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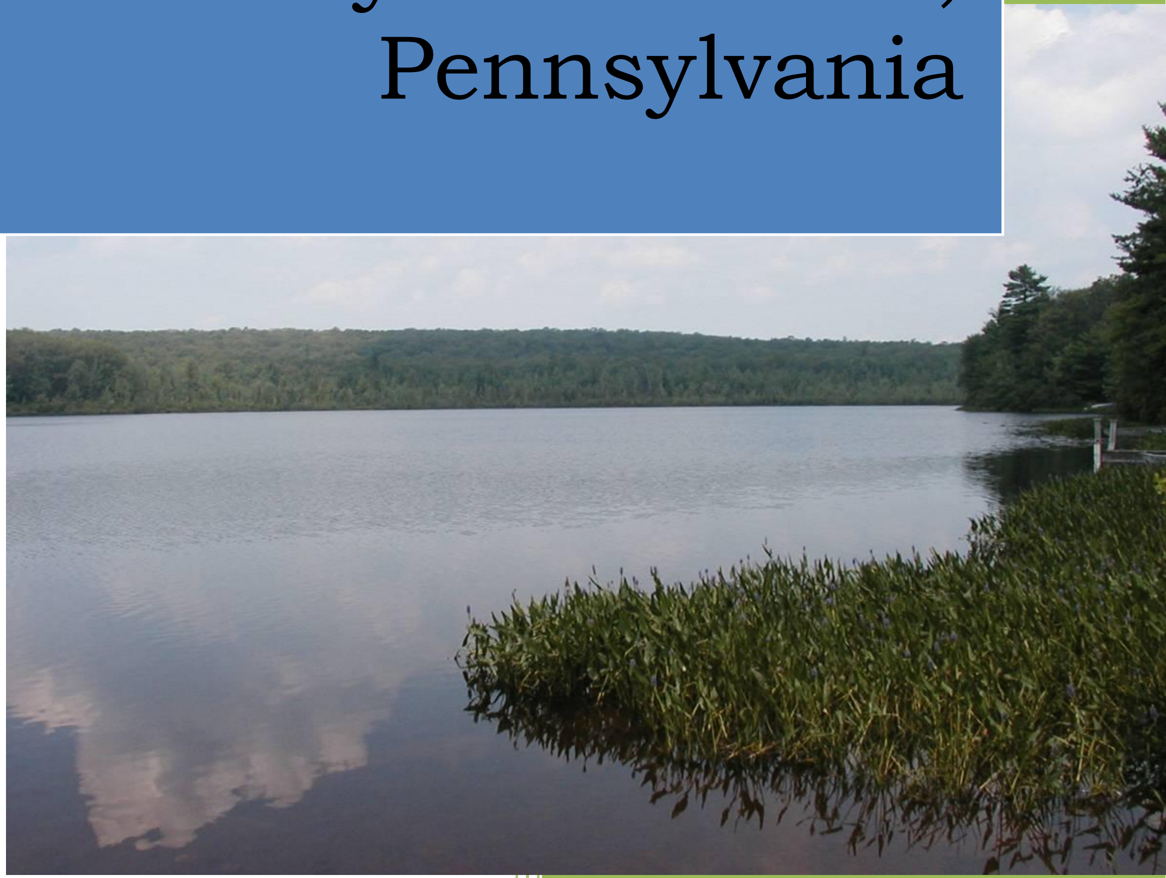
Forecasting Land Use Change in Pike and Wayne Counties, Pennsylvania



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County of Wayne, Pennsylvania
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National Park Service Upper Delaware Scenic & Recreational River (NPS UPDE)
National Park Service Delaware Water Gap (NPS DEWA)
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River Valley GIS Users Group*

** NOTE: The River Valley GIS Users Group includes Pike and Wayne Counties in PA, Delaware, Sullivan, and Orange Counties in NY, and the National Park Service UPDE and National Park Service DEWA. Due to Pike and Wayne County's instigation of this project, the New York Communities are implementing a similar effort whereby the entire Upper Delaware Watershed will be modeled for change.*

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- The Community Conservation Partnerships Program, Environmental Stewardship Fund, under the administration of the Pennsylvania Department of Conservation and Natural Resources, Bureau of Recreation and Conservation (BRC-TAG 11.5-31)
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Table of contents

FIGURES

TABLES

1.0 Introduction

According to the U.S. Census Bureau's 2007 estimates, Pike County is the fastest growing county in the Commonwealth and Wayne County ranks 9th. In terms of increases in population density, or increases in people per square mile, Pike County ranks 11th and Wayne County ranks 21st in Pennsylvania. Prime farmland and forestland are being lost to new residential developments that serve the high levels of population growth—and growth is projected to continue into the future. These counties contain a wealth of natural resources, including the Upper Delaware Scenic and Recreational River (Figure 1), Delaware Water Gap National Recreation Area, state parks and federal lands, a variety of wetlands, high quality and exceptional value watersheds and other unique natural areas. Because of the recreational opportunities afforded by these resources, they are an important component of the economic base.

***Figure 1**: A stretch of the Upper Delaware Scenic and Recreational River in Pike County*

Particularly in the south where growth pressures are highest, recent residential and commercial development is threatening the integrity of many of these resources, primarily through forest fragmentation, impairment of water quality, loss of open space and wildlife habitat, and degradation of scenic views. The need was identified to develop land use strategies that can accommodate population and economic growth without sacrificing the natural resources and quality of life that attract visitors and residents to this area.

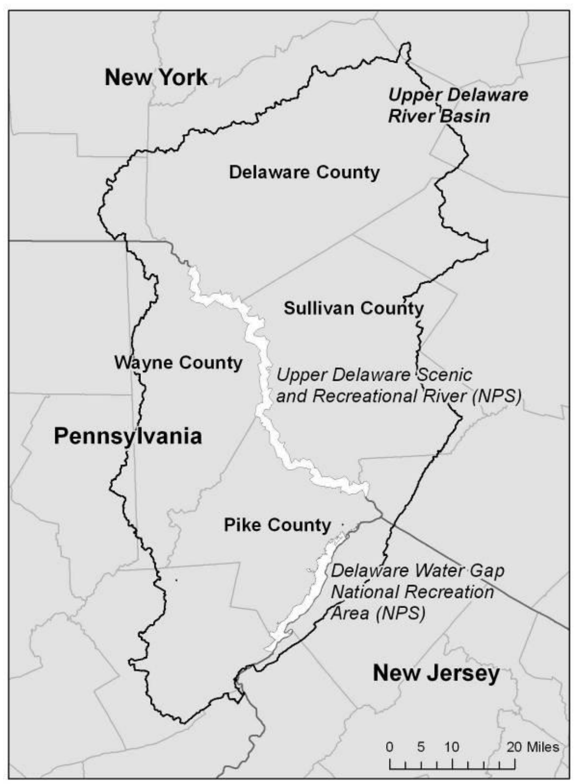


Figure 2: Upper Delaware River Basin

To address this need, the counties of Pike and Wayne implemented a land cover change model that provides forecasts of future development patterns. Funding was provided to Pike County by the Pennsylvania Department of Conservation and Natural Resources (DCNR). In support of this effort, Dr. Eric Brown de Colstoun (SAIC/NASA) obtained funding from NASA to use satellite imagery to create maps of historic and current urban development. Using these maps, Dr. Claire Jantz, from Shippensburg University's Department of Geography, implemented an urban land cover change model called SLEUTH to create forecasts of urban development trends into the future. Dr. Jantz and Dr. Scott Goetz, from the Woods Hole Research Center, were also able to leverage funds from a NASA Land Cover Land Use Change Program grant to support this work.

While several counties have participated in this project (Pike and Wayne counties in Pennsylvania and Delaware and Sullivan counties in New York) (Figure 2), this report will focus on the results for Pike and Wayne counties.

2.0 Methods

2.1 The SLEUTH-3r model

SLEUTH[1] belongs to a class of models referred to as *cellular automata*, where the study area is represented as a regular grid of cells (pixels) and each cell has only two states: urbanized or non-urbanized. Whether or not a cell will become urbanized is determined by four growth rules, discussed below, each of which attempts to simulate a particular aspect of the development process. In their seminal application of the SLEUTH model in the San Francisco Bay area, Clarke, Hoppen, and Gaydos (1997) stress the utility of the model in simulating historic change, the description of which can aid in the explanation of growth processes at a regional scale, and in predicting future urbanization patterns. SLEUTH has been applied to dozens of locations across the U.S. and the world (U.S. Geological Survey 2007).

This project has benefitted from research and development related to the SLEUTH model undertaken in previous applications in the Washington, DC region (Jantz and Goetz 2005; Jantz, Goetz, and Shelley 2004) and Chesapeake Bay watershed (Goetz et al. 2004; Jantz, Goetz, and Jantz 2005). In our previous work with SLEUTH, we developed a new version of the model, SLEUTH-3r,that is more computationally efficient and creates more accurate simulations at finer resolutions than the original version of the model (Jantz et al. in review). SLEUTH-3r is the version of the model used in this work.

Implementation of the model occurs in two general phases: calibration, where historic growth patterns are simulated; and forecasting, where the historic patterns of growth are projected into the future. For calibration, the model requires inputs of historic urban extent for at least two time periods, a historic transportation network for at least two time periods, slope, and a data layer that describes where development is more or less likely to occur (exclusion/attraction layer). The exclusion/attraction layer contains probabilities of exclusion or attraction; areas that should be partially or completely excluded from development are assigned values between 51 and 100; areas that are neutral for development are given a value of 50; and areas that will attract development are given values less than 50. Based on these inputs, the model "learns" to replicate historic patterns of development (calibration) and the results are used for forecasting future urbanized extent.

SLEUTH simulates four types of growth (summarized in Table 1 below), which are applied sequentially during each annual growth cycle:

1. Spontaneous new growth simulates dispersed development patterns,
2. New spreading centers simulates the development of new urban areas,
3. Edge growth stems from existing urban centers,

[1] SLEUTH is an acronym based on the inputs to the model: slope, land use, exclusion, urban extent, transportation, and hillshade. Full documentation about the model as well as the model code is available at the Project Gigalopolis Urban and Land Cover Modeling website (http://www.ncgia.ucsb.edu/projects/gig/).

4. Road influenced growth simulates the influence of the transportation network on development patterns.

These growth types are defined through a set of five growth coefficients: slope, diffusion, breed, spread, and road gravity. Each growth coefficient can take on a value from 1 to 100, which indicates the relative influence of each parameter on development patterns, with higher values producing a stronger influence. The specific value for each growth coefficient is derived during calibration, so the model is tailored to replicate the growth patterns for a specific study area. In conjunction with the exclusion/attraction layer, these five growth coefficients determine the probability of any given location becoming urbanized. The slope coefficient determines the effect of slope on the probability of urbanization and affects all growth types in the same way: as each location is being considered for urbanization, the slope at that location is considered. Higher slope coefficients result in a lower likelihood of urbanization on steep slopes. In this application, slopes above 21% cannot be urbanized.

Table 1: Summary of growth rules

Growth rule	Growth coefficient	Growth coefficient value range	Description of simulated growth patterns
Spontaneous new growth	Diffusion	0-100	Randomly selects potential new growth cells. High values for diffusion will result in dispersed urban patterns.
New spreading center growth	Breed	0-100	Creates new clusters of urbanized cells.
Edge growth	Spread	0-100	Growth that occurs along the edges of existing or newly created urban clusters
Road-influenced growth	Road-gravity, diffusion and breed	0-100	Growth that occurs along the transportation network
Slope resistance	Slope	0-100	Simulates the effect of slope on reducing the likelihood of urbanization
Exclusion/attraction layer	User-defined map layer	0-100 (0-49 indicates attraction, 50 is neutral, 51-100 indicates exclusion)	Specifies areas that are more or less likely to experience development.

2.2 Input data sets for calibration

As noted above, the SLEUTH-3r model requires the following input data sets for calibration: a series of maps showing urban development through time for at least two points in time, a transportation network for at least two points in time, a slope layer and an exclusion/attraction layer. All inputs are grids (rasters) and the cell (pixel) resolution for all inputs in this particular application is 28.5 m x 28.5 m (93.5 ft x 93.5 ft). The minimum mapping unit is therefore 812.25 m^2 or about 0.2 acres.

2.2.1 Urban development time series

Eric Brown de Colstoun, our collaborator at SAIC/NASA, created a time series of urban development that was derived from LANDSAT 5 Thematic Mapper (TM) satellite imagery for the years 1984, 1995 and 2005 (see Figure 3 for an example). These data were processed by the USGS and were purchased by Dr. Brown de Colstoun for further processing. Multi-date LANDSAT images (a total of 16) covering the Upper Delaware River watershed region were utilized to support this project and include both winter ("leaf-off") as well as summer ("leaf-on") scenes. The need for both leaf-on and leaf-off data was dictated by the need to detect impervious surfaces which may have been hidden by trees during the growing season (e.g. roads and/or houses). Table 2 shows the list of the total number of LANDSAT scenes available to this project through our collaboration with NASA, although only those images corresponding to the 1984, 1995, and 2005 eras were used in the creation of the urban development time series. Dr. Brown de Colstoun is also developing a corresponding time series of tree cover maps.

Table 2: LANDSAT Satellite imagery available for use in this project

No.	Acquisition Date
1	8/20/84
2	9/21/84
3	4/17/85
4	6/12/88
5	7/30/88
6	3/27/89
7	8/19/95
8	4/15/96
9	9/23/99
10	1/29/00
11	10/1/02
12	7/2/04
13	8/4/04
14	9/20/04
15	11/15/04

To create maps of urban land cover from the LANDSAT imagery, high spatial resolution (i.e. 1 m^2) aerial photography and/or commercial satellite data from the IKONOS satellite were used. The air photography was interpreted into impervious/not impervious maps at their original resolution, and then these were aggregated to the 28.5 m x 28.5 m resolution of LANDSAT. These points provided a linkage between the proportions of bare/impervious surfaces with the signal of the LANDSAT data at many sampling sites in the counties. These "training data" were then used to generate impervious cover maps for the entire region, and for multiple years. A great deal of effort was put into making the 2005 map as accurate as possible to minimize errors in the 1995 and 1984 maps. The initial data set produced from this method shows the *fractional impervious surface area* (ISA) within each 28.5 x 28.5 m pixel for 1984, 1995 and 2005 (Figure 3)—in other words, each the value for each cell indicates the proportion of that cell that is made up of impervious surfaces. Values range from 0 (no impervious surface) to 100 (100% covered by impervious surface). An independent accuracy assessment of the spatial location of urban development in 2005 was performed by SU and found an overall accuracy of 86%, although the commission error rate (i.e. the rate of non-impervious pixels that were mapped as impervious surface) was found to be high.

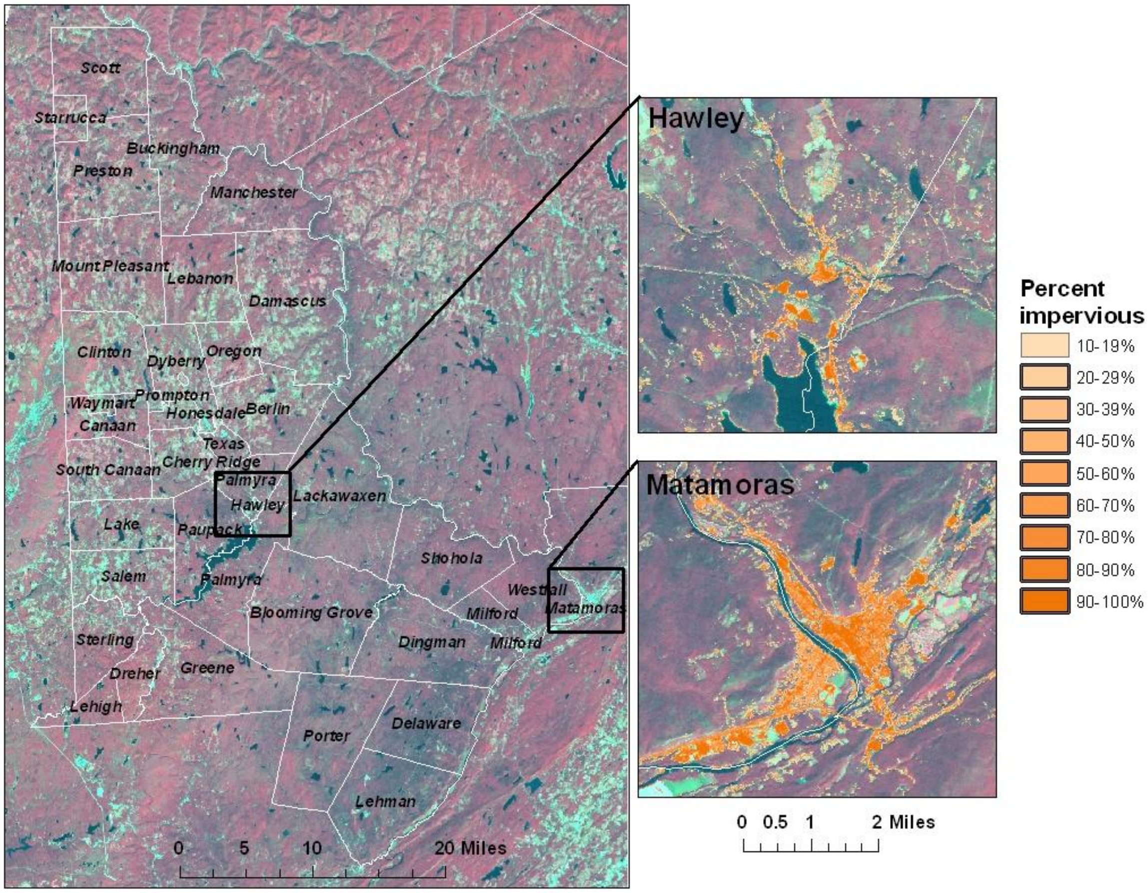


Figure 3: Landsat satellite image from October 2005 (left) and fractional impervious surface area (right)*. In the left-hand image, reds indicate vegetation (forest), light cyan indicates agricultural fields, bright cyan indicates impervious surfaces and black indicates water. The inset images on the right show examples of the impervious surface data set that was derived from the satellite imagery. In these images, the amount of impervious surface cover within each 28.5 x 28.5 pixel is shown in shades of orange.*

Before they could be used in the SLEUTH-3r model, these initial maps of fractional impervious surface area (ISA) required additional processing (Figure 4). First, SLEUTH requires maps that show pixels being either urban or not, so we were not able to incorporate the fractional ISA values. We therefore considered all pixels that had an ISA value greater than or equal to 20% as being "urban." Second, SLEUTH-3r is extremely sensitive to the accuracy of the input maps. In particular, a high commission error rate can result in an over-estimation of urban development. To address this issue, we used high resolution air photos to visually assess the accuracy of the 2005 urban land cover map within the study area. Pixels that were incorrectly mapped as urban (i.e. bare agricultural fields) were removed manually, as were occurrences of rock outcrops. This process of manually editing the urban land cover maps was labor intensive and was performed by three undergraduate students at Shippensburg University, each working 10 hours/week for roughly 6 weeks. However, it greatly improved the quality of the maps that would be used as input into the model.

Our county planning partners expressed remaining concerns about single, isolated pixels, often scattered across agricultural landscapes, being mapped as urban when they apparently were not. In response to this concern, we performed an analysis of these single, isolated pixels within Pike and Wayne counties. All single pixels were identified in the 2005 urban map. We found 42,606 single urban pixels, corresponding to an area of roughly 35 km^2 (8,649 acres), which constituted about 12% of the total urban area in Pike and Wayne counties. An accuracy assessment was conducted to examine if single pixels identified as urban were actually urban. We found that these pixels were mapped correctly only 23% of the time in Wayne County and 49% of the time in Pike County. We also found that errors were more likely to occur if the pixel had a low fractional impervious surface value and if the pixel was located in an agricultural landscape. We therefore identified a fractional ISA threshold to eliminate pixels that were likely to be commission errors: any single pixel with a fractional ISA value of less than 40% was eliminated unless it was located in an agricultural landscape (as identified from the National Land Cover Data (US Geological Survey 2001)); in those cases pixels with a fractional ISA value of less than 70% were eliminated.

This final map for 2005 was then used to derive the maps for 1995 and 1984 by assuming that only unidirectional growth has occurred. In other words, if the 1995 map had a pixel identified as urban, but the same pixel in the 2005 map was classified as not urban, the pixel was assumed to be not urban in 1995. The 1995 urban map was then used to create the 1984 urban map. Thus, urban growth is unidirectional between 1984 and 2005.

Because roads are provided to the model as a separate input layer, roads were removed from the urban land cover map. Within areas of high road density (i.e. within villages), roads remained as part of the urban land cover; in areas outside of high road density zones, urban pixels associated with roads were eliminated using a roads mask based on county roads GIS data. To eliminate roads in rural areas a three pixel wide mask was created; a pixel was added on each side of the road pixel to account for spatial alignment errors between the GIS roads and the urban land cover map.

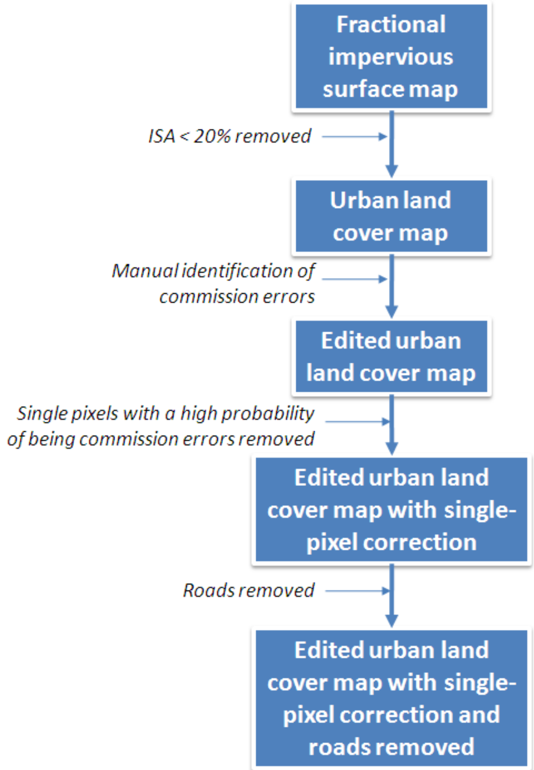


Figure 4: Editing steps *applied to the original 2005 impervious surface map to prepare it for input into SLEUTH-3r.*

The last step in preparing the urban land cover maps for input into SLEUTH was to identify areas where no data were available at any point in the time series. Areas of no data occurred due to cloud cover or incomplete coverage in the original LANDSAT imagery. For calibration, all "no data" pixels were removed from the time series, regardless of which map the "no data" pixel occurred in. This maintained the logical consistency of unidirectional urban land cover change. Complete data were available for 2005 for the study area, so we therefore have complete coverage for the forecast maps.

2.2.2 Slope and Roads

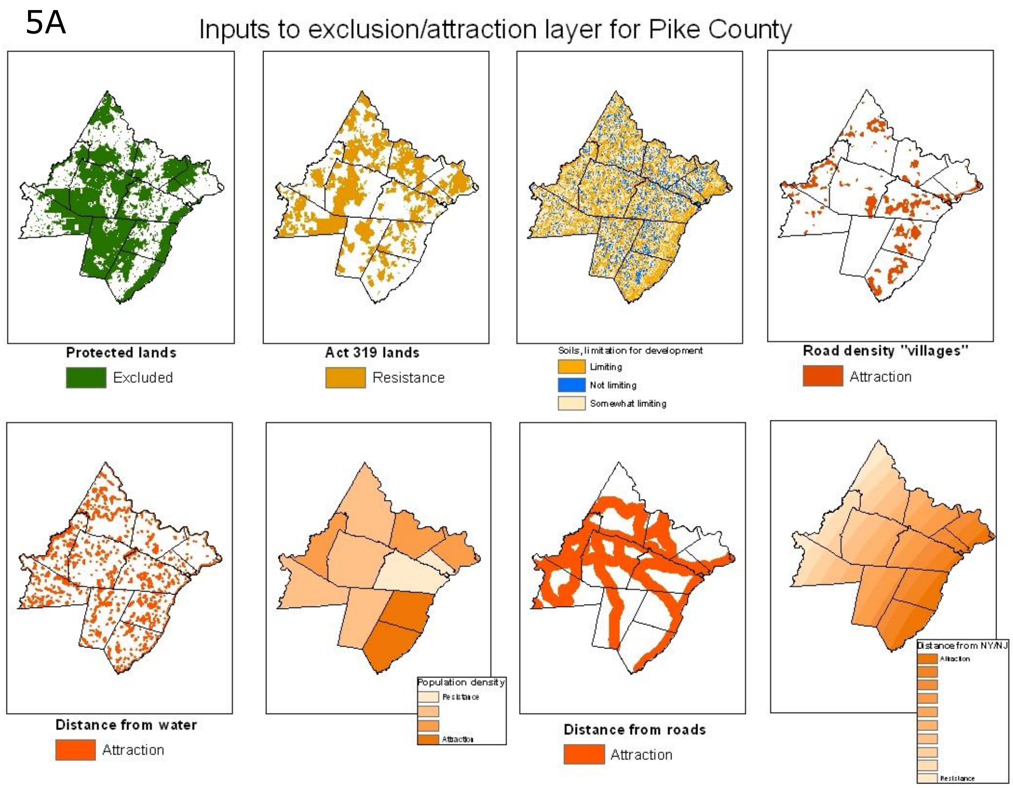
The slope layer was derived from the National Elevation data set (US Geological Survey n.d.). Only primary roads were used to represent the transportation network, and were derived from the ESRI Streetmap data set (Environmental Systems Research Institute 2003) to maintain consistency across the study area. Once primary roads had been identified for circa 2003, this road network was checked against the 1984 LANDSAT imagery. Primary roads that did not exist in 1984 were removed to represent the 1984 road network, although instances of this were rare.

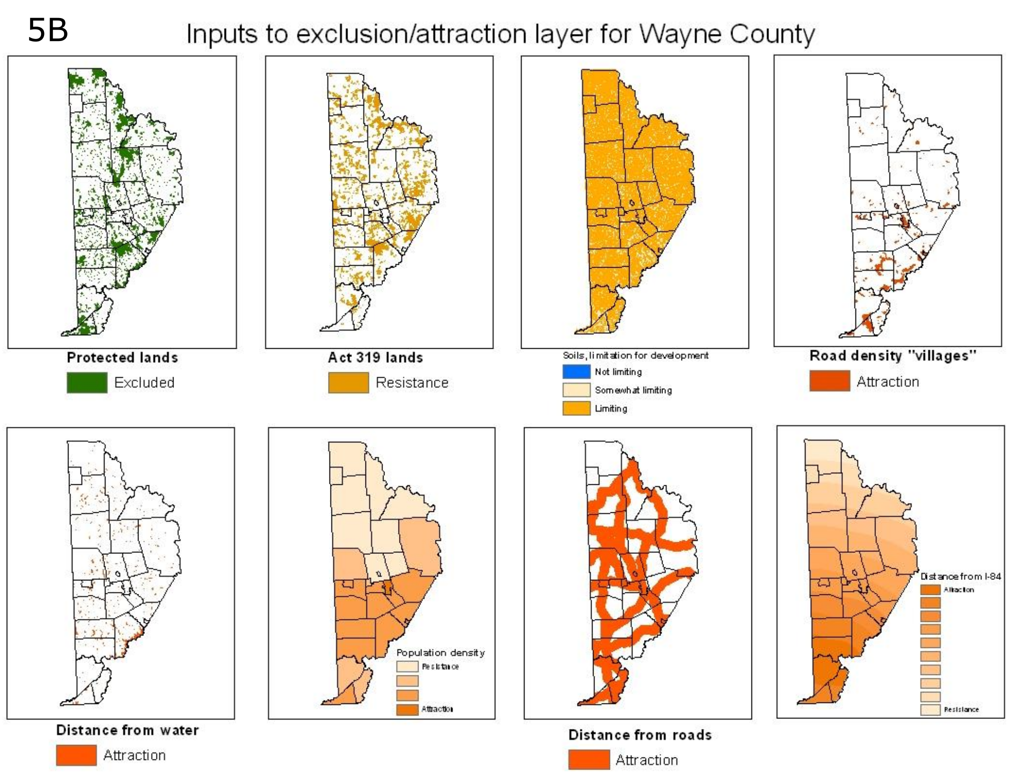
2.2.3 Excluded/attraction layers

Excluded/attraction layers were developed separately for each county in the study region. The general approach used was to identify factors that would either attract development (i.e. proximity to roads) or repel development (i.e. engineering limitations of soils) (Figure 5). These exclusion and attraction factors for each county were combined using GIS overlay modeling, and the resulting map was classified into seven classes to identify the degree of exclusion or attraction. The class values ranged from 40 (attraction) to 90 (strong resistance), with 50 representing a neutral value. We then identified lands that would be completely excluded from development, such as parks and water bodies, and assigned a value of 100 to indicate complete resistance to development, and added those features to the final excluded/attraction layer. Appendices A and B describe all of the data layers that were included for the exclusion/attraction models for Pike and Wayne counties, respectively, and Figure 6 shows the final exclusion/attraction layers used for calibration.

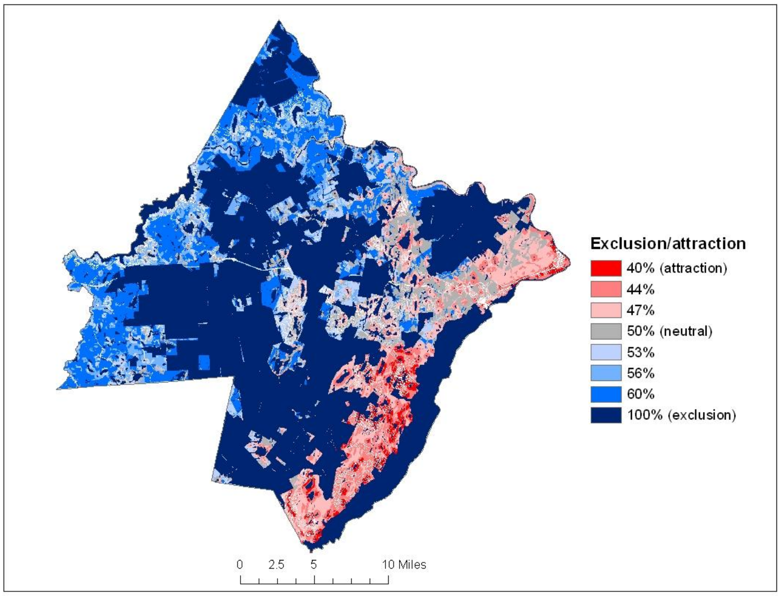
Factors that attract development include distance to major roads, which was represented by a 1500 meter (0.9 miles) buffer around the roads, and distance to lakes, portrayed with a 300 meter (0.2 miles) buffer around lakes. For Pike County, the linear distance to the New York/New Jersey metropolitan region was considered an attraction, while the linear distance from I-84 in southern Wayne County acted as a factor that would attract development. Population density for municipalities (U.S. Bureau of the Census 2000) acts as an attraction to development. Areas of high road density, as calculated from the county GIS roads datasets, were also considered to act as an attraction for development. These are referred to as road density "villages" in Appendices A and B.

The contributing factors that resist development are the engineering limitations of certain soils, as defined in the Soil Survey Geographic Database (SSURGO) (Soil Survey Staff n.d.). Act 319 conservation easements were also taken into account. However, Act 319 lands were not considered to be completely protected from development. In areas where the resistance/attraction layer had a protection of greater than 50, Act 319 lands were given a resistance value of 60%. If the resistance/attraction layer value is less than 50% (indicating that development pressures were high), Act 319 status was ignored. Areas of complete protection include all water bodies, wetlands, all parks, and cemeteries. Hunting and fishing clubs were also assumed to be completely protected; even though these lands are privately owned, they are so highly valued by their users that it is unlikely they would be sold for development.





Figures 5: Attraction and resistance layers used in Pike (5a) and Wayne (5b) counties



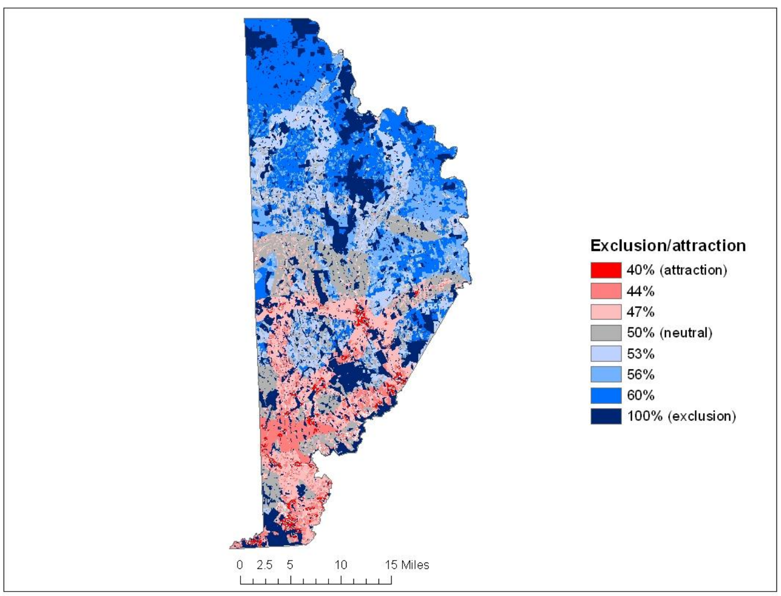


Figure 6: Exclusion/attraction layers *for Pike (upper) and Wayne (lower) counties. Reds indicate attraction, blues indicate resistance and gray shows areas that are neutral for development. Note that the excluded layers were created separately for each county, not jointly. However, since the model was also run separately for each county, edge effects due to differences in the exclusion/attraction maps at the county boundaries were avoided.*

The creation of the exclusion/attraction layers was a repetitive process, and input from the Pike County and Wayne County planning offices was important. At the beginning of the project, a workshop was held with the counties to identify factors that were driving growth. An initial exclusion/attraction layer was created and then submitted to the county planning offices for review. Based on the comments of the county planning offices, several changes were made to the exclusion/attraction layers to better represent growth pressures and barriers to growth. The value of the input from the county planning offices cannot be understated: they provided “on the ground” knowledge of growth processes that we were able to incorporate into the model, ultimately producing a much more accurate simulation of growth patterns and rates (see section 3.1).

2.3 Calibrating the SLEUTH model

Calibration of the SLEUTH model is a technical process. As such, this section of the report is technical in nature. Its inclusion is important to clearly document the methods used in this study.

A model was developed separately for each county, which means that SLEUTH was calibrated separately for Pike and Wayne counties. This allowed us to account for differences in growth patterns and drivers of land use change between the counties. Another benefit of creating separate models for both counties is that each county now has a calibrated modeling tool to run additional scenarios beyond the scope of this project.

The goal of SLEUTH calibration is to find a set of values for the growth parameters (diffusion, breed, spread, road-gravity and slope) that can accurately reproduce historic land-cover change within the study area. Calibration is typically undertaken using what is referred to as a "brute force" methodology. That is, a large number of combinations of parameter values are tested automatically and the user evaluates the results, locating a "best fit" set of parameter values through the use of statistics that measure how well the model is replicating historic patterns of urbanization (Table 3). In this study, we tested 3,125 unique parameter combinations, a sufficient number of parameter sets to find a good fit for the model.

The choice of statistics is important, since it determines how SLEUTH will simulate urban patterns and how forecasts of urban growth will be created. For the calibration procedure in this work, we therefore focused on two metrics we considered most relevant to the application: the population fractional difference (PFD) and the clusters fractional difference (CFD), statistics that quantify the model's ability to simulate rates and patterns of observed development. The PFD and CFD metrics are direct comparisons between the number of urban pixels and the number of urban clusters, respectively, in the control maps and the corresponding simulated maps. We selected parameter sets that were able to match both of these fit statistics within +/- 5%.

SLEUTH is a random model and thus utilizes the Monte Carlo method to generate growth simulations, which means that multiple simulations (or trials) of growth are created for each unique parameter set. The fit statistics that SLEUTH-3r calculates are therefore averaged over the total numbers of Monte Carlo trials that were run. The Monte Carlo method also produces maps that show the *likelihood* or *probability* of development. For calibration, we initially used only seven Monte Carlo trials to economize computational processing time. Based on these initial results, we selected up to five parameter sets that did the best job of simulating rates and patterns of development. Then, each parameter set was tested by running the model in calibrate mode for twenty-five Monte Carlo trials. Running the model in calibrate mode ensured that each candidate parameter set was compared to the historic input data sets and that robust statistics were calculated.

Table 3: New fit metrics available in SLEUTH-3r. *For each of the metrics described below, SLEUTH-3r writes the following three quantities to a ratio log file: (i) the algebraic difference between the observed value and modeled value (diff), (ii) the ratio of the modeled value to the observed value (ratio), and (iii) the fractional change in the modeled value relative to the observed value (fract). Measurements derived from the modeled data are averaged over the set of Monte Carlo trials. It does this for each run, and for each control year.*

Fit statistic	Definition
Area (area)	Modeled urban pixels compared to actual urban pixels for each control year.
Edges (edges)	Modeled urban edge pixels compared to actual urban edge pixels for each control year.
Clusters (clusters)	Modeled number of urban clusters compared to actual urban clusters for each control year. Urban clusters are areas of contiguous urban land. In cell space, clusters can consist of a single pixel or multiple, contiguous urban pixels. Contiguity is determined using the eight-neighbor rule.
Population (pop)	Modeled urban pixels compared to actual urban pixels for each control year.
Cluster size (mn_cl_sz)	Modeled average cluster size compared to actual average urban cluster size for each control year. This is not an area-weighted mean.
Slope (avg_slope)	The average slope for modeled urban pixels compared to actual average slope for urban pixels for each control year.
% Urban (pct_urban)	The percent of available pixels urbanized during simulation compared to the actual urbanized pixels for each control year.
X-mean (xmean)	Average x-axis values for modeled urban pixels compared to actual average x-axis values for each control year.
Y-mean (ymean)	Average y-axis values for modeled urban pixels compared to actual average y-axis values for each control year.
Radius (radius)	Average radius of the circle that encloses the simulated urban pixels compared to the actual urban pixels for each control year.

SLEUTH also has a “self-modification” function (Clarke et al, 1997), which changes the values for the growth coefficients as the model iterates through time, and which is intended to more realistically simulate the different rates of growth that occur in an urban system over time. When the rate of growth exceeds a specified critical threshold, the growth coefficients are multiplied by a factor greater than one, simulating a development “boom” cycle. Likewise, when the rate of development falls below a specified critical threshold, the growth coefficients are multiplied by a factor less than one, simulating a development “bust” cycle. Without self-modification, SLEUTH will simulate a linear growth rate, producing the same number of new urban pixels, on average, each year until the availability of developable land diminishes. Since growth rates were nearly linear between 1984 and 2005 (e.g. Figure 11), we did not invoke the self-modification function for calibration. As discussed in the next section, however, we did utilize self-modification when creating forecasts.

In order to provide additional assessments of the accuracy and utility of the model simulations, beyond those calculated by the model during calibration, we performed an extensive accuracy assessment. After the best fit parameters were identified for each sub-region, the model was initialized in 1984 and run in predict mode to 2005, with 25 Monte Carlo trials. This resulted in a predicted development probability surface for 2005, which was then compared to the observed patterns for 2005. While aggregate performance measures for each county were calculated during calibration (i.e. model fit statistics), this additional assessment allowed us to quantify model performance at finer scales within each county. Using regression analysis, we compared observed and simulated urban land cover for 2005 across multiple scales: counties, municipalities, and 1 km^2 grid cells.

2.4 Forecasts of future urbanization

Forecasts of future urbanization were created through modifications of the exclusion/attraction layers and by applying different future growth rates (i.e. booms and busts) using SLEUTH's self-modification function. For the baseline scenarios, we used the same excluded layer that was developed for calibration—in other words, we assumed no change in land use policies. A set of alternative scenario narratives, outlined below for Pike County in Table 4 and Wayne County in Table 5, were also developed in conjunction with the county planning offices to explore issues they identified as being most relevant. Based on these narratives, an exclusion/attraction map was generated for each scenario to represent the corresponding spatial changes to policies or drivers of land use change. These exclusion/attraction maps (Figures 7 and 8) were provided as input to the growth model. Specific data sets and weighting factors used to represent these scenarios are included in Appendices A and B.

For each scenario, forecasts for high-, mid-, and low-range growth rates were completed. For example, Pike County has a total of six scenario narratives, so a total of 18 forecasts were created; Wayne County has a total of four scenario narratives, so a total of 12 forecasts were created. These forecast ranges were implemented using SLEUTH's "self-modification" functionality, which allows the model to dynamically change growth rates over the forecast time period (see Appendix C). For each scenario, the high-, mid-, and low-range growth estimates are roughly equal; thus, the main difference between each scenario will be in the spatial arrangement of development.

Table 4: Alternative future scenario narratives for Pike County

1. Baseline/current trends: Assume no changes in policies or land use change drivers
    a. Assume no change in policies or land use change drivers, except remove attraction related to proximity to the New York/New Jersey metropolitan region.

2. Best for the protection of natural resources
    a. Assume full protection of Act 319 lands
    b. Assume continued protection of all existing hunt clubs
    c. Assume a protected buffer (94 ft, or the width of one 28.5m pixel) around water bodies, streams, wetlands and floodplains
    d. Assume growth will occur in or near existing villages and near primary road network
    e. Assume no new roads or road upgrades, or other transport upgrades; retain proximity to the New York/New Jersey metropolitan region as a driver; retain existing population density trends

3. Protection of natural resources while accommodating growth
    a. Assume full protection of Act 319 lands
    b. Assume continued protection of all existing hunt clubs
    c. Assume a protected buffer (94 ft, or the width of one 28.5m pixel) around water bodies, streams, wetlands and floodplains
    d. Assume growth will occur in or near existing villages and near primary road network or rail stations.
    e. Assume roads improvements (NJ Rt. 206) and rail improvements (Lackawanna Cutoff New Jersey Transit line); retain proximity to the New York/New Jersey metropolitan region as a driver; retain existing population density trends
    f. Constrain regional growth impacts of Highland Village. This is a proposed 2,900 acre mixed-use development planned for approximately 5,250 residential building lots, 350,000 square feet of commercial space, and a 250-room hotel in Pike County, Lehman Township, Pennsylvania.

4. Amenity growth
    a. Assume partial or no protection of Act 319 lands
    b. Assume limited protection of existing hunt clubs, except Blooming Grove Hunting and Fishing Club, which will retain full protection
    c. Wetlands remain protected
    d. Lakes, rivers and parks attract growth
    e. Large lot, estate style development
    f. Assume road improvements (NJ Rt. 206) and rail improvements (Lackawanna Cutoff New Jersey Transit line); enhance proximity to the New York/New Jersey metropolitan region as a driver; retain existing population density trends
    g. Maximize regional growth impacts of Highland Village.

5. High growth
    a. Assume no protection of Act 319 lands
    b. Assume no protection of existing hunt clubs, except Blooming Grove, which will retain full protection
    c. Wetlands are not protected
    d. Lakes, rivers and parks attract growth
    e. High density development
    f. Assume road improvements (NJ Rt. 206) and rail improvements (Lackawanna Cutoff New Jersey Transit line); retain proximity to the New York/New Jersey metropolitan region as a driver; retain existing population density trends
    g. Maximize regional growth impacts of Highland Village.

Table 5: Alternative future scenario narratives for Wayne County

1. Baseline/current trends: Assume no change in policies or land use change drivers

2. Village clustering
    a. Encourage development to occur in or near existing villages, expanded by adding a 750 m (0.5 mile) buffer
    b. Encourage development to occur near major roads or transit locations, assuming that the Lackawanna Cutoff New Jersey Transit line is completed
    c. Protections on wetlands, parks, hunt clubs, Act 319 lands, etc. remains as in current trends

3. Increasing conservation of farm and forest land
    a. All current Act 319 lands will be permanently protected
    b. Forests and farmlands have a lower chance of being developed
        i. These lands will not be completely excluded from development, but will have a lower likelihood of being developed to reflect an increased willingness to put these lands into easements—especially 10 acres or greater for Clean and Green; agricultural lands have a higher weight than forest lands
    c. Protection on riparian zones and wetland buffer zones (94 ft, or the width of one 28.5m pixel)
    d. Other development resistance/attraction remains the same as current trends

4. Village clustering combined with increasing conservation
    a. Encourage development to occur in or near existing villages, expanded by adding a 750 m (0.5 mile) buffer
    b. Encourage development to occur near major roads or transit locations, assuming that the Lackawanna Cutoff New Jersey Transit line is completed
    c. Current Act 319 lands will be permanently protected
    d. Forests and farmlands have a lower chance of being developed
        i. These lands will not be completely excluded from development, but will have a lower likelihood of being developed to reflect an increased willingness to put these lands into easements—especially 10 acres or greater for Clean and Green; agricultural lands have a higher weight than forest lands
    e. Protection on riparian zones and wetland buffer zones (94 ft, or the width of one 28.5m pixel)

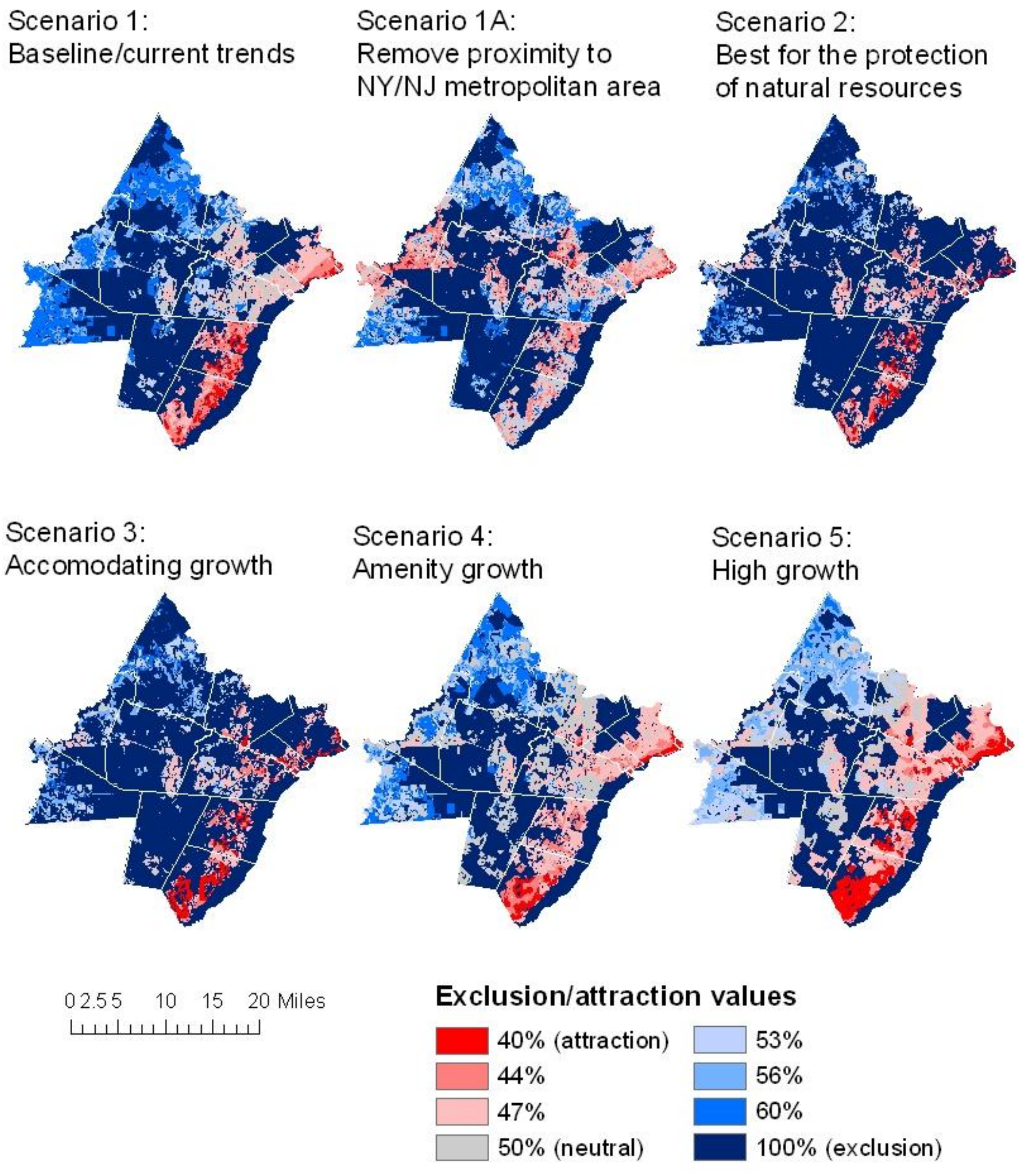


Figure 7: Exclusion/attraction layers used in each scenario for Pike County.

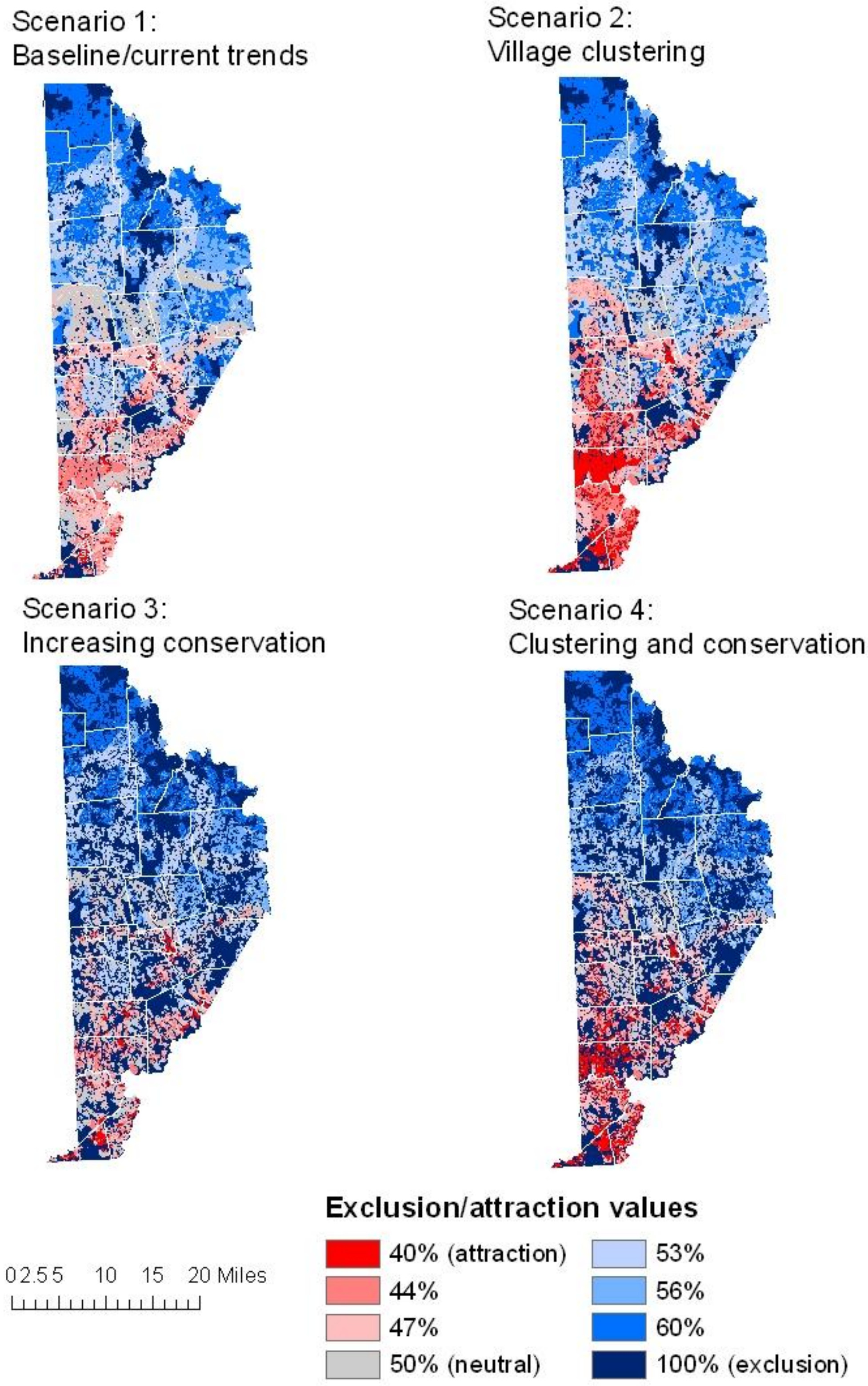


Figure 8: Exclusion/attraction layers used in each scenario for Wayne County.

3.0 Results and discussion

3.1 Calibration results

As noted in section 2.3, each county was calibrated separately to capture rates and patterns of observed development as accurately as possible. Two measurements were used to identify the values for the growth parameters: the population fractional difference (PFD) (a direct comparison between the number of urban pixels in the urban land cover maps and the corresponding simulated maps) and the clusters fractional difference (CFD) (a direct comparisons between the number of urban clusters in the urban land cover maps and the corresponding simulated maps). For both Pike and Wayne counties, these two fit statistics were matched within 5% (Table 6).

Table 6: Calibration results for Pike and Wayne counties. *The "best" fit values for the growth parameters are given. As noted in section 2.1 and Table 1, these growth parameters can take on a value between 0-100, depending on the specific urban development patterns within a study area. The values for the population fractional difference (PFD) and clusters fractional difference (CFD) metrics are also given. For these metrics, values close to zero indicate a good fit, positive or negative values indicate whether or not the model is over- or under-estimating development.*

	Diffusion	Breed	Spread	Slope	Road Growth	PFD	CFD
Pike	50	50	50	50	25	0.028	-0.051
Wayne	50	100	50	100	75	-0.030	-0.026

While the results above indicate that SLEUTH-3r was able to perform well at the county scale, the additional accuracy assessments that were performed at the municipal scale and using 1 km x 1km grid cells showed that the model was also able to reproduce historic growth patterns at finer scales (Table 7). Spatial accuracy results for the 1 km x 1 km grid cells (Figure 9) show that for most areas the amount of development simulated for 2005 matches the amount of growth mapped for 2005 within 2%. Growth is slightly underestimated in densely built-up areas, and slightly overestimated in low-density areas. These patterns are a result of the model attempting to balance these two very different growth processes.

Table 7: Linear regression results (r^2) comparing simulated and observed development for municipalities and 1km x 1km grid cells. *The closer the r^2 value is to 1, the better the fit. R^2 values in parentheses are from the first calibration procedure, and indicate that the model's performance improved after refining the exclusion/attraction layers following input from the county planners.*

	Municipal scale accuracy		1 km x 1km scale accuracy	
	N	**r^2**	**N**	**r^2**
Pike	13 municipalities	0.99 *(0.99)*	1,464 cells	0.83 *(0.71)*
Wayne	28 municipalities	0.98 *(0.95)*	1,938 cells	0.82 *(0.69)*

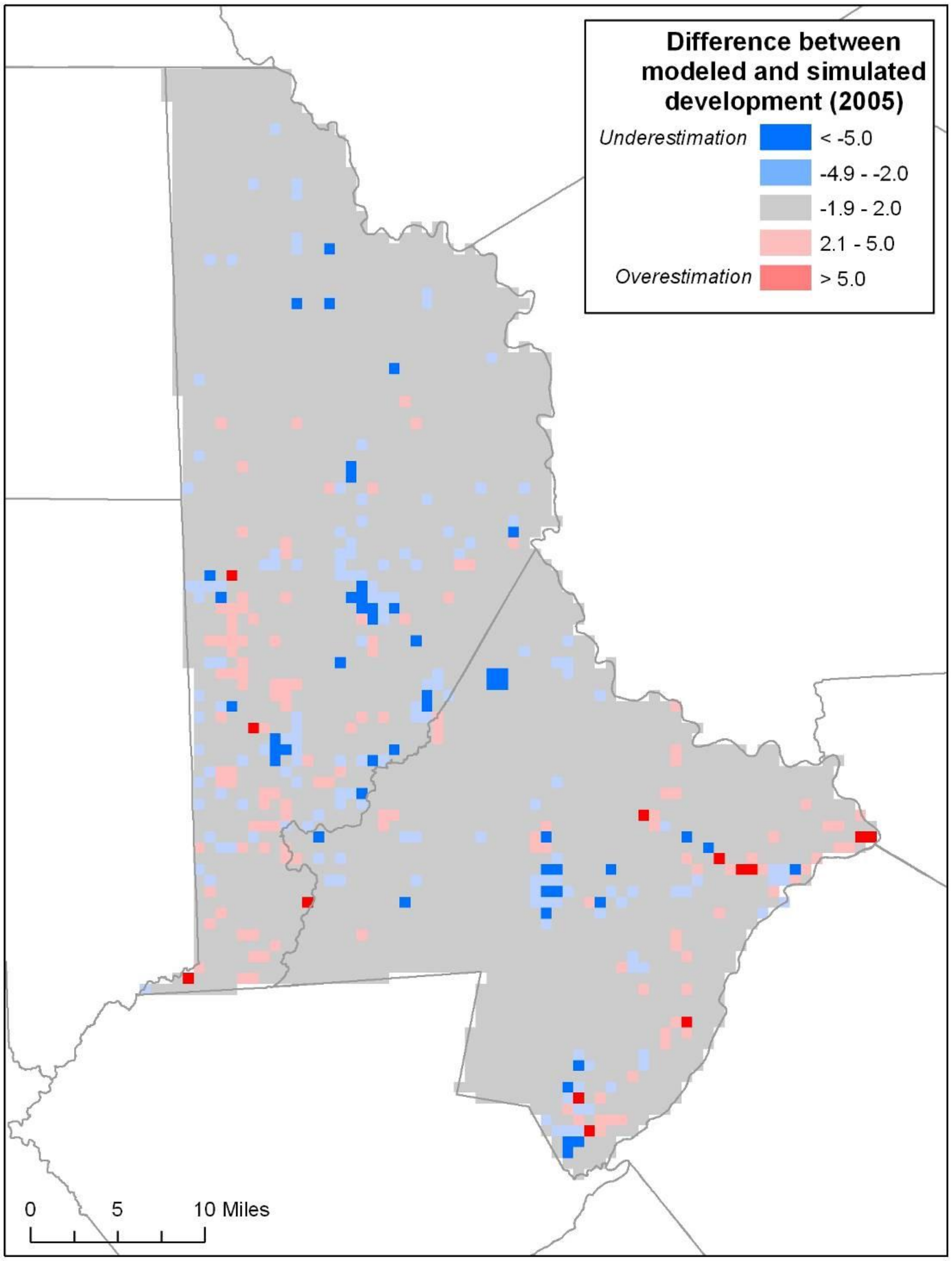


Figure 9: Calibration accuracy at the 1km² scale. *The difference between the percentage of development within each grid cell that was mapped in 2005 and the percentage of development that the model estimates for 2005 is shown. Blues indicate areas where the model is underestimating development in 2005, and reds show areas where the mode is overestimating development. Gray shows areas where the model has accurately estimated the amount of development within 2%.*

3.2 Historic and future growth

Between 1950 and 1980, the population in Pike County grew from 8,425 to 18,271. By 2000, the population had grown to 46,302—a more than five-fold increase in the 50 year time period. Growth rates in Wayne County were not as high: in 1950, the population was 28,478. By 1980, the population had grown to 35,237. Between 1980 and 2000 the population grew to 47,422, over one and half times the population in 1950. Over the 50 year period, Wayne County averaged 379 new people per year compared to 758 in Pike County; for every one new person in Wayne County there were two in Pike County. Figure 10 illustrates these dramatic trends in population growth.

It is important to note the differences between the two counties, both in terms of expected growth pressures and the nature of land use and land cover change. It is clear that, of the two counties, Pike County faces significant growth pressure going into the future. Recent observations of land use change confirm this trend. For example, a study recently conducted by the Wayne County Planning Commission on agricultural land use change from 1959 to 2002 shows that, during this period, more agricultural land was reforested than was lost to residential development. It also showed prime farmland was less likely to be abandoned than non-prime farmland during the study period, indicating that the less suitable agricultural parcels were being abandoned in response to economic decisions by farmers to divest themselves of the less productive agricultural land. In the Wayne County study, it was apparent that farmland generally is becoming idle for sometimes a long period of time before being developed. In Pike County, on the other hand, large-scale residential developments are common.

Given the population growth noted above, urbanized land as mapped in the satellite imagery also expanded significantly (Table 8). As noted in section 2.2.1 above, the model requires that roads be removed from the urban land cover time series, and that developed land consists of 28.5 m x 28.5 m pixels that have 20% or more impervious surface cover. Table 8 presents estimates of urban land including roads and with roads removed, and illustrates that roads can comprise a major component of the urban land cover within an area, particularly in more rural landscapes. In 1984 in Pike County, for example, roads make up more than half of the developed land. By 2005, however, roads make up roughly 28% of the urban land cover.

Table 8 also emphasizes the dramatic changes that have taken place between 1984 and 2005 in Pike and Wayne counties. In Pike County, urban land has increased 191% (or 331% if roads are not considered). Wayne County has seen an increase of 260% (or 425% if roads are not considered). If these trends continue into the future, dramatic changes are observed. Figure 11 charts the growth in urban land between 1984 and 2005, and its projected increase by 2030 under a current trends scenario, with mid-, low- and high-range growth estimates.

Figure 10: Trends in population growth and population density

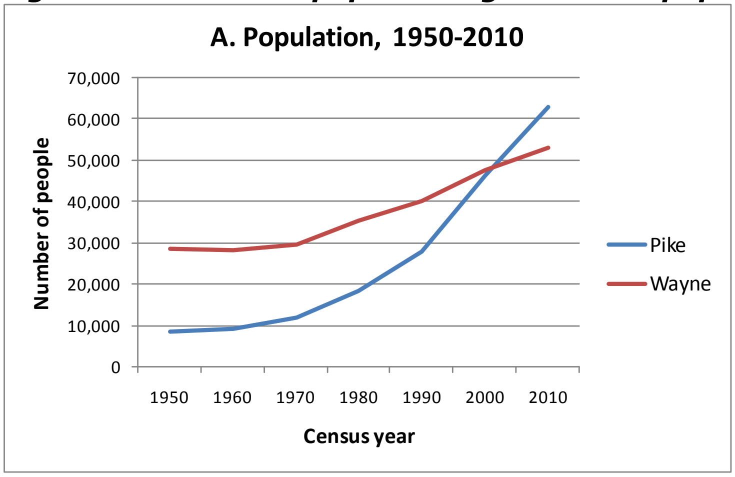


Figure 10: Trends in population growth (A) and population density (B) between 1950 and 2010 in Pike and Wayne counties. Source: U.S. Census (2000). Estimates for 2010 were extrapolated from 2007 Census estimates.

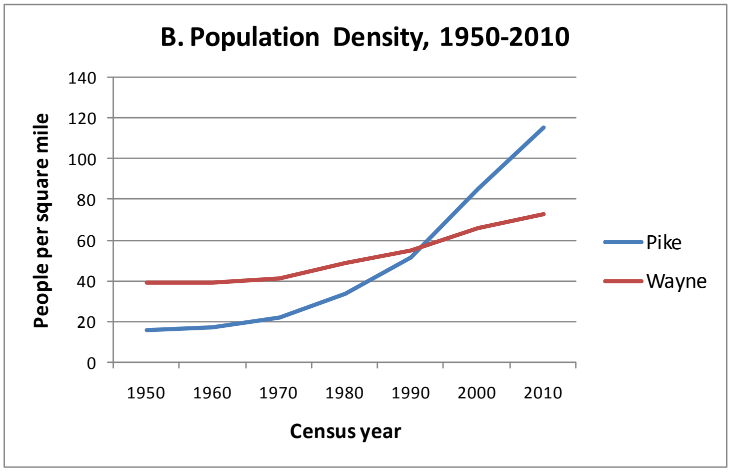
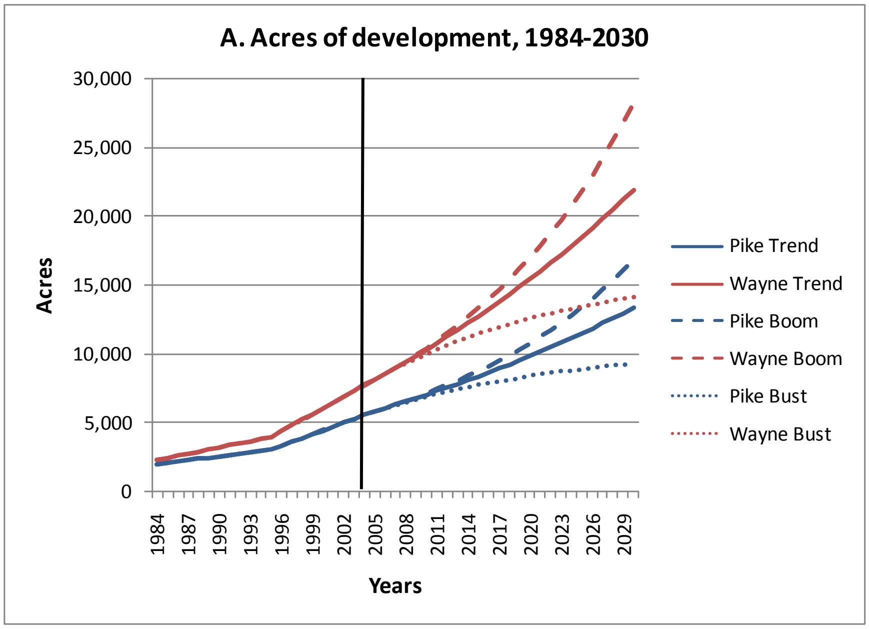


Table 8: Urban land increases (in acres) between 1984 and 2005 as estimated from the satellite-derived maps.

	Including roads		**Excluding roads**	
	Pike County	Wayne County	Pike County	Wayne County
1984	2,019	2,250	976	1,515
2005	5,883	8,100	4,211	7,960
Increase between 1984-2005 (%)	191%	260%	331%	425%

Figure 11: Trends in development



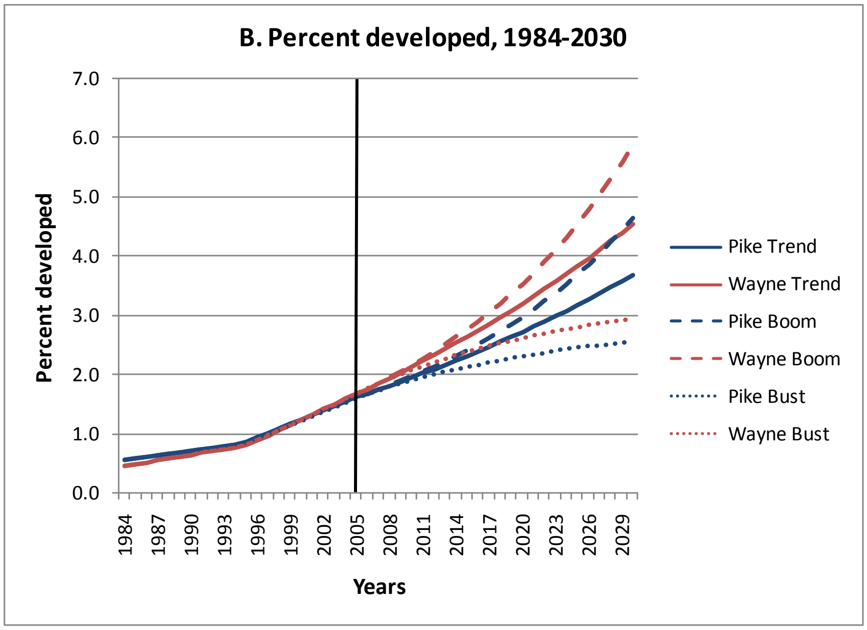


Figure 11: Trends in acres developed (A) and percent developed land (B) between 1984 and 2030 in Pike and Wayne counties. Data derived from satellite images span 1984-2005, as indicated by the black vertical line. Forecast data span 2006-2030. The mid-range forecasts are indicated by solid lines, the low-range forecasts are indicated by dotted lines, and the high-range forecasts are indicated by dashed lines. High-, mid- and low-range growth estimates are roughly equal across all scenarios. These estimates do not include roads.

In Figures 12 and 13, spatial patterns of change can be observed between 1984, 2005 and 2030 for Pike and Wayne counties for the current trends scenarios. Figures 14 and 15 show a comparison of maps of development in 2030 between the current trends scenario and the alternative scenarios for each county for the mid-range growth trend. Because the high-, mid-, and low-range growth forecasts are roughly equal across all scenarios, the main difference between the scenarios will be in the spatial allocation of growth. In interpreting Figure 12-15, note that the fine scale results (at a resolution of 28.5 meters) have been scaled up to 1 km x 1km cells so that county-wide patterns can be observed. Table 9 provides examples of the expected development intensity for each category used in Figures 12-15.

Table 9: Examples of development intensity within 1km x 1km areas for each category used in Figures 12-15. *Examples from both Pike and Wayne counties are included, using high resolution air photos to illustrate landscape details.*

Percent developed	Example from Pike County	Example from Wayne County
2-5% developed *Low intensity development; lot sizes tend to be large; roads are narrow and relatively sparse.*		
6-10% developed *Primarily low intensity development; can be more extensive within the area; can include more roads or some intensive development (i.e. portion of air strip or large parking lots).*		
11-25% developed *Medium intensity development; lots sizes tend to be smaller; road development might be more intensive; some intensive development may be present.*		
>25% developed *Intensive development; landscape dominated by large roads, parking lots, and large commercial complexes.*		

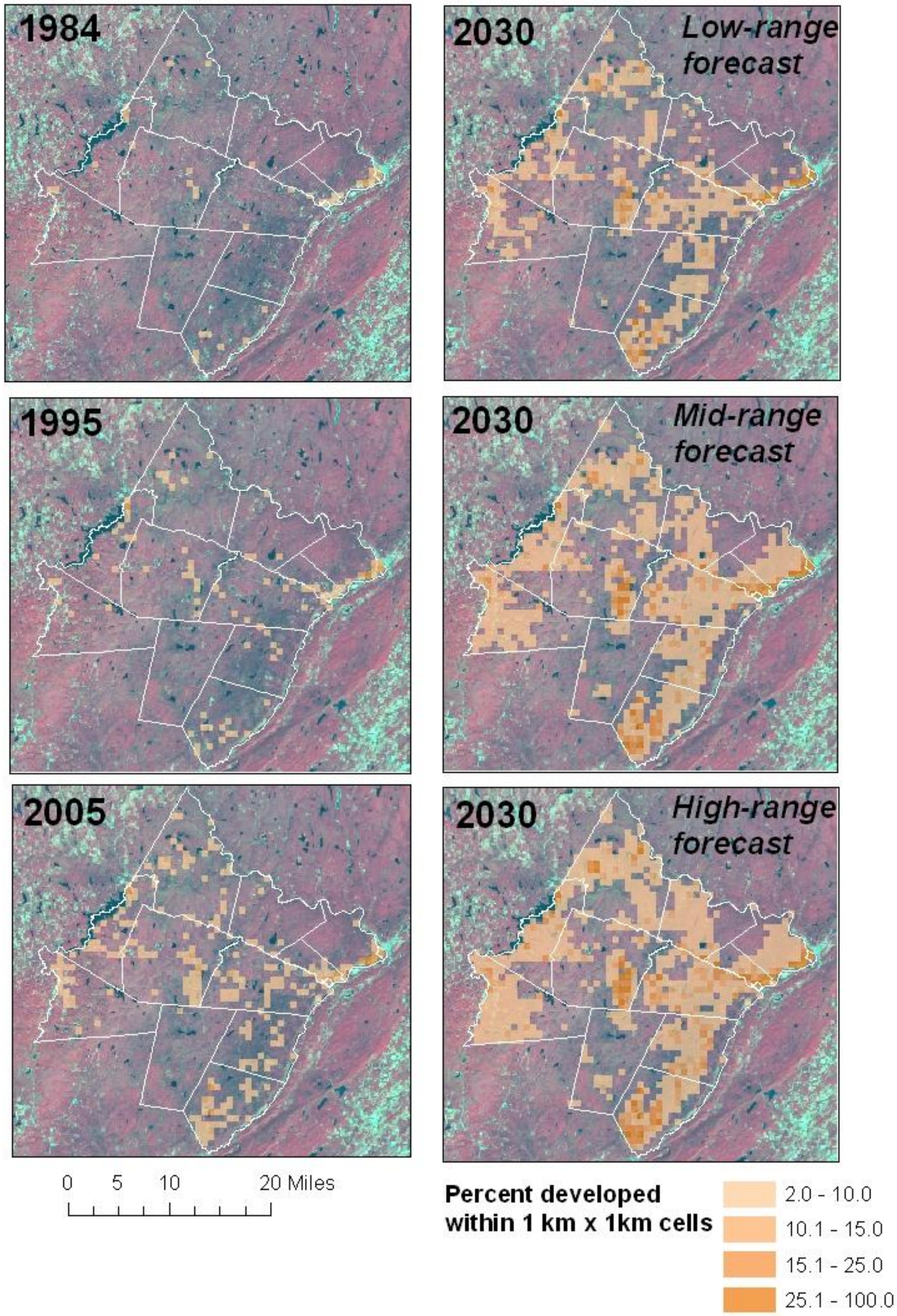


Figure 12: Developed Land in Pike County *as mapped in 1984 and 2005, and forecasted development in 2030 under current trends. These results have been scaled up from 28.5m x 28.5 m pixels to 1 km x 1 km cells so that county-wide patterns can be observed. Cells that are less than 2% developed (areas of lowest certainty) are not shown. Note that this threshold differs from Wayne County, where a 5% threshold is applied. A lower threshold was used in Pike County due to the high forest cover, which reduces the satellite signal for impervious surfaces. The background image is a satellite image where reds indicate vegetation (forest), light cyan indicates agricultural fields, bright cyan indicates impervious surfaces and black indicates water. These estimates are derived with roads excluded from consideration.*

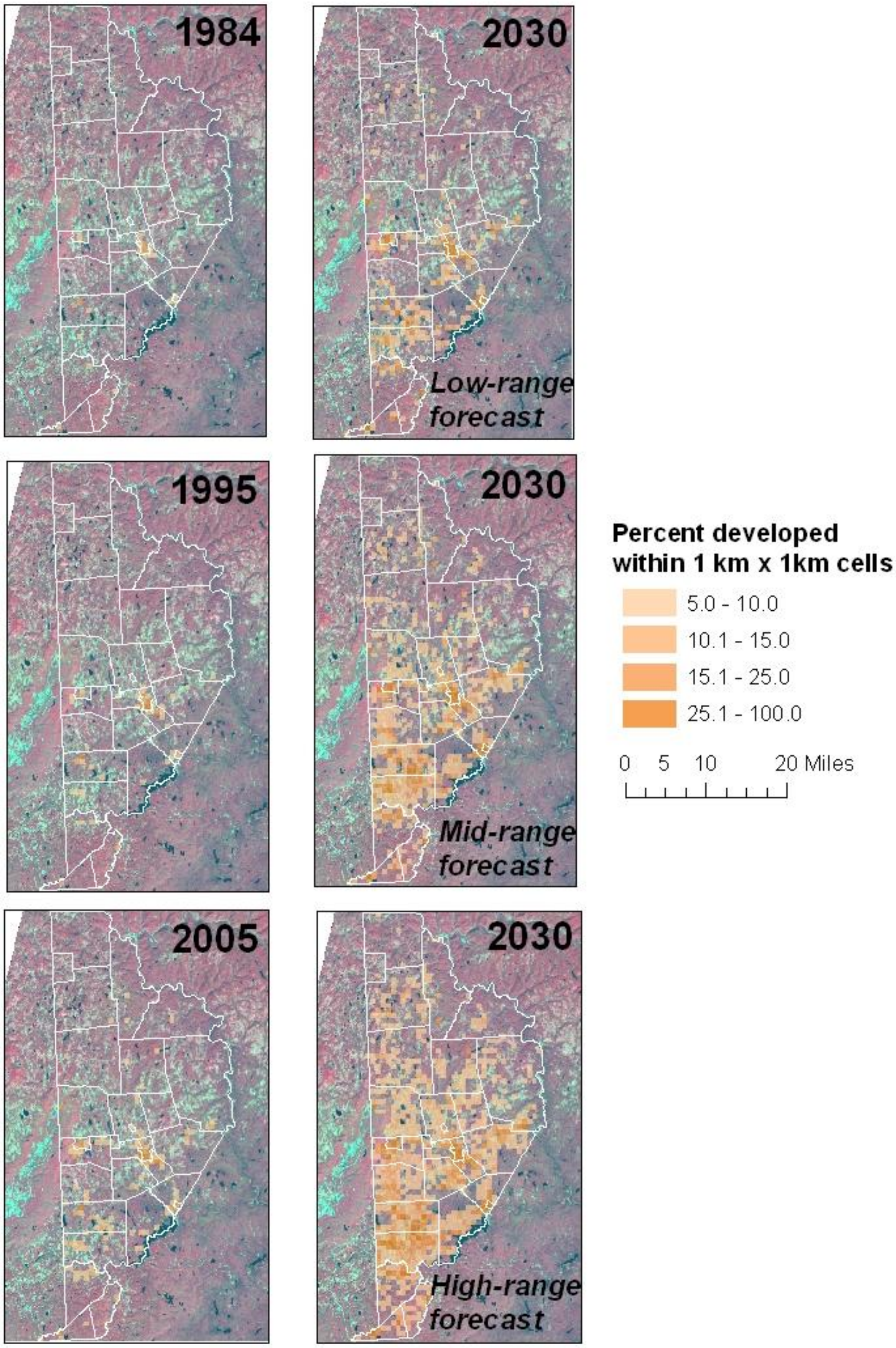


Figure 13: Developed Land in Wayne County *as mapped in 1984 and 2005, and forecasted development in 2030 under current trends. These results have been scaled up from 28.5m x 28.5 m pixels to 1 km x 1 km cells so that county-wide patterns can be observed. Cells that are less than 5% developed (areas of lowest certainty) are not included. Note that this threshold differs from Pike County, where a 2% threshold is applied. A lower threshold was used in Pike County due to the high forest cover, which reduces the satellite signal for impervious surfaces. The background image is a satellite image where reds indicate vegetation (forest), light cyan indicates agricultural fields, bright cyan indicates impervious surfaces and black indicates water. These estimates are derived with roads excluded from consideration.*

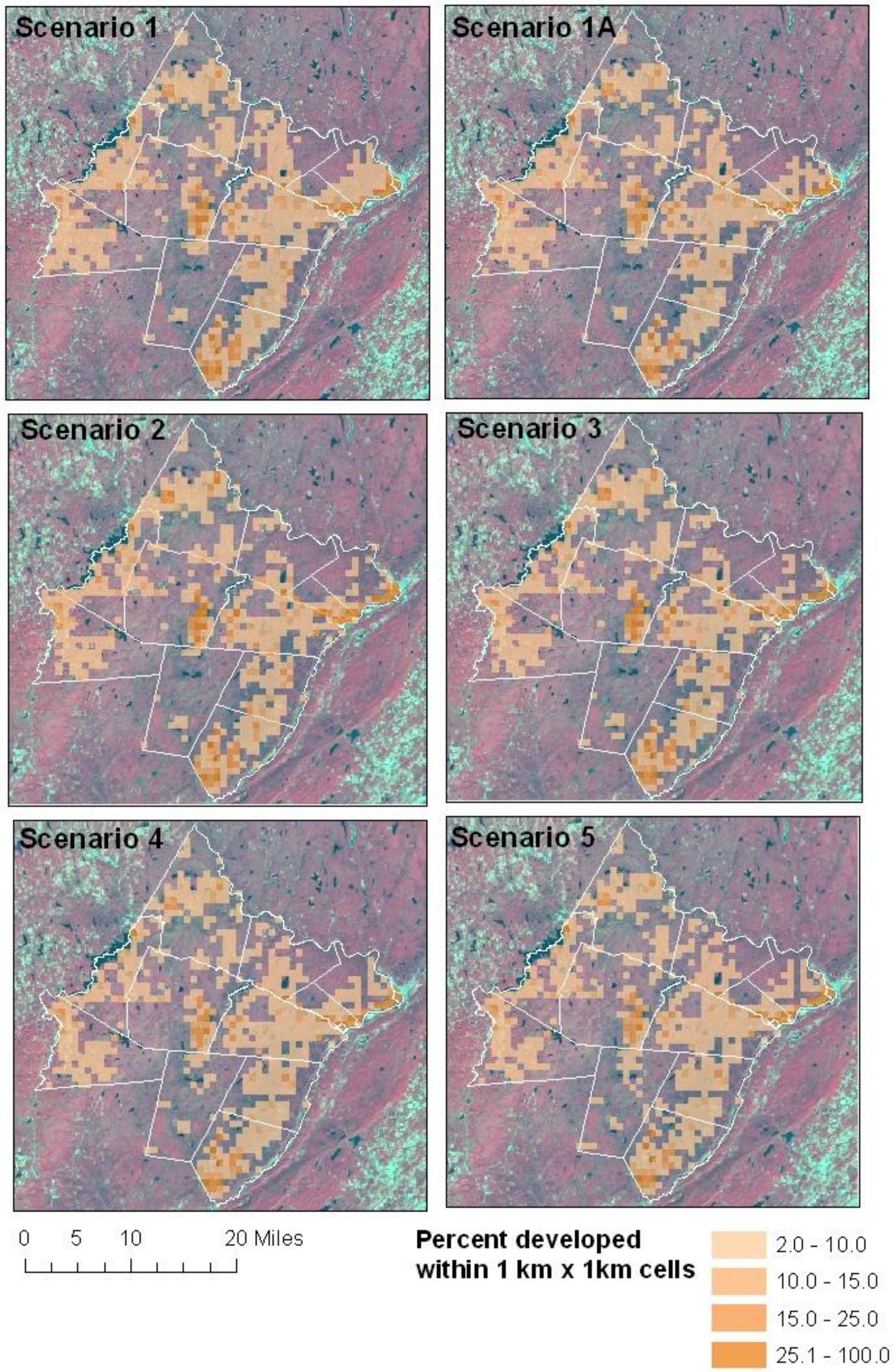


***Figure 14: Comparison of alternative futures for Pike County, 2030**. Refer to Table 4 for a description of each scenario. These results have been scaled up from 28.5m x 28.5 m pixels to 1 km x 1 km cells so that county-wide patterns can be observed. Cells that are less than 2% developed (areas of lowest certainty) are not included. Note that this threshold differs from Wayne County, where a 5% threshold is applied. A lower threshold was used in Pike County due to the high forest cover, which reduces the satellite signal for impervious surfaces. The background image is a satellite image where reds indicate vegetation (forest), light cyan indicates agricultural fields, bright cyan indicates impervious surfaces and black indicates water. These estimates are derived with roads excluded from consideration and are based on the mid-range growth forecast.*

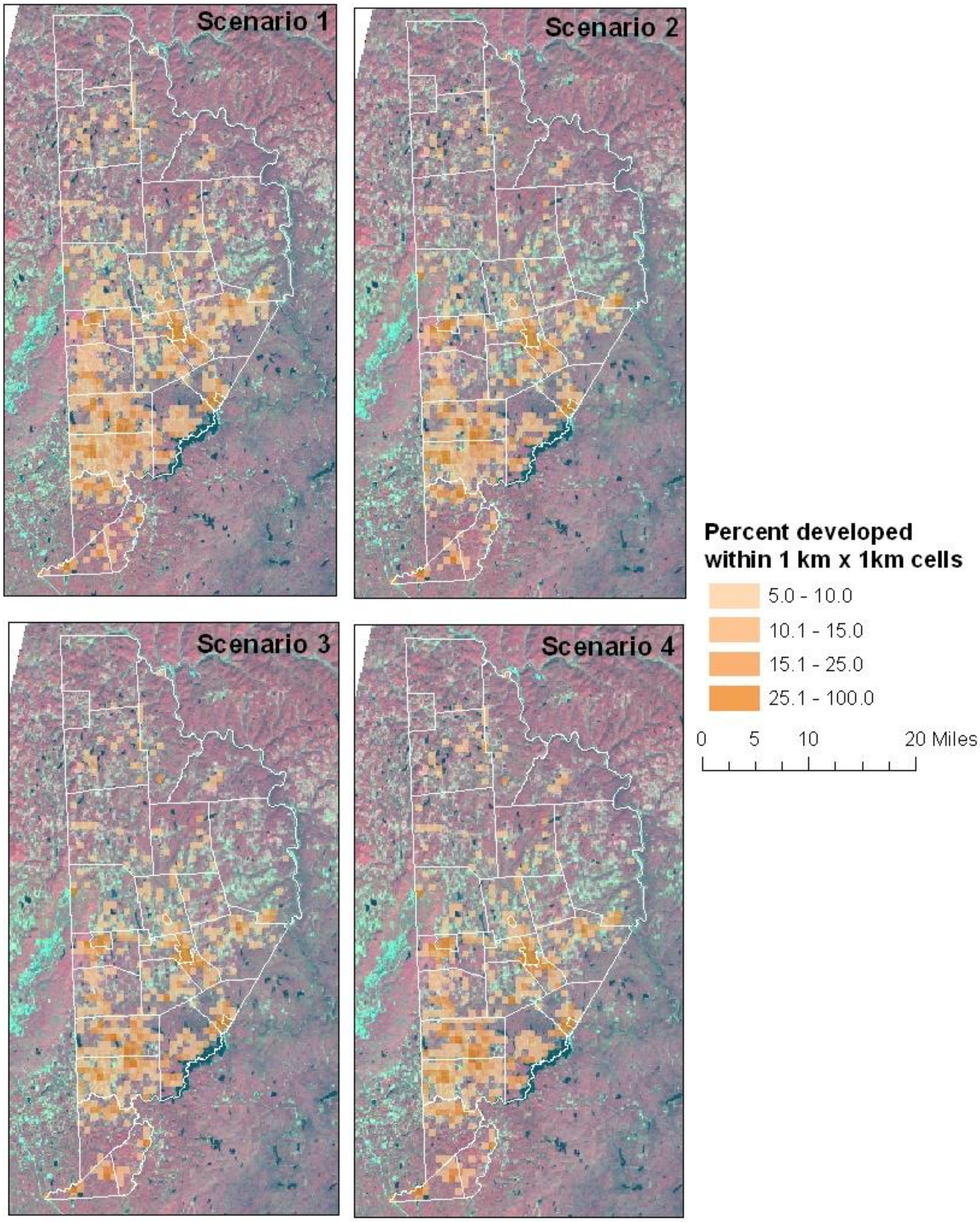


Figure 15: Comparison of alternative futures for Wayne County, 2030*. Refer to Table 5 for a description of each scenario. These results have been scaled up from 28.5m x 28.5 m pixels to 1 km x 1 km cells so that county-wide patterns can be observed. Cells that are less than 5% developed (areas of lowest certainty) are not included. Note that this threshold differs from Pike County, where a 2% threshold is applied. A lower threshold was used in Pike County due to the high forest cover, which reduces the satellite signal for impervious surfaces. The background image is a satellite image where reds indicate vegetation (forest), light cyan indicates agricultural fields, bright cyan indicates impervious surfaces and black indicates water. These estimates are derived with roads excluded from consideration and are based on the mid-range growth forecast.*

4.0 Methods for addressing identified growth

With the recent and projected growth identified in this report, *Forecasting Land Use Change in Pike and Wayne Counties, Pennsylvania*, Pike and Wayne counties need to proactively plan for the future and the potential impacts this projected growth may have on these communities. The SLEUTH model used in this study was found to be a useful tool in visualizing the alternate future development scenarios for Pike and Wayne Counties. The model can provide direction to county and municipal officials in identifying infrastructure needs, important natural resource and open space areas, critical areas for stormwater planning, areas of fragmented forest cover or increases in impervious surface cover. The model identifies projected growth areas and lands that have growth limitations due to current level of protection and/or natural features that may limit future growth. This study identifies which valuable resources in the region are threatened through forest fragmentation, loss of large tracts of open space, decreases in water quality or degradation of wildlife habitat and scenic views.

Pike and Wayne Counties have been actively planning for the escalating increases in population and housing through updates and implementation of their Comprehensive Plans. Municipalities need to be informed of the projected growth scenarios that are identified in this model as well. In order to protect the quality of life that area residents and visitors enjoy, implementation of county and municipal Comprehensive Plans must remain a priority.

To minimize possible future growth impacts identified in this study, the following are suggested actions for consideration:

- Direct development away from identified important environmental resources and open space/forested lands. It should be noted that in Wayne County, forestland is increasing as farmlands are abandoned, indicating that the identification of important natural resources should be county-specific.
- Encourage quality development in future residential and commercial development;
- Consider the use of residential development alternatives. Conservation Subdivision Design, Transfer of Development Rights, Traditional Neighbourhood Development, etc. are examples of such alternatives;
- Consider the investment in the revitalization of existing towns and existing commercial centers to reduce commercial sprawl;
- Continue the efficient use of public investment in infrastructure;
- Work with municipalities and land owners in providing educational resources on land preservation programs;
- Encourage the use of the results from this project, and continue the development of the use of GIS and related technology to support ongoing and future planning initiatives at the municipal and county level;
- Encourage municipal and county leaders to support updates to local planning to address future growth in order to minimize the impacts on environmental degradation and decreases in quality of life;
- Engage in dialogue with state agencies in planning for future growth. PennDOT, DCED, DEP and DCNR, among others, should take an active role in growing regions of the Commonwealth

5.0 Summary and conclusions

This study has focused on mapping and simulating urban growth trends in Pike and Wayne counties. Methodologically, the synthesis of satellite-derived maps, urban simulation modeling, and GIS analysis has provided a synoptic and sophisticated view of urban land cover change processes in this region. Because these counties are rural in comparison to most urban study regions, this represents an unprecedented application of the new version of the SLEUTH model, SLEUTH-3r. That we were able to accurately simulate urban land cover change patterns between 1984 and 2005 with SLEUTH-3r illustrates the improved performance of the model and the invaluable role of local planners' knowledge.

At the conclusion of this project, each county was provided with a data library so that the results of this application can be integrated into county and municipal planning. With these existing data sets, an array of applications now exists, such as evaluating the impact of potential future development on forest and agricultural resources, water quality, etc. Furthermore, each county was provided with the calibrated model, so the potential exists for new scenarios to be developed and visualized.

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Appendix A: Data sets and levels of exclusion/attraction used in Pike County's scenarios

Pike County Exclusions/Attractions for Calibration and Baseline Scenarios

	Description	Data source	GIS file name(s)	Date	Level of protection
Protected areas	Lakes and water bodies	NLCD water class and Pike County lakes	water_all GRID (Pike_utm (GRID) and PikeLakes.shp)	Jul-06	100%
	Wetlands	Pike County	wetlands GRID (PikeWetlands.shp)	Jun-06	100%
	Riparian buffer zone	30 m (~100 ft) buffer around Pike County wetlands, lakes and water bodies and streams	Hydro_buffer (GRID)	Jun-08	No protection
	State and local parks, cemeteries	NPS and Pike County	dela_sf, open_space, promised_land (GRIDS); Delaware State Forest.shp, PikeOpenSpacePerm.shp, Promised_Land.shp	Jan-06	100%
	Hunt clubs, fishing clubs, camps, etc.	NPS and Pike County	bloom_grove, dela_sf, hunt_clubs, os_quasi, other_clubs (GRIDS); hunt_clubs.shp, other_clubs.shp, PikeOpenSpaceQuasi.shp, Blooming_Grove_HF.shp	Jun-06	100%
	Act 319 easements	Pike County	act319 GRID (Act_319.shp)	Jul-06	60% (if GIS model > 50; otherwise no effect)
Other resistance/attraction	Soils	SSURGO engineering limitation (0=water, 1 = no limitation, 2 = somewhat limited, 3 = severely limited)	soils GRID (soilmu_a_pa103.shp)	Jul-06	GIS model (resistance)
	Slope and elevation	NED	basin_slope	Jun-07	Model calibrated; 21% critical slope
	Distance to major roads	Derived from ESRI Streetmap	New roads distance layer, weighted based on speed limit (used in forecast).	Jul-07; Jun-08	GIS model (proximity attraction)
	Distance to lakes	Derived from Pike County lake file	water_dis300 (GRID with 300 meter buffer around water)	Jul-07	GIS model (attraction)
	Distance to NY/NJ *(removed for Current Trends scenario D)*	Derived from NY/NJ centroid	nyc_dist (GRID classified into 10 classes)	Jul-07	GIS model (proximity attraction)
	Population density by municipality	Derived from U.S. Census 2000	pop_dens (GRID classified into 4 classes)	Jul-07	GIS model (density attraction at township scale)
	Road density “villages”	Derived from road density analysis of county roads file	road_dens (GRID classified into 2 classes)	Jul-07	GIS model (proximity attraction)

Pike County Exclusions/Attractions for Scenario 2: Best for the protection of natural resources

	Description	Data source	GIS file name(s)	Date	Level of protection
Protected areas	Lakes and water bodies	NLCD water class and Pike County lakes	water_all GRID (Pike_utm (GRID) and PikeLakes.shp)	Jul-06	100%
	Wetlands	Pike County	wetlands GRID (PikeWetlands.shp)	Jun-06	100%
	Riparian buffer zone	30 m (~100 ft) buffer around Pike County wetlands, lakes and water bodies and streams	Hydro_buffer (GRID)	Jun-08	100%
	Hunt clubs, fishing clubs, camps, etc.	NPS and Pike County	bloom_grove, dela_sf, hunt_clubs, os_quasi, other_clubs (GRIDS); hunt_clubs.shp, other_clubs.shp, PikeOpenSpaceQuasi.shp, Blooming_Grove_HF.shp	Jun-06	100%
	State and local parks, cemeteries	NPS and Pike County	dela_sf, open_space, promised_land (GRIDS); Delaware State Forest.shp, PikeOpenSpacePerm.shp, Promised_Land.shp	Jan-06	100%
	Act 319 easements	Pike County	act319 GRID (Act_319.shp)	Jul-06	100%
Other resistance/attraction	Soils	SSURGO engineering limitation (0=water, 1 = no limitation, 2 = somewhat limited, 3 = severely limited)	soils GRID (soilmu_a_pa103.shp)	Jul-06	GIS model (resistance)
	Slope and elevation	NED	basin_slope	Jun-07	Model calibrated; 21% critical slope
	Distance to major roads	Derived from ESRI Streetmap	New roads distance layer, weighted based on speed limit.	Jun-08	GIS model (stronger proximity attraction)
	Distance to lakes	Derived from Pike County lake file	water_dis300 (GRID with 300 meter buffer around water)	Jul-07	GIS model (attraction)
	Distance to NY/NJ	Derived from NY/NJ centroid	nyc_dist (GRID classified into 10 classes)	Jul-07	GIS model (proximity attraction)
	Population density by municipality	Derived from U.S. Census 2000	pop_dens (GRID classified into 4 classes)	Jul-07	GIS model (density attraction at township scale)
	Road density "villages"	Derived from road density analysis of county roads file	road_dens (GRID classified into 2 classes)	Jul-07	GIS model (stronger proximity attraction)

Pike County Exclusions/Attractions for Scenario 3: Accommodating growth

	Description	Data source	GIS file name(s)	Date	Level of protection
Protected areas	Lakes and water bodies	NLCD water class and Pike County lakes	water_all GRID (Pike_utm (GRID) and PikeLakes.shp)	Jul-06	100%
	Wetlands	Pike County wetlands from draft comprehensive plan	wetlands GRID (PikeWetlands.shp)	Jun-06	100%
	Riparian buffer zone	28.5 m (~100 ft) buffer around Pike County wetlands, lakes and water bodies and streams	Hydro_buffer (GRID)	Jun-08	100%
	Hunt clubs, fishing clubs, camps, etc.	NPS and Pike County	bloom_grove, dela_sf, hunt_clubs, os_quasi, other_clubs (GRIDS); hunt_clubs.shp, other_clubs.shp, PikeOpenSpaceQuasi.shp, Blooming_Grove_HF.shp	Jun-06	100%
	State and local parks, cemeteries	NPS and Pike County	dela_sf, open_space, promised_land (GRIDS); Delaware State Forest.shp, PikeOpenSpacePerm.shp, Promised_Land.shp	Jan-06	100%
	Act 319 easements	Pike County	act319 GRID (Act_319.shp)	Jul-06	100%
Other resistance/attraction	Soils	SSURGO engineering limitation (0=water, 1 = no limitation, 2 = somewhat limited, 3 = severely limited)	soils GRID (soilmu_a_pa103.shp)	Jul-06	GIS model (resistance)
	Slope and elevation	NED	basin_slope	Jun-07	Model calibrated; 21% critical slope
	Distance to major roads	Derived from ESRI Streetmap	New roads distance layer, weighted based on speed limit.	Jun-08	GIS model (stronger proximity attraction)
	Distance to lakes	Derived from Pike County lake file	water_dis300 (GRID with 300 meter buffer around water)	Jul-07	GIS model (attraction)
	Distance to NY/NJ	Derived from NY/NJ centroid	nyc_dist (GRID classified into 10 classes)	Jul-07	GIS model (proximity attraction)
	Distance from rail stations	Derived from locations of current and future rail stations	Raildist_new (GRID)	Jul-08	GIS model proximity attraction
	Population density by municipality	Derived from U.S. Census 2000	pop_dens (GRID classified into 4 classes)	Jul-07	GIS model (density attraction at township scale)
	Road density “villages”	Derived from road density analysis of county roads file	Rddens_hv1200; Including Highland Village (High_vil_buf) with 1200m radius.	Jul-07 Jul-08	GIS model (stronger proximity attraction)

Pike County Exclusions/Attractions for Scenario 4: Amenity growth

	Description	Data source	GIS file name(s)	Date	Level of protection
Protected areas	Lakes and water bodies	NLCD water class and Pike County lakes	water_all GRID (Pike_utm (GRID) and PikeLakes.shp)	Jul-06	100%
	Wetlands	Pike County	wetlands GRID (PikeWetlands.shp)	Jun-06	100%
	Riparian buffer zone	30 m (~100 ft) buffer around Pike County wetlands, lakes and water bodies and streams	Hydro_buffer (GRID)	Jun-08	No protection
	Blooming grove hunt club	Pike County	bloom_grove	Jun-06	100%
	State and local parks, cemeteries	NPS and Pike County	dela_sf, open_space, promised_land (GRIDS); Delaware State Forest.shp, PikeOpenSpacePerm.shp, Promised_Land.shp	Jan-06	100%
	Act 319 easements	Pike County	act319 GRID (Act_319.shp)	Jul-06	60% (if GIS model > 50; otherwise no effect)
Other resistance/attraction	Soils	SSURGO engineering limitation (0=water, 1 = no limitation, 2 = somewhat limited, 3 = severely limited)	soils GRID (soilmu_a_pa103.shp)	Jul-06	GIS model (resistance)
	Slope and elevation	NED	basin_slope	Jun-07	Model calibrated; 21% critical slope
	Distance to major roads	Derived from ESRI Streetmap	New roads distance layer, weighted based on speed limit.	Jun-08	GIS model (stronger proximity attraction)
	Distance to lakes, rivers and parks	Derived from water_all and open_space GRIDS	Amen_dist_rc (GRID)	Jul-08	GIS model (attraction)
	Distance to NY/NJ	Derived from NY/NJ centroid	nyc_dist (GRID classified into 10 classes)	Jul-07	GIS model (proximity attraction)
	Distance from rail stations	Derived from locations of current and future rail stations	Raildist_new (GRID)	Jul-08	GIS model proximity attraction
	Population density by municipality	Derived from U.S. Census 2000	pop_dens (GRID classified into 4 classes)	Jul-07	GIS model (density attraction at township scale)
	Road density "villages"	Derived from road density analysis of county roads file	Rddens_hv3000; Including Highland Village (High_vil_buf) with larger impact area (3000m)	Jul-07 Jul-08	GIS model (stronger proximity attraction)

Pike County Exclusions/Attractions for Scenario 5: High growth

	Description	Data source	GIS file name(s)	Date	Level of protection
Protected areas	Lakes and water bodies	NLCD water class and Pike County lakes	water_all GRID (Pike_utm (GRID) and PikeLakes.shp)	Jul-06	100%
	Wetlands	Pike County	wetlands GRID (PikeWetlands.shp)	Jun-06	No protection
	Riparian buffer zone	30 m (~100 ft) buffer around Pike County wetlands, lakes and water bodies and streams	Hydro_buffer (GRID)	Jun-08	No protection
	Blooming grove hunt club	Pike County draft comprehensive plan	bloom_grove	Jun-06	100%
	State and local parks, cemeteries	NPS and Pike County	dela_sf, open_space, promised_land (GRIDS); Delaware State Forest.shp, PikeOpenSpacePerm.shp, Promised_Land.shp	Jan-06	100%
	Act 319 easements	Pike County	act319 GRID (Act_319.shp)	Jul-06	No protection
Other resistance/attraction	Soils	SSURGO engineering limitation (0=water, 1 = no limitation, 2 = somewhat limited, 3 = severely limited)	soils GRID (soilmu_a_pa103.shp)	Jul-06	GIS model (resistance)
	Slope and elevation	NED	basin_slope	Jun-07	Model calibrated; 21% critical slope
	Distance to major roads	Derived from ESRI Streetmap	New roads distance layer, weighted based on speed limit.	Jun-08	GIS model (stronger proximity attraction)
	Distance to lakes, rivers and parks	Derived from water_all and open_space GRIDS	Amen_dist (GRID)	Jul-08	GIS model (attraction)
	Distance to NY/NJ	Derived from NY/NJ centroid	nyc_dist (GRID classified into 10 classes)	Jul-07	GIS model (proximity attraction)
	Distance from rail stations	Derived from locations of current and future rail stations	Raildist_new (GRID)	Jul-08	GIS model proximity attraction
	Population density by municipality	Derived from U.S. Census 2000	pop_dens (GRID classified into 4 classes)	Jul-07	GIS model (density attraction at township scale)

Appendix B: Data sets and levels of exclusion/attraction used in Wayne County's scenarios

Wayne County Exclusions/Attractions for Calibration and Baseline Scenarios

	Description	Data source	GIS file name	Date	Level of protection
Protected areas	Lakes and water bodies	NLCD water class and Wayne lakes	wa_nlcdwater GRID (Wayne_utm (GRID) and WayneHydroPoly.shp)	Jul-06	100%
	Wetlands	NPS	wa_wetlands (GRID) (WayneWetlands.shp)	Jan-06	100%
	Hunt clubs, fishing clubs, camps, etc.	NPS	wa_quasi (GRID) (Wayne_quasiprotected.shp)	Feb-06	100%
	State and local parks, cemeteries	NPS	wa_prot_open GRID (Wayne_protectedOpen.shp)	Jan-06	100%
	Act 319 easements	Wayne County	wa_act319 GRID (Wayne_County_Act_319_Enrollments.shp)	Jul-06	60% (if GIS model > 50; otherwise no effect)
Other resistance/attraction	Soils	SSURGO engineering limitation (0=water, 1 = no limitation, 2 = somewhat limited, 3 = severely limited)	wa_soils (GRID) (soilmu_a_pa127.shp)	Jul-06	GIS model (resistance)
	Slope and elevation	NED	slope_utm	Aug-07	Model calibrated; 21% critical slope
	Distance to major roads	Derived from ESRI street map	rds_dis1500 (GRID with 1500 meter buffer around roads	Jun-08	GIS model (proximity attraction)
	Distance to lakes	Derived from Wayne lake file	water_dis300 (GRID with 300 meter buffer around water)	Jul-08	GIS model (proximity attraction)
	Distance from I-84	Derived from I-84 linear distance	inter_84dist (GRID classified into 10 classes)	Jul-07	GIS model (resistance)
	Population density by municipality	Derived from U.S. Census 2000	pop_dens_recl (GRID)	Jul-07	GIS model (density attraction at township scale)
	Road density "villages"	Derived from road density analysis of county roads file	road_dens (GRID)	Jul-07	GIS model (attraction)

Wayne County Exclusions/Attractions for Scenario 2: Village clustering

	Description	Data source	GIS file name	Date	Level of protection
Protected areas	Lakes and water bodies	NLCD water class and Wayne lakes	wa_nlcdwater GRID (Wayne_utm (GRID) and WayneHydroPoly.shp)	Jul-06	100%
	Wetlands	NPS	wa_wetlands (GRID) (WayneWetlands.shp)	Jan-06	100%
	Hunt clubs, fishing clubs, camps, etc.	NPS	wa_quasi (GRID) (Wayne_quasiprotected.shp)	Feb-06	100%
	State and local parks, cemeteries	NPS	wa_prot_open GRID (Wayne_protectedOpen.shp)	Jan-06	100%
	Act 319 easements	Wayne County	wa_act319 GRID (Wayne_County_Act_319_Enrollments.shp)	Jul-06	60% (if GIS model > 50; otherwise no effect)
Other resistance/attraction	Soils	SSURGO engineering limitation (0=water, 1 = no limitation, 2 = somewhat limited, 3 = severely limited)	wa_soils (GRID) (soilmu_a_pa127.shp)	Jul-06	GIS model (resistance)
	Slope and elevation	NED	slope_utm	Aug-07	Model calibrated; 21% critical slope
	Distance to major roads	Derived from ESRI street map	rds_dis1500 (GRID with 1500 meter buffer around roads	Jul-08	GIS model (proximity attraction)
	Distance from rail stations	Derived from locations of current and future rail stations	Raildist_new (GRID)	Jul-08	GIS model proximity attraction
	Distance to lakes	Derived from Wayne lake file	water_dis300 (GRID with 300 meter buffer around water)	Jul-07	GIS model (proximity attraction)
	Distance from I-84	Derived from I-84 linear distance	inter_84dist (GRID classified into 10 classes)	Jul-07	GIS model (resistance)
	Population density by municipality	Derived from U.S. Census 2000	pop_dens_recl (GRID)	Jul-07	GIS model (density attraction at township scale)
	Road density "villages" , expanded with a 750 m buffer	Derived from road density analysis of county roads file	road_dens_buf (GRID)	Aug-08	GIS model (attraction)

Wayne County Exclusions/Attractions for Scenario 3: Increasing conservation

	Description	Data source	GIS file name	Date	Level of protection
Protected areas	Lakes and water bodies	NLCD water class and Wayne lakes	wa_nlcdwater GRID (Wayne_utm (GRID) and WayneHydroPoly.shp)	Jul-06	100%
	Wetlands	NPS	wa_wetlands (GRID) (WayneWetlands.shp)	Jan-06	100%
	Hunt clubs, fishing clubs, camps, etc.	NPS	wa_quasi (GRID) (Wayne_quasiprotected.shp)	Feb-06	100%
	State and local parks, cemeteries	NPS	wa_prot_open GRID (Wayne_protectedOpen.shp)	Jan-06	100%
	Act 319 easements	Wayne County	wa_act319 GRID (Wayne_County_Act_319_Enrollments.shp)	Jul-06	100%
	Riparian buffer zone	28.5 m (~100 ft) buffer around Pike County wetlands, lakes and water bodies and streams	Riparian_buff (GRID)	Jun-08	100%
Other resistance/attraction	Soils	SSURGO engineering limitation (0=water, 1 = no limitation, 2 = somewhat limited, 3 = severely limited)	wa_soils (GRID) (soilmu_a_pa127.shp)	Jul-06	GIS model (resistance)
	Slope and elevation	NED	slope_utm	Aug-07	Model calibrated; 21% critical slope
	Forest and farm parcels, greater than 10 acres	Wayne county parcel land use data (Derek Williams)	Wa_crop_gt10ac and Wa_for_gt10ac (GRIDs)	Aug-08	GIS model resistance, with higher resistance given to farmland
	Distance to major roads	Derived from ESRI street map	rds_dis1500 (GRID with 1500 meter buffer around roads	Jul-08	GIS model (proximity attraction)
	Distance to lakes	Derived from Wayne lake file	water_dis300 (GRID with 300 meter buffer around water)	Jul-08	GIS model (proximity attraction)
	Distance from I-84	Derived from I-84 linear distance	inter_84dist (GRID classified into 10 classes)	Jul-07	GIS model (resistance)
	Population density by municipality	Derived from U.S. Census 2000	pop_dens_recl (GRID)	Jul-07	GIS model (density attraction at township scale)
	Road density "villages"	Derived from road density analysis of county roads file	road_dens (GRID)	Jul-07	GIS model (attraction)

Wayne County Exclusions/Attractions for Scenario 4: Village clustering with increasing conservation

	Description	Data source	GIS file name	Date	Level of protection
Protected areas	Lakes and water bodies	NLCD water class and Wayne lakes	wa_nlcdwater GRID (Wayne_utm (GRID) and WayneHydroPoly.shp)	Jul-06	100%
	Wetlands	Leslie Morlock (NPS)	wa_wetlands (GRID) (WayneWetlands.shp)	Jan-06	100%
	Hunt clubs, fishing clubs, camps, etc.	Leslie Morlock (NPS)	wa_quasi (GRID) (Wayne_quasiprotected.shp)	Feb-06	100%
	State and local parks, cemeteries	Leslie Morlock (NPS)	wa_prot_open GRID (Wayne_protectedOpen.shp)	Jan-06	100%
	Act 319 easements	Wayne County	wa_act319 GRID (Wayne_County_Act_319_Enrollments.shp)	Jul-06	100%
	Riparian buffer zone	28.5 m (~100 ft) buffer around Pike County wetlands, lakes and water bodies and streams	Riparian_buff (GRID)	Jun-08	100%
Other resistance/attraction	Soils	SSURGO engineering limitation (0=water, 1 = no limitation, 2 = somewhat limited, 3 = severely limited)	wa_soils (GRID) (soilmu_a_pa127.shp)	Jul-06	GIS model (resistance)
	Slope and elevation	NED	slope_utm	Aug-07	Model calibrated; 21% critical slope
	Forest and farm parcels, greater than 10 acres	Wayne county parcel land use data (Derek Williams)	Wa_crop_gt10ac and Wa_for_gt10ac (GRIDs)	Aug-08	GIS model resistance, with higher resistance given to farmland
	Distance to major roads	Derived from ESRI street map	rds_dis1500 (GRID with 1500 meter buffer around roads		GIS model (proximity attraction)
	Distance from rail stations	Derived from locations of current and future rail stations	Raildist_new (GRID)	Jul-08	GIS model proximity attraction
	Distance to lakes	Derived from Wayne lake file	water_dis300 (GRID with 300 meter buffer around water)	Jul-07	GIS model (proximity attraction)
	Distance from I-84	Derived from I-84 linear distance	inter_84dist (GRID classified into 10 classes)	Jul-07	GIS model (resistance)
	Population density by municipality	Derived from U.S. Census 2000	pop_dens_recl (GRID)	Jul-07	GIS model (density attraction at township scale)

Appendix C: Self-modification

As noted in section 2.4 of this report, SLEUTH's so-called "self-modification" functionality was used to create high- and low-range growth rate forecasts, and in some cases the mid-range forecast. The self-modification function is intended to dynamically change growth rates over a forecast time period, and its function is based on user-specified critical values for growth rates. When the growth rate falls below low critical value, SLEUTH will go into "bust" mode, where the growth rate decreases. If the growth rate exceeds a high critical value, SLEUTH goes into "boom" model, where the growth rate increases. The growth rate is increased or decreased by applying a user-specified multiplier that is either greater than or less than one to the diffusion, breed and spread growth parameter values. For example, if a "bust" multiplier is specified to be 0.95 and the model goes into "bust" mode when the growth rate falls below the critical threshold, the model will systematically adjust the values of the growth parameters by multiplying the parameter values by 0.95. So, if the spread parameter has a value of 25 when the critical threshold is reached, in the subsequent time step the new value for spread will be 23.75; in the next time step the value will be 22.56; and so on until the value reaches zero or until the forecast reaches its terminal year.

In this application, growth values were allowed to increase up to 150 under a "boom" scenario. Boom and bust multiplier values were set using a trial and error approach for each scenario, and the amount of growth forecasted in each scenario's high-, mid-, and low-range forecasts was roughly equivalent to the high-, mid-, and low-range forecasts for the current trends scenario. Finally, the model was set to go into either boom or bust mode in 2006, the first forecast year.

Table 11: Self-modification multipliers for Pike County.

Scenario	Multiplier for low-range forecast	Multiplier for mid-range forecast	Multiplier for high-range forecast
Scenario 1	0.95	1.00	1.02
Scenario 1A	0.93	0.99	1.02
Scenario 2	0.97	1.01	1.05
Scenario 3	0.97	1.01	1.05
Scenario 4	0.91	0.98	1.01
Scenario 5	0.91	0.97	1.005

Table 12: Self-modification multipliers for Wayne County.

Scenario	Multiplier for low-range forecast	Multiplier for mid-range forecast	Multiplier for high-range forecast
Scenario 1	0.95	1.00	1.02
Scenario 2	0.90	0.98	1.01
Scenario 3	0.95	1.00	1.04
Scenario 4	0.95	1.00	1.04