraro Creek	2	0.0%	1,158	5.7%	169	0.8%	3,166	15.6%	0	0.0%	15,329	75.5%	467	2.3%	20,291
West Branch Octoraro Creek	0	0.0%	205	1.6%	86	0.7%	1,390	11.0%	0	0.0%	10,859	85.5%	156	1.2%	12,695
Total	14,220		216,945		12,586		444,054		48		663,851		27,162		1,378,867

Area of urban land by HUC 11 watershed (in acres and percent coverage of watershed) in 1992 and 2001 and change during the intervening time period in acres and as a percent of urban land in 1992.

	1992		2001		1992-2001	
Watershed	**Acres**	**% of County**	**Acres**	**% of County**	**Acreage Change**	**Change as % of 1992 Urban**
Bushkill	5,670	42.4%	5,849	43.7%	178	3.1%
Mud Run	1,290	34.1%	1,328	35.1%	38	2.9%
Delaware River Tributaries	151	4.8%	149	4.8%	-2	-1.3%
Frya Run	121	2.4%	121	2.5%	1	0.6%
Tinicum and Cooks Creeks	1,180	2.2%	1,095	2.0%	-85	-7.2%
Tohickon Creek	5,632	7.9%	5,831	8.2%	199	3.5%
Paunnacussing Creek	28	1.1%	28	1.1%	1	3.2%
Jordan Creek	2,305	60.1%	2,348	61.2%	43	1.9%
Little Lehigh Creek	16,293	35.0%	17,389	37.4%	1,096	6.7%
Lower Lehigh River	24,372	35.6%	25,844	37.7%	1,472	6.0%
North Branch Neshaminy Creek	1,152	15.1%	1,338	17.5%	186	16.2%
Maiden Creek	8,021	14.5%	8,716	15.7%	695	8.7%
Tulpehocken Creek	7,507	17.5%	8,258	19.2%	751	10.0%
Middle Schuylkill River	23,989	19.8%	26,390	21.8%	2,402	10.0%
Manatawny Creek	3,149	5.4%	3,532	6.0%	383	12.2%
French Creek	1,062	2.6%	1,090	2.7%	28	2.7%
Perkiomen Creek	23,779	12.7%	25,410	13.6%	1,631	6.9%
Lower Schuylkill River	9,579	23.2%	10,606	25.7%	1,027	10.7%
West Branch Brandywine Creek	1,632	4.8%	1,749	5.1%	117	7.2%
East Branch Brandywine Creek	2,089	6.4%	2,230	6.8%	141	6.8%
Yellow Breeches Creek	2,230	24.6%	2,356	26.1%	127	5.7%
Quittapahilla Creek	4,708	17.0%	5,127	18.5%	419	8.9%
Swatara Creek	6,885	26.3%	7,626	29.1%	741	10.8%
Conewago Creek, East Bank Susquehanna River	7,844	13.6%	8,353	14.5%	510	6.5%
Conewago Creek, West Bank Susquehanna River	2,066	12.5%	2,199	13.3%	133	6.5%
Chickies Creek	7,143	11.4%	7,601	12.1%	459	6.4%
Cocalico Creek	12,523	15.0%	13,305	16.0%	781	6.2%
Little Conestoga Creek	768	27.6%	856	30.8%	89	11.6%
Conestoga River	10,653	11.9%	11,605	13.0%	952	8.9%
Pequea Creek	4,029	6.9%	4,192	7.2%	163	4.1%
Susquehanna River Tributaries	2,905	14.7%	3,059	15.5%	153	5.3%
East Branch Octoraro Creek	1,075	5.3%	1,158	5.7%	83	7.7%
West Branch Octoraro Creek	195	1.5%	205	1.6%	10	5.4%
Total	202,023		216,945		14,922	7.4%

Area of forest by HUC 11 watershed (in acres and percent coverage of forest) in 1992 and 2001 and change during the intervening time period in acres and as a percent of forest in 1992.

	1992		2001		1992-2001	
Watershed	**Acres**	**% of County**	**Acres**	**% of County**	**Acreage Change**	**Change as % of 1992 Forest**
Bushkill	864	6.5%	680	5.1%	-184	-21.3%
Mud Run	711	18.8%	649	17.1%	-62	-8.8%
Delaware River Tributaries	1,539	49.4%	1,515	48.6%	-24	-1.6%
Frya Run	2,115	42.9%	2,049	41.5%	-66	-3.1%
Tinicum and Cooks Creeks	26,858	49.8%	26,763	49.7%	-95	-0.4%
Tohickon Creek	32,854	46.1%	33,090	46.4%	237	0.7%
Paunnacussing Creek	1,200	47.3%	1,206	47.5%	6	0.5%
Jordan Creek	125	3.3%	101	2.6%	-25	-19.7%
Little Lehigh Creek	13,883	29.8%	13,635	29.3%	-247	-1.8%
Lower Lehigh River	17,376	25.4%	17,483	25.5%	107	0.6%
North Branch Neshaminy Creek	1,595	20.9%	1,552	20.3%	-43	-2.7%
Maiden Creek	14,693	26.5%	14,458	26.1%	-235	-1.6%
Tulpehocken Creek	12,599	29.3%	12,102	28.1%	-498	-4.0%
Middle Schuylkill River	52,368	43.3%	52,838	43.7%	470	0.9%
Manatawny Creek	24,279	41.4%	24,832	42.4%	553	2.3%
French Creek	19,558	48.7%	19,645	48.9%	87	0.4%
Perkiomen Creek	64,911	34.8%	68,078	36.4%	3,167	4.9%
Lower Schuylkill River	10,825	26.2%	10,995	26.7%	169	1.6%
West Branch Brandywine Creek	11,365	33.4%	11,581	34.1%	215	1.9%
East Branch Brandywine Creek	9,735	29.7%	9,742	29.7%	7	0.1%
Yellow Breeches Creek	3,760	41.6%	3,504	38.7%	-256	-6.8%
Quittapahilla Creek	5,311	19.1%	4,810	17.3%	-501	-9.4%
Swatara Creek	6,388	24.4%	6,153	23.5%	-236	-3.7%
Conewago Creek, East Bank Susquehanna River	21,580	37.3%	21,660	37.5%	80	0.4%
Conewago Creek, West Bank Susquehanna River	8,365	50.7%	8,015	48.6%	-350	-4.2%
Chickies Creek	10,254	16.3%	10,437	16.6%	183	1.8%
Cocalico Creek	28,193	33.9%	28,246	33.9%	53	0.2%
Little Conestoga Creek	16	0.6%	9	0.3%	-7	-42.5%
Conestoga River	22,300	24.9%	22,285	24.9%	-14	-0.1%
Pequea Creek	9,519	16.4%	9,199	15.8%	-320	-3.4%
Susquehanna River Tributaries	2,205	11.2%	2,186	11.1%	-20	-0.9%
East Branch Octoraro Creek	3,213	15.8%	3,166	15.6%	-47	-1.5%
West Branch Octoraro Creek	1,442	11.4%	1,390	11.0%	-51	-3.5%
Total	442,002		444,054		2,052	0.5%

Area of agriculture by HUC 11 watershed (in acres and percent coverage of agriculture) in 1992 and 2001 and change during the intervening time period in acres and as a percent of agriculture in 1992.

	1992		2001		1992-2001	
Watershed	**Acres**	**% of County**	**Acres**	**% of County**	**Acreage Change**	**Change as % of 1992 Agriculture**
Bushkill	6,620	49.5%	6,765	50.6%	145	2.2%
Mud Run	1,486	39.3%	1,552	41.0%	66	4.4%
Delaware River Tributaries	1,250	40.1%	1,195	38.4%	-55	-4.4%
Frya Run	2,583	52.3%	2,619	53.1%	36	1.4%
Tinicum and Cooks Creeks	23,126	42.9%	22,737	42.2%	-388	-1.7%
Tohickon Creek	29,368	41.2%	28,326	39.7%	-1,042	-3.5%
Paunnacussing Creek	1,193	47.0%	1,158	45.6%	-34	-2.9%
Jordan Creek	1,393	36.3%	1,377	35.9%	-17	-1.2%
Little Lehigh Creek	15,740	33.8%	14,829	31.9%	-911	-5.8%
Lower Lehigh River	23,367	34.1%	21,359	31.2%	-2,007	-8.6%
North Branch Neshaminy Creek	4,756	62.3%	4,641	60.8%	-116	-2.4%
Maiden Creek	31,008	55.9%	30,506	55.0%	-502	-1.6%
Tulpehocken Creek	22,547	52.4%	22,278	51.8%	-269	-1.2%
Middle Schuylkill River	40,534	33.5%	36,815	30.4%	-3,718	-9.2%
Manatawny Creek	29,448	50.3%	28,157	48.1%	-1,291	-4.4%
French Creek	18,519	46.1%	18,186	45.3%	-333	-1.8%
Perkiomen Creek	92,557	49.6%	86,842	46.5%	-5,715	-6.2%
Lower Schuylkill River	19,854	48.1%	18,263	44.3%	-1,591	-8.0%
West Branch Brandywine Creek	19,462	57.2%	18,747	55.1%	-715	-3.7%
East Branch Brandywine Creek	19,762	60.3%	19,353	59.1%	-409	-2.1%
Yellow Breeches Creek	2,980	32.9%	3,112	34.4%	132	4.4%
Quittapahilla Creek	17,497	63.1%	17,597	63.4%	100	0.6%
Swatara Creek	12,115	46.3%	11,492	43.9%	-623	-5.1%
Conewago Creek, East Bank Susquehanna River	23,724	41.0%	22,625	39.1%	-1,100	-4.6%
Conewago Creek, West Bank Susquehanna River	5,753	34.9%	5,921	35.9%	169	2.9%
Chickies Creek	44,595	71.1%	43,827	69.9%	-768	-1.7%
Cocalico Creek	40,340	48.5%	39,212	47.1%	-1,128	-2.8%
Little Conestoga Creek	1,995	71.7%	1,903	68.4%	-92	-4.6%
Conestoga River	53,249	59.5%	51,838	57.9%	-1,411	-2.6%
Pequea Creek	42,584	73.2%	42,334	72.8%	-251	-0.6%
Susquehanna River Tributaries	12,492	63.2%	12,097	61.2%	-395	-3.2%
East Branch Octoraro Creek	15,469	76.2%	15,329	75.5%	-140	-0.9%
West Branch Octoraro Creek	10,846	85.4%	10,859	85.5%	13	0.1%
Total	688,211		663,851		-24,360	-3.5%

[Pennsylvania] Potential drivers tested with stratification by county ranked in decreasing order of receiver operating characteristic statistic (ROC). An ROC of 1 indicates a perfect fit to the validation data while a 0.5 indicates a random fit. Number of quantiles indicates the grouping scheme that gave the best ROC for each driver (10, 20, 30, 50, or 100 quantile classes). N/A indicates categorical data not grouped.

Driver name (county-stratified)	Number of quantiles	ROC
Density of 1992 development in a 200 ft radius	20	0.937359
Minimum distance from urban land use/cover class (1992)	30	0.932307
Density of 1992 development in a 100 ft radius	10	0.902603
Minimum distance from densely developed areas (50% developed within 600 ft radius in 1995)	30	0.876645
Minimum distance from grid cells with greater than 34% impervious surface coverage in 1985	50	0.844356
Size of patch of contiguous land use/cover (1992)	100	0.833038
Minimum distance from edge of patch of contiguous land use/cover (1992)	20	0.81927
Density of 1992 development in a 2,500 ft radius	20	0.800767
Density of 1992 development in a 2,400 ft radius	20	0.800119
Density of 1992 development in a 2,300 ft radius	20	0.799628
Density of 1992 development in a 2,200 ft radius	20	0.798453
Density of 1992 development in a 2,100 ft radius	20	0.796394
Density of 1992 development in a 2,000 ft radius	10	0.794215
Density of 1992 development in a 1,900 ft radius	10	0.792921
Density of 1992 development in a 1,800 ft radius	10	0.791602
Minimum distance from urban area	50	0.788301
Density of 1992 development in a 1,600 ft radius	10	0.788132
Density of 1992 development in a 1,700 ft radius	10	0.787752
Percentage of houses that have 4+ bedrooms	100	0.787407
Density of 1992 development in a 1,500 ft radius	10	0.786323
Percent of people 18 and older who have had one or more years of college	100	0.786199

Number of people in construction	100	0.785885
Percent of population under age of 18	100	0.783547
Density of 1992 development in a 1,400 ft radius	10	0.783528
Minimum distance from state or local road	20	0.779891
Minimum distance from state, local, or unpaved road	20	0.779262
Commuting distance from employment base	100	0.779015
Populations ages 45 to 64	100	0.778672
Number of people working in service occupations	100	0.777483
Density of 1992 development in a 1,100 ft radius	20	0.777111
Density of 1992 development in a 1,000 ft radius	30	0.775057
Percent of population over age 65	100	0.774505
Number of people 16 and over in the labor force	100	0.774445
Density of 1992 development in a 1,300 ft radius	20	0.774155
Median household income	100	0.774146
Median value non-condo housing unit	100	0.773648
Populations ages 65 and over	100	0.773381
Housing units	100	0.773323
Density of 1992 development in a 900 ft radius	10	0.772397
Populations ages 30 to 44	100	0.772083
Total population	100	0.770248
Density of 1992 development in a 800 ft radius	10	0.768027
Populations ages 18 to 29	100	0.766045
Density of 1992 development in a 700 ft radius	10	0.762595
Population density	10	0.761537
Density of 1992 development in a 600 ft radius	20	0.759245
Population density ages 45 to 64	10	0.758811
Minimum distance from city center	50	0.757919

Minimum distance from box store		100	0.757248
Name of bedrock geologic unit.	N/A		0.756009
Density of 1992 development in a 500 ft radius		100	0.754824
Housing density		10	0.75401
Size of patch of contiguous land use/cover (1986)		30	0.753862
Minimum distance from interstate exits		100	0.752994
Land use/cover (1992)	N/A		0.751789
Minimum distance from active railroad lines		100	0.751599
Percentage of the civilian labor force that is unemployed		100	0.75034
Minimum distance from state road		30	0.750106
Density of 1992 development in a 400 ft radius		20	0.748315
Dominant lithology, volumetrically, in bedrock unit	N/A		0.74712
Population density ages 30 to 44		50	0.744722
Millrate		100	0.74312
Density of 1992 development in a 300 ft radius		50	0.74308
Minimum distance from scenic river		100	0.741594
Minimum distance from swamp, marsh, lake, pond, or reservoir larger than 25 acres		100	0.740589
Minimum distance from facilities reporting toxic releases		100	0.740167
Minimum distance from wetland land use/cover class (1992)		100	0.739587
Minimum distance from lakes and ponds of size 13 to132 acres		100	0.739488
Elevation		100	0.739364
Density of people working in service occupations		10	0.738616
Minimum distance from lakes and ponds of size 9 to132 acres		100	0.738314
Population density ages 18 to 29		20	0.736793
Population density ages under 18		10	0.73554
Minimum distance from lakes and ponds of size 33 to132 acres		100	0.735538
Construction labor force density		10	0.735485

Percent in poverty		100	0.735157
Minimum distance from lakes and ponds of size 25 to132 acres		100	0.733699
Minimum distance from swamp, marsh, lake, pond, or reservoir larger than 25 acres(high resolution map)		100	0.733699
Per capita income		100	0.733411
Minimum distance from lakes and ponds of size 58 to132 acres		100	0.728798
Minimum distance from local road		20	0.728292
Minimum distance from local or unpaved road		20	0.727914
Minimum distance from rangeland land use/cover class (1992)		100	0.726262
Population density ages over 65		10	0.723434
Minimum distance from forest land use/cover class (1992)		50	0.71882
Origin of surficial material	N/A		0.714983
Minimum distance from lakes and ponds of size 3 to132 acres		100	0.711775
Minimum distance from unpaved road		100	0.711342
Minimum distance from lakes and ponds of size 1 to132 acres		100	0.707851
Minimum distance from inactive railroad lines		100	0.707125
Minimum distance from lakes and ponds of size 5 to132 acres		100	0.705204
Minimum distance from barren land use/cover class (1992)		100	0.702763
Minimum distance from major river		10	0.701293
Minimum distance from private school		100	0.697041
Percent impervious surface cover within grid cells in 1985		10	0.695676
Topographic slope		20	0.680964
Maximum value for the range in depth to bedrock	N/A		0.680546
Surface soil texture	N/A		0.668538
Minimum value for the range in depth to bedrock	N/A		0.667064
Minimum distance from lake and pond		50	0.666275
Minimum distance from lake and pond larger than 25 acres		50	0.666275
Minimum distance from reservoir		50	0.666275

Minimum distance from swamp or marsh		50	0.666275
Minimum distance from swamp, marsh, lake, pond, or reservoir		50	0.666275
Minimum distance from agriculture land use/cover class (1992)		10	0.66542
Minimum distance from lakes and ponds of size less than 1 to132 acres		20	0.657461
Minimum distance from lakes or ponds (high resolution map)		20	0.654914
Minimum distance from lakes or ponds larger than 25 acres (high resolution map)		20	0.654914
Minimum distance from reservoir (high resolution map)		20	0.654914
Minimum distance from swamp or marsh (high resolution map)		20	0.654914
Minimum distance from swamp, marsh, lake, pond, or reservoir (high resolution map)		20	0.654914
Soil drainage class	N/A		0.654156
Maximum value for the range in depth to the seasonally high water table	N/A		0.652934
Hydrologic group	N/A		0.652573
Minimum value for the range in depth to the seasonally high water table	N/A		0.648726
Minimum distance from canal or ditch		30	0.647718
Minimum distance from stream or river		30	0.647718
Minimum distance from stream, river, canal, or ditch		30	0.647718
Minimum distance from canal or ditch (high resolution map)		20	0.646961
Minimum distance from canal, ditch, stream, or river (high resolution map)		20	0.646961
Minimum distance from stream or river (high resolution map)		20	0.646961
Farmland soil classification	N/A		0.641839
Topographic aspect		10	0.640383
Size of scenic view		30	0.640298

[Pennsylvania] Potential drivers tested without stratification by county ranked in decreasing order of receiver operating characteristic statistic (ROC). An ROC of 1 indicates a perfect fit to the validation data while a 0.5 indicates a random fit. Number of quantiles indicates the grouping scheme that gave the best ROC for each driver (10, 20, 30, 50, or 100 quantile classes). N/A indicates categorical data not grouped.

Driver name (non-stratified)	Number of quantiles	ROC
Density of 1992 development in a 200 ft radius	20	0.934966
Minimum distance from urban land use/cover class (1992)	100	0.92014
Density of 1992 development in a 100 ft radius	10	0.891188
Minimum distance from densely developed areas (50% developed within 600 ft radius in 1995)	100	0.872455
Minimum distance from grid cells with greater than 34% impervious surface coverage in 1985	10	0.832312
Size of patch of contiguous land use/cover (1992)	100	0.798416
Minimum distance from edge of patch of contiguous land use/cover (1992)	20	0.786847
Density of 1992 development in a 2,500 ft radius	100	0.782692
Density of 1992 development in a 2,400 ft radius	50	0.780922
Density of 1992 development in a 2,300 ft radius	100	0.779178
Density of 1992 development in a 2,200 ft radius	100	0.777213
Density of 1992 development in a 2,100 ft radius	100	0.774041
Density of 1992 development in a 2,000 ft radius	30	0.771624
Density of 1992 development in a 1,900 ft radius	50	0.768875
Density of 1992 development in a 1,800 ft radius	50	0.765913
Density of 1992 development in a 1,700 ft radius	50	0.763185
Density of 1992 development in a 1,600 ft radius	30	0.759612
Minimum distance from urban area	50	0.757874
Density of 1992 development in a 1,500 ft radius	30	0.756648

Density of 1992 development in a 1,400 ft radius	50	0.752573
Minimum distance from state or local road	50	0.751512
Minimum distance from state, local, or unpaved road	20	0.750699
Density of 1992 development in a 1,300 ft radius	20	0.748122
Density of 1992 development in a 1,100 ft radius	30	0.738561
Density of 1992 development in a 1,000 ft radius	50	0.733895
Population density	100	0.729932
Density of 1992 development in a 900 ft radius	50	0.728173
Minimum distance from city center	50	0.726418
Housing density	50	0.721828
Minimum distance from interstate exits	100	0.720983
Density of 1992 development in a 800 ft radius	50	0.720128
Name of bedrock geologic unit.	N/A	0.716207
Population density ages 45 to 64	30	0.716182
Minimum distance from active railroad lines	100	0.71219
Density of 1992 development in a 700 ft radius	50	0.711491
Population density ages 30 to 44	50	0.710314
Minimum distance from state road	30	0.708579
Millrate	100	0.708422
Density of 1992 development in a 600 ft radius	100	0.705104
Percent of population under age of 18	100	0.701855
Minimum distance from facilities reporting toxic releases	100	0.701746
Minimum distance from box store	100	0.70106
Populations ages 30 to 44	100	0.70098
Density of people working in service occupations	50	0.700678

Land use/cover (1992)	N/A	0.700346
Size of patch of contiguous land use/cover (1986)	30	0.698861
Dominant lithology, volumetrically, in bedrock unit	N/A	0.697392
Density of 1992 development in a 500 ft radius	50	0.696995
Commuting distance from employment base	100	0.696712
Number of people in construction	100	0.696415
Population density ages 18 to 29	50	0.696283
Median value non-condo housing unit	100	0.694071
Minimum distance from local road	50	0.691716
Population density ages under 18	50	0.691645
Minimum distance from local or unpaved road	50	0.691253
Elevation	100	0.690212
Number of people working in service occupations	100	0.68935
Density of 1992 development in a 400 ft radius	30	0.685501
Number of people 16 and over in the labor force	100	0.684406
Percentage of houses that have 4+ bedrooms	100	0.684232
Construction labor force density	50	0.683008
Percent of people 18 and older who have had one or more years of college	100	0.681914
Total population	100	0.680076
Median household income	100	0.679239
Populations ages 18 to 29	100	0.677276
Density of 1992 development in a 300 ft radius	50	0.676166
Housing units	100	0.673142
Percent of population over age 65	100	0.669967
Populations ages 45 to 64	100	0.66767

Population density ages over 65	50	0.667266
Populations ages 65 and over	100	0.656207
Minimum distance from wetland land use/cover class (1992)	100	0.653771
Minimum distance from barren land use/cover class (1992)	50	0.645869
Origin of surficial material	N/A	0.634175
Minimum distance from forest land use/cover class (1992)	100	0.633256
Minimum distance from private school	50	0.629289
Minimum distance from unpaved road	100	0.621925
Percent in poverty	100	0.618878
Minimum distance from scenic river	100	0.617691
Minimum distance from lakes and ponds of size 13 to132 acres	100	0.617078
Minimum distance from lakes and ponds of size 9 to132 acres	100	0.613841
Minimum distance from rangeland land use/cover class (1992)	100	0.61342
Percentage of the civilian labor force that is unemployed	100	0.613166
Minimum distance from inactive railroad lines	100	0.609189
Percent impervious surface cover within grid cells in 1985	30	0.605749
Minimum distance from lakes and ponds of size 33 to132 acres	100	0.605008
Per capita income	100	0.599722
Minimum distance from major river	10	0.598442
Topographic slope	100	0.594929
Minimum distance from lakes and ponds of size 58 to132 acres	100	0.591571
Minimum distance from lakes and ponds of size 25 to132 acres	100	0.589305
Minimum distance from swamp, marsh, lake, pond, or reservoir larger than 25 acres(high resolution map)	100	0.589305
Minimum distance from lakes and ponds of size 5 to132 acres	100	0.576852
Maximum value for the range in depth to bedrock	N/A	0.574306

Minimum distance from swamp, marsh, lake, pond, or reservoir larger than 25 acres	100	0.573369
Minimum distance from lakes and ponds of size 3 to132 acres	100	0.558589
Minimum distance from agriculture land use/cover class (1992)	20	0.558414
Minimum distance from lakes and ponds of size less than 1 to132 acres	30	0.554844
Minimum distance from lakes or ponds (high resolution map)	50	0.547601
Minimum distance from lakes or ponds larger than 25 acres (high resolution map)	50	0.547601
Minimum distance from reservoir (high resolution map)	50	0.547601
Minimum distance from swamp or marsh (high resolution map)	50	0.547601
Minimum distance from swamp, marsh, lake, pond, or reservoir (high resolution map)	50	0.547601
Minimum distance from lake and pond	100	0.546032
Minimum distance from lake and pond larger than 25 acres	100	0.546032
Minimum distance from reservoir	100	0.546032
Minimum distance from swamp or marsh	100	0.546032
Minimum distance from swamp, marsh, lake, pond, or reservoir	100	0.546032
Minimum distance from lakes and ponds of size 1 to132 acres	100	0.545164
Surface soil texture	N/A	0.543121
Soil drainage class	N/A	0.535142
Maximum value for the range in depth to the seasonally high water table	N/A	0.534432
Minimum value for the range in depth to bedrock	N/A	0.533753
Minimum value for the range in depth to the seasonally high water table	N/A	0.533232
Minimum distance from canal or ditch	50	0.531717
Minimum distance from stream or river	50	0.531717
Minimum distance from stream, river, canal, or ditch	50	0.531717
Minimum distance from canal or ditch (high resolution map)	10	0.530434
Minimum distance from canal, ditch, stream, or river (high resolution map)	10	0.530434

Minimum distance from stream or river (high resolution map)	10	0.530434
Hydrologic group	N/A	0.517466
Topographic aspect	50	0.514538
Farmland soil classification	N/A	0.504556
Size of scenic view	50	0.499987

[Pennsylvania] Eight sets of twelve drivers each used as initial variables entered into optimization procedure to find driver weights that maximize ROC of final suitability map.

1) Top 12 Either Physio-economic or demographic Drivers by ROC (Stratified)	**Quantile Number**	**ROC**	**Weight**
Density of 1992 development in a 200 ft radius	20	0.937359	39
Minimum distance from urban land use/cover class (1992)	30	0.932307	25
Minimum distance from densely developed areas (50% developed within 600 ft radius in 1995)	30	0.876645	16
Minimum distance from grid cells with greater than 34% impervious surface coverage in 1985	50	0.844356	4.5
Size of patch of contiguous land use/cover (1992)	100	0.833038	11
Minimum distance from edge of patch of contiguous land use/cover (1992)	20	0.819270	1
Minimum distance from urban area	50	0.788301	0
Percentage of houses that have 4+ bedrooms	100	0.787407	0
Percent of people 18 and older who have had one or more years of college	100	0.786199	0
Number of people in construction	100	0.785885	11.5
Percent of population under age of 18	100	0.783547	0
Minimum distance from state or local road	20	0.779891	11.5
Composite Suitability Map		**0.955763**	

2) Top 12 Physio-economic Drivers by ROC (Non-Stratified)			
Density of 1992 development in a 200 ft radius	20	0.934966	6.2
Minimum distance from urban land use/cover class (1992)	100	0.92014	6.3
Minimum distance from densely developed areas (50% developed within 600 ft radius in 1995)	100	0.872455	3
Minimum distance from grid cells with greater than 34% impervious surface coverage in 1985	10	0.832312	2.3
Size of patch of contiguous land use/cover (1992)	100	0.798416	2.6
Minimum distance from edge of patch of contiguous land use/cover (1992)	20	0.786847	3.1
Minimum distance from urban area	50	0.757874	1.8

Minimum distance from state or local road	50	0.751512	5.6
Minimum distance from city center	50	0.726418	1
Minimum distance from interstate exits	100	0.720983	3.9
Name of bedrock geologic unit.	N/A	0.716207	4.3
Minimum distance from active railroad lines	100	0.71219	2.4
Composite Suitability Map		**0.955744**	

3) Top 6 Physio-economic Drivers and Top 6 Dempographic Drivers by ROC (Stratified)			
Density of 1992 development in a 200 ft radius	20	0.937359	20.75
Minimum distance from urban land use/cover class (1992)	30	0.932307	14.75
Minimum distance from densely developed areas (50% developed within 600 ft radius in 1995)	30	0.876645	5.75
Minimum distance from grid cells with greater than 34% impervious surface coverage in 1985	50	0.844356	2.75
Size of patch of contiguous land use/cover (1992)	100	0.833038	5.75
Minimum distance from edge of patch of contiguous land use/cover (1992)	20	0.81927	3.25
Percentage of houses that have 4+ bedrooms	100	0.787407	5
Percent of people 18 and older who have had one or more years of college	100	0.786199	1
Number of people in construction	100	0.785885	0
Percent of population under age of 18	100	0.783547	0
Commuting distance from employment base	100	0.779015	3.25
Populations ages 45 to 64	100	0.778672	0
Composite Suitability Map		**0.9555**	

4) Top 12 Physio-economic Drivers by ROC (Stratified)			
Density of 1992 development in a 200 ft radius	20	0.937359	3.7
Minimum distance from urban land use/cover class (1992)	30	0.932307	2.3
Minimum distance from densely developed areas (50% developed within 600 ft radius in 1995)	30	0.876645	1.75
Minimum distance from grid cells with greater than 34% impervious surface coverage in 1985	50	0.844356	0.55
Size of patch of contiguous land use/cover (1992)	100	0.833038	1.1

Minimum distance from edge of patch of contiguous land use/cover (1992)	20	0.81927	0
Minimum distance from urban area	50	0.788301	0
Minimum distance from state or local road	20	0.779891	1.05
Minimum distance from city center	50	0.757919	0
Minimum distance from box store	100	0.757248	1
Name of bedrock geologic unit.		0.756009	0
Size of patch of contiguous land use/cover (1986)	30	0.753862	0
Composite Suitability Map		**0.955433**	

5) Top 12 Either Physio-economic or Demographic Drivers by ROC (Non-Stratified)			
Density of 1992 development in a 200 ft radius	20	0.934966	9.375
Minimum distance from urban land use/cover class (1992)	100	0.92014	8.125
Minimum distance from densely developed areas (50% developed within 600 ft radius in 1995)	100	0.872455	4.5
Minimum distance from grid cells with greater than 34% impervious surface coverage in 1985	10	0.832312	3.25
Size of patch of contiguous land use/cover (1992)	100	0.798416	3.625
Minimum distance from edge of patch of contiguous land use/cover (1992)	20	0.786847	2.125
Minimum distance from urban area	50	0.757874	2.375
Minimum distance from state or local road	50	0.751512	6.5
Population density	100	0.729932	0
Minimum distance from city center	50	0.726418	1
Housing density	50	0.721828	1.125
Minimum distance from interstate exits	100	0.720983	3.375
Composite Suitability Map		**0.955203**	

6) Top 6 Physio-economic Drivers and Top 6 Demographic Drivers by ROC (Non-Stratified)			
Density of 1992 development in a 200 ft radius	20	0.934966	5.25
Minimum distance from urban land use/cover class (1992)	100	0.92014	6.083333

Minimum distance from densely developed areas (50% developed within 600 ft radius in 1995)	100	0.872455	2.333333
Minimum distance from grid cells with greater than 34% impervious surface coverage in 1985	10	0.832312	1.916667
Size of patch of contiguous land use/cover (1992)	100	0.798416	2
Minimum distance from edge of patch of contiguous land use/cover (1992)	20	0.786847	1.916667
Population density	100	0.729932	0
Housing density	50	0.721828	0
Population density ages 45 to 64	30	0.716182	0
Population density ages 30 to 44	50	0.710314	1
Percent of population under age of 18	100	0.701855	2.666667
Populations ages 30 to 44	100	0.70098	1.583333
Composite Suitability Map		**0.954248**	

7) Top 12 Demographic Drivers by ROC (Stratified)			
Percentage of houses that have 4+ bedrooms	100	0.787407	1.235294
Percent of people 18 and older who have had one or more years of college	100	0.786199	1.352941
Number of people in construction	100	0.785885	0
Percent of population under age of 18	100	0.783547	1.382353
Commuting distance from employment base	100	0.779015	1
Populations ages 45 to 64	100	0.778672	0
Number of people working in service occupations	100	0.777483	1.058824
Percent of population over age 65	100	0.774505	1.176471
Number of people 16 and over in the labor force	100	0.774445	0
Median household income	100	0.774146	1.176471
Median value non-condo housing unit	100	0.773648	1.176471
Populations ages 65 and over	100	0.773381	1.176471
Composite Suitability Map		**0.816262**	

8) Top 12 demographic Drivers by ROC (Non-Stratified)

Population density	100	0.729932	0
Housing density	50	0.721828	1.153846
Population density ages 45 to 64	30	0.716182	1.025641
Population density ages 30 to 44	50	0.710314	1.025641
Percent of population under age of 18	100	0.701855	1.025641
Populations ages 30 to 44	100	0.70098	1.025641
Density of people working in service occupations	50	0.700678	1
Commuting distance from employment base	100	0.696712	1.025641
Number of people in construction	100	0.696415	0
Population density ages 18 to 29	50	0.696283	0
Median value non-condo housing unit	100	0.694071	1.025641
Population density ages under 18	50	0.691645	1.025641
Composite Suitability Map		**0.78966**	

[Pennsylvania] All possible permutations of suitability images, projection methods, and neighborhood constraints with associated percent correct, kappa statistic, and user's and producer's accuracies.

Suitability map origin	Projection method	Neighborhood constraints	Overall Accuracy	Kappa	User's Accuracy Dev	User's Accuracy Undev	Producer's Accuracy Dev	Producer's Accuracy Undev
GEOMOD, stratified	Non-stratified	None	98.16947583	96.33895	44.5958	99.06936	44.59576	99.069364
GEOMOD, stratified	Non-stratified	5 X 5	98.16947583	96.33895	44.5958	99.06936	44.59576	99.069364
GEOMOD, stratified	Non-stratified	7 X 7	98.16947583	96.33895	44.5958	99.06936	44.59576	99.069364
GEOMOD, stratified	Non-stratified	3 X 3	98.16882059	96.33764	44.5759	99.06903	44.57592	99.069031
GEOMOD, stratified	Stratified	3 X 3	98.1576815	96.31536	44.2388	99.06337	44.23878	99.063368
GEOMOD, stratified	Stratified	None	98.15746308	96.31493	44.2322	99.06326	44.23217	99.063257
GEOMOD, stratified	Stratified	5 X 5	98.15746308	96.31493	44.2322	99.06326	44.23217	99.063257
GEOMOD, stratified	Stratified	7 X 7	98.15746308	96.31493	44.2322	99.06326	44.23217	99.063257
GEOMOD,non-stratified	Stratified	None	98.15702626	96.31405	44.2189	99.06303	44.21895	99.063035
GEOMOD,non-stratified	Stratified	3 X 3	98.15702626	96.31405	44.2189	99.06303	44.21895	99.063035
GEOMOD,non-stratified	Stratified	5 X 5	98.15702626	96.31405	44.2189	99.06303	44.21895	99.063035
GEOMOD,non-stratified	Stratified	7 X 7	98.15702626	96.31405	44.2189	99.06303	44.21895	99.063035
GEOMOD,non-stratified	Non-stratified	None	98.13496648	96.26993	43.5513	99.05182	43.55127	99.05182
GEOMOD,non-stratified	Non-stratified	3 X 3	98.13496648	96.26993	43.5513	99.05182	43.55127	99.05182
GEOMOD,non-stratified	Non-stratified	5 X 5	98.13496648	96.26993	43.5513	99.05182	43.55127	99.05182
GEOMOD,non-stratified	Non-stratified	7 X 7	98.13496648	96.26993	43.5513	99.05182	43.55127	99.05182
Logistic regression, stratified	Stratified	3 X 3	98.12448263	96.24897	43.234	99.04649	43.23395	99.04649
Logistic regression, stratified	Stratified	5 X 5	98.12448263	96.24897	43.234	99.04649	43.23395	99.04649

Logistic regression, non-stratified	Stratified	3 X 3	98.12426422	96.24853	43.2273	99.04638	43.22734	99.046379
Logistic regression, non-stratified	Stratified	5 X 5	98.12426422	96.24853	43.2273	99.04638	43.22734	99.046379
Logistic regression, stratified	Stratified	None	98.12426422	96.24853	43.2273	99.04638	43.22734	99.046379
Logistic regression, stratified	Stratified	7 X 7	98.12426422	96.24853	43.2273	99.04638	43.22734	99.046379
Logistic regression, non-stratified	Stratified	None	98.12404581	96.24809	43.2207	99.04627	43.22073	99.046268
Logistic regression, non-stratified	Stratified	7 X 7	98.12404581	96.24809	43.2207	99.04627	43.22073	99.046268
Logistic regression, non-stratified	Non-stratified	3 X 3	98.11072258	96.22145	42.8175	99.03949	42.81748	99.039494
Logistic regression, non-stratified	Non-stratified	5 X 5	98.11072258	96.22145	42.8175	99.03949	42.81748	99.039494
Logistic regression, non-stratified	Non-stratified	None	98.11050416	96.22101	42.8109	99.03938	42.81087	99.039383
Logistic regression, non-stratified	Non-stratified	7 X 7	98.11050416	96.22101	42.8109	99.03938	42.81087	99.039383
Logistic regression, stratified	Non-stratified	None	98.10373334	96.20747	42.6059	99.03594	42.60594	99.035941
Logistic regression, stratified	Non-stratified	3 X 3	98.10373334	96.20747	42.6059	99.03594	42.60594	99.035941
Logistic regression, stratified	Non-stratified	5 X 5	98.10373334	96.20747	42.6059	99.03594	42.60594	99.035941
Logistic regression, stratified	Non-stratified	7 X 7	98.10373334	96.20747	42.6059	99.03594	42.60594	99.035941

[PA] Regional-level impact metric values for years 1992 and 2001 using historic data and in 2022 using 3 development projection scenarios.

Indicator	1992		2001		Constraints BAU 2022		Constraints Low 2022		High 2022	
	%	Measure	%	Measure	%	Measure	%	Measure	%	Measure
Perimeter:Area Ratio (ft/acres)	N/A	258	N/A	213	N/A	212	N/A	215	N/A	215
Interior Forest	10.19	139,507	11.75	160,777	11.62	159,026	11.60	158,735	11.62	159,016
Largest Forest Patch	5.25	71,917	5.44	74,521	5.44	74,466	5.44	74,409	5.44	74,403
Impervious Surface	4.68	64,057	5.08	69,528	5.97	81,757	5.97	81,757	5.97	81,757
Altered Land	66.08	905,048	65.56	897,208	66.32	907,708	66.27	907,026	66.15	905,353
Developed Prime Farmland	14.47	169,712	15.77	184,880	18.73	219,629	18.75	219,863	18.76	219,974
Altered Riparian Area (295 ft)	56.96	111,383	54.09	105,322	55.18	107,447	54.81	106,720	54.39	105,904
Altered Riparian Area (100 ft)	54.56	80,634	50.79	74,658	52.02	76,467	51.51	75,713	50.99	74,941

Note: Perimeter: area ratio measure is in ft/acres, all others are acres.

[PA] Percent composition by forest type for 2001 and 3 projection to 2022 differing in constraint scenario.

					Constraints					
					BAU		Low		High	
	1992		2001		2022		2022		2022	
Forest Type	%	acres	%	acres	%	acres	%	acres	%	acres
Core	18.41376	81519.27	23.43	104121.93	23.66	103024.86	23.58	102795.34	23.54	102949.02
Patch	11.00987	48741.61	8.99	39947.67	8.87	38618.20	9.07	39538.69	9.05	39563.598
Transition	14.4694	64057.28	13.86	61614.05	13.87	60394.43	13.89	60528.31	13.88	60707.12
Edge	29.65671	131292.8	35.49	157750.00	35.79	155860.31	35.59	155127.07	35.62	155756.23
Perforated	26.38722	116818.5	18.17	80778.48	17.76	77356.27	17.82	77654.27	17.85	78058.144

[PA] County most and least impacted in 1992.

County	Perimeter:Area Ratio (ft/acres)	Interior Forest %	Largest Forest Patch %		Altered Land %	Developed Prime Farmland %	Altered Riparian Area % (295 ft)	Altered Riparian Area % (100 ft)
Least Impact	Lebanon 200.41	Lebanon 16.90	Bucks 33.03	Chester 2.20	York 52.37	Bucks 4.38	Bucks 45.45	Chester 44.63
Most Impact	Dauphin 381.23	Dauphin 4.11	Lancaster 3.98	Northampton 10.89	Lancaster 80.03	Northampton 34.85	Lancaster 75.81	Lancaster 73.54

[PA] County-level impact metric values for year 1992.

County Name	1992 Perimeter:Area Ratio (ft/acres)	Interior Forest %	Largest Forest Patch %	Impervious Surface %	Altered Land %	Developed Prime Farmland %	Altered Riparian Area % (295 ft)	Altered Riparian Area % (100 ft)
Lancaster	266.68	6.82	3.98	3.75	80.03	11.61	75.81	73.54
Montgomery	333.41	5.56	6.51	5.92	68.70	17.94	53.65	51.69
Dauphin	381.23	4.11	4.71	6.36	74.55	20.23	65.04	60.33
Northampton	356.28	5.09	6.03	10.89	73.37	34.85	62.84	60.08
Chester	275.87	10.02	13.45	2.20	62.72	7.16	47.42	44.63
Berks	242.18	14.07	12.76	4.38	57.87	13.10	50.34	48.00
York	272.41	15.36	7.72	6.09	52.37	19.40	49.88	51.37
Bucks	245.40	13.48	33.03	2.60	53.44	4.38	45.45	46.35
Lehigh	341.45	6.43	5.84	10.23	70.14	30.07	60.05	57.93
Lebanon	200.41	16.90	24.27	3.73	65.84	11.74	61.00	65.86
Average	291.53	9.78	11.83	5.62	65.90	17.05	57.15	55.98
Minimum	200.41	4.11	3.98	2.20	52.37	4.38	45.45	44.63
Maximum	381.23	16.90	33.03	10.89	80.03	34.85	75.81	73.54

[PA] County most and least impacted in 2001.

County	Perimeter:Area Ratio (ft/acres)	Interior Forest %	Largest Forest Patch %	Impervious Surface %	Altered Land %	Developed Prime Farmland %	Altered Riparian Area % (295 ft)	Altered Riparian Area % (100 ft)
Least Impact	Lebanon 141.51	Lebanon 18.78	Bucks 33.48	Chester 2.42	Bucks 52.44	Bucks 4.76	Bucks 42.27	Chester 37.61
Most Impact	Northampton 301.29	Northampton 5.40	Lancaster 4.19	Northampton 11.64	Lancaster 79.70	Northampton 37.32	Lancaster 74.03	Lancaster 70.76

[PA] County-level impact metric values for year 2001 with year 1992 urban areas included (e.g. transitions of development in 1992 to another class ignored).

	2001							
County Name	Perimeter:Area Ratio (ft/acres)	Interior Forest %	Largest Forest Patch %	Impervious Surface %	Altered Land %	Developed Prime Farmland %	Altered Riparian Area % (295 ft)	Altered Riparian Area % (100 ft)
Lancaster	222.07	7.66	4.19	4.04	79.70	12.55	74.03	70.76
Montgomery	264.11	8.56	13.09	6.49	66.58	19.74	48.87	46.36
Dauphin	286.47	5.56	5.32	7.04	74.29	22.22	62.91	56.86
Northampton	301.29	5.40	5.45	11.64	73.92	37.32	59.15	55.33
Chester	229.30	11.96	17.03	2.42	62.00	7.88	42.65	37.61
Berks	199.78	16.00	12.59	4.86	57.24	14.63	47.46	44.36
York	214.13	16.33	5.83	6.59	54.70	21.01	50.39	51.26
Bucks	217.39	15.09	33.48	2.80	52.44	4.76	42.27	42.88
Lehigh	286.81	7.30	7.94	10.83	69.41	31.85	57.04	54.32
Lebanon	141.51	18.78	18.09	4.06	66.47	12.83	60.68	65.10
Average	236.28	11.26	12.30	6.08	65.67	18.48	54.54	52.48
Minimum	141.51	5.40	4.19	2.42	52.44	4.76	42.27	37.61
Maximum	301.29	18.78	33.48	11.64	79.70	37.32	74.03	70.76

[PA] Counties least and most impacted after projecting development to year 2022 using medium development rate and "business as usual" development constraints.

Town	Perimeter:Area Ratio (ft/acres)	Interior Forest %	Largest Forest Patch %	Impervious Surface %	Altered Land %	Developed Prime Farmland %	Altered Riparian Area % (295 ft)	Altered Riparian Area % (100 ft)
Least Impact	Lebanon 140.28	Lebanon 18.77	Buck 33.47	Chester 2.60	Bucks 52.50	Bucks 4.95	Bucks 42.36	Chester 37.80
Most Impact	Northampton 292.54	Northampton 5.25	Lancaster 4.19	Northampton 14.08	Lancaster 79.75	Northampton 45.19	Lancaster 74.12	Lancaster 70.89

[PA] Projected county-level impact metric values for year 2022 using "business as usual" constraints.

	"Business As Usual" Constraints							
County Name	Perimeter:Area Ratio (ft/acres)	Interior Forest %	Largest Forest Patch %	Impervious Surface %	Altered Land %	Developed Prime Farmland %	Altered Riparian Area % (295 ft)	Altered Riparian Area % (100 ft)
Lancaster	221.36	7.66	4.19	4.27	79.75	13.26	74.12	70.89
Montgomery	262.08	8.53	13.03	7.85	67.61	23.80	50.66	48.25
Dauphin	289.49	5.48	5.21	8.52	75.10	26.95	63.95	58.00
Northampton	292.54	5.25	5.44	14.08	76.36	45.19	65.56	62.70
Chester	228.67	11.96	17.03	2.60	62.11	8.51	42.72	37.80
Berks	200.93	15.69	12.40	6.42	58.45	19.60	49.33	46.31
York	210.28	16.30	5.81	7.20	55.40	22.97	51.86	53.12
Bucks	216.58	15.09	33.47	2.92	52.50	4.95	42.36	42.97
Lehigh	289.72	6.58	7.88	12.99	72.63	38.80	60.80	58.14
Lebanon	140.28	18.77	18.02	4.33	66.64	13.70	60.88	65.29
Average	235.19	11.13	12.25	7.12	66.66	21.77	56.22	54.35
Minimum	140.28	5.25	4.19	2.60	52.50	4.95	42.36	37.80
Maximum	292.54	18.77	33.47	14.08	79.75	45.19	74.12	70.89

[PA]. HUC 11 watersheds most and least impacted in 1992.

HUC 11 Name	Perimeter:Area Ratio (ft/acre)	Interior Forest %	Largest Forest Patch %	Impervious Surface %	Altered Land %	Developed Prime Farmland %	Altered Riparian Area % (295 ft)	Altered Riparian Area % (100 ft)
	Cocalico Creek	French Creek	French Creek	Paunnacussing Creek	Delaware River Tributaries	Paunnacussing Creek	Paunnacussing Creek	French Creek
Least Impact	177.60	19.78	41.35	0.41	46.91	0.69	35.07	34.43
	Little Conestoga Creek	Little Conestoga Creek and Jordan Creek	Little Conestoga Creek	Jordan Creek	Little Conestoga Creek	Jordan Creek	Little Conestoga Creek	Little Conestoga Creek
Most Impact	1256.85	0.00	0.07	18.84	99.34	67.36	100.00	100.00

[PA]. HUC 11 watersheds most and least impacted in 2001.

	HUC 11 Name	Perimeter:Area Ratio (ft/acre)	Interior Forest %	Largest Forest Patch %	Impervious Surface %	Altered Land %	Developed Prime Farmland %	Altered Riparian Area % (295 ft)	Altered Riparian Area % (100 ft)
Least Impact	Cocalico Creek	147.82	French Creek	22.17	French Creek	41.85	Paunnacussing Creek	0.49	Delaware River Tributaries	45.41	Paunnacussing Creek	0.84	Paunnacussing Creek	21.07	Paunnacussing Creek	23.35
Most Impact	Little Conestoga Creek	1061.64	Little Conestoga Creek and Jordan Creek	0.00	Little Conestoga Creek	0.07	Jordan Creek	19.21	Little Conestoga Creek	99.60	Jordan Creek	68.56	Little Conestoga Creek	100.00	Little Conestoga Creek	100.00

[PA]. HUC 11 watershed-level impact metric values for year 1992.

	1992							
Watershed	Perimeter:Area Ratio (ft/acres)	Interior Forest %	Largest Forest Patch %	Impervious Surface %	Altered Land %	Developed Prime Farmland %	Altered Riparian Area % (295 ft)	Altered Riparian Area % (100 ft)
Bushkill	675.92	0.29	0.92	13.30	92.14	42.42	76.28	80.30
Mud Run	473.81	3.53	8.35	11.08	76.69	32.92	67.32	64.90
Delaware River Tributaries	303.05	11.03	38.15	1.61	46.91	4.79	48.85	48.82
Frya Run	267.74	10.82	21.89	0.83	55.85	1.16	58.23	53.98
Tinicum and Cooks Creeks	225.59	16.33	34.71	0.76	47.03	1.49	39.90	40.45
Tohickon Creek	218.40	15.55	29.29	2.58	51.18	4.77	45.44	45.68
Paunnacussing Creek	268.56	11.07	25.15	0.41	49.39	0.69	35.07	40.89
Jordan Creek	824.03	0.00	0.58	18.84	96.71	67.36	91.46	89.52
Little Lehigh Creek	280.74	9.98	15.46	11.00	69.27	31.44	57.51	55.88
Lower Lehigh River	347.06	5.18	4.58	11.24	71.32	35.60	61.55	58.13
North Branch Neshaminy Creek	473.63	0.67	1.95	4.78	78.45	24.55	59.56	57.94
Maiden Creek	317.60	6.69	5.14	4.68	72.45	14.14	60.55	55.37
Tulpehocken Creek	244.44	12.93	23.29	5.52	70.25	18.73	62.07	64.81
Middle Schuylkill River	234.84	15.43	18.11	6.29	54.44	18.56	48.41	47.62

Manatawny Creek	236.88	12.98	31.67	1.75	56.69	5.38	46.86	44.07
French Creek	200.38	19.78	41.35	0.89	49.45	2.74	38.92	34.43
Perkiomen Creek	289.62	7.93	12.62	4.06	63.66	10.74	52.98	51.53
Lower Schuylkill River	392.53	4.22	6.23	7.37	72.22	23.18	52.05	48.24
West Branch Brandywine Creek	297.57	6.10	13.66	1.59	63.89	4.86	41.38	37.57
East Branch Brandywine Creek	271.37	7.88	17.60	2.07	68.11	7.13	52.64	49.79
Yellow Breeches Creek	339.19	9.40	18.30	7.76	57.98	24.73	55.55	58.38
Quittapahilla Creek	326.77	7.47	6.28	5.38	80.70	17.06	77.77	80.79
Swatara Creek	353.29	5.60	5.21	8.32	74.03	25.87	62.12	56.05
Conewago Creek, East Bank Susquehanna River	252.52	12.71	9.73	4.54	58.90	14.41	57.80	57.72
Conewago Creek, West Bank Susquehanna River	246.84	17.86	12.48	4.00	48.12	12.64	37.82	37.46
Chickies Creek	265.76	7.02	11.06	3.62	83.02	12.82	73.88	70.86
Cocalico Creek	177.60	17.70	18.91	4.79	64.56	14.28	62.30	61.86
Little Conestoga Creek	1256.85	0.00	0.07	8.68	99.34	27.87	100.00	100.00

Conestoga River	205.52	10.58	11.34	3.79	72.95	11.74	77.93	79.01
Pequea Creek	292.26	4.54	2.60	2.24	81.49	7.21	82.35	83.76
Susquehanna River Tributaries	506.26	0.90	2.90	5.12	86.27	16.39	66.69	57.95
East Branch Octoraro Creek	376.95	1.77	4.04	1.73	82.30	5.30	72.20	70.34
West Branch Octoraro Creek	419.48	0.94	2.49	0.56	87.57	1.53	81.15	81.19
Average	359.49	8.33	13.82	5.19	69.19	16.50	60.75	59.55
Minimum	177.60	0.00	0.07	0.41	46.91	0.69	35.07	34.43
Maximum	1256.85	19.78	41.35	18.84	99.34	67.36	100.00	100.00

[PA] HUC 11 watershed-level impact metric values for year 2001 with year 1992 urban areas included (e.g. transitions of development in 1992 to another class ignored).

	2001							
Watershed	Perimeter:Area Ratio (ft/acres)	Interior Forest %	Largest Forest Patch %	Impervious Surface %	Altered Land %	Developed Prime Farmland %	Altered Riparian Area % (295 ft)	Altered Riparian Area % (100 ft)
Bushkill	494.31	0.29	0.92	14.07	94.63	45.06	77.56	82.22
Mud Run	376.25	3.73	8.41	11.83	79.70	35.47	70.88	66.87
Delaware River Tributaries	268.24	11.16	37.95	1.70	45.41	4.95	32.12	32.13
Frya Run	240.22	11.27	21.79	0.88	56.74	1.27	57.35	51.41
Tinicum and Cooks Creeks	206.15	17.37	34.29	0.81	46.36	1.59	36.68	36.48
Tohickon Creek	195.13	17.02	34.53	2.75	50.16	5.04	42.42	42.34
Paunnacussing Creek	248.56	11.27	24.95	0.49	48.24	0.84	21.07	23.35
Jordan Creek	605.95	0.00	0.60	19.21	97.37	68.56	92.55	90.93
Little Lehigh Creek	229.31	10.52	13.12	11.77	69.73	33.76	56.90	55.03
Lower Lehigh River	306.18	5.69	4.59	11.97	70.71	37.93	56.64	52.33
North Branch Neshaminy Creek	411.18	0.69	1.97	5.72	79.07	30.64	59.93	58.40
Maiden Creek	249.04	7.49	5.00	5.14	72.87	15.50	59.27	53.39
Tulpehocken Creek	183.53	13.38	22.30	6.11	71.40	20.78	62.85	65.53
Middle Schuylkill River	193.50	17.48	18.45	6.95	53.51	20.67	44.82	42.47
Manatawny Creek	201.94	15.18	33.20	1.99	55.34	6.16	43.17	39.97

French Creek	170.84	22.17	41.85	0.96	48.86	2.98	35.55	29.25
Perkiomen Creek	237.04	11.07	13.81	4.38	61.60	11.71	48.70	46.98
Lower Schuylkill River	313.81	5.31	6.79	8.22	71.05	25.92	46.48	40.66
West Branch Brandywine Creek	241.74	9.30	20.09	1.75	62.31	5.32	33.13	26.44
East Branch Brandywine Creek	225.76	9.62	17.48	2.24	67.62	7.73	49.21	45.57
Yellow Breeches Creek	269.13	10.49	8.49	8.29	60.79	26.43	56.28	59.13
Quittapahilla Creek	206.25	7.72	6.20	5.90	82.54	18.71	79.63	82.03
Swatara Creek	251.98	7.04	8.71	9.26	74.67	28.59	61.08	53.62
Conewago Creek, East Bank Susquehanna River	192.86	16.43	7.28	4.96	58.28	15.77	55.20	54.23
Conewago Creek, West Bank Susquehanna River	195.32	18.92	12.43	4.34	50.14	13.76	37.30	36.09
Chickies Creek	226.91	7.79	11.25	3.88	82.57	13.84	72.04	68.02
Cocalico Creek	147.82	19.00	19.65	5.11	64.25	15.26	59.87	58.17
Little Conestoga Creek	1061.64	0.00	0.07	9.80	99.60	31.55	100.00	100.00
Conestoga River	170.28	12.02	11.23	4.17	72.60	12.93	76.25	76.90

Pequea Creek	250.84	4.86	3.93	2.45	81.49	7.87	82.11	83.25
Susquehanna River Tributaries	420.54	1.32	2.95	5.50	85.58	17.55	61.59	49.73
East Branch Octoraro Creek	331.12	1.87	4.85	1.88	82.11	5.78	70.75	68.22
West Branch Octoraro Creek	370.12	1.15	2.49	0.60	87.83	1.67	81.27	80.82
Average	293.74	9.35	13.99	5.61	69.25	17.93	58.20	56.12
Minimum	147.82	0.00	0.07	0.49	45.41	0.84	21.07	23.35
Maximum	1061.64	22.17	41.85	19.21	99.60	68.56	100.00	100.00

[PA] HUC 11 watersheds most and least impacted after projecting development to year 2022 using medium development rate and "business as usual" development constraints

HUC 12 Name	Perimeter:Area Ratio (ft/acre)	Interior Forest %	Largest Forest Patch %	Impervious Surface %	Altered Land %	Developed Prime Farmland %	Altered Riparian Area % (295 ft)	Altered Riparian Area % (100 ft)
	Cocalico Creek	French Creek	French Creek	Paunnacussing Creek	Delaware River Tributaries	Paunnacussing Creek	Paunnacussing Creek	Paunnacussing Creek
Least Impact	147.48	22.17	41.84	0.49	45.87	0.84	59.64	57.69
	Little Conestoga Creek	Little Conestoga Creek	Little Conestoga Creek	Little Conestoga Creek	Little Conestoga Creek	Jordan Creek	Little Conestoga Creek	Little Conestoga Creek
Most Impact	1061.64	0.00	0.07	19.95	99.60	70.47	100.00	100.00

[PA] Projected HUC 11 watershed-level impact metric values for year 2022 under "business as usual" constraints.

	"Business As Usual" Constraints							
Watershed	Perimeter:Area Ratio (ft/acres)	Interior Forest %	Largest Forest Patch %	Impervious Surface %	Altered Land %	Developed Prime Farmland %	Altered Riparian Area % (295 ft)	Altered Riparian Area % (100 ft)
Bushkill	559.32	0.23	0.78	16.81	96.48	54.24	84.78	88.34
Mud Run	402.93	3.01	6.81	13.96	82.78	42.58	78.30	75.54
Delaware River Tributaries	266.86	11.16	37.93	2.16	45.87	6.32	36.15	36.14
Frya Run	240.11	11.25	21.76	1.06	56.81	1.85	57.47	51.62
Tinicum and Cooks Creeks	206.11	17.37	34.29	0.85	46.39	1.72	36.75	36.53
Tohickon Creek	194.11	17.02	34.52	2.86	50.24	5.25	42.51	42.42
Paunnacussing Creek	248.56	11.27	24.95	0.49	48.24	0.84	21.07	23.35
Jordan Creek	612.49	0.00	0.56	19.95	97.67	70.47	93.81	92.41
Little Lehigh Creek	229.51	9.48	12.94	14.23	73.84	41.70	60.84	58.95
Lower Lehigh River	300.29	5.38	4.58	14.55	73.57	46.27	62.77	59.34
North Branch Neshaminy Creek	409.76	0.69	1.97	5.88	79.15	31.40	60.04	58.54
Maiden Creek	254.27	7.01	4.77	8.91	74.25	29.48	61.66	55.89
Tulpehocken Creek	187.90	12.96	21.80	7.09	72.42	24.20	64.83	67.86

Middle Schuylkill River	193.12	17.23	18.28	8.34	55.23	25.16	47.47	45.58
Manatawny Creek	201.81	15.05	32.54	2.61	55.89	8.15	44.28	41.04
French Creek	170.71	22.17	41.84	1.01	48.88	3.12	35.56	29.27
Perkiomen Creek	235.74	11.06	13.79	5.20	62.07	14.16	49.59	47.87
Lower Schuylkill River	313.00	5.25	6.59	9.65	72.43	30.49	48.66	43.24
West Branch Brandywine Creek	241.56	9.30	20.09	1.82	62.32	5.55	33.15	26.46
East Branch Brandywine Creek	225.70	9.62	17.48	2.49	67.68	8.65	49.33	45.65
Yellow Breeches Creek	262.46	10.43	8.45	9.07	61.95	28.90	58.00	62.40
Quittapahilla Creek	204.43	7.69	6.14	6.32	82.78	20.05	79.93	82.29
Swatara Creek	253.43	6.95	8.53	11.00	75.56	34.00	62.13	54.70
Conewago Creek, East Bank Susquehanna River	190.90	16.41	7.21	5.63	58.82	17.89	56.17	55.34
Conewago Creek, West Bank Susquehanna River	193.81	18.89	12.38	4.65	50.47	14.73	37.97	36.82
Chickies Creek	226.25	7.79	11.24	4.09	82.61	14.65	72.11	68.13
Cocalico Creek	147.48	18.96	19.64	5.43	64.38	16.21	60.06	58.45
Little Conestoga Creek	1061.64	0.00	0.07	10.26	99.60	33.05	100.00	100.00
Conestoga River	171.16	11.93	11.19	4.58	72.81	14.09	76.61	77.25
Pequea Creek	250.60	4.86	3.93	2.56	81.52	8.28	82.16	83.31

Susquehanna River Tributaries	420.50	1.32	2.94	5.89	85.72	18.81	61.82	50.04
East Branch Octoraro Creek	330.57	1.87	4.85	1.97	82.14	6.07	70.80	68.29
West Branch Octoraro Creek	370.12	1.15	2.49	0.62	87.84	1.72	81.27	80.82
Average	296.28	9.24	13.86	6.42	69.95	20.61	59.64	57.69
Minimum	147.48	0.00	0.07	0.49	45.87	0.84	21.07	23.35
Maximum	1061.64	22.17	41.84	19.95	99.60	70.47	100.00	100.00

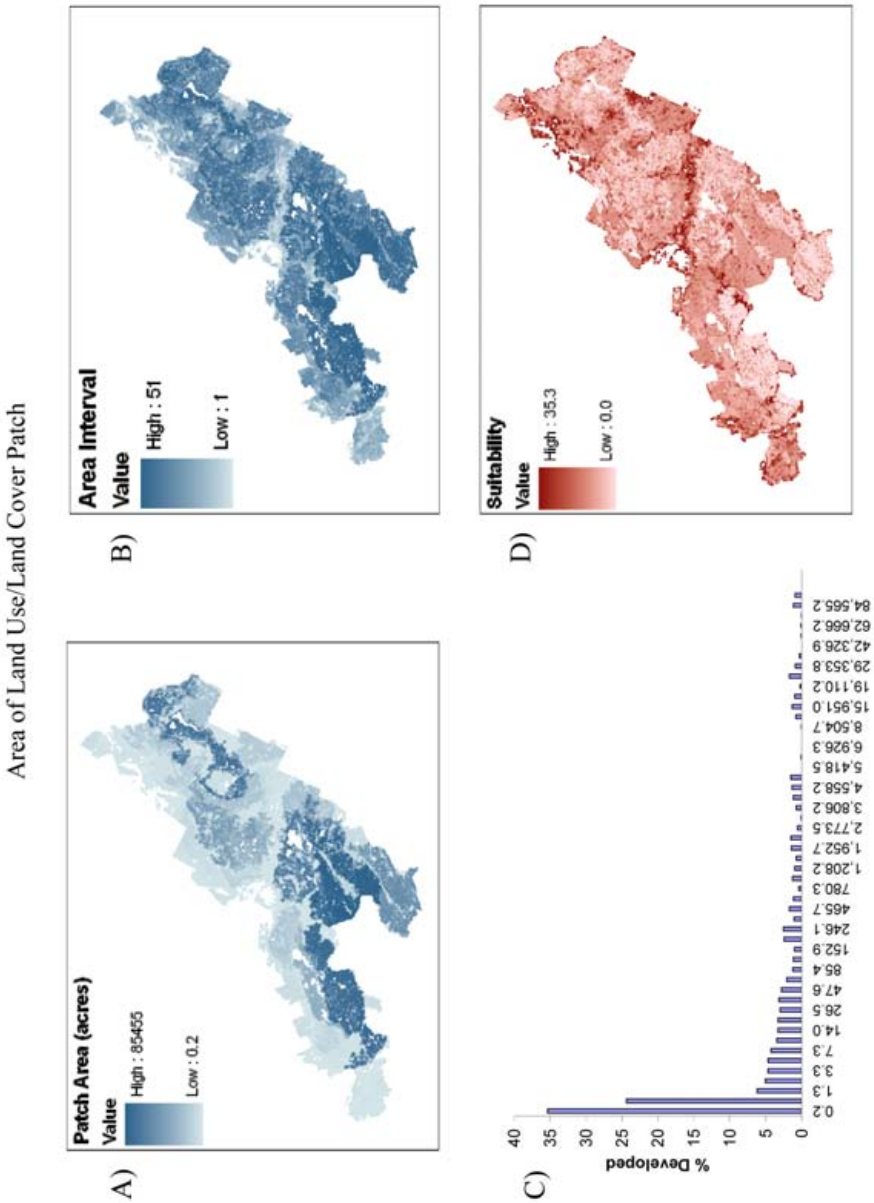


Illustration of operations involved in creation of individual suitability map based on area of LULC patch. A) Map of LULC patch areas (data from 2001). B) Map of LULC patch areas classified into intervals (data from 2001). C) Histogram showing percent of cells available for development in each LULC patch area interval (patch data from 1992) that were developed between 1992 and 2001. D) Suitability map created by assigning percent developed values in histogram to 2001 LULC patch area interval map.

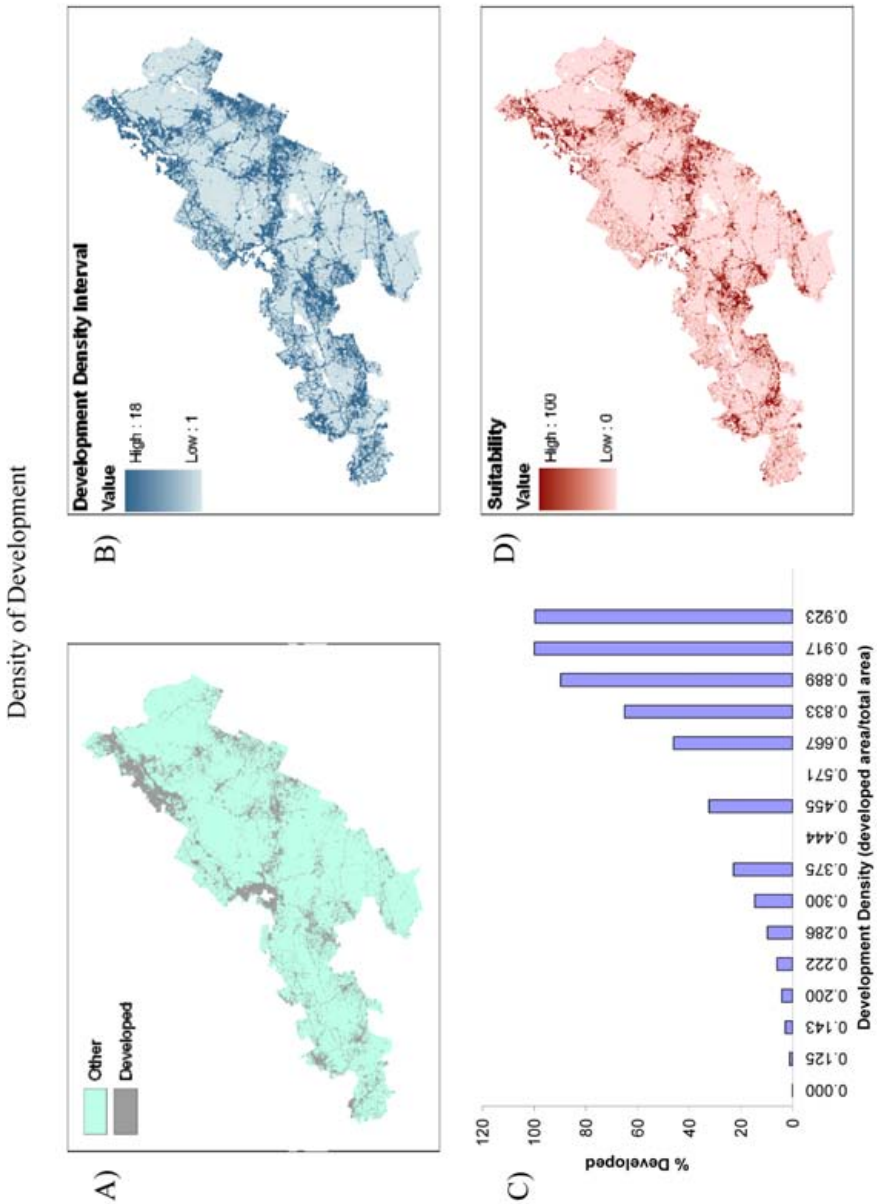


Illustration of operations involved in creation of individual suitability map based on density of development in a 200 ft radius. A) Map of development (data from 2001). B) Map of density of development classified into intervals (data from 2001). C) Histogram showing percent of cells available for development in each density interval (density data from 1992) that were developed between 1992 and 2001. D) Suitability map created by assigning percent developed values in histogram to density interval map.

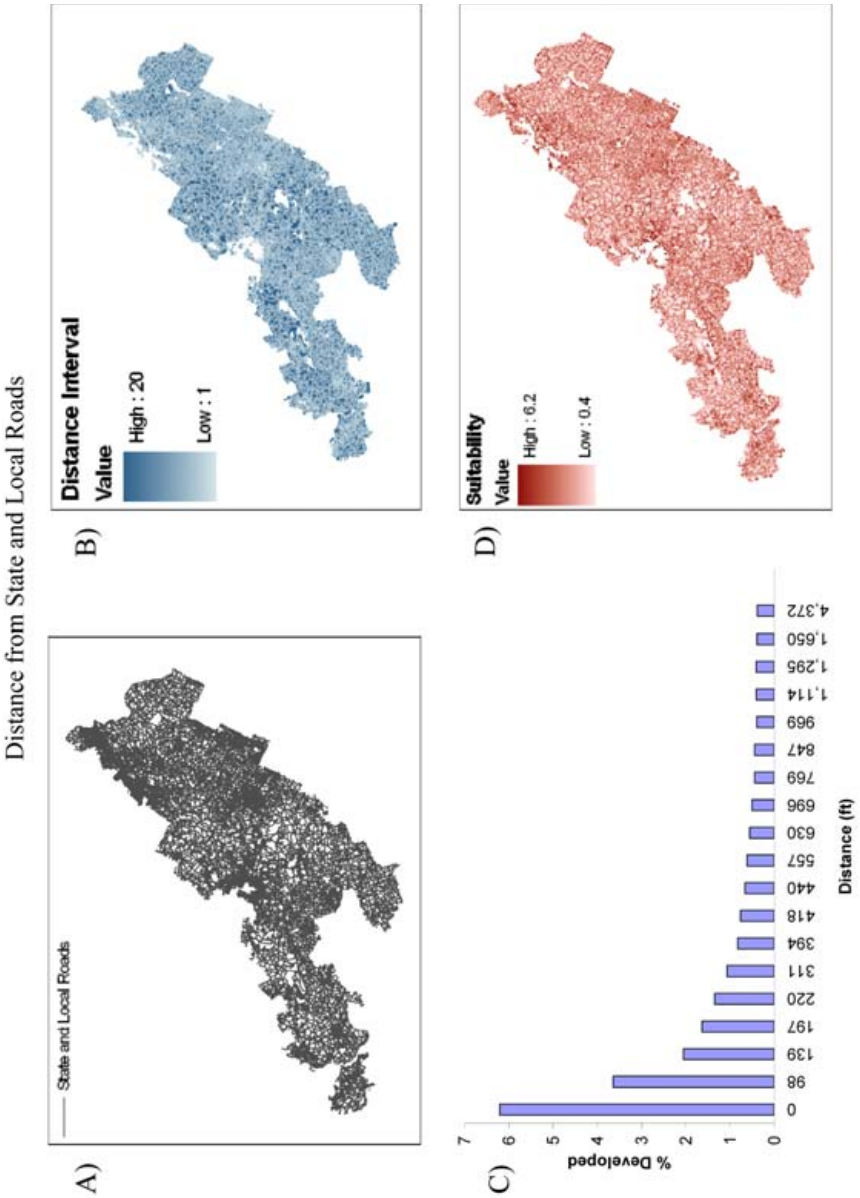


Illustration of operations involved in creation of individual suitability map based on distance from state and local roads. A) Map of state and local roads. B) Map of Euclidean distance from state and local roads classified into intervals. C) Histogram showing percent of cells available for development in each distance interval that were developed between 1992 and 2001. D) Suitability map created by assigning percent developed values in histogram to distance interval map.

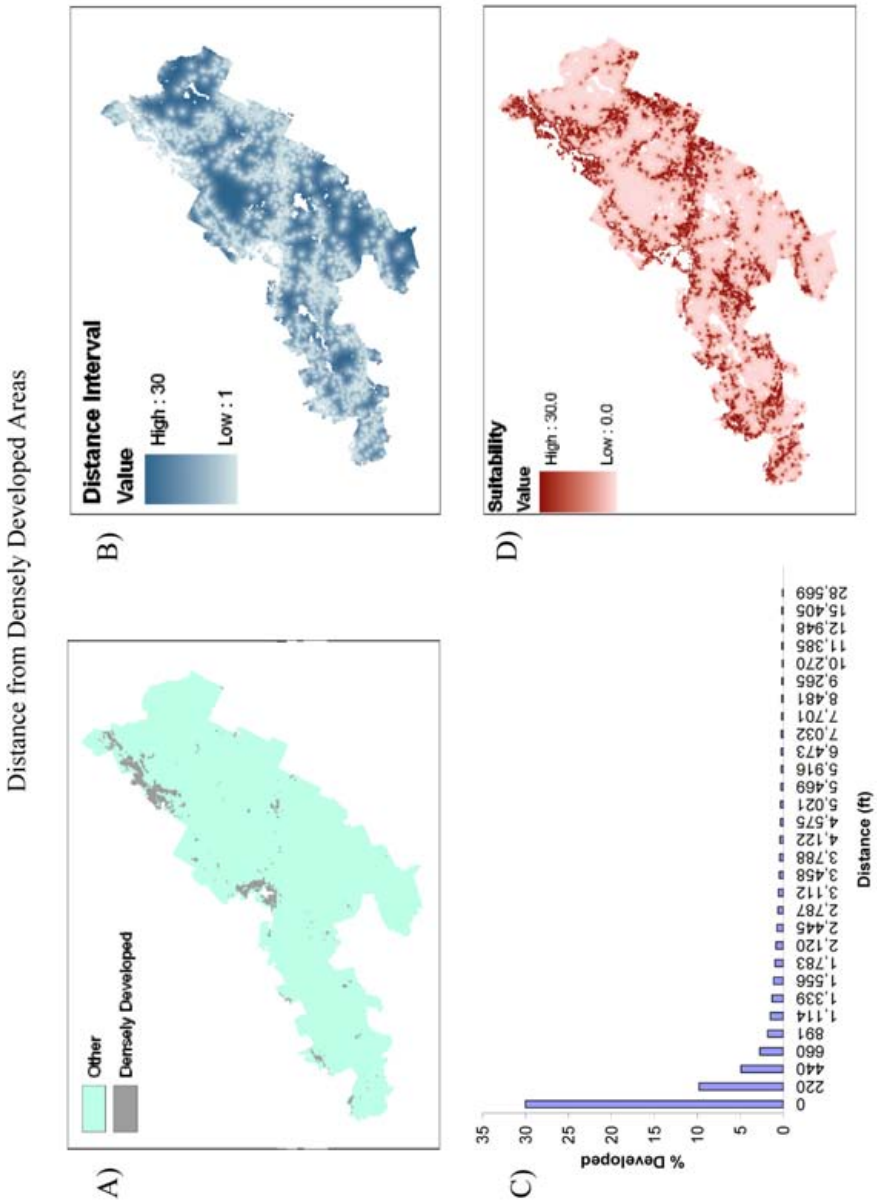


Illustration of operations involved in creation of individual suitability map based on distance from densely developed areas (50% developed within 600 ft radius). A) Map of densely developed areas (data from 2001). B) Map of Euclidean distance from densely developed areas classified into intervals (data from 2001). C) Histogram showing percent of cells available for development in each distance interval (development data from 1992) that were developed between 1992 and 2001. D) Suitability map created by assigning percent developed values in histogram to distance interval map.

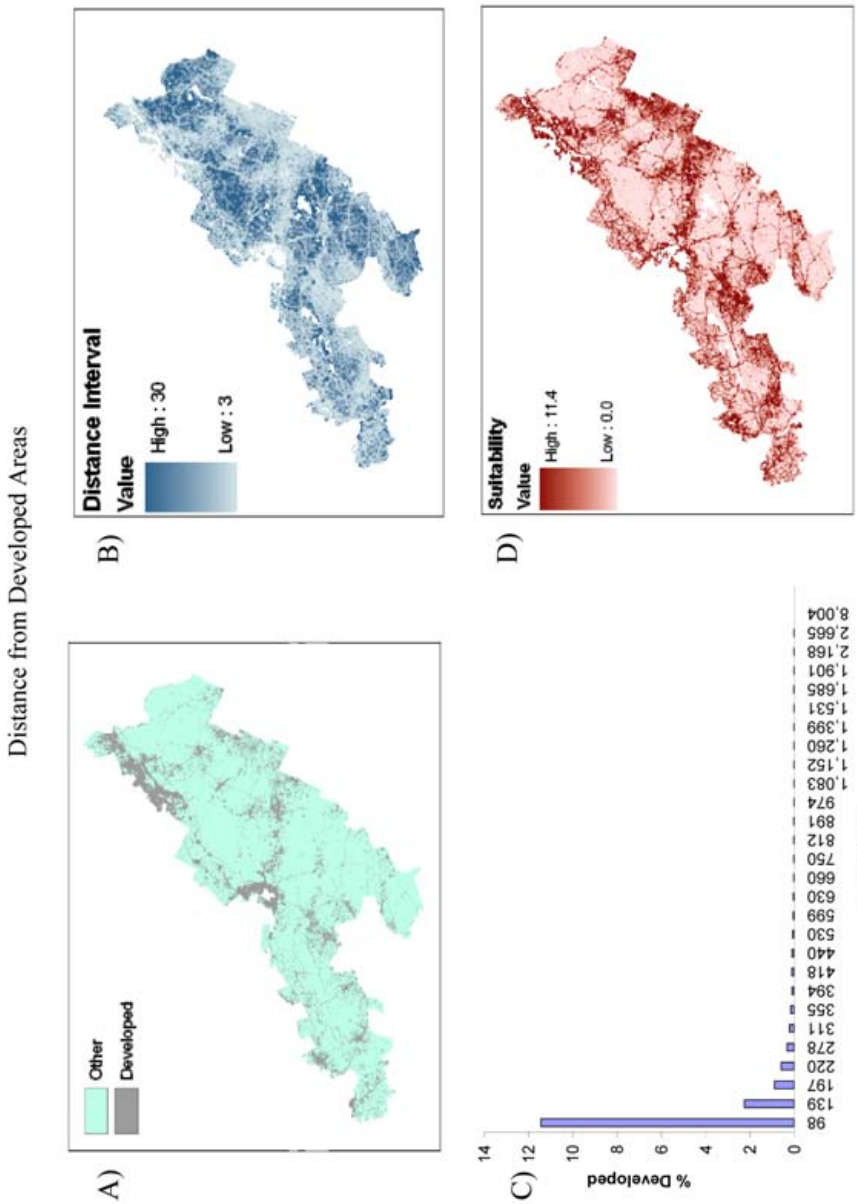


Illustration of operations involved in creation of individual suitability map based on distance from developed areas. A) Map of development (data from 2001). B) Map of Euclidean distance from development classified into intervals (data from 2001). C) Histogram showing percent of cells available for development in each distance interval (development data from 1992) that were developed between 1992 and 2001. D) Suitability map created by assigning percent developed values in histogram to distance interval map.

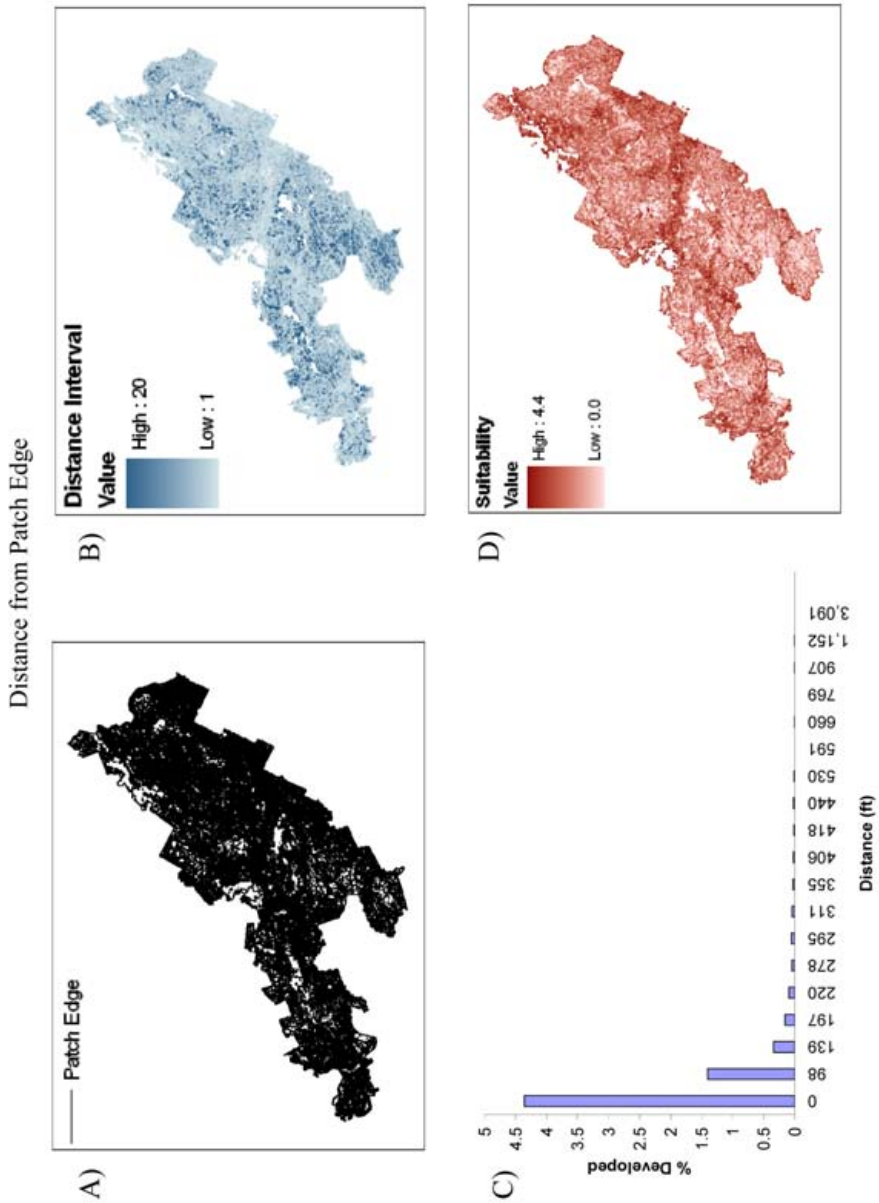


Illustration of operations involved in creation of individual suitability map based on distance from patch edge. A) Map of LULC patch edges (data from 2001). B) Map of Euclidean distance from LULC patch edges classified into intervals (data from 2001). C) Histogram showing percent of cells available for development in each distance from patch edge interval (patch data from 1992) that were developed between 1992 and 2001. D) Suitability map created by assigning percent developed values in histogram to distance interval map.

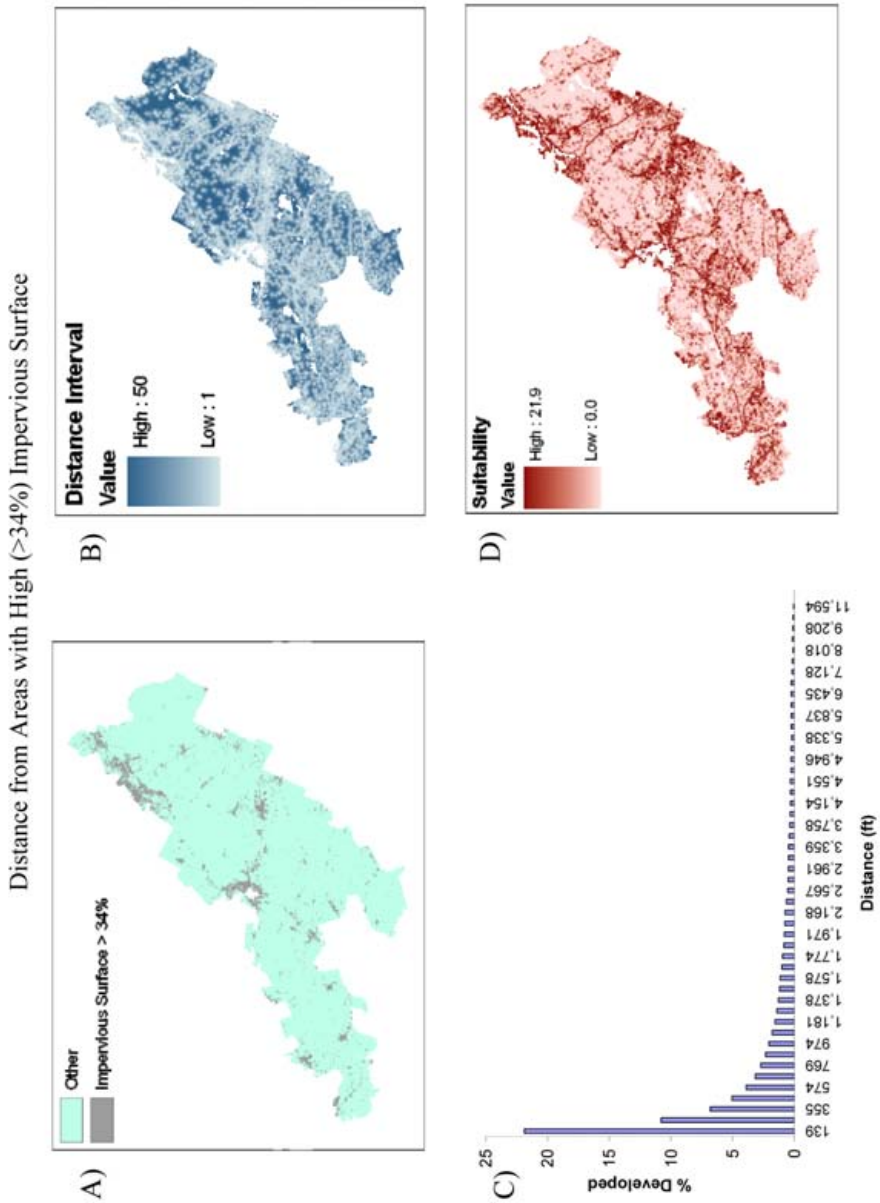


Illustration of operations involved in creation of individual suitability map based on distance from areas with high (>34%) impervious surface coverage. A) Map of areas with impervious surface coverage >34% (data from 2000) . B) Map of Euclidean distance from areas of impervious surface coverage >34% classified into intervals (data from 2000). C) Histogram showing percent of cells available for development in each distance interval (impervious surface data from 1985) that were developed between 1992 and 2001. D) Suitability map created by assigning percent developed values in histogram to distance interval map.

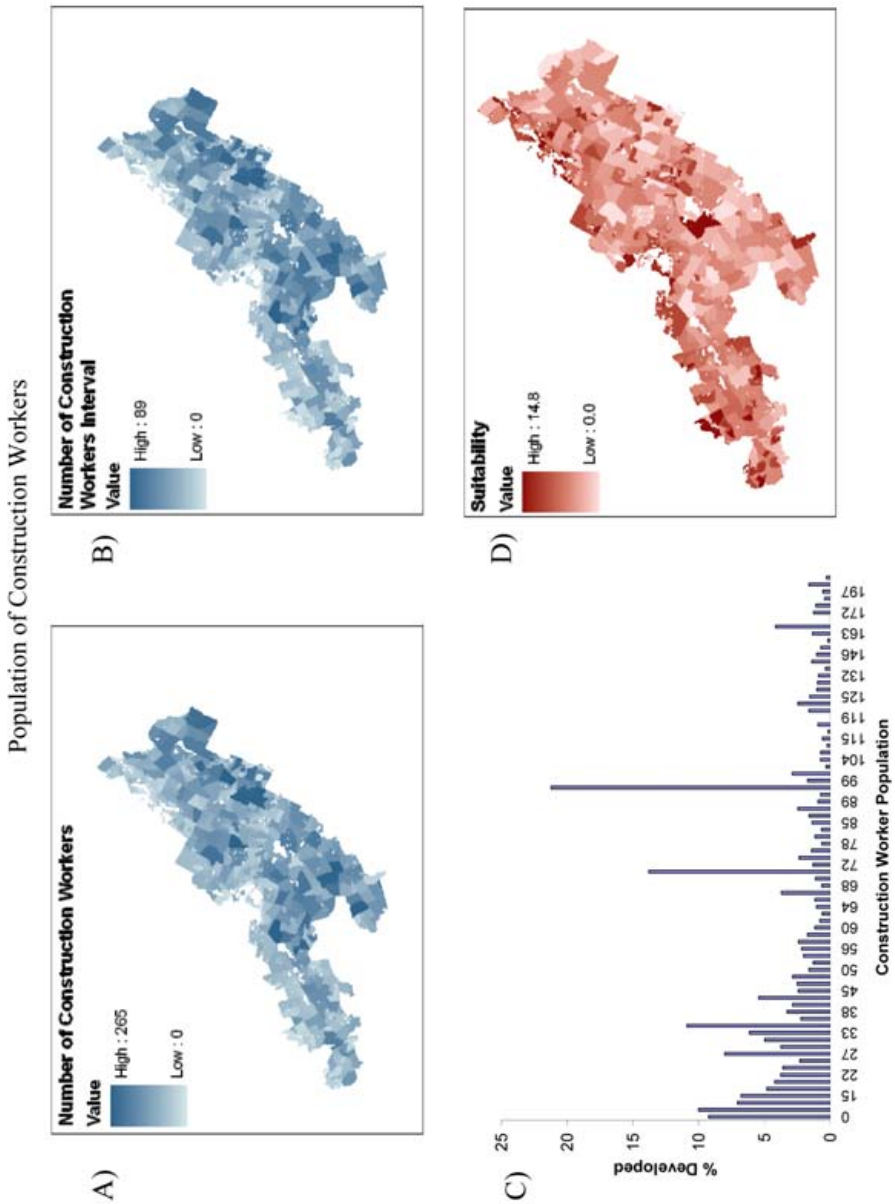


Illustration of operations involved in creation of individual suitability map based on number of construction workers residing in each census block group. A) Map of number of constructions workers per census block group (data from 2000 U.S. Census). B) Map of number of construction workers classified into intervals (data from 2000 U.S. Census). C) Histogram showing percent of cells available for development in each number of construction workers interval (population data from 1990 U.S. Census) that were developed between 1992 and 2001. D) Suitability map created by assigning percent developed values in histogram to number of construction workers interval map.

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