A COMPARISON OF FUTURE URBAN SCENARIOS AND ENVIRONMENTAL IMPACTS IN THE ETOWAH RIVER WATERSHED, GA

by

KEVIN WESLEY SAMPLES

(Under the Direction of Elizabeth Kramer)

ABSTRACT

Historical Landsat TM Satellite derived land cover and impervious surface cover are used with the SLEUTH cellular automata urban growth model to predict future urban scenarios within the Etowah River watershed and surrounding areas. Three future scenarios as well as previous extents of urbanization are analyzed to determine the hydrologic and water quality effects on the regions streams. Six streams sites were modeled over time to provide detailed unit hydrographs based on the various scenario outcomes. Each site demonstrates the drastic changes that may occur in the watershed, even with the most conservative outlook for increased development. Stream impairment thresholds were also determined via the 303d Impaired Waters list for the Etowah watershed area. With the knowledge of the effects various growth strategies may have on area streams, communities can plan by modeling future developments and assess the potential effectiveness of smart growth policies in the Etowah River watershed via stream impairment thresholds and hydrologic analysis for three future scenarios.

INDEX WORDS: Land use, Impervious surface, Urbanization, Water quality

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CHAPTER 1

INTRODUCTION

The present pattern of urban and suburban development in the metropolitan Atlanta area, including the southern and eastern portions of the Etowah River watershed, has increasingly taken the form of low-density and decentralized residential, commercial, and industrial development at the expense of agricultural and forested land. This type of development, which is commonly referred to as sprawl, is central to the debates over the impact of development on the environment and quality of life where it occurs. The goal of this study is to generate spatially explicit data sets that accurately depict the future distribution of urban development across the Etowah and analyze the effects on stream health for various scenarios.

Ecological Status of the Etowah River System

The metropolitan Atlanta area, which covers portions of the Etowah River watershed, is one of the fastest growing metropolitan areas in the country, with a 2000 census population of over four million. Because of the fast pace of suburban growth, the aquatic habitats of the Etowah River watershed, which are highly biodiverse and imperiled, have recently become the focus of conservation efforts (Freeman 2002). The Etowah watershed has a high level of biodiversity and endemism, supporting approximately 90 fish species of the approximately 800 that occur in North America north of Mexico (Burkhead 1997). The encroachment of metropolitan Atlanta into the Etowah watershed has negatively impacted the native aquatic species and thus it now supports several federally and state protected fish and mussel species (Freeman 2002).

The Etowah River is representative of the typical southern Appalachian river system in that it drains Appalachian physiography, has relatively high aquatic diversity and endemism and is plagued by a litany of environmental threats (Burkhead 1997). The environmental threats on this watershed are in part due to the proximity to the Atlanta area and pressure from sprawl development. Those areas in the Upper Etowah watershed closest to Atlanta have been particularly impacted by sprawl type development and are experiencing fragmentation of the natural landscape, increased non-point source pollution, habitat destruction, as well as the effects of traffic pollution and congestion.

As an essential element of ecological function, land cover can have dramatic effects on the hydrological processes, stream ecosystem health, and the recreational opportunities of a watershed (Landers 2002). As urbanization occurs, the natural landscape is replaced or transformed into surfaces that are less permeable or impervious to water. As impervious surfaces increase, water quality is negatively impacted and the hydrological regime is drastically altered (Booth 1997). This includes higher flood levels in shorter intervals, causing sudden changes in stream channel morphology, bank destabilization, and erosion (Burkhead 1997). Relationships have also been drawn between poor water quality and the percentage of urban land cover (Booth 1997; Roy 2003). Not only does impervious surface from urban areas contribute to surface runoff, but urban areas also contribute waste discharges, air pollutants, road surface and vehicular pollutants, street litter, animal wastes, and lawn and garden chemical waste (Duda 1982). However, these impacts can be mitigated by the spatial location and the building practices of newly developed impervious surfaces within a watershed, which can have various effects on stream ecology and hydrology (Paul 2001). Predicting the spatial pattern of future land use changes is essential in determining the environmental impacts of that change.

Objective and Justification of Study

In order to assess the potential effectiveness of smart growth policies in the Etowah River watershed, geographic information systems (GIS) and remote sensing (RS) are employed to quickly acquire and assess landscape scale data. In conjunction with the GIS, a cellular automata (CA) based urbanization model, SLEUTH (Slope, Land-use, Exclusion, Urban-extent, Transportation, and Hillshade) (USGS) was chosen for its ability to incorporate different levels of habitat and landscape protection for priority areas within the study watershed.

This study focuses on the hydrologic and water quality impacts of the entire 4,800 km^2 Etowah watershed – past, present, and future – using hydrological relations derived for Georgia (Inman 1986; 1995; 2000) and impervious surface thresholds of stream impairment. Three future scenarios were developed that compare the possible future impacts of different land use and land management policies within and surrounding the Etowah watershed. A more general analysis is applied to study the effects of urbanization on storm runoff and water quality, thus giving an overall impact to the watershed at various scales.

Literature Review

There are a myriad of land use and urban change modeling approaches. These models may include mathematical equation-based, system dynamics, statistical, expert systems, cellular automata, or hybrid type models (Parker 2003). These models typically range from rigid simplistic models to a more complex and flexible hybrid model approach. The equation based model approach uses a set of equations based on population growth theories or economic theories. This type of models usually lack complexity, whereas the system models are more complex and represent flows of material or energy as differential equations. Although more complex, time is usually considered in these models, they have difficulty incorporating spatial relationships, which is important for the incorporation of geographic data. Statistical models are more commonly used to model urban trends, and can incorporate spatial statistical methods. These models are typically very strict, therefore they can diminish the importance of decision making and social phenomena in the process of urbanization. Another model type is the expert models, which addresses the decision making problems of the previous model by allowing the use of qualitative expert knowledge in a quantitative mold. Many of these models are too simplistic and too rigid in their implementation to accurately represent the processes of urbanization and land use change.

In recent years, complex, spatially explicit urban growth simulation models have been developed. Many of these are specifically used in micro-level, large-scale situations with rules governing future land use choices and behavior, thus requiring highly detailed parcel-level GIS data (Jantz 2003). Model complexity and limited data availability hinder the use of these types of models for large study areas or studies in disparate regions.

In contrast to the spatially explicit urban simulations, a simpler more elegant type of model, cellular automata (CA), has been utilized to predict the spatial patterns of urban development. A CA model operates based on a set of assumptions. These include a designated specific spatial extent, a set of initial conditions, and a set of behavior rules usually applied to a pixel, the basic unit of a raster dataset, based on the state of its neighbor or neighborhood. The model behavior is generated by repetitive application of the rules to the entire study area beyond the initial conditions (Clarke 1998).

The most recent CA models are a hybridization of the two previously mentioned CA modeling techniques and can also include aspects of the other previously mentioned urban modeling methods. These models integrate the complexity of the spatially explicit models with the more general basic CA pattern models, and thus they are better equipped to account for the complex urban processes. SLEUTH, as well as Allen's logistic regression CA model, falls into the hybrid category (Allen 2003). Model integration makes a compromise between landscape and data detail and model flexibility. General CA modeling and the described hybrid approach naturally lends itself to be a powerful planning tool for suburban and urban development at the metropolitan or regional scale. Cellular automata models are also raster based – therefore increasing their utility by allowing the incorporation of remotely sensed (RS) imagery and GIS data. The coupling of CA models with GIS and RS enables easy quantification and analysis of past, current, or potential land changes with commonly used GIS spatial analysis tools.

The SLEUTH model has been utilized previously to model large metropolitan areas such as Baltimore-Washington (Clarke 1998; Jantz 2003), San Francisco (Clarke 1997; 1998) and Atlanta (Lo 2002; Yang 2003). A previous study has also coupled the SLEUTH model with complex hydrologic models analyzing storm water runoff responses to increased urbanization, however only as a proof of concept (Arthur-Hartranft 2002). Other rule based models have also been developed utilizing logistic regression and applied to the Charleston region of South Carolina (Allen 2003).

Lo (2002) and Yang (2003) have successfully studied the effects of urbanization in the Atlanta metropolitan area with the SLEUTH model, though with slightly different goals. The goal of the analysis conducted by Lo, was to determine what the drivers for land use and land cover changes and growth were for the period from 1973 to 1999 in the 13 county metropolitan area. To understand the underlying causes of the land use changes, demographic and socio-economic data were integrated with the land use change data and statistically analyzed. From this analysis it was determined that the SLEUTH model would adequately represent the drivers of change and a current trends change simulation was conducted from 1999 to 2050 for the Atlanta metropolitan area.

Yang's analysis of the Atlanta area is similar to Lo's, in that it only studied the 13 metropolitan counties. However, Yang also utilized three future scenarios for comparison. These scenarios include a current growth trends scenario, a future road development and environmental protection scenario, and an anti-growth scenario. While the studies of both Lo and Yang are similar to the one described in this analysis, they lack a detailed and comprehensive environmental focus. This includes a lack of in-depth analysis of the environmental impacts of any future scenarios as well as the lack of extensive environmental protection scenarios.

Previous attempts to model the patterns of future urbanization for large urban areas have been successful and thus warrant more detailed study and analysis. Utilizing the hybrid cellular type SLEUTH model is the best approach to model future urban growth in the Atlanta area. Using this model will allow for accurate and detailed analysis on the ecological affects of the quantity and spatial location of future urban areas in the Etowah watershed.

CHAPTER 2

LOCATION AND SITE DESCRIPTION

Physical Description

At the convergence of the Piedmont, Ridge and Valley, and Blue Ridge regions in northwest Georgia is the Etowah River watershed (Figure 1). The Etowah River watershed falls completely within the state of Georgia and encompasses an area of approximately 4,800 km^2. The Etowah River is split by Lake Allatoona, a 12,000 acre U.S. Army Corps of Engineers impoundment. Lake Allatoona became operational in 1950 for the purposes of flood control, hydroelectric power generation, water supply and water quality, recreation, and fish and wildlife management. The Etowah watershed includes the northwestern portions of metropolitan Atlanta and fourteen Georgia counties (Figures 1 and 2). Ultimately the Etowah River joins the Oostanaula River in Rome, Georgia, to form the Coosa River that then flows west into Alabama and to the Gulf of Mexico.

The Etowah watershed straddles three ecological regions, of which the largest region, the Piedmont, covers 227,000 hectares of the watershed (Figure 3). The Piedmont is the transitional area between the mountainous Appalachians to the north and the northwest and the flat coastal plain region to the southeast. The region, which runs from Montgomery, Alabama to New York City, consists of moderately dissected irregular plains and some hills. The Piedmont area has reverted to pine and hardwood woodlands, and more recently, sprawling urban and suburbanization from a once largely agricultural landscape.

The Blue Ridge region, which extends from Pennsylvania to north Georgia and comprises approximately 126,000 hectares of the Etowah watershed, consists of narrow ridges, hilly plateaus, and mountainous areas with high peaks. Streams in this area are mostly high gradient, with cool and clear water. The southern Blue Ridge is one of the richest centers of biodiversity in the eastern United States and is one the most floristically diverse ecoregions (Omernik 1987; McMahon 2001)

The Ridge and Valley is a low-lying region between the Blue Ridge on the east and the Southwestern Appalachians on the west (Figure 3). The parallel ridges and valleys are of varying widths, heights, and geologic materials and contain numerous springs and caves. Typical land cover consists of forested ridges with pasture and cropland valleys. This region is the second largest of the Etowah watershed, encompassing approximately 130,000 hectares.

For this study, analysis also incorporates the surrounding areas from adjacent watersheds, including the Oostanaula, Coosawattee, and Toccoa River watersheds to the north, the Chattahoochee River watershed to the east and south, and the Tallapoosa and Coosa River watersheds to the west (Figure 4). These areas were included to account for extra-watershed urban influences as well as to provide spatial context. The entire study area therefore, covers over 1.1 million hectares.

Historical and Current Land Uses

The pre-European landscape was managed primarily by fire and was completely covered in old growth deciduous forest with continuous canopy across the entire area (Godfrey 1997). European arrival brought drastically different land management practices than those of the Native Americans who traditionally lived in this area. The land and its features were typically viewed as commodities by Europeans which ultimately led to a system of scarce labor and cheap plentiful land. This led to the rejection of old-world sustainable farming practices for the more cost effective practice of land abandonment (Godfrey 1997).

Clearing land provided the cheapest source of nutrients for soil-exhausting crops, thus producing the most profits. Once the nutrients from the soil were exhausted, the land would be abandoned and the cycle would continue. The abandonment of land with little to no vegetative cover was one of the most erosive practices of the European settlers (Trimble 1974). These techniques define the ecology of the region today, with patterns of old field succession on poor, eroded soils.

The Etowah region of the piedmont was mostly settled by the late 1800s, which began several periods of farmland abandonment. This includes abandonment following the Civil War, the agricultural depression of the 1880s, the introduction of the boll weevil in the 1920s, and the period following World War II. Each period of agricultural depression brought successively larger proportions of land abandonment. The waves of land exhaustion and abandonment have resulted in soil losses from 4.5 to 7 inches in depth across the area since European settlement (Trimble 1974). Since the 1920s, with the decline of agricultural land uses and the increase of soil conservation practices, soil erosion has decreased significantly across the piedmont.

The predominant land use of concern today in the Etowah watershed is suburbanization and the growth related to the Atlanta metropolitan area. Urbanization concerns include the negative impact to stream biota, increases in stream turbidity, stream nutrients, sedimentation, and non-point source pollution (Roy 2003).

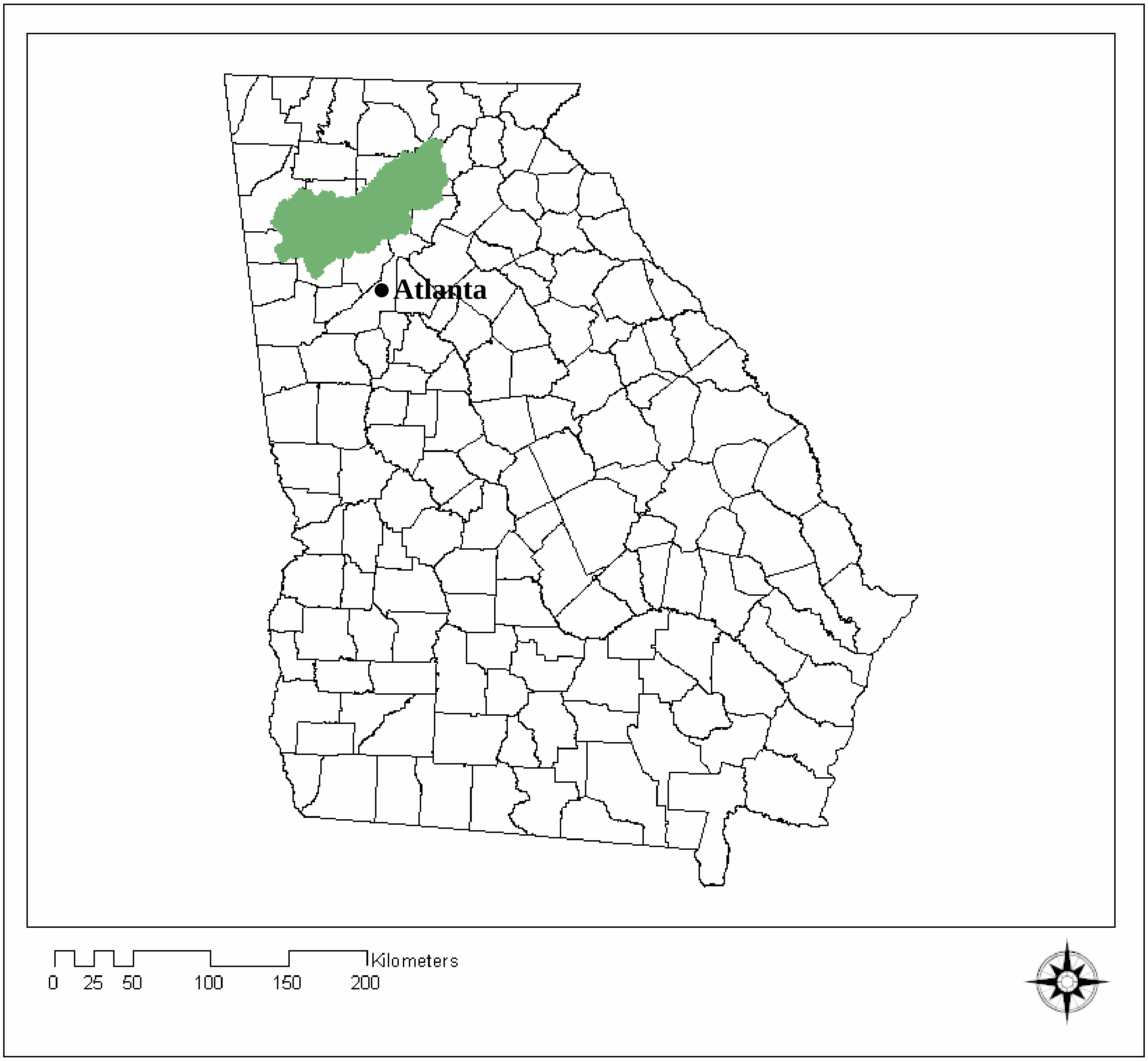


Figure 1. Location of the Etowah River Watershed (green) within Georgia.

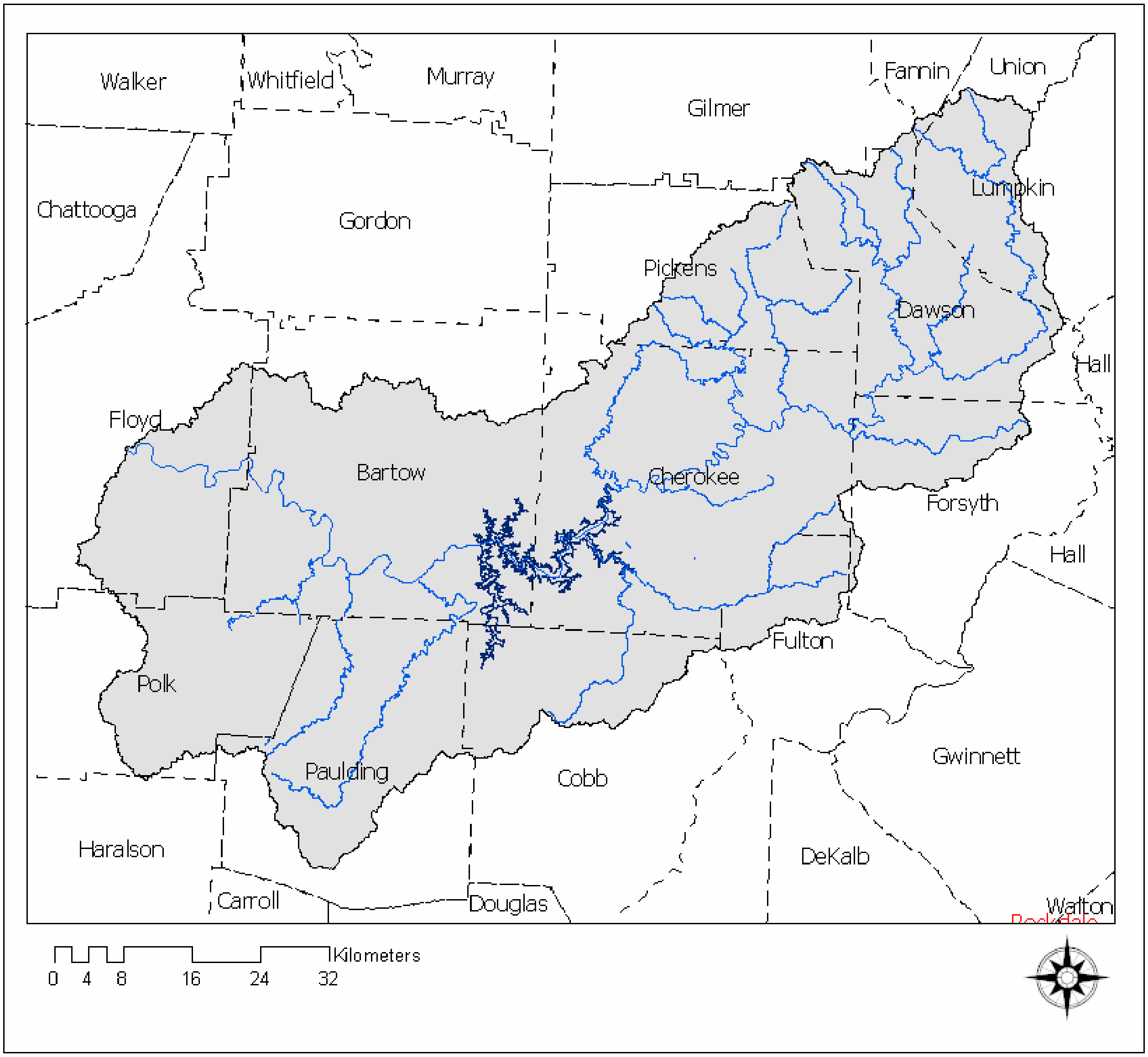


Figure 2. Etowah River watershed (solid grey) and encompassing counties.

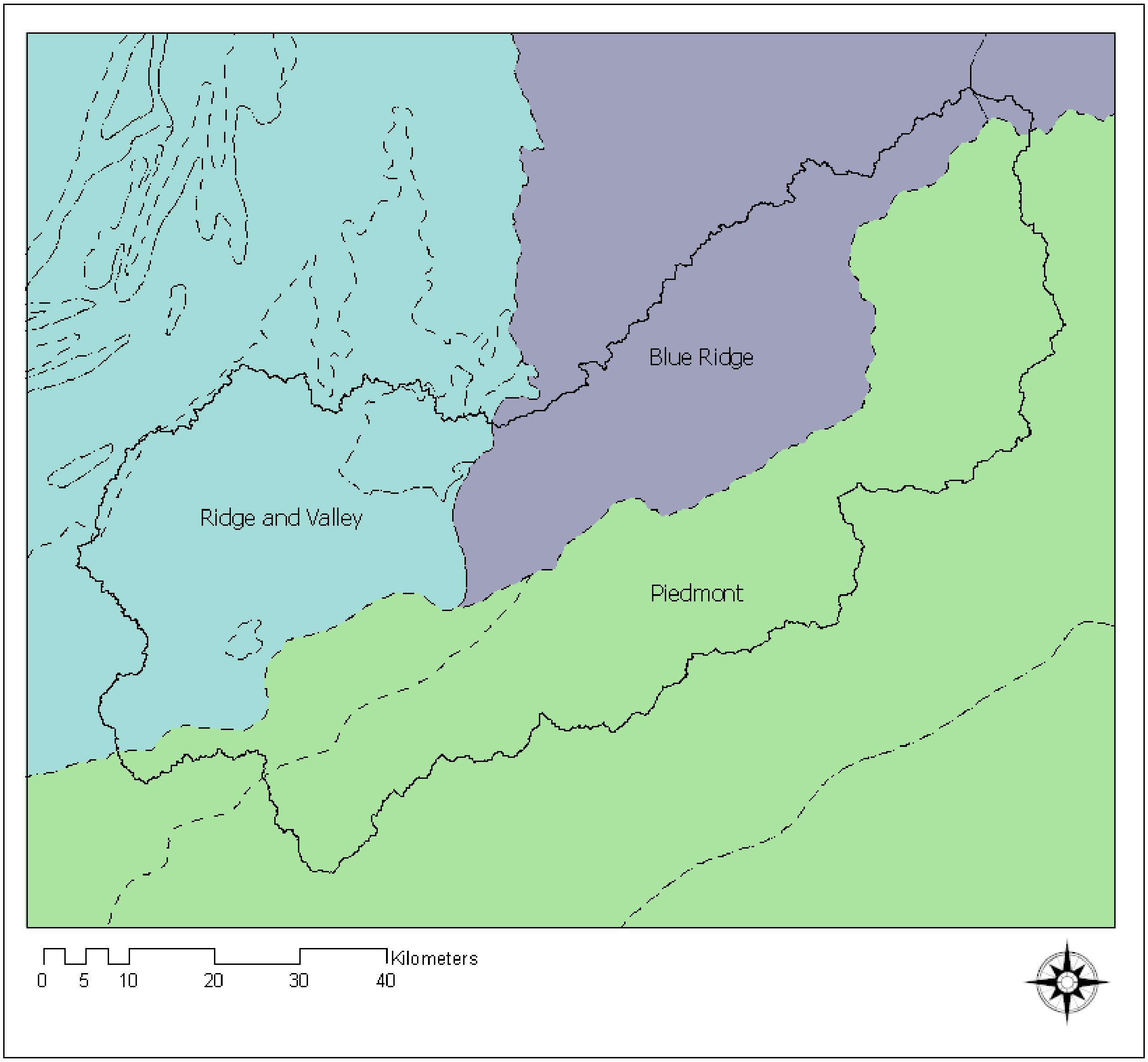


Figure 3. Etowah River Watershed and encompassing ecological regions.

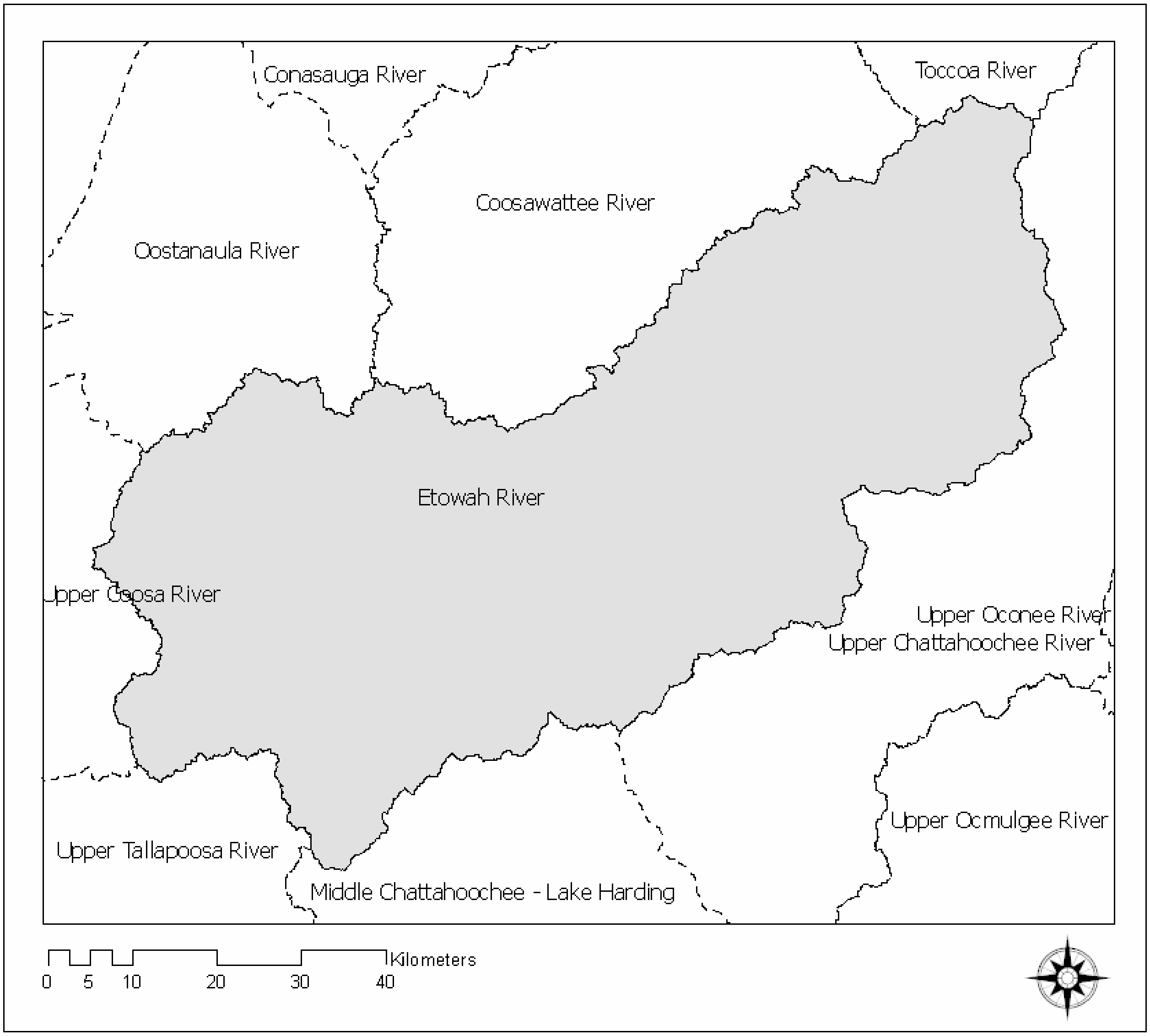


Figure 4. Etowah River Watershed (solid grey) and surrounding watersheds.

CHAPTER 3

METHODS

Introduction

The SLEUTH model, version 3.0 beta, consists of two components – an urban modeling component and a general land cover change component. For this study only the impacts of newly developed urban areas were a concern, therefore only the urban change component of the model was used. Following a set of urban development rules, the urban change modeling component of SLEUTH designates any given cell within the study area as urbanized or non-urbanized. The model relies on historical urban data, which it in turn simulates to determine what growth processes were and are occurring at a regional scale and to ultimately predict future urban trends.

The model simulates four types of urban growth – spontaneous growth, new spreading centers, edge growth, and road-influenced growth. Each of these growth rules is sequentially and iteratively applied to the data for each growth cycle and is regulated by five growth coefficients (Table 1). The five growth coefficients are: dispersion, breed, spread, slope, and road gravity. Each is calibrated by comparing simulated land cover change through the historical time period to the study area's actual historical data. The resulting coefficient values range from zero to 100.

In conjunction with the coefficient values, the exclusion layer determines the probability of any given location converting to an urbanized area. The exclusion layer is an important part of determining where and how build-out will occur by distinguishing areas that can be completely or partially unavailable for development. Each pixel of this layer also has values that range from zero to 100, with 100 indicating 100 percent probability of exclusion, 50 indicating 50 percent probability of exclusion, et cetera.

SLEUTH Cellular Automata Software

SLEUTH is a cellular automata type model developed by the USGS. Because of the inherent binary nature of cellular automata models, the study area is represented as a tessellation of grid cells with each consisting of two states – urbanized or non-urbanized. SLEUTH currently does not, however, determine development density within a cell. The state of each cell or pixel in the study area is determined by four growth rules, as mentioned earlier, that simulate different aspects of the development process.

The model is implemented in two phases – a calibration phase, where historical land use patterns are simulated, and the prediction phase, where the historical trends and patterns are projected into the future. The calibration requires at least four historical urban extents from different periods of time, historical transportation layers, terrain slope, and a layer determining undevelopable areas or areas resistant to development (exclusion layer). Each cell within the exclusion layer is assigned a value to represent the probability of exclusion. Areas which are undevelopable, such as steep slopes or water are assigned a value of 100, while areas that are open to development are assigned lower probabilities of exclusion. Once each of these layers is created, the model is then calibrated to the historical data and the results are used to predict the various future scenarios.

The SLEUTH model simulates four types of urban growth – spontaneous growth, urban spreading center, edge growth, and road influenced growth. Each type of growth rule is applied sequentially and iteratively during each growth cycle and depends upon four corresponding growth coefficients to determine the outcome of each step (Table 1). The slope coefficient and the exclusion layer have an overarching effect on each growth step and growth cycle by determining whether a cell will become urbanized by its percent slope and probability of development.

The SLEUTH model simulates random urbanization of land with the spontaneous new growth function. This function enables any non-urban cell within the study area a small probability of becoming urbanized in any give time step, which is determined by the dispersion coefficient (Table 1). The applied value is derived from the coefficient as follows:

$$a = ((b \times 0.005) \times \sqrt{x^2 + y^2} \qquad (1)$$

Where *a* is the dispersion value, *b* is the dispersion coefficient, *x* is the number of pixel rows of the study area extent, and *y* is the number of columns in the extent.

The next urban growth step determines new spreading centers. Newly spontaneously urbanized cells are selected as spreading centers via the breed coefficient, which defines the probability of a cell becoming a spreading center, given that at least two neighboring cells are also available for urbanization. Once an urban spreading center is identified, the two adjacent cells are also urbanized. When the spreading centers are identified, the edge growth dynamics for the spreading centers also need to be determined (Table 1).

Edge growth is propagated from the new urban centers as well as previously established centers from earlier cycles. This type of growth occurs if a non-urban cell has at least three urbanized neighbors, with its probability of urbanization determined by the spread coefficient (Table 1).

The final growth step, road-influenced growth, is determined by the existing transportation infrastructure as well as the most recent urbanization completed in any previous steps. Road influenced growth probability is defined by three coefficients. Once the cells are selected, a road is sought with a radius defined by the road gravity coefficient. When a road is found within the radius, a temporary urban cell is placed at a point on the road that is nearest to the initially selected cell. Next, a random walk along the road is conducted where the number of steps is determined by the dispersion coefficient. The number of random walks or road trips is finally determined by the breed coefficient. This final location of the cell on the road is then determined to be a new spreading nucleus, not a spreading center, as roads cannot be urbanized. If any neighboring cells are available for urbanization, a cell will be randomly selected to create a newly urbanized cell adjacent to the road. Two adjacent non-urbanized cells will also be randomly urbanized (Table 1).

Finally, the slope coefficient affects all growth rules in the same way. When a pixel is being considered for urbanization, the slope at that location is considered. The slope coefficient acts as a multiplier. As the slope coefficient approaches zero, increases in slope have little affects on urbanization likelihood. However, as the slope coefficient gets closer to 100 increasingly steeper slopes are less likely to urbanize.

GLUT/Impervious Surface

The requirements of the SLEUTH urban model include at least three previous raster maps depicting the state of urbanization at a prior point in time. Since the Etowah River watershed is completely within the state of Georgia, a source of this GIS data is the Georgia Land Use Trends project (GLUT). The GLUT project has developed raster GIS maps of Georgia land cover for five different years. The source satellite imagery includes Multi-Spectral Scanner (MSS) and Thematic Mapper (TM) Landsat imagery. These include land cover datasets from 1974 and 1985, using MSS imagery, and land cover from 1992, 1998, and 2001, using TM imagery

(Figures 5-9). Each dataset, with the exception of the 2001 land cover, were created using an unsupervised ISODATA clustering technique, along with logical land use and land cover change scenarios and rules from year to year.

The 2001 GLUT dataset was created with the classification and regression tree (CART) data mining technique, which utilizes multiple input variables instead of relying exclusively on satellite imagery to produce the final product (Homer 2001). A percentage impervious surface raster dataset was also created with the CART technique as a companion dataset to the general land cover classification (Yang 2002). The impervious surface dataset enumerates the percentage of impervious surface per 30 meter pixel.

To create the inputs for the SLEUTH model, the urban classes for each of the five land cover datasets were recoded to a single value (1) and all other classes eliminated (recoded to zero) (Figures 10-14). Each land cover dataset was clipped to a rectangular extent encompassing the entire Etowah watershed. Differences between the 2001 urban extent and previous extents, where urban areas may shrink in subsequent years, were eliminated due to model limitations where losses of urban areas cannot be predicted.

Impervious surface layers were also created for each of the past and future time periods for hydrologic analysis. To create the impervious surface for the four previous time periods, the 2001 impervious surface dataset was masked with the urban extents of the four previous years. This creates a logical equivalent of impervious surface for those years.

To create impervious surface for the future scenarios, the 2001 impervious surface dataset was used to estimate what the impervious surface might be for any given pixel with the study area. An assumption is made that future impervious surface will be similar to its neighbors. As roads tend to be drivers for growth and high percentages of impervious tend to cluster near roads, the 2001 impervious surface values were expanded to their nearest neighbors with roads limiting the pixels assignments. This results in every pixel within the study area having a potential impervious surface value (Figures 15-16). It is noted that using this method to create impervious surface datasets for past or future time periods can be inaccurate and is only a logical estimation.

Impairment Threshold

The water quality and hydrologic effects of past (GLUT) and future (SLEUTH) impervious surface scenarios were analyzed by first determining an impervious surface threshold at which a stream becomes impaired. Current literature states that when approximately 10 percent of a watershed is covered with impervious surface, streams become impaired in terms of fish assemblages (Booth 1997; Wang 1997). Another study conducted within the Etowah watershed suggests that above 15-20 percent urban land cover, macroinvertebrate assemblages reflect poor water quality (Roy 2003). Other studies have also noted that impervious surface mitigation is severely limited at percentages greater than 30 percent (Paul 2001).

In order to verify a 10 percent impairment threshold for the Etowah watershed and surrounding areas, an analysis was conducted on the 2002 Georgia EPD 303d listed streams (Figure 17). The listed streams are classified as supporting their designated use, partially supporting their designated use, and not supporting their designated use. For the analysis, logistic regression was used to determine impairment probabilities. Impairment probabilities are calculated as follows;

$$\mu = \frac{\exp(\beta_0 + \beta_1 x)}{1 + \exp(\beta_0 + \beta_1 x)} \qquad (2)$$

Where β_0 and β_1 are estimates from the sample data using a preliminary linear model or sample proportions, x is the percent impervious surface, and μ is the resulting probability. Thus, the streams were classified as impaired (presence) and not impaired (absence). Impaired streams include the partially supporting and not supporting streams while unimpaired streams only include supporting streams. Logistic regression also makes no assumption about the distribution of the independent variables, therefore they do not have to be normally distributed, linearly related or of equal variance.

Hydrologic Effects

Hydrology was evaluated by estimating the flood magnitude and frequency, flood lagtime, and hydrograph simulation for a 2-year recurrence interval flood in the Etowah watershed. Changes in flood and hydrograph characteristics can be indicative of geomorphic adjustments, such as bank stability, and in-stream habitat changes (Dunne 1978; Freeman 2002). These simulations were accomplished by using the flood-frequency relations, lagtime relations, and a dimensionless hydrograph developed for Georgia by the USGS (Inman 1986; 1995; 2000). A dimensionless hydrograph was developed for use in urban basins up to 64.7 km^2 and up to 1295 km^2 rural basins in Georgia (Inman 1986). Peak discharge and lagtime convert the dimensionless hydrograph into a simulated hydrograph. The simulated hydrograph is only a typical hydrograph for the peak discharge (Inman 2000). The flood frequency regression equations were developed using peak-discharge data for stream flow utilizing gauging stations with at least 10 years of records collected from stations in Georgia and surrounding areas (Inman 1995). The hydrologic simulations were computed for every stream location in the Etowah watershed that was within the boundaries of the regression equation limitations. However, specific watersheds or stream segments are also highlighted to illustrate differences between the scenarios.

Unit hydrographs representing the peak discharge for floods with a two year recurrence interval, typically bankfull, were created for each future scenario (2025 and 2050), for each historical dataset (1974-2001), and for a hypothetical rural watershed consisting of no impervious surface at each of the selected streams. Discharge was computed, following Inman, 1995, for urban streams as follows:

$$Q_2 = 167A^{0.73}TIA^{0.31} \qquad (3)$$

Where Q_2 is the peak discharge for a recurrence interval of 2 years in cubic feet per second, A is drainage area in square miles, and TIA is total contributing impervious area in percent. This regression equation is applicable where the drainage area is 0.04 to 19.1 square miles and the total impervious area is 1.0 to 62.0 percent. Discharge was computed for rural watersheds, following Stamey, 1993, as follows:

$$Q_2 = 207A^{0.654} \qquad (4)$$

Where Q_2 is the peak discharge for a recurrence interval of 2 years in cubic feet per second and A is drainage area in square miles. This equation is only applicable where the drainage area is 0.17 to 730 square miles. Lagtime was computed, following Inman, 2000, for urban (5) and Inman, 1987, for rural (6) streams as follows:

$$T_L = 7.86DA^{0.35}TIA^{-0.22}S^{-0.31} \qquad (5)$$

$$T_L = 4.64DA^{0.49}S^{-0.21} \qquad (6)$$

Where T_L is the lagtime in hours, *DA* is drainage area in square miles, *TIA* is percent contributing impervious area, and *S* is slope in feet per mile. The independent variables are limited to a drainage area of 0.04 to 19.1 square miles, 1 to 61.6 percent contributing impervious surface, and 9.4 to 772 feet per mile slope for urban areas. For rural areas, the variables are limited to 0.3 to 500 square miles for drainage areas and 5 to 200 feet per mile slope.

Future Scenarios

Three future scenarios were developed, with varying degrees of land protection, in order to analyze the effects of different types of urban growth on stream water quality and hydrologic response. The exclusion layer is the primary means in which the future scenarios are developed. The scenarios include a current trends scenario, a land use zoning scenario, and a rigorous suitability scenario. Each scenario presents increasing restrictions as to where newly created impervious surface development can occur.

One important input to the SLEUTH model is a weighted road layer. The road layer represents the extent of all roads in the study area as of 2001. The roads were weighted from zero to 100 via road density, which is the density of roads in a circular 150-meter^2 neighborhood. The weighted roads layer, as well as the percent slope layer, remains constant for each of the future scenarios.

The three scenarios are driven by the coefficient values determined by SLEUTH from the historical Georgia land use trends (GLUT) raster GIS data. These data represent the years 1974, 1985, 1992, 1998, and 2001 as previously stated. Different satellite imagery was used to create the land cover datasets, with the earliest two created at a resolution of 60 meters^2 and the final three created at a 30 meter^2 resolution. Because of these differences and in order to maintain a consistent spatial resolution, all of the land cover datasets were resampled to a resolution of 60 meters^2. Once these datasets were consistent, in terms of resolution and urban extent, they were processed in the SLEUTH model's calibration phase in order to determine the values of the five growth coefficients. Once these values are determined, they remain constant for each of the three future scenarios.

The calibration phase consists of three calibration steps – coarse, fine, and a final calibration. Each calibration step gradually narrows the range of the five growth coefficients. Each stage consists of several thousand brute force Monte-Carlo iterations. A Monte-Carlo analysis is the generation of large numbers of constructed data sets that are similar to the historical data set, but each with different random normally distributed noise. Each new data set is analyzed and several spatial statistics are recorded. The resulting set of distributions can then be analyzed, allowing probability to be calculated. The recorded spatial statistics include cluster size, slope, percent urban, and several others described in Table 2. The values of the growth coefficients used to create each Monte-Carlo iteration are also recorded. This links the growth coefficients to the fit statistics, allowing one to determine the best coefficients.

To narrow the range of the five growth coefficients, the eleven spatial statistics are averaged per iteration. These averages were then sorted from low to high to determine the best range of the five growth coefficients. The lower values determine which coefficients will produce the closest match to the historical GLUT datasets. Each calibration step narrows the range of values until the best growth coefficients are determined. The final coefficient values were 58, 65, 34, 1, and 12 for dispersion, breed, spread, slope, and road gravity respectively.

From these results one can make several generalizations about the rate of growth, what is influencing growth, and the type of growth that has historically occurred in the Etowah watershed. This means that the percent slope has historically had little effect on the location of new urban development. The low road gravity coefficient of 12, suggests that development tends to occur at close proximity to roads. The moderate spread coefficient indicates that spreading centers have greater than 34 percent chance of continuing to spread. Dispersion controls the number of times pixels will be selected for urbanization. A value of 100 would urbanize 50 percent of the image – therefore a value of 58 suggests a swift rate of urbanization.

Current Trends Build-out Scenario

The current trends scenario consists of a weighted roads layer (Figure 18), a slope layer (Figure 19), as mentioned previously, as well as a unique exclusion layer for this scenario. The exclusion layer consists of the Georgia GAP conservation lands, which incorporate federal, state, and locally protected lands (Georgia GAP 2002) (Figure 20). The probability of exclusion for the conservation lands is based on the length of the land lease. In the exclusion layer, long-term leases are given a probability of 100 percent exclusion; while short-term leases are given only a 25 percent probability of exclusion. These values were determined by the estimated number of years the area will be protected out of 100 years. For this scenario stream buffers are not maintained, as they are generally smaller than the 60 $meter^2$ minimum mapping unit. However, open water is completely excluded.

Alternative Scenario I

This land-use zoning scenario consists of the current trends exclusion layer, with the addition of an approximately 30-meter wide stream buffer (Figure 21). The stream buffers are approximately 30-meters wide due to the 60-$meter^2$ minimum pixel size; however state and local laws generally dictate a minimum 25 feet wide stream buffer, therefore the 30-meter (94.4 ft) buffer is more than representative of current buffer widths. The stream buffers are assigned a value of 100, or complete exclusion from development. Also included in this scenario's exclusion layer is the general future land use zoning for nine counties that lie within the Etowah watershed. These counties include Fulton, Cherokee, Bartow, Cobb, Paulding, Dawson, Lumpkin, Forsyth, and Pickens. The future land uses for these counties are categorized (and ranked for probability of exclusion) into several classes as defined in Table 3. These exclusion probability values were determined by the likely number of years, out of one hundred years, that any particular zone would be protected.

Alternative Scenario II

This suitability scenario was developed utilizing hydrological and ecological principles and is the most complex of the three scenarios. The exclusion layer for this scenario has a probability of exclusion for every cell within the study area, which is determined at any given cell by six criteria. These criteria include – landscape roughness, distance from a stream, the natural log of the watershed size, and the percent impervious surface of the watershed upstream – each determined at the pixel level and initially ranked from zero to 100. However, in one exception, the watershed size was initially ranked from 0 to 50 to limit its influence on the final ranking. Landscape roughness is defined as the result of the difference between the maximum and minimum elevation pixel values within a five by five pixel analysis window. This is included in the exclusion layer to limit the impact of development within rough landscape and encourage development in flatter areas in order to reduce disturbance erosion and protect areas with higher biodiversity.

The final two criteria are applied to a network of approximately 5 km^2 sub-watersheds. These criteria include the 2001 percent impervious surface of the entire contributing watershed, ranked from zero to 100, and the natural log of the contributing watershed area, again ranked from (zero to 50) (Figures 22-23). Each entire sub-watershed is given a value for the final two criteria, thus each pixel is ultimately assigned six values for each of the six criteria (Figure 24). The six values are added together and rescaled from zero to 50 to give an overall ranking representing the initial probability of exclusion (Figure 25).

In addition, all pixels that are within a 5-km^2 sub-watershed consisting of five to 12 percent impervious surface are assigned a 100 percent probability of exclusion (Figure 22; Figure 25). This essentially freezes build-out within these sub-watershed, thus protecting the streams from further degradation. These streams are close to or are at the established impervious surface threshold for streams impairment and should be identified and prioritized for protection and restoration.

All small watersheds that are greater than 30 percent impervious surface are given a zero percent probability of exclusion (Figure 22; Figure 25). These sub-watersheds are beyond the thresholds of mitigation having a substantial impact and are also the locations of most of the municipal infrastructure, i.e. roads and sewage, making these watersheds ideal for further build-out and thus limiting overall newly created impervious surface. All conservation lands, stream buffers, and open water are added to this layer with a 100 percent probability of exclusion to create the final exclusion layer for this scenario (Figure 26).

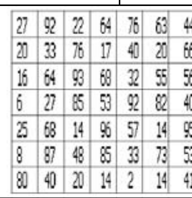
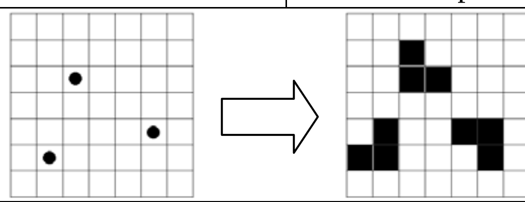
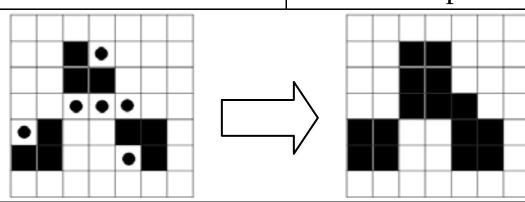
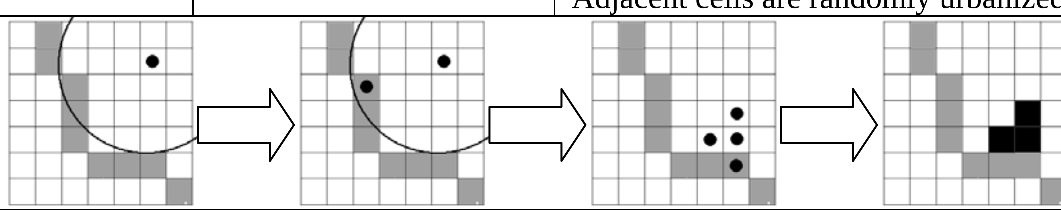
The six exclusion criteria follow well established hydrological and ecological observations and principles and will be used to determine where build-out should occur (Booth 1997; Duda 1982; Paul 2001; Roy 2003; Walters 2003). The placement of impervious surface may contribute foremost to stream health (Brabec 2002). Therefore, to alleviate the impact of future urbanization on stream health, future build-out should occur near existing urban areas where infrastructure is already present, allowing for focused mitigation and less new impervious surface development. Also, building away from streams and building lower in the watershed (e.g. large contributing areas upstream) can be beneficial by reducing the hydrologic and pollution effects of impervious surface on the watershed as a whole. Build-out high in the watershed (e.g. at or closer to headwaters) affects more stream miles while build-out lower in the watershed creates more concentrated impacts affecting less of the overall watershed (Brabec 2002). Finally, the use of landscape roughness is used to prioritize areas based on elevation diversity. This index essentially identifies areas that have less elevation change as more desirable for build-out than areas with steeper slopes and higher diversity.

The three future scenarios were processed by the SLEUTH model's prediction module, which utilizes multiple Monte-Carlo iteration to produce probability maps of urbanization for any range of years that are desired. For this study, the percentage of urbanization was predicted yearly from 2001 to 2050. However, the hydrologic analysis only occurs for the historical years, 1970 through 2001, and the years 2025 and 2050. Each pixel within the resulting maps is assigned a probability of urbanization from zero to 100. A threshold of 50 percent probability was selected to determine the urbanization state of a pixel.

Once each scenario is complete and the extents of the predicted urban areas are known, a hydrological analysis needs to be performed to determine the total impact of the newly created urban areas. However, in order to perform the hydrologic analysis, the percentage of impervious surface in those areas is needed. Therefore, to estimate the impervious surface, the layer previously created for the future scenarios is clipped to the newly predicted urban extents.

An analysis of the impacts of the three future scenarios requires impervious surface percentages to estimate the amount of urban runoff that is affecting the watershed. As described above, an impervious surface dataset has been developed by the GLUT project for the year 2001. This dataset was used to estimate the impervious surfaces of any future urbanized areas. To accomplish this, an assumption is made that future build-out will consist of impervious surfaces that are similar to adjacent areas of existing impervious surface. Any newly urbanized pixels are given the impervious percentage of its closest 2001 impervious neighbor, with roads limiting the assignment of the impervious values. The road limiting approach prevents the assignment of neighbor values across roads, thus breaking up and preventing large tracts of high impervious surfaces. Although this technique is expected to estimate fairly well the percentages of impervious surfaces for the near future, the predictions for many years from the original source data are expected to be significantly underestimated at the pixel level or overestimated due to the model over generalizing the urban extents.

Table 1. Definitions and examples of growth types and their controlling growth coefficients.

Step	**Growth Type**	**Controlling Growth Coefficient**	**Definition**
1	Spontaneous	Dispersion/ Slope/Exclusion	Non urban cells are given a probability of becoming urbanized.
Example			
2	Spreading Centers	Breed/Slope/Exclusion	Determines probability of become a spreading center.
Example			
3	Edge	Spread/Slope/Exclusion	Determines probability of spread from previous centers.
Example			
4	Road-influenced	Breed/Road Gravity/Dispersion/ Slope/Exclusion	Road influence defined by Breed. Radius defined by Road Gravity. Random walk defined by Dispersion. Adjacent cells are randomly urbanized.
Example			

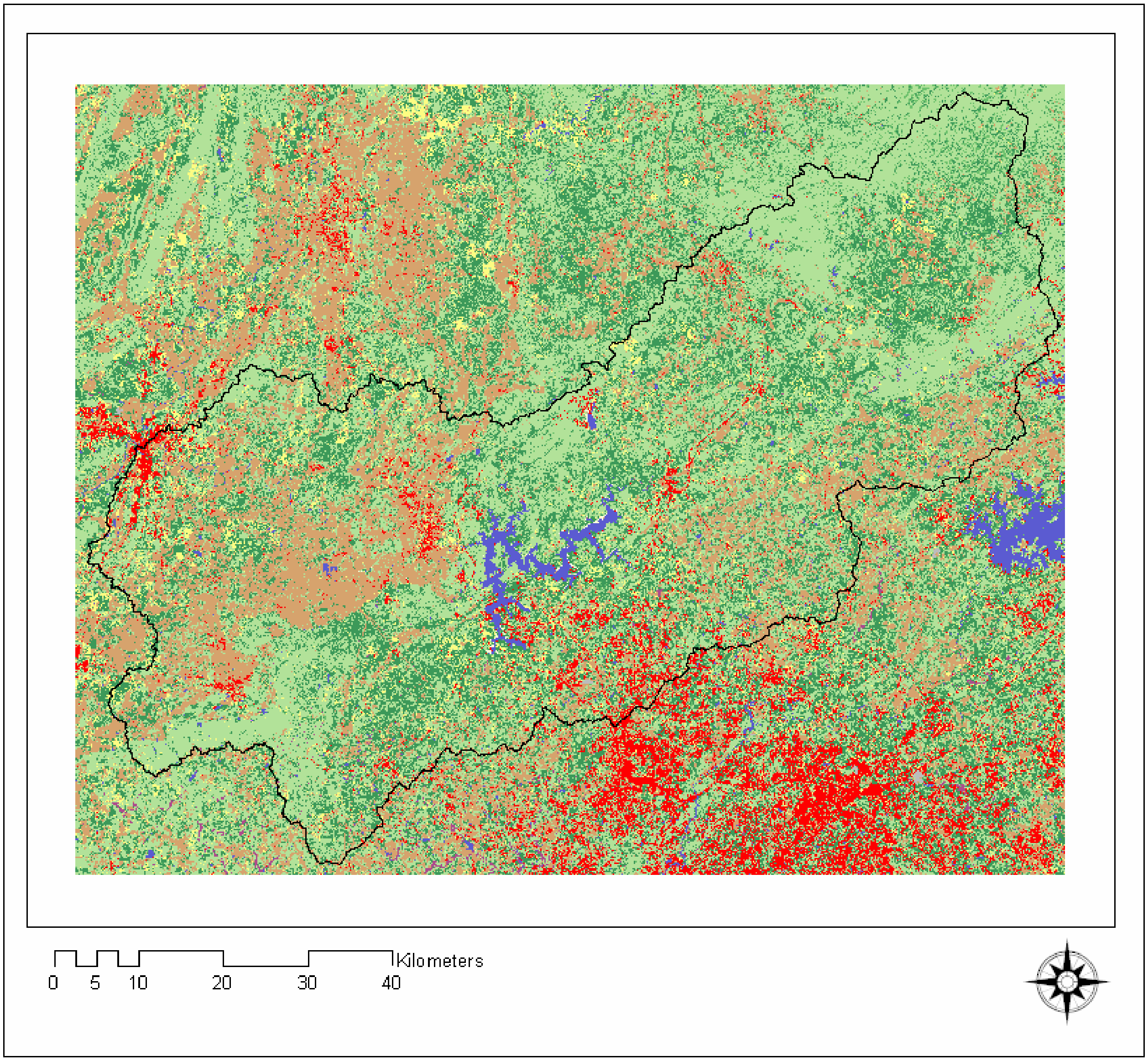


Figure 5. Etowah River watershed land cover, 1974. Watershed boundary is black, forest is green, water is blue, pasture is tan, urban and suburban areas are red.

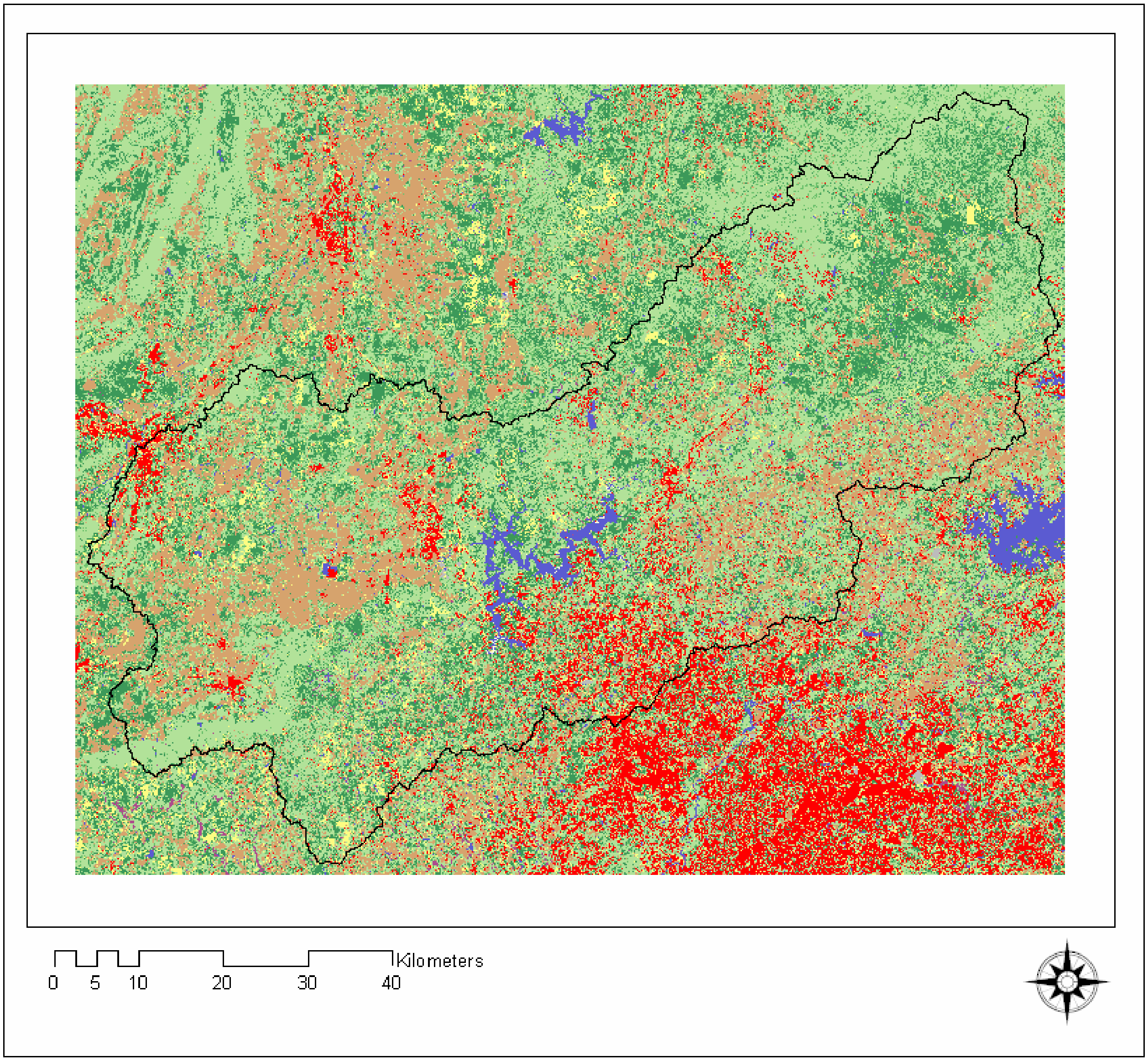


Figure 6. Etowah River watershed land cover, 1985. Watershed boundary is black, forest is green, water is blue, pasture is tan, urban and suburban areas are red.

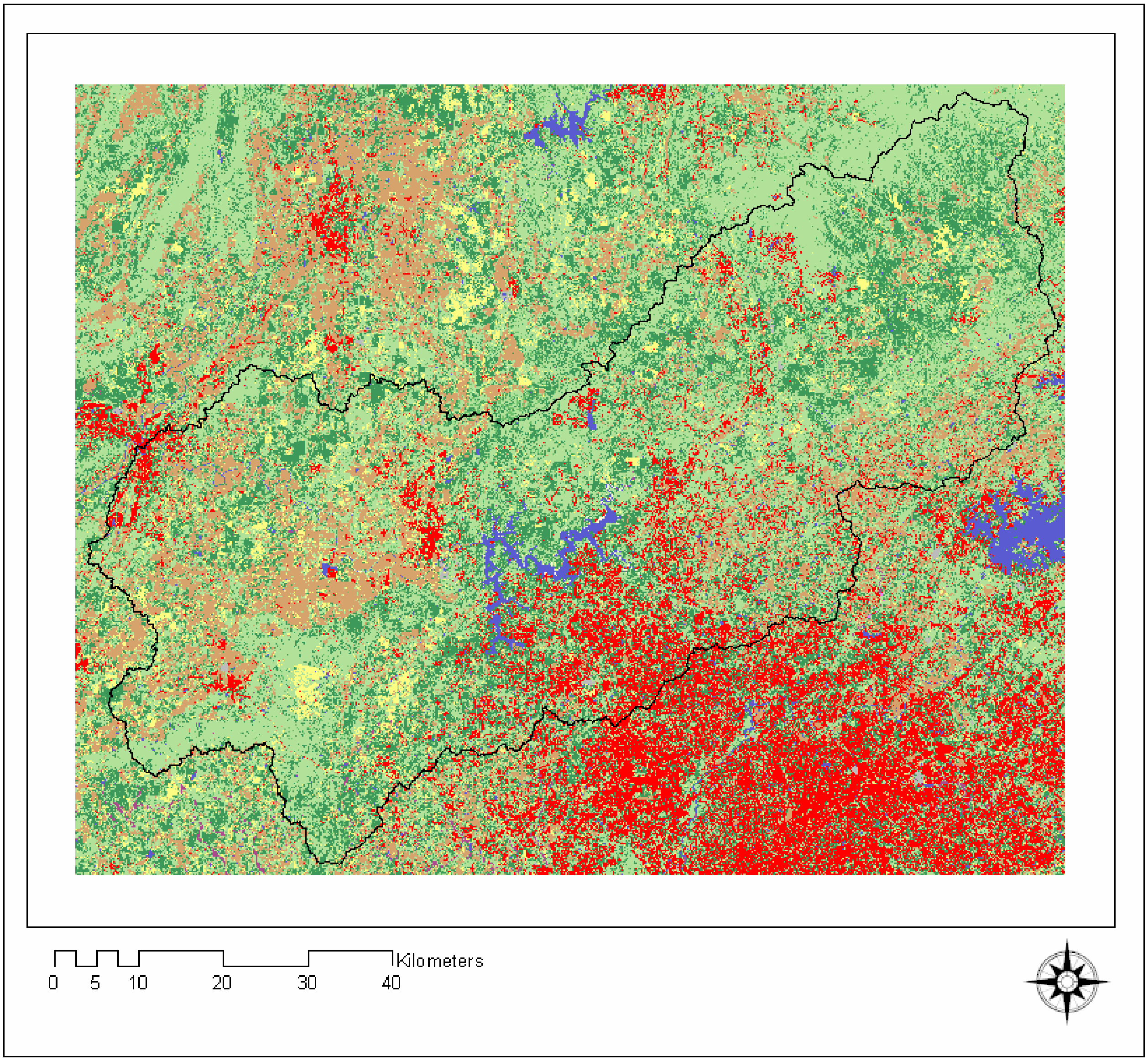


Figure 7. Etowah River watershed land cover, 1992. Watershed boundary is black, forest is green, water is blue, pasture is tan, urban and suburban areas are red.

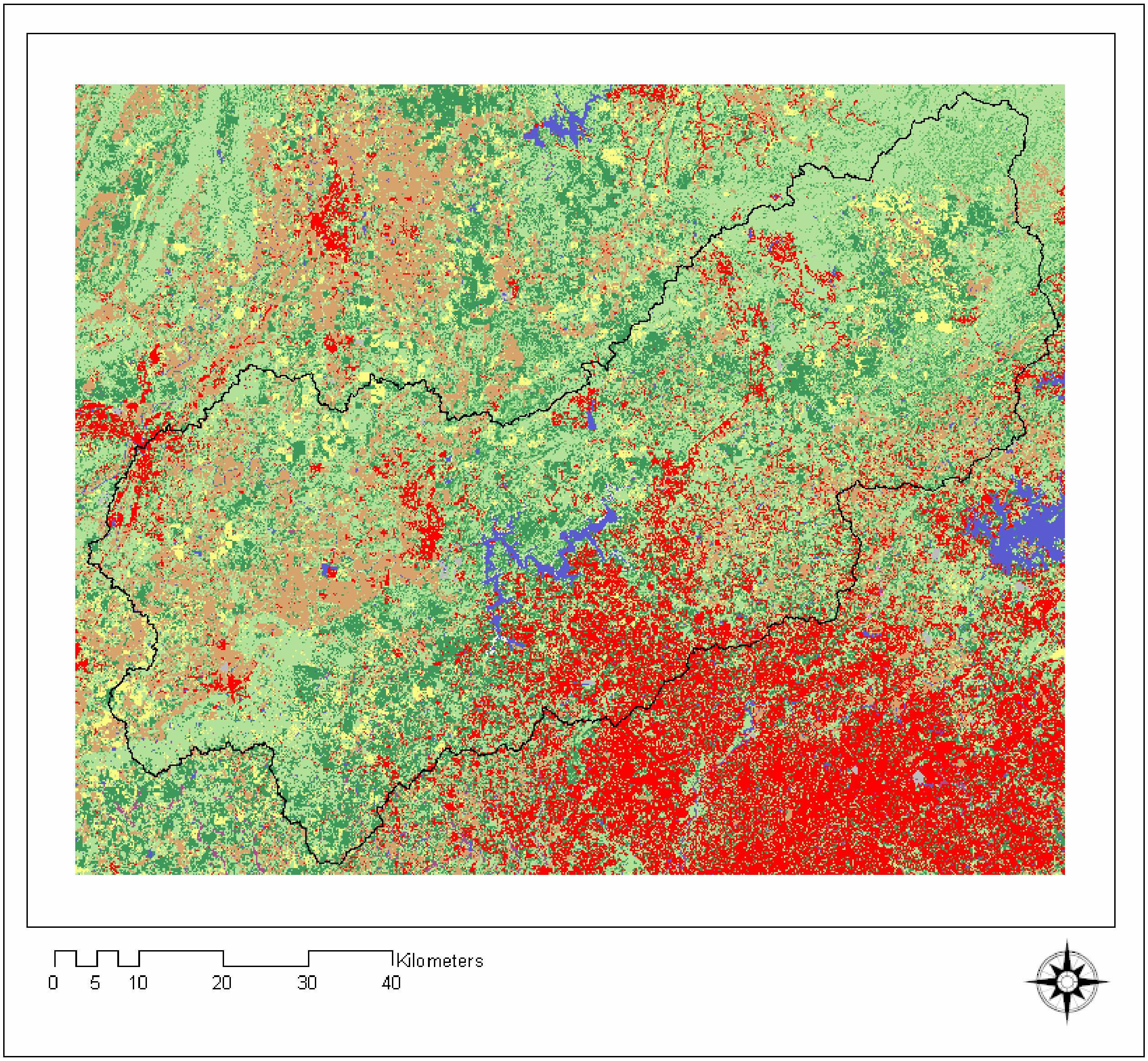


Figure 8. Etowah River watershed land cover, 1998. Watershed boundary is black, forest is green, water is blue, pasture is tan, urban and suburban areas are red.

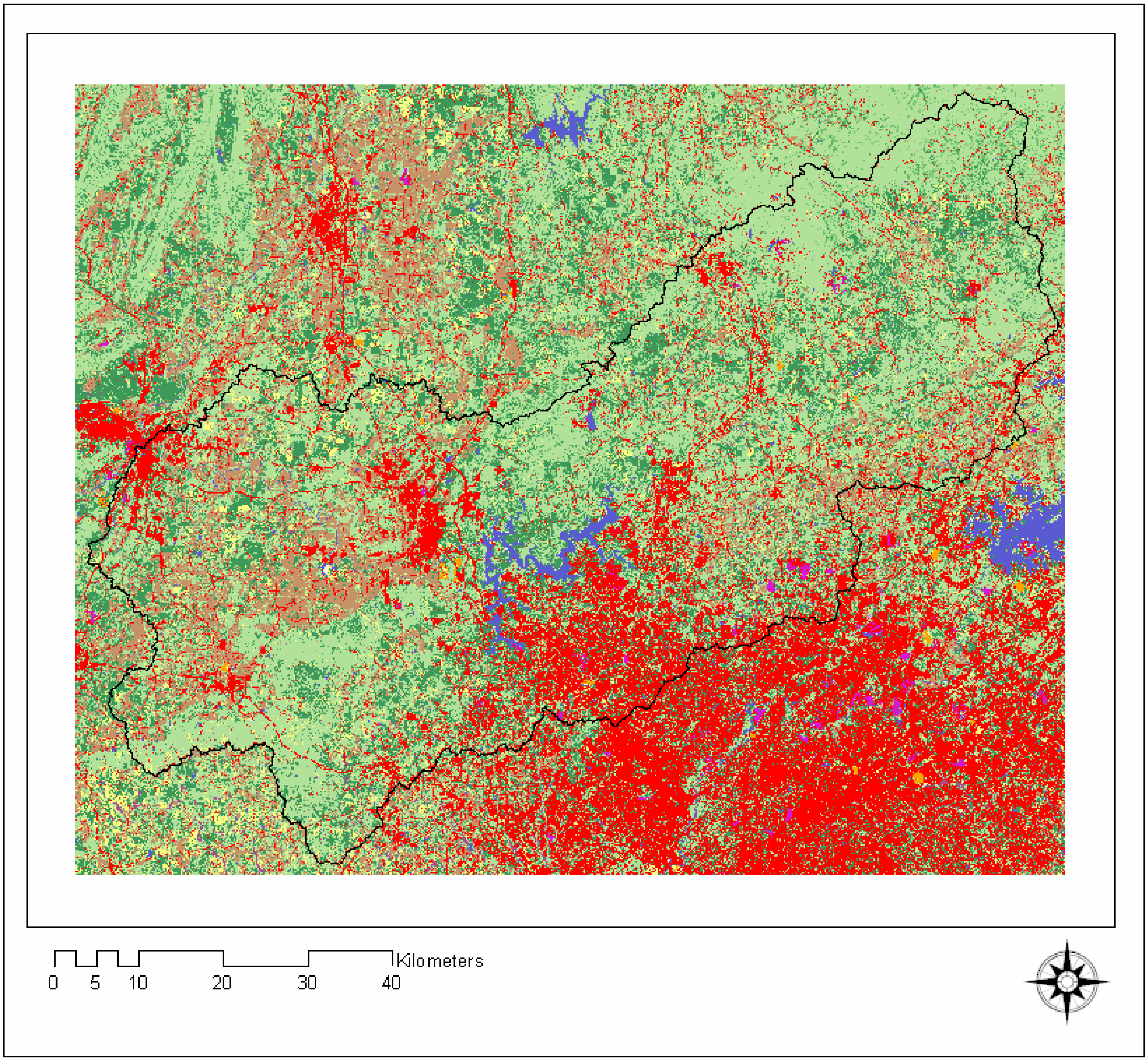


Figure 9. Etowah River watershed land cover, 2001. Watershed boundary is black, forest is green, water is blue, pasture is tan, urban and suburban areas are red.

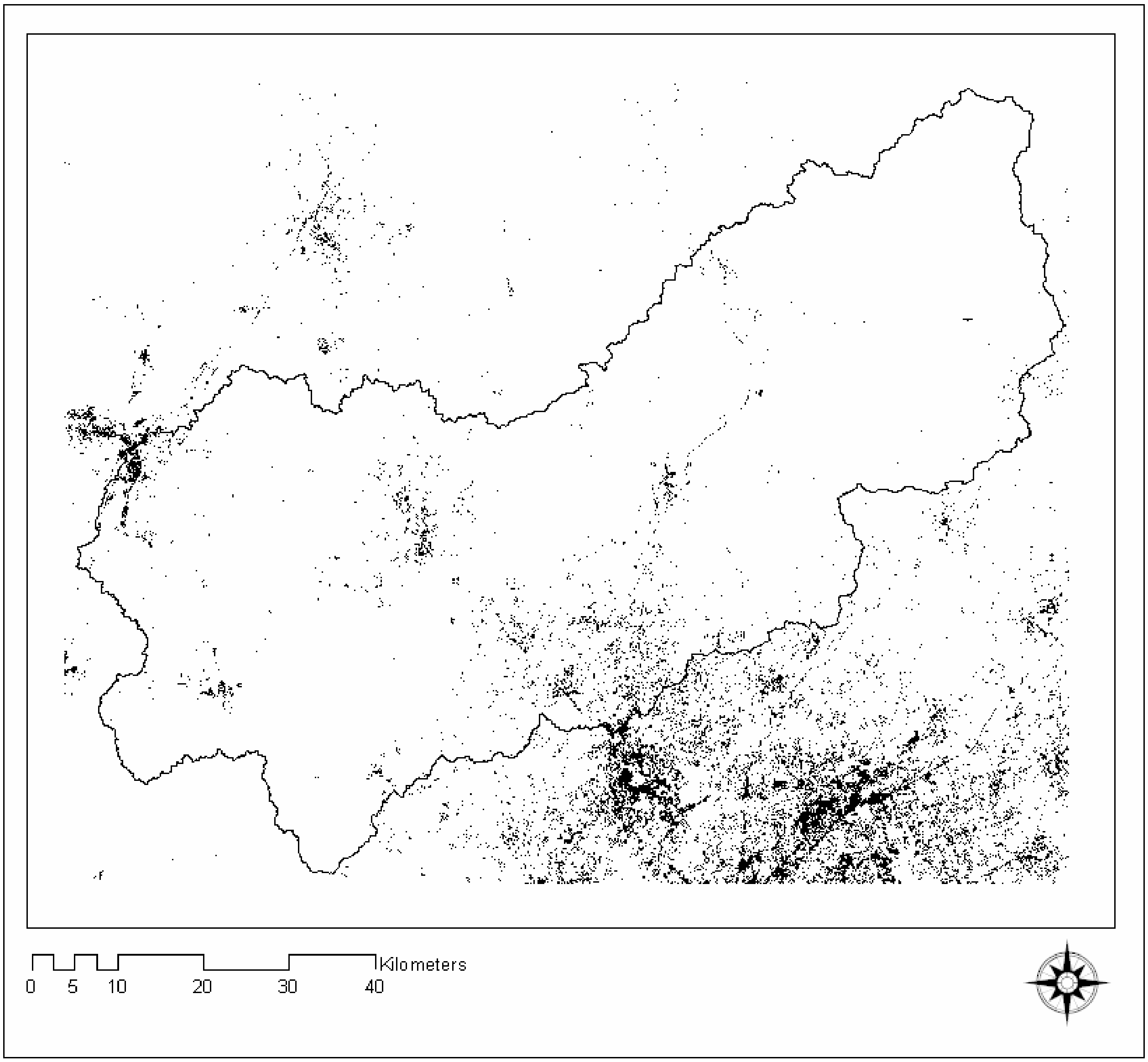


Figure 10. Etowah River watershed urban areas, 1974. Watershed boundary is black line, urban areas are solid black.

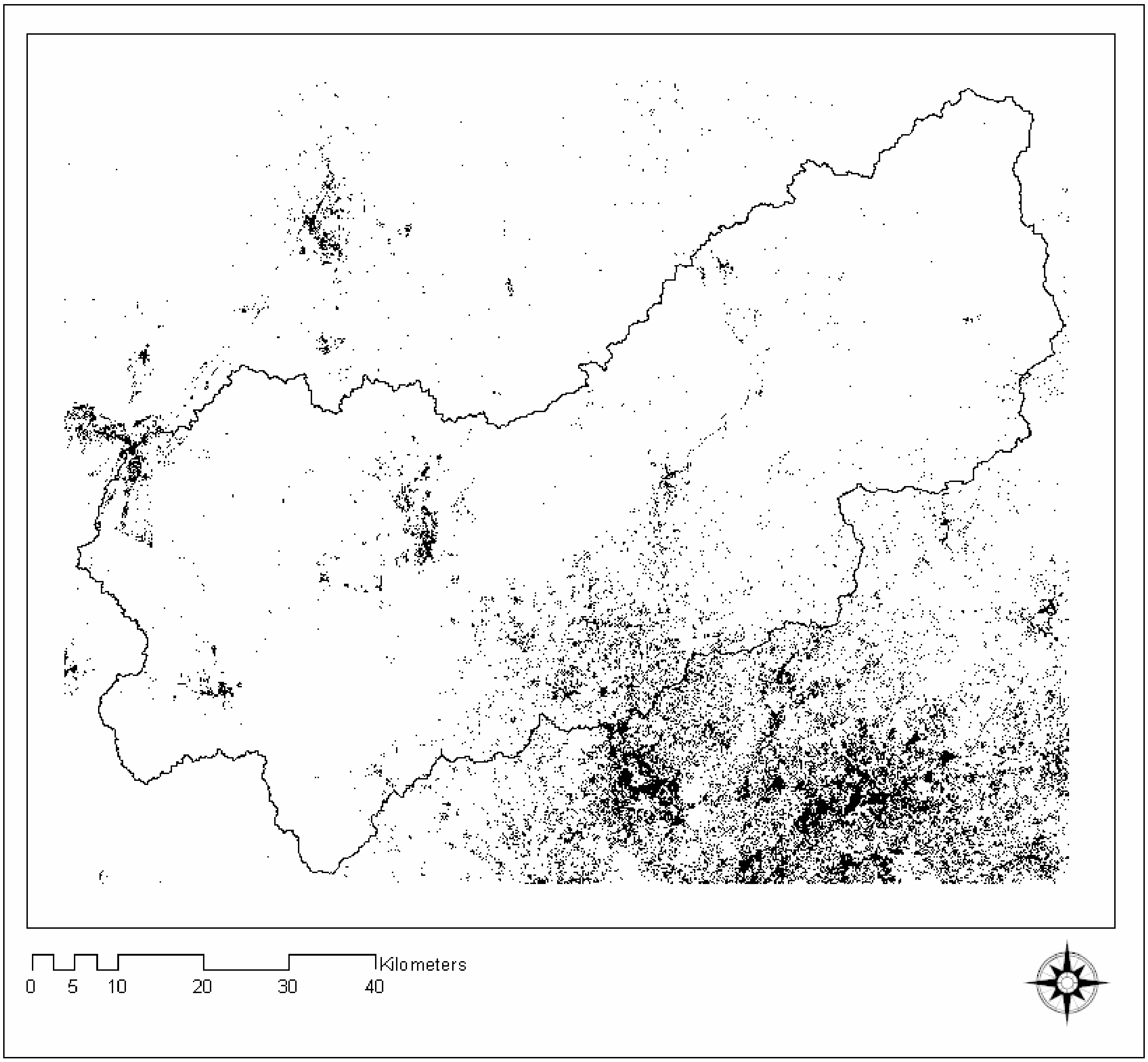


Figure 11. Etowah River watershed urban areas, 1985. Watershed boundary is black line, urban areas are solid black.

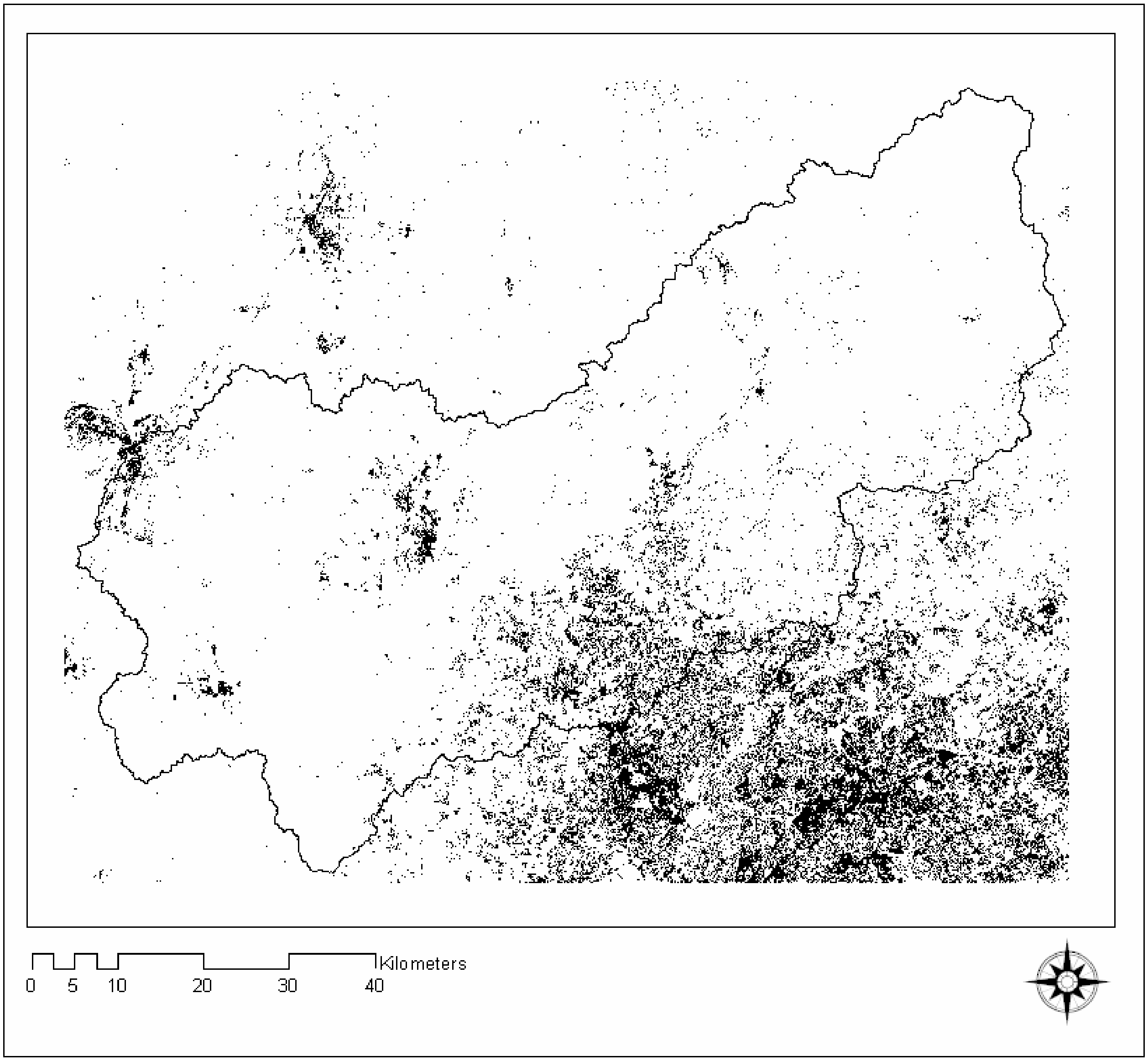


Figure 12. Etowah River watershed urban areas, 1992. Watershed boundary is black line, urban areas are solid black.

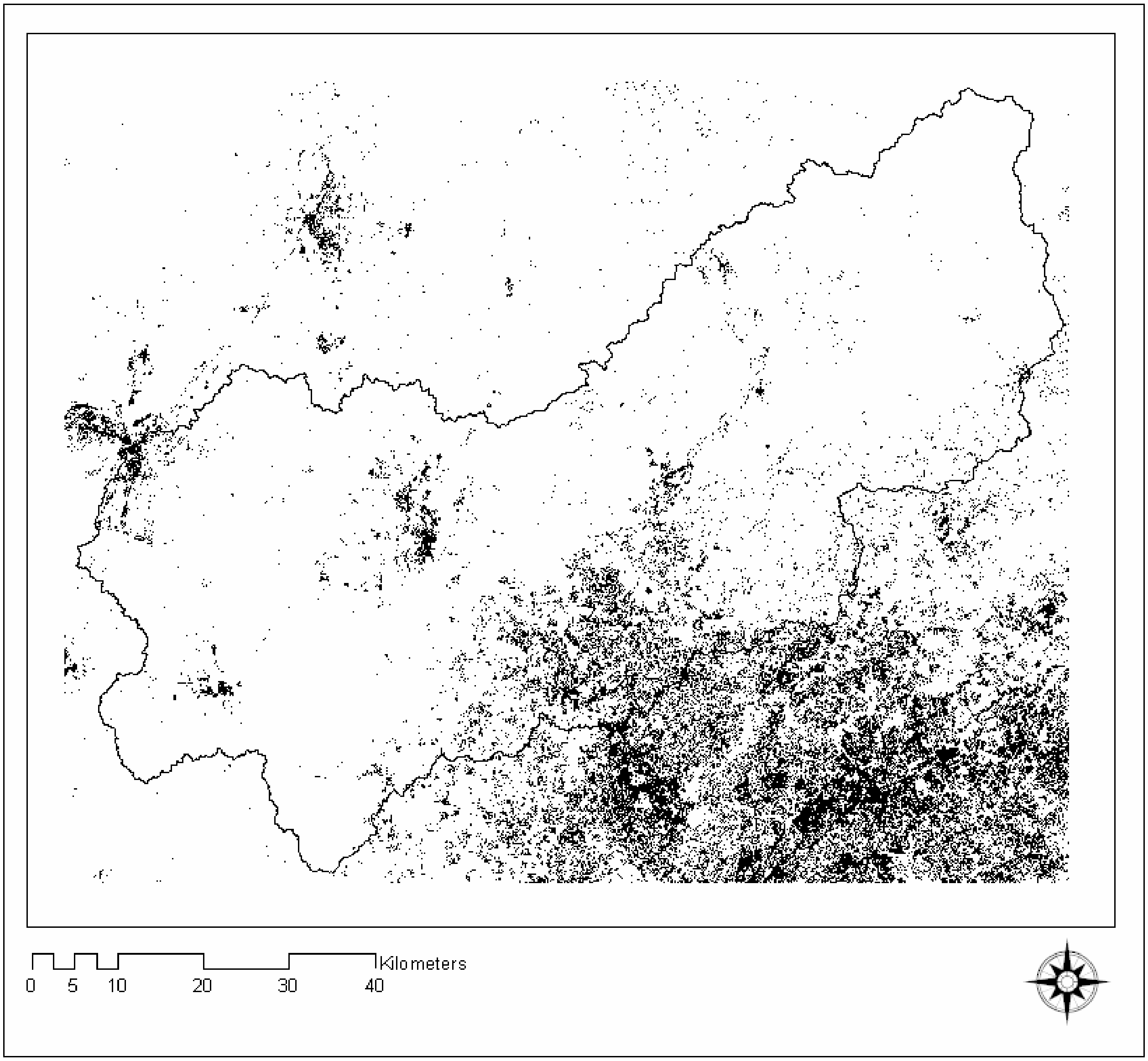


Figure 13. Etowah River watershed urban areas, 1998. Watershed boundary is black line, urban areas are solid black.

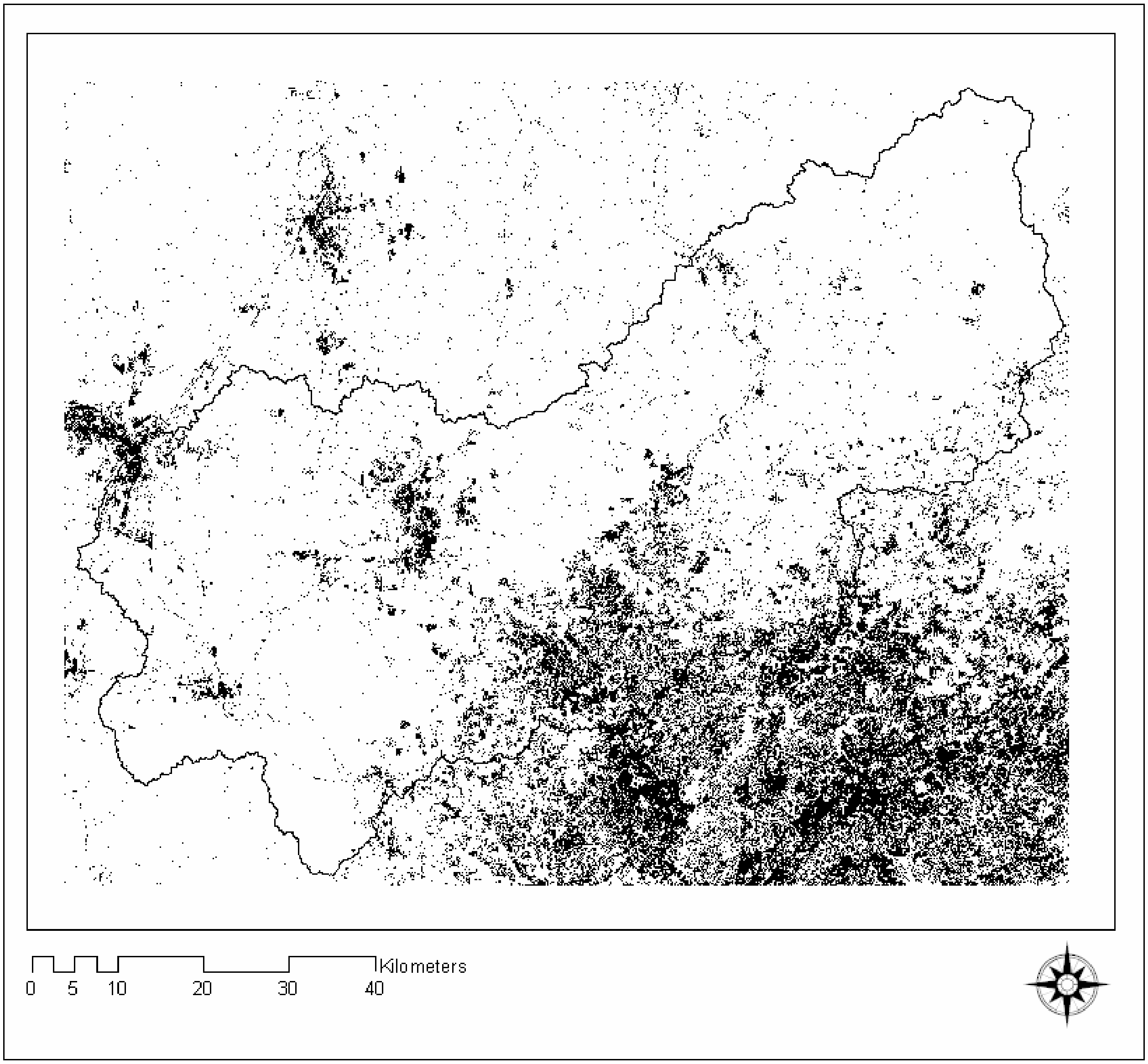


Figure 14. Etowah River watershed urban areas, 2001. Watershed boundary is black line, urban areas are solid black.

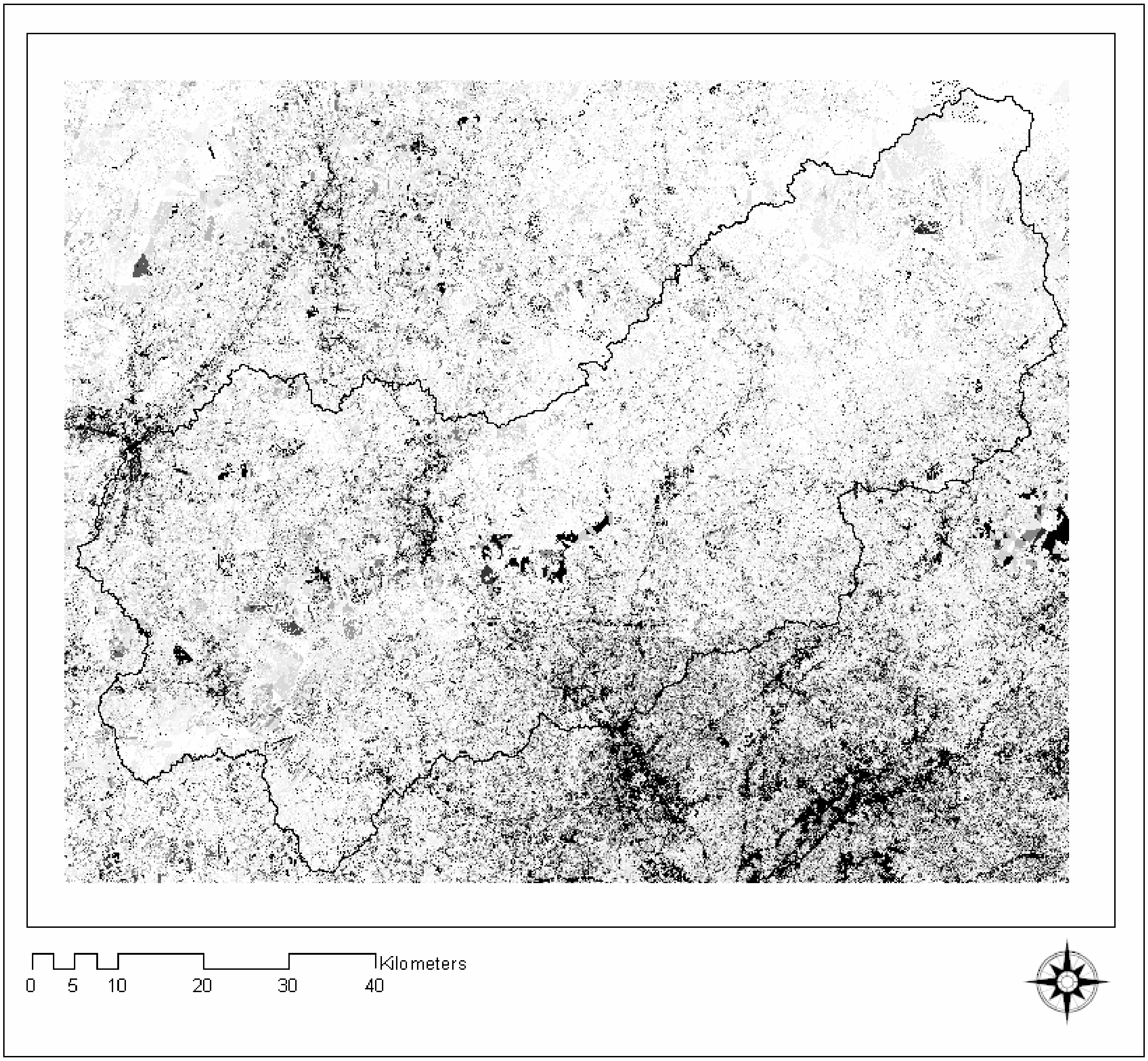


Figure 15. Impervious surface estimation for the Etowah watershed. Impervious surface values range from 1 (white) to 100 (black).

Figure 16. Impervious surface estimation near Cartersville, GA. Impervious surface values range from 1 (white) to 100 (black).

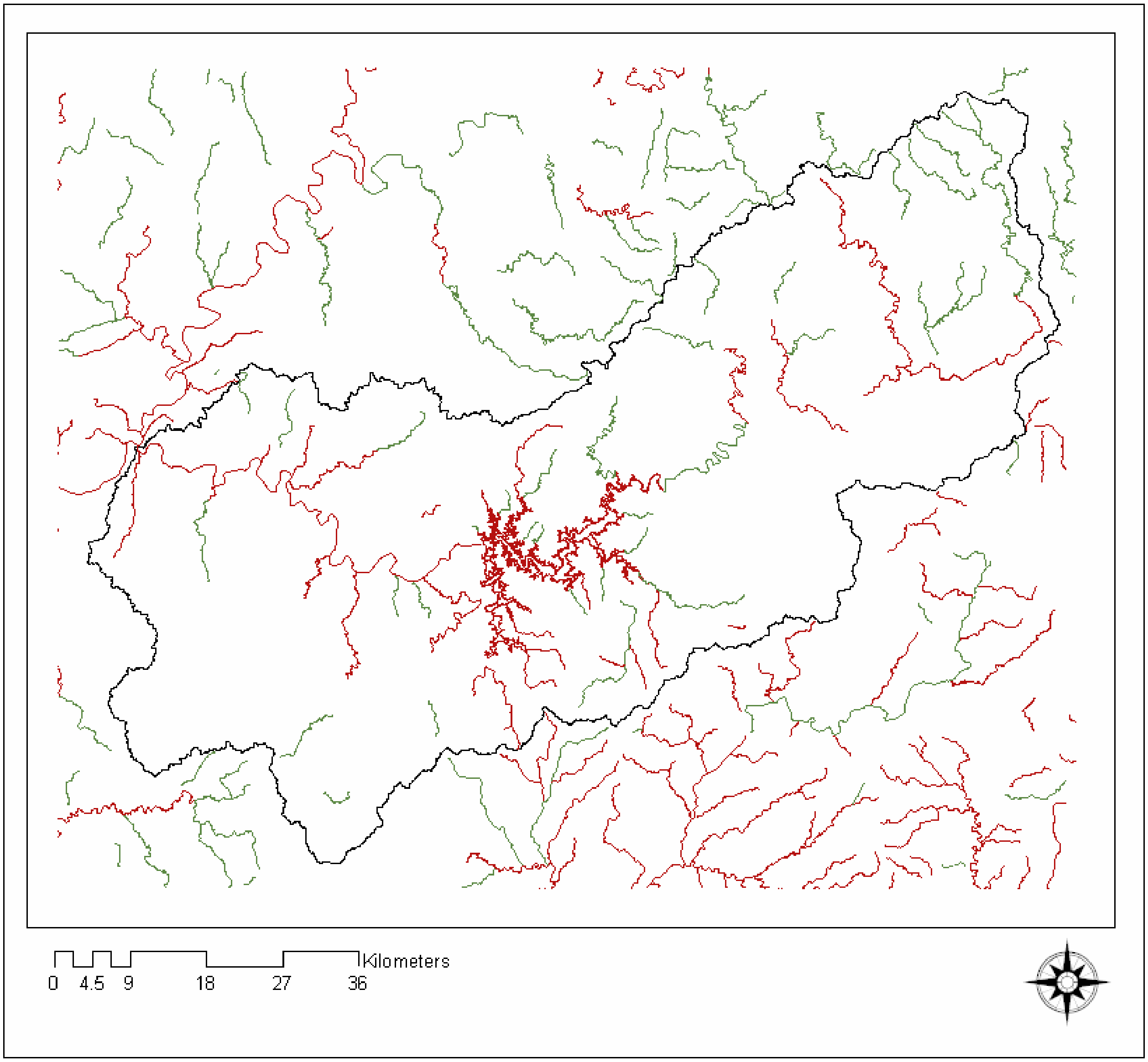


Figure 17. 303d Impaired Waters for the Etowah River and surrounding areas, 2002. The Etowah River watershed boundary is the black line. Impaired streams are red, non-impaired streams are green.

Table 2. Statistics collected in comparison of the Monte-Carlo simulations and the historical datasets.

SLEUTH Statistic	**Definition**
Product:	the product of all the statistics
Compare:	the modeled count of urban pixels for the final year divided by the actual count of pixels for the final year
Pop:	the least squares regression statistic for the modeled urbanization compared to the actual urbanization for the control (GLUT) years
Edges:	the least squares regression statistic for the modeled urban edge count compared to the actual urban edge count for the control years
Cluster:	least squares regression statistic for the modeled urban clusters compared to the known urban clusters for the control years
Cluster size:	least squares regression statistic for modeled average urban cluster size compared to known average urban cluster size for the control years
Leesalee:	the measurement of the spatial fit between the model's growth and the known urban extent for the control years
Slope:	the least squares regression of the average slope for the modeled urbanized cells compared to the average slope of known urban cells for the control years
Percent Urban:	the least squares regression of the percent of available pixels urbanized compared to the urbanized pixels for the control years
X mean:	the least squares regression of the average x coordinate values for modeled urbanized cells compared to the average x coordinate values of the known urban cells for the control years
Y mean:	the least squares regression of the average y coordinate values for modeled urbanized cells compared to the average y coordinate values of the known urban cells for the control years
Rad:	the least squares regression of the average radius of the circle which encloses the urban pixels

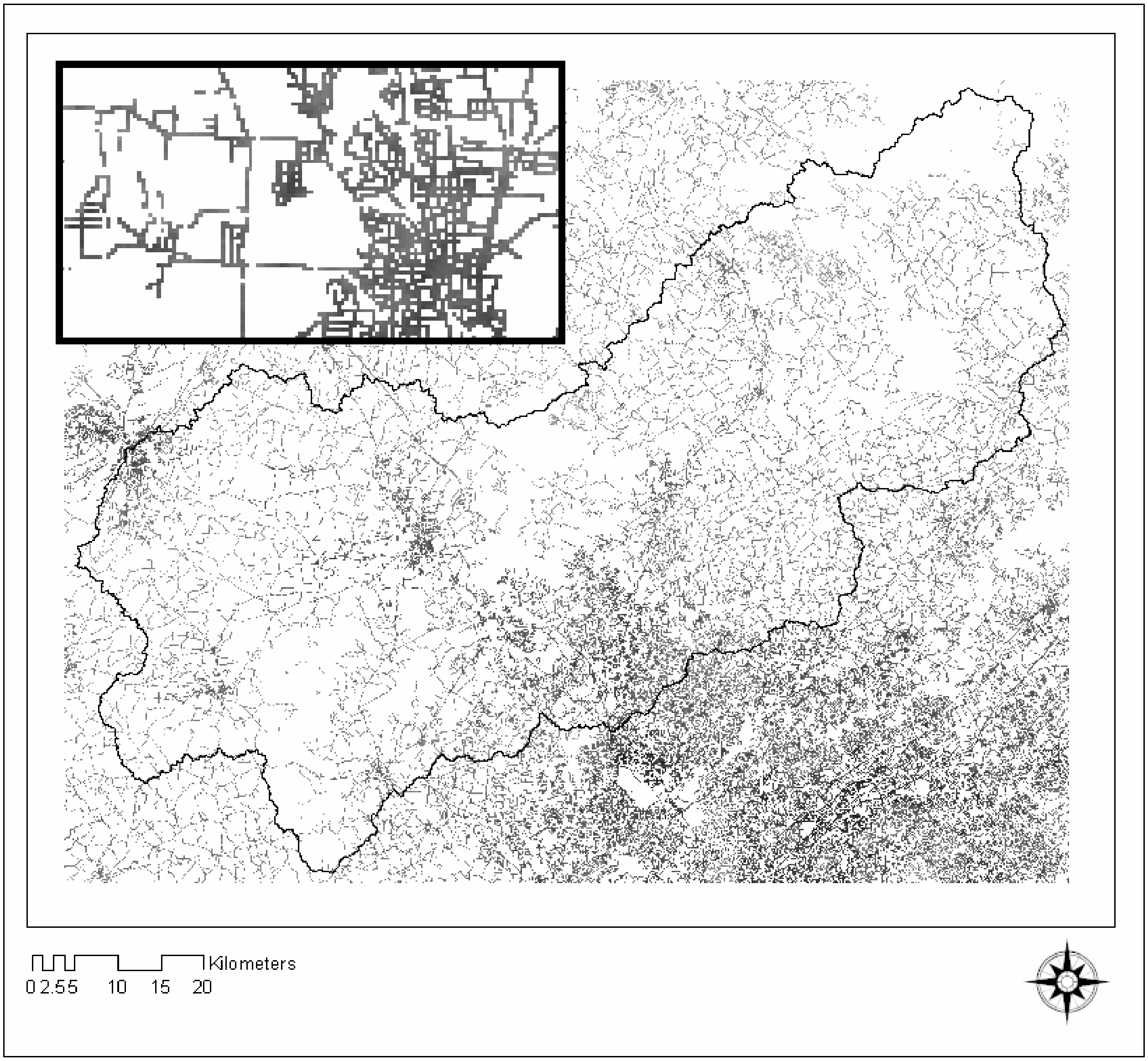


Figure 18. Density weighted roads, 2002. Roads are weighted zero (white) to 100 (black). Inset near Cartersville, GA.

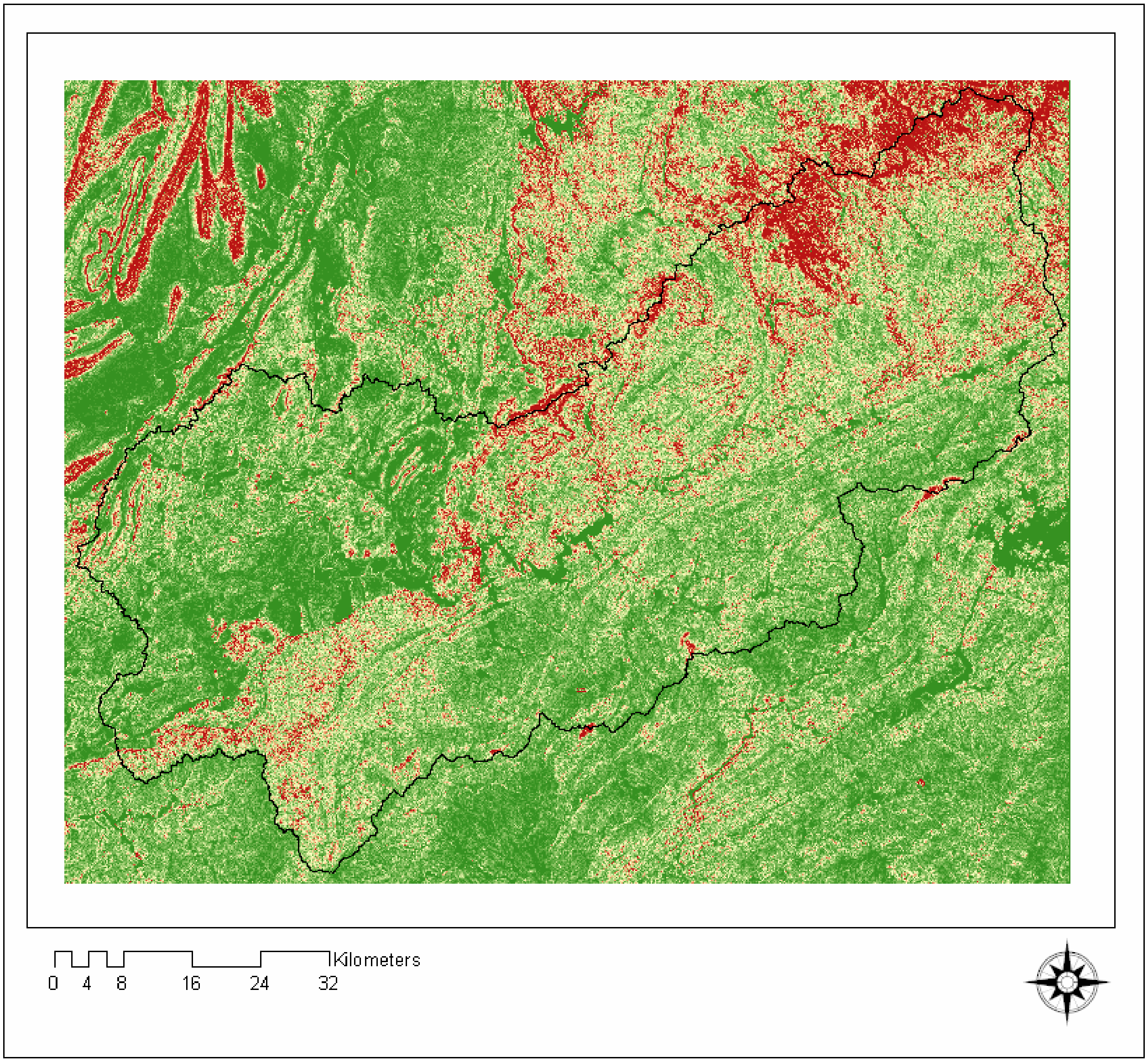


Figure 19. Study area percent slope. Slopes range from zero (green) to 100 (red). Watershed boundary outlined in black.

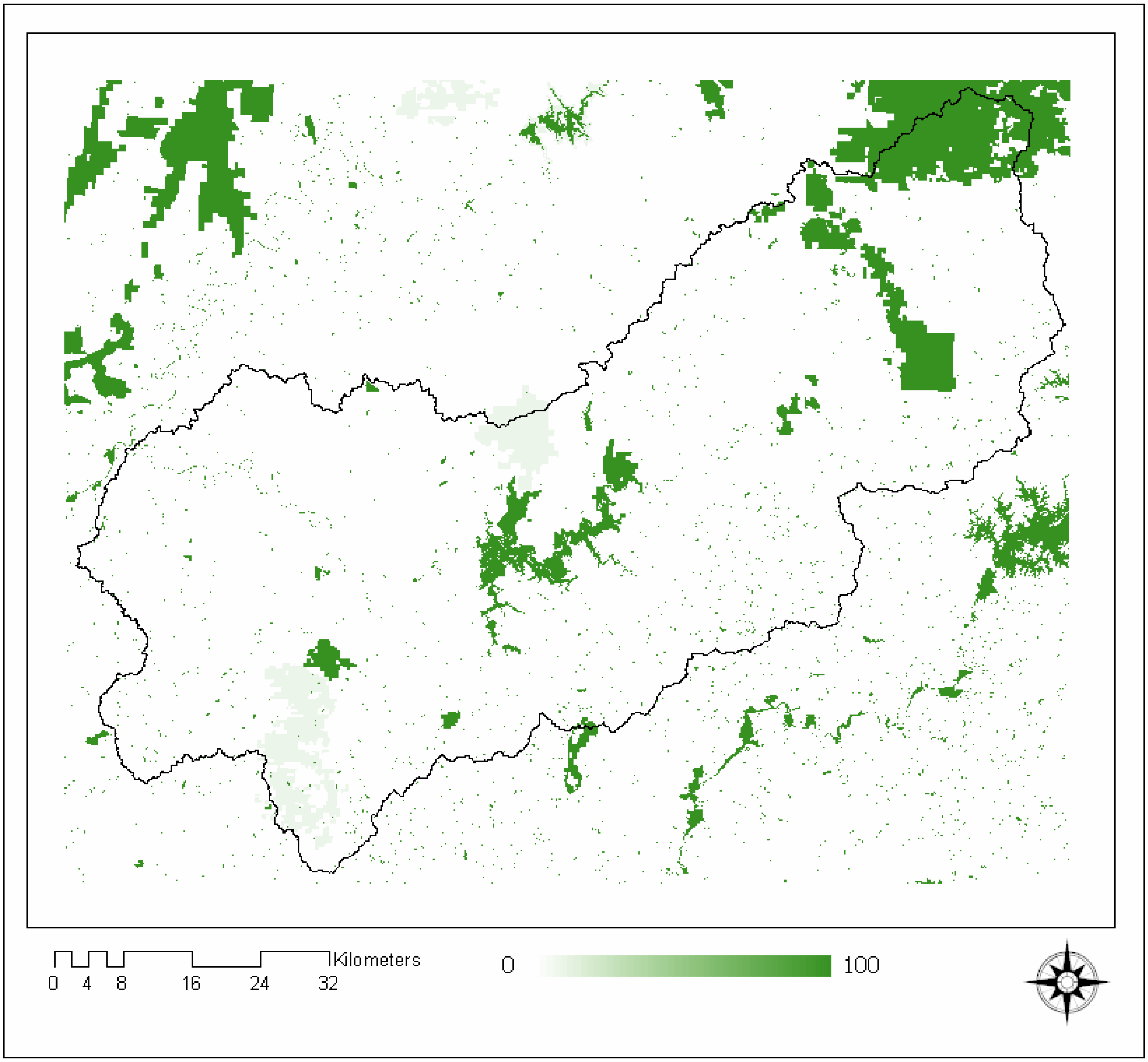


Figure 20. Current Trends Build-out Scenario exclusion layer. The values range from zero (white) to 100 (green).

Table 3. Alternative Scenario I future land use ranking.

Class	Probability of Exclusion
Park/recreation/conservation:	100%
Water:	100%
Agriculture/forestry:	75%
Commercial:	0%
Industrial:	0%
Municipal:	0%
Public/institutional:	0%
Residential:	0%
Transportation/communication:	0%
Undeveloped:	0%
Unknown:	0%

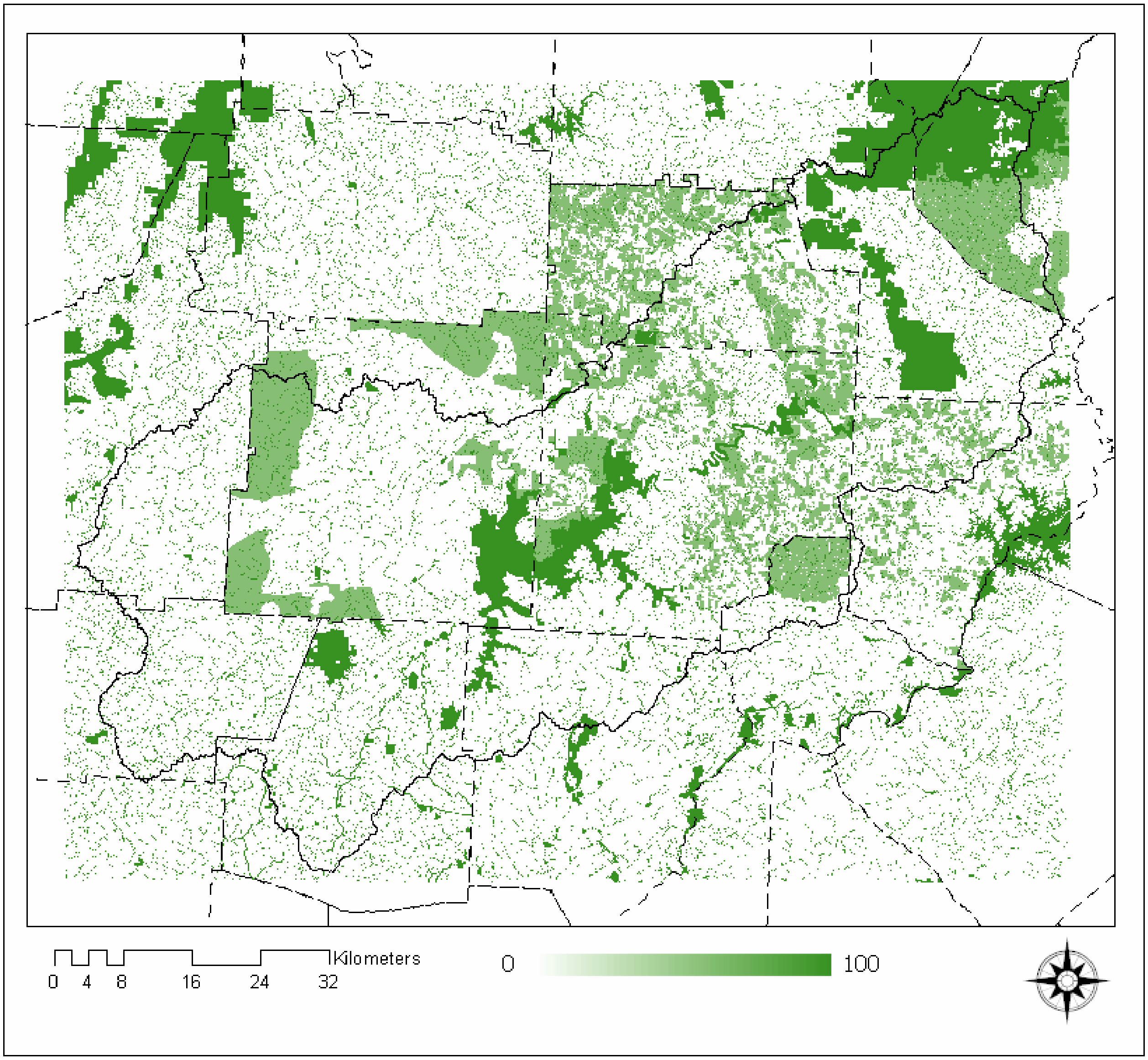


Figure 21. Alternative Scenario I exclusion layer. The values range from zero (white) to 100 (green).

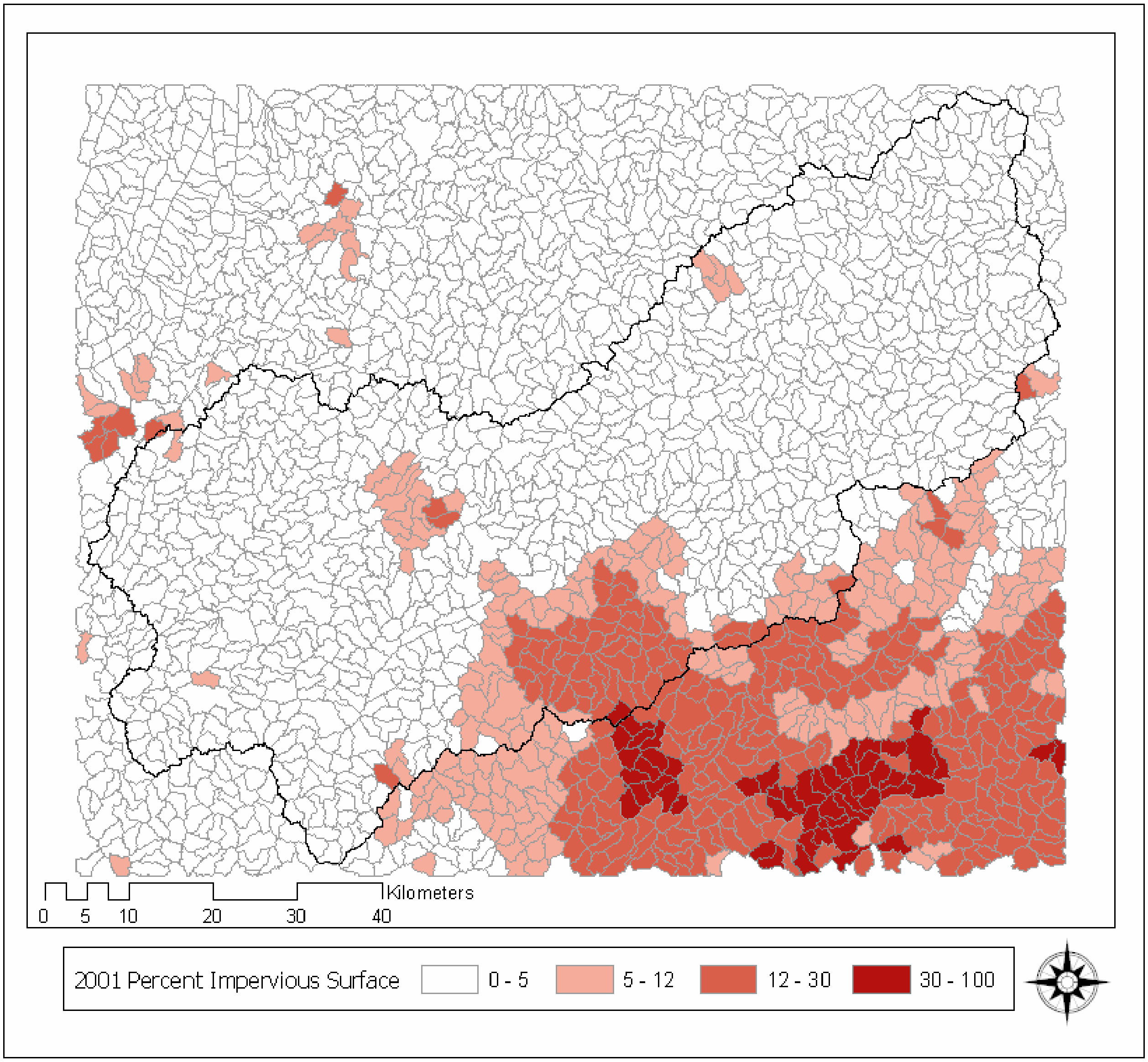


Figure 22. Percent contributing impervious surface for 5k^2 sub-watersheds, 2001. The Etowah watershed boundary is in black.

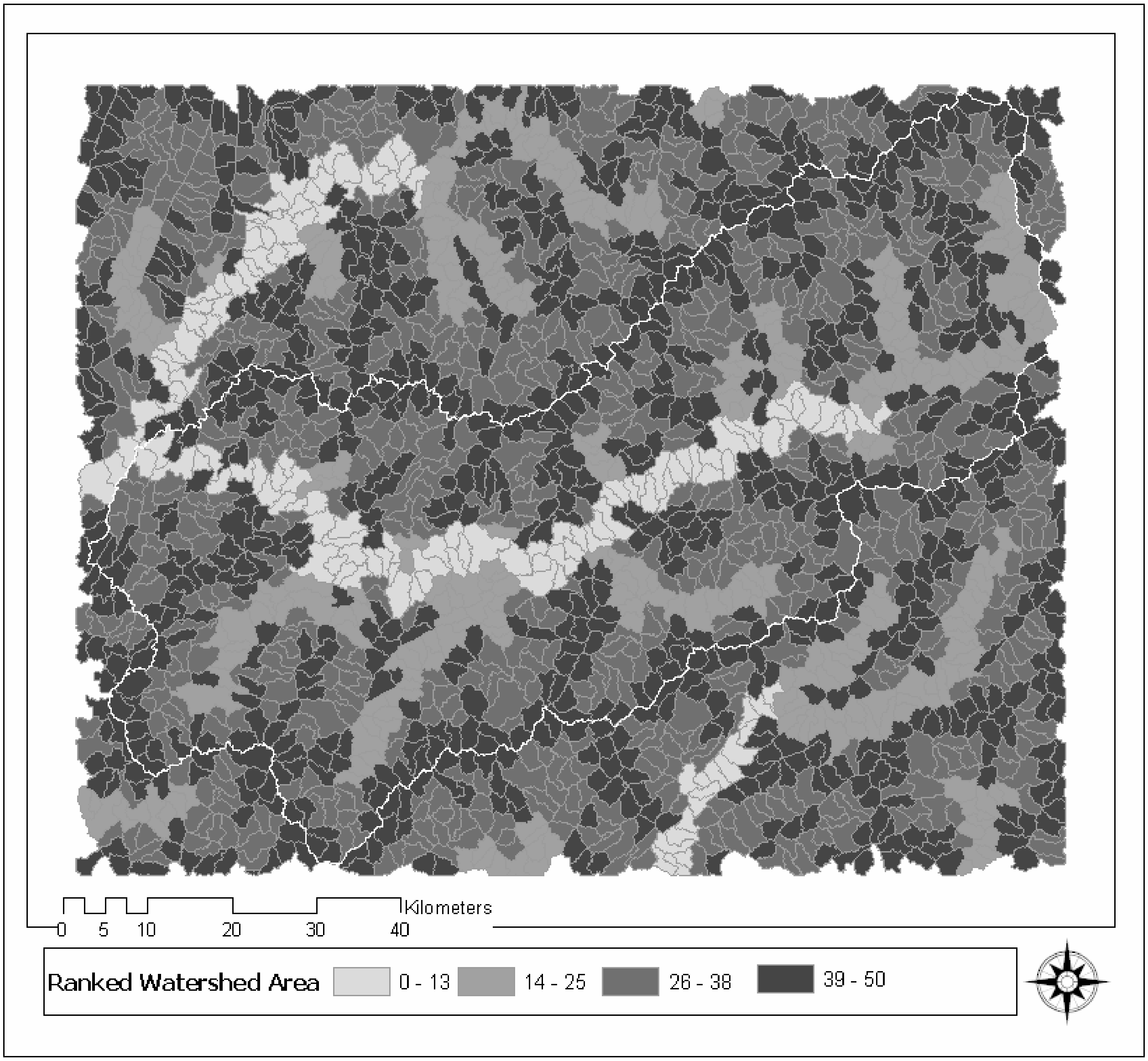


Figure 23. Alternative Scenario II ranked contributing watershed area for 5k^2 sub-watersheds. The Etowah watershed boundary is in white.

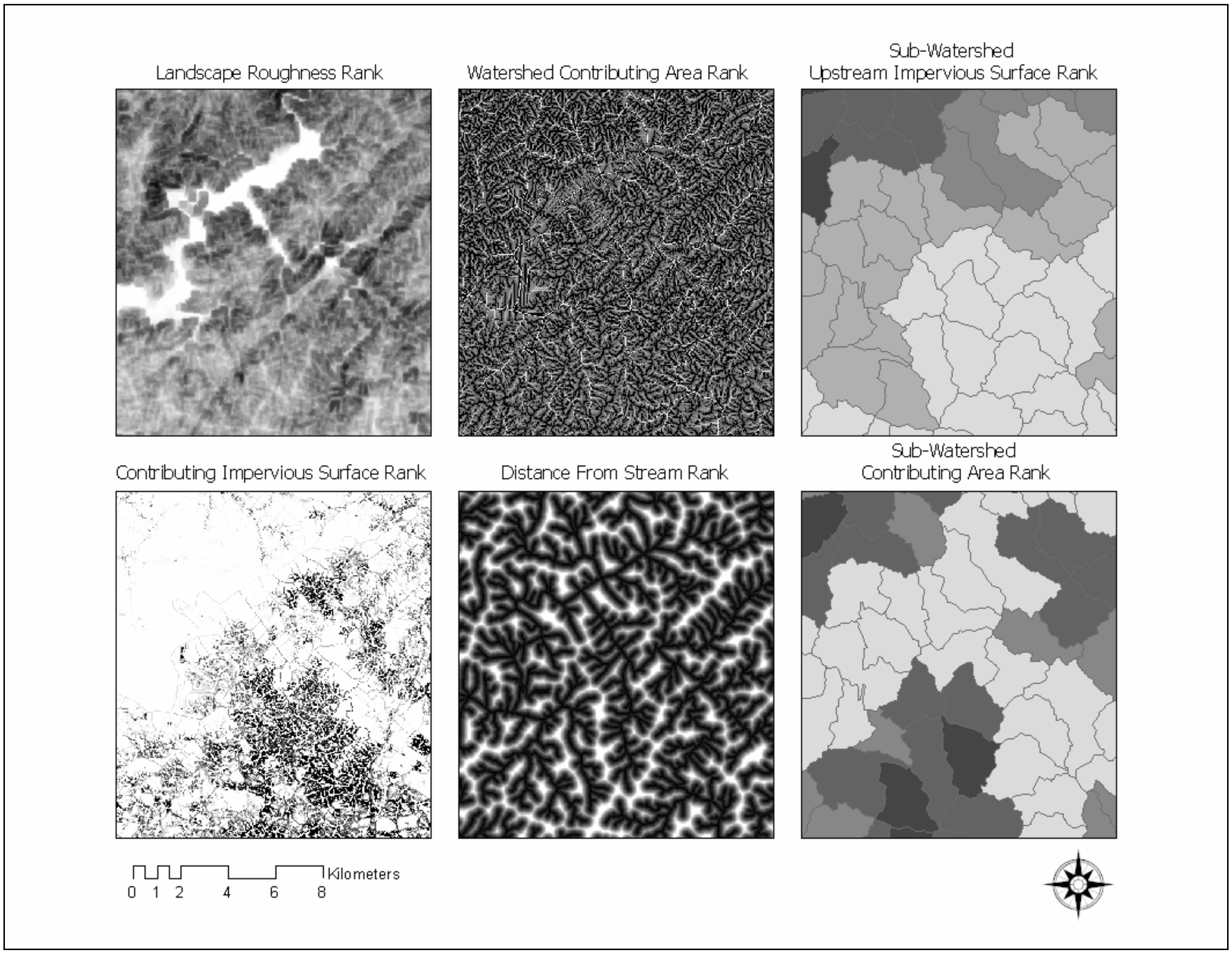


Figure 24. Six criteria for establishing probability of exclusion for Alternative Scenario II, near Lake Allatoona. Values range from zero to 50 for contributing area ranks (white to black) and zero to 100 for all others (white to black).

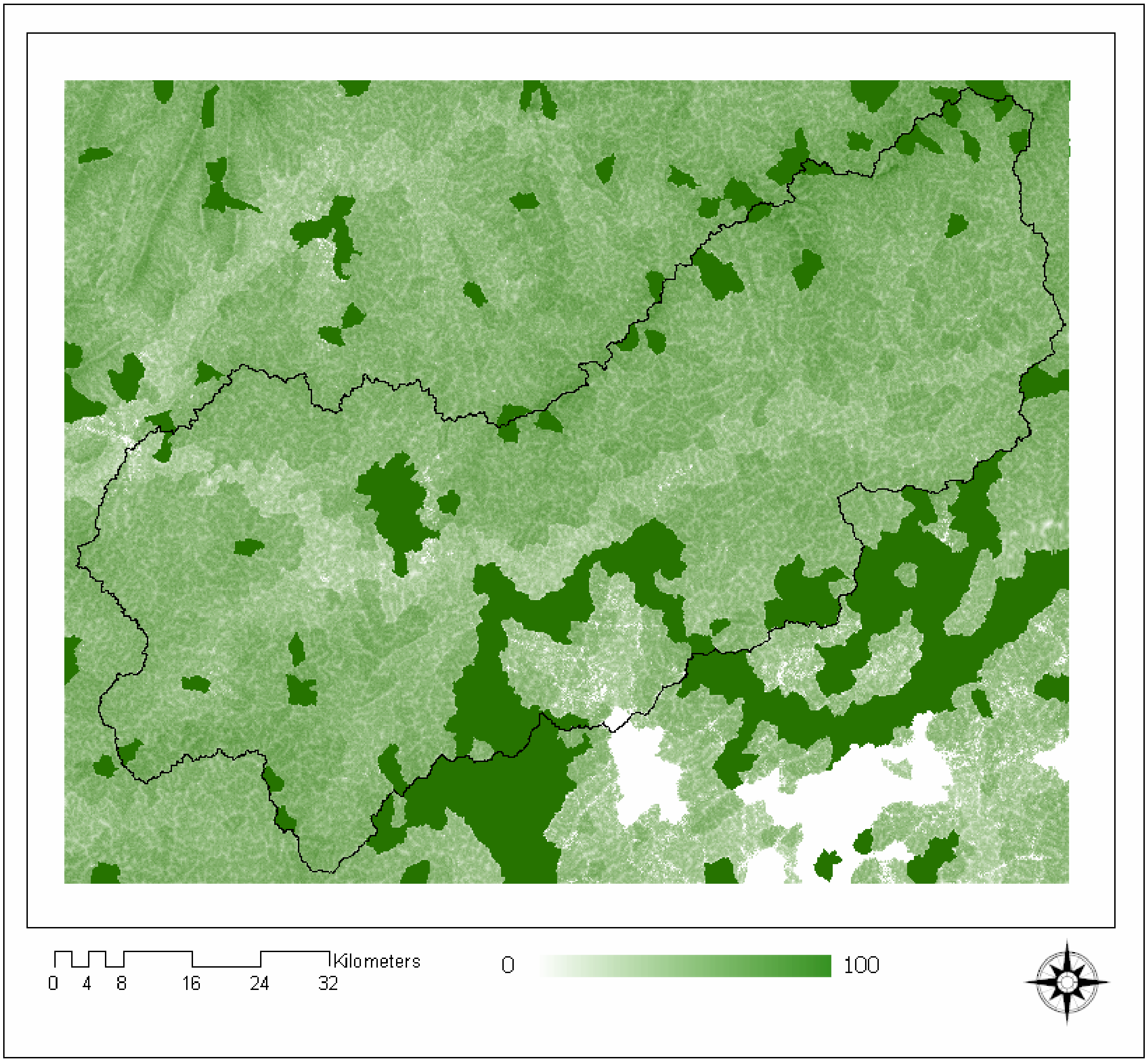


Figure 25. Initial probability of exclusion for Alternative Scenario II excluding existing urban areas, conservation lands, stream buffers, and water. Values range from zero to 100 (white to green).

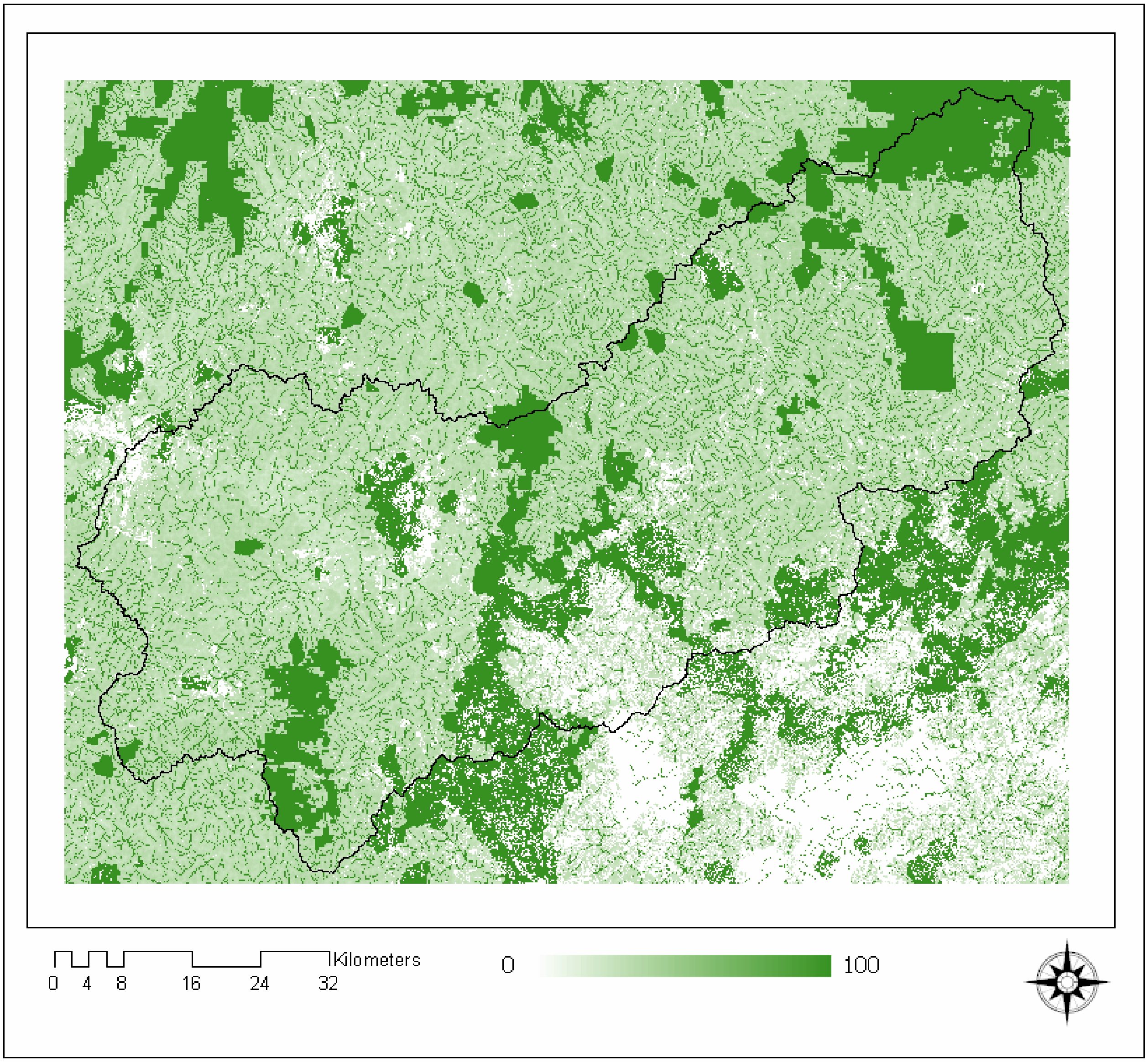


Figure 26. Final probability of exclusion for Alternative Scenario II. Values range from zero to 100 (white to green).

CHAPTER 4

RESULTS

Introduction

Images of the results of the urbanization scenario predictions are presented graphically followed by the results of an accuracy assessment of the predicted impervious surface from 1992 to 2001. Next, the results of the determined stream impairment threshold as well as the hydrologic effects are presented and comparisons are graphically presented for selected stream sites from 1974 through 2050.

Final Urbanization Predictions

The results of the three future urban scenarios are presented in figures at the end of this section along with images representing the actual past urbanized areas from 1974 through 2001 (Figures 27-37). These images depict the predicted future state of the entire Etowah watershed study area for 2025 and 2050. The watershed boundary is represented in black and urbanization is depicted with a gradient of white to black with white consisting of no impervious surfaces and black 100 percent impervious surface.

Visually, most of the growth that has occurred in the past and is modeled in each scenario appears to be edge growth. All of the future scenarios appear to follow the established rules of the model and provide adequate results to perform the stream and hydrologic analysis.

Predicted Impervious Surface Accuracy

An accuracy assessment of the predicted impervious surface was conducted using an independent impervious surface dataset from 1992 (GLUT). The methods described previously were used to estimate the impervious surface for the 2001 urban extent with the 1992 dataset. The 2001 impervious estimates were then compared to the actual 2001 impervious surface dataset at 1,000 sample locations, each representing a 30 by 30 meter pixel, to determine the overall accuracy of the prediction. The accuracy assessment for the impervious surface prediction is summarized with the scatter plot in Figure 38. The overall correlation coefficient for the comparison was 0.71.

The scatter plot shows little confusion and overall agreement between the predicted and actual impervious surface. The figure shows that the prediction generally underestimated the actual impervious surface values for any given pixel. This is due to the nearest neighbor method used to create the prediction as well as the nature of the impervious surface dataset. Typically higher densities of impervious surface occur towards the center of developments, thus new pixels of development are assigned the value of their nearest neighbor, which is generally a lower density edge pixel.

The results of this comparison can then be applied to the impervious estimates derived from the 2001 impervious surface dataset. It can be implied from these results that the predicted impervious surface values for future development will generally be underestimated and likely will be dramatically under predicted the further into the future the estimation is applied.

Comparison of Future Scenarios

The results for the Current Trends Scenario are shown in Figure 32 and Figure 33. This scenario illustrates the results of continued urban build-out at the current rate of growth. For the entire study area (approximately 1,102,433 hectares), the total urban area in 2001 was 148,649 hectares (13%), which is predicted to grow to approximately 359,180 hectares (33%) in 2025 and

882,637 hectares (80%) in 2050, if current trends continue. Total impervious surface for the area increased from 4.3 percent in 2001 to 6.7 percent in 2025 and 10 percent in 2050.

The results for Alternative Scenario I are shown in Figure 34 and Figure 35. This scenario accounts for the future land use of the counties within the study area. Under this scenario, the total urban area grows to approximately 339,083 hectares, or 31 percent of the total study area by 2025. By 2050, the urban area is expected to encompass 713,039 hectares, or 65 percent of the total area. The total impervious surface for the area follows the same trends as above, consisting of 6.4 percent in 2025 and 9 percent impervious surface in 2050.

The most conservative scenario, Alternative Scenario II, which has six restrictions on overall general growth, severely limited new urban growth and increases in impervious surface. These results are presented in Figures 36 and 37. The total urban area grew to 287,270 hectares (26%) in 2025 from 148,649 hectares in 2001. By 2050, the total amount of urban area increased to 354,773 hectares (32%). A similar trend is demonstrated with the total amount of impervious surface. The impervious totals are calculated at 5.8 percent and 6.4 percent in 2025 and 2050 respectively.

Impairment Threshold Comparison

In order to establish a stream impairment threshold for the Etowah watershed and surrounding areas, a logistic regression was performed with the 303d impaired streams data. To complete the logistic regression, more than 2,500 sites were randomly sampled across the Etowah study area (Figure 39). At each of the sites, the dependent variable was determined to be impaired or non-impaired as stated above. The independent variable is the percentage of impervious surface calculated for each drainage area corresponding to the randomly selected sites.

The results of the logistic regression demonstrate that a threshold of 10 percent impervious surface yields a 63.3 percent probability of impairment within the sampled area (Figure 40). The probability of stream impairment based on percent contributing impervious surface is summarized in Figure 40 and is determined as follows;

$$\mu = \frac{\exp(-1.398 + 0.194x)}{1 + \exp(-1.398 + 0.194x)} \qquad (7)$$

Where x is the percent contributing impervious surface and μ is the resulting probability of impairment. With the 10 percent statistic, we can comfortably assert that at this impervious surface threshold, a stream is likely impaired. As the extent of stream impairment in the past is generally unknown and the effects of new impervious surface are unknown, an analysis was performed to calculate actual total length of stream impairment for the past and future scenarios.

Once the threshold for impervious surface and stream impairment was verified for the Etowah watershed, the past five (GLUT) and three future scenarios were analyzed to determine the actual percentage and total length of stream impairment in the watershed (Figure 41). In 2002, the Georgia EPD designated approximately 1,275 km (406 km in the watershed proper) of stream in the Etowah study area as not supporting or partially supporting the designated use (impaired). The estimated length of streams, based on the 10 percent impervious threshold, that was impaired in 1974, 1985, 1992, 1998, and 2001 was 491 km (33 km proper), 885 km (73 km), 1,447 km (207 km), 1,746 km (282 km), and 1,886 km (323 km) respectively. This is a 284 percent increase of impaired stream length from 1974 to 2001 while the total urban area grew from 559 km^2 to 1,486 km^2 or 166 percent, a 1.5 to 1 relationship.

Estimated impaired stream length was also studied for the three future scenarios. Continuing with the 10 percent threshold, 4,747 km (1,129 km proper) and 7,177 km (2,419 km) would be impaired in 2025 and 2050 respectively if urbanization continues following the Current

Trends Scenario, a 252 percent increase through 2025 and a 381 percent increase through 2050 from the estimated impaired length in 2001. In the Alternate Scenario I, stream impairment decreases slightly relative to the Current Trends scenario during the initial 25 year prediction, but remains the same for the remaining 25 years prediction to 2050. At 2025 the impaired stream length is predicted to be 4,576 km (1,037 km) and 6,381 km (1,896 km) for the Alternate Scenario I, or a 243 percent and 338 percent increase. For the Alternate Scenario II, the predicted impaired stream length is again lower than the previous scenarios, a 192 percent and 217 percent increase, for the two predicted time periods respectively (3,624 km (739 km proper) and 4,096 km (991 km)).

Hydrologic Effects Comparison

Six specific areas of the watershed are featured to illustrate the performance of the three build-out scenarios and any distinct difference in terms of hydrologic and water quality effects. These areas were chosen to represent a gradient of past urban land uses. Hydrologic changes were evaluated by analyzing differences in flood magnitude and frequency, flood lagtime, and the simulated hydrograph. Changes in these flow characteristics can suggest geomorphic adjustments, which in turn can alter and be detrimental to in-stream habitats and bank stability. These simulations were created using the flood-frequency relations, lagtime relations, and a dimensionless hydrograph following Inman 1986, 1995, and 2000. Six specific watersheds are highlighted to illustrate the differences between scenarios. These include Pettit Creek, Picketts Mill Creek, Padgett Creek, Copper Sandy Creek, Allatoona Creek, and Toonigh Creek, representing the least to most urbanized respectively, as shown in Figure 42.

Figure 43 and Table 4 illustrate the effects of increased impervious surface on the flood hydrograph, lagtime, and peak discharge, over time. Pettit creek is the most startling, with the hydrograph showing the storm discharge rapidly increasing from a hypothetical rural hydrograph to each future scenario's hydrograph, as well as a sharp decrease in lagtime. As shown in Table 4, each stream location shows a trend of increasing storm discharges and shorter lagtimes. However, the performance of the three scenarios can also been seen, with each alternative scenario generally hindering stream discharge and flashiness.

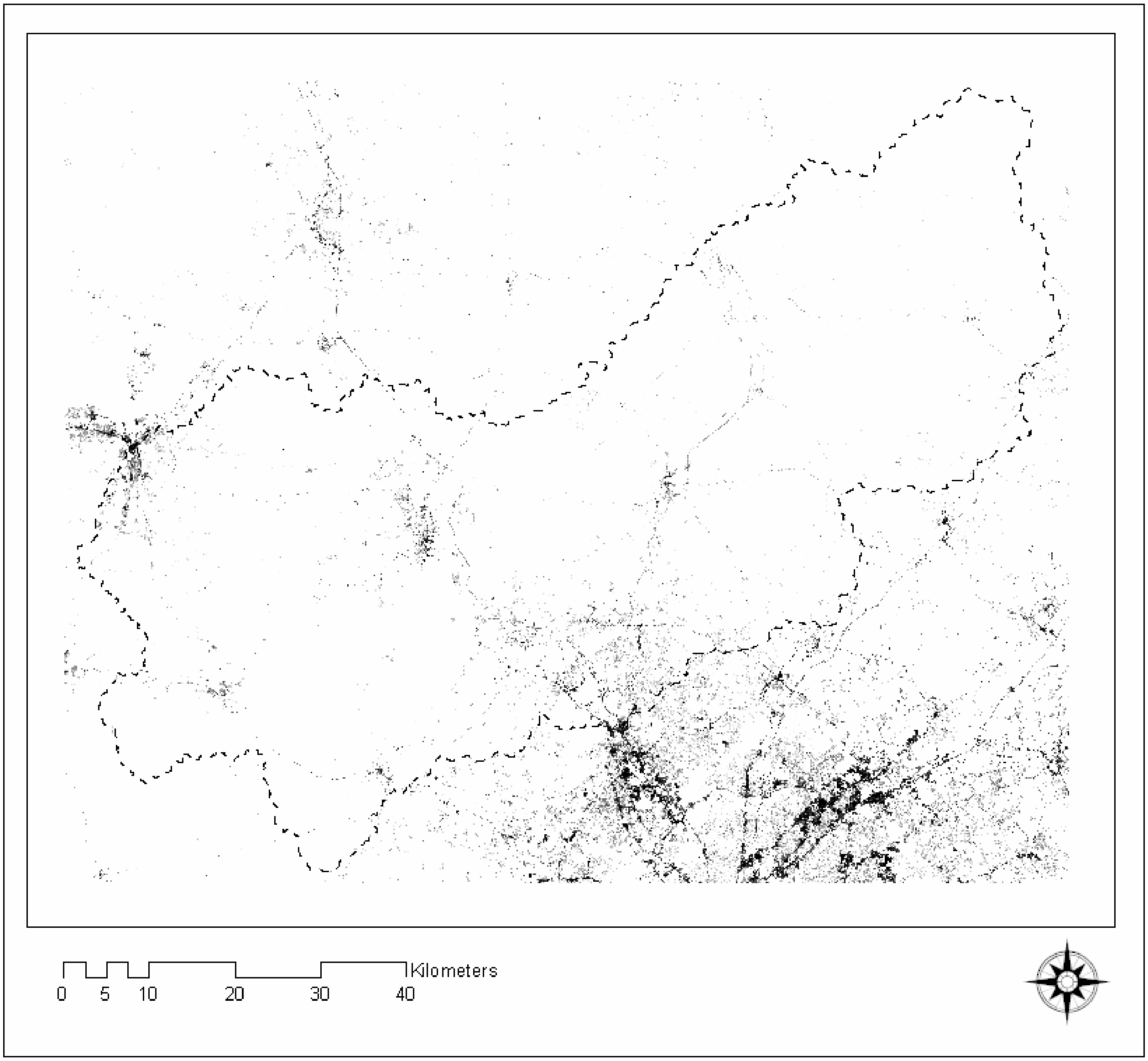


Figure 27. Etowah watershed percent impervious surface, 1974. Values range from zero (white) to 100 (black).

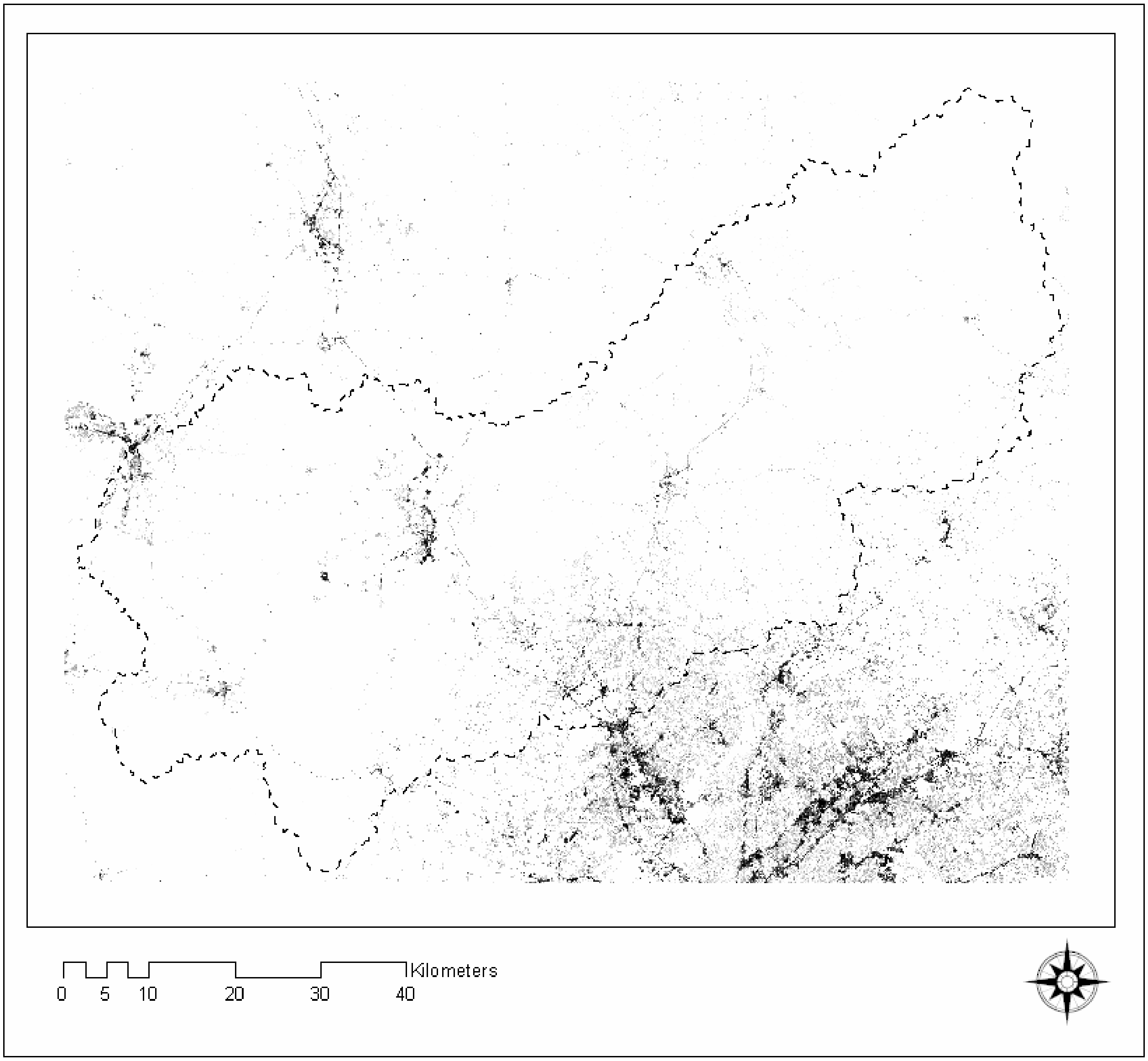


Figure 28. Etowah watershed percent impervious surface, 1985. Values range from zero (white) to 100 (black).

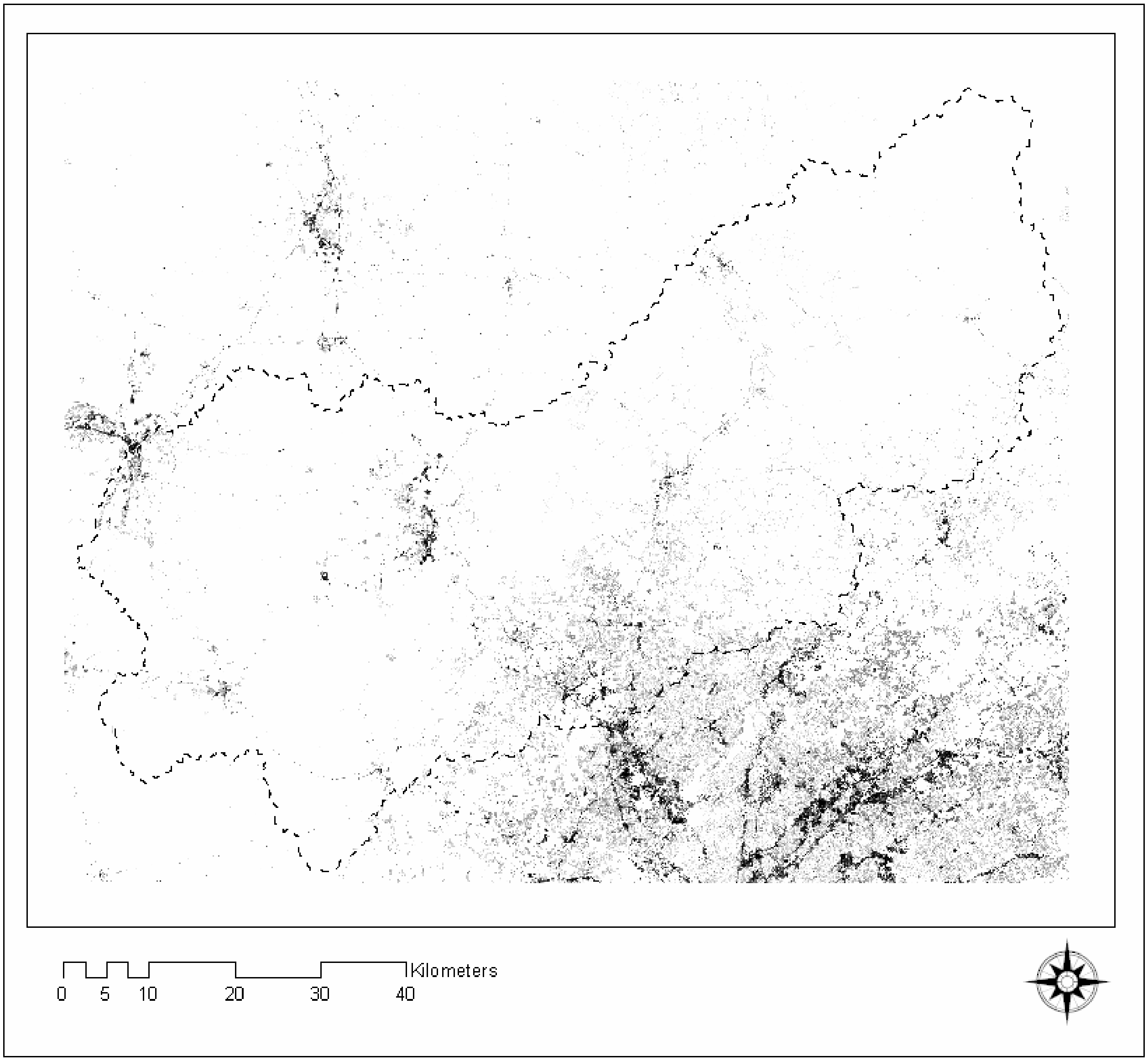


Figure 29. Etowah watershed percent impervious surface, 1992. Values range from zero (white) to 100 (black).

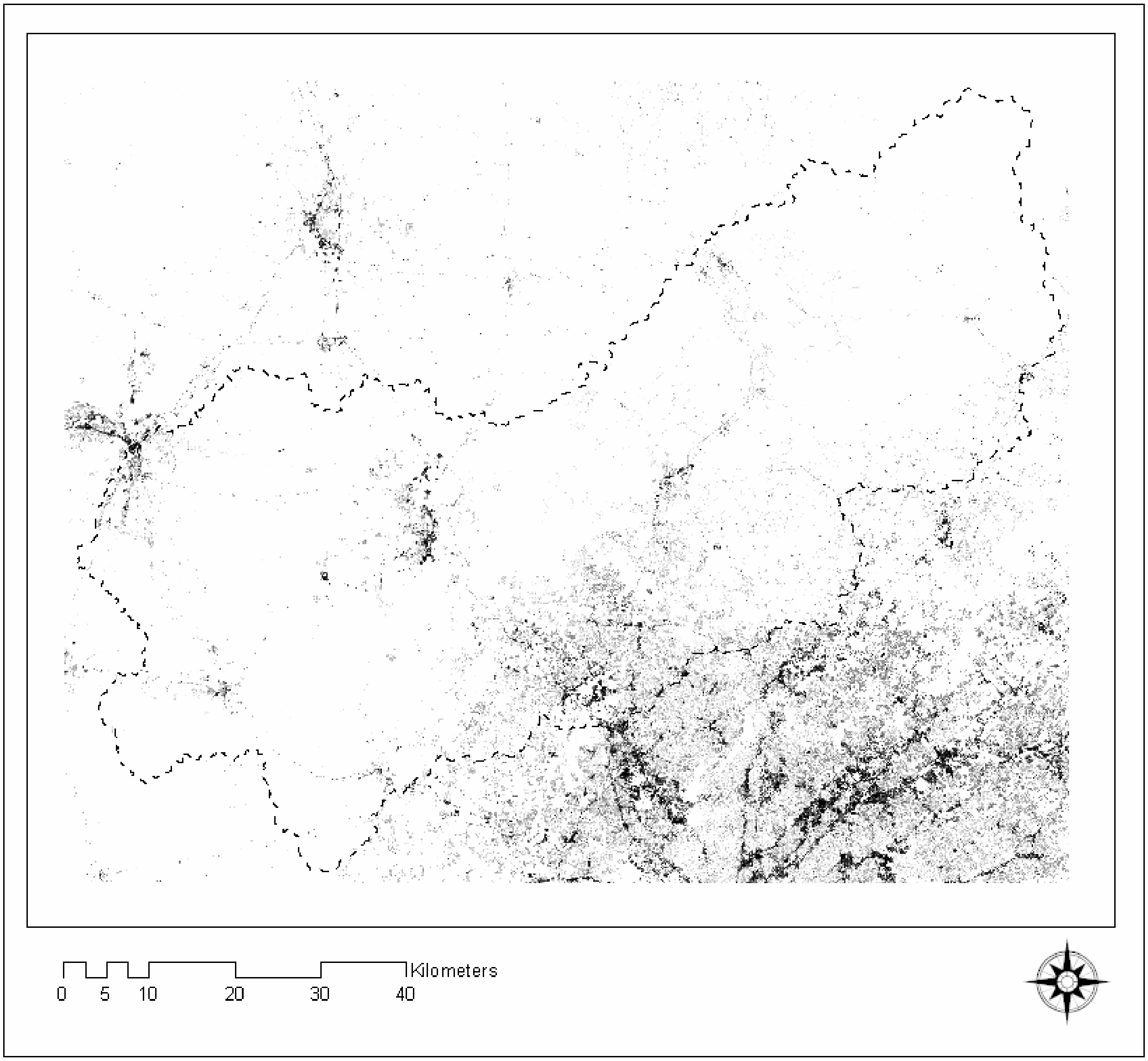


Figure 30. Etowah watershed percent impervious surface, 1998. Values range from zero (white) to 100 (black).

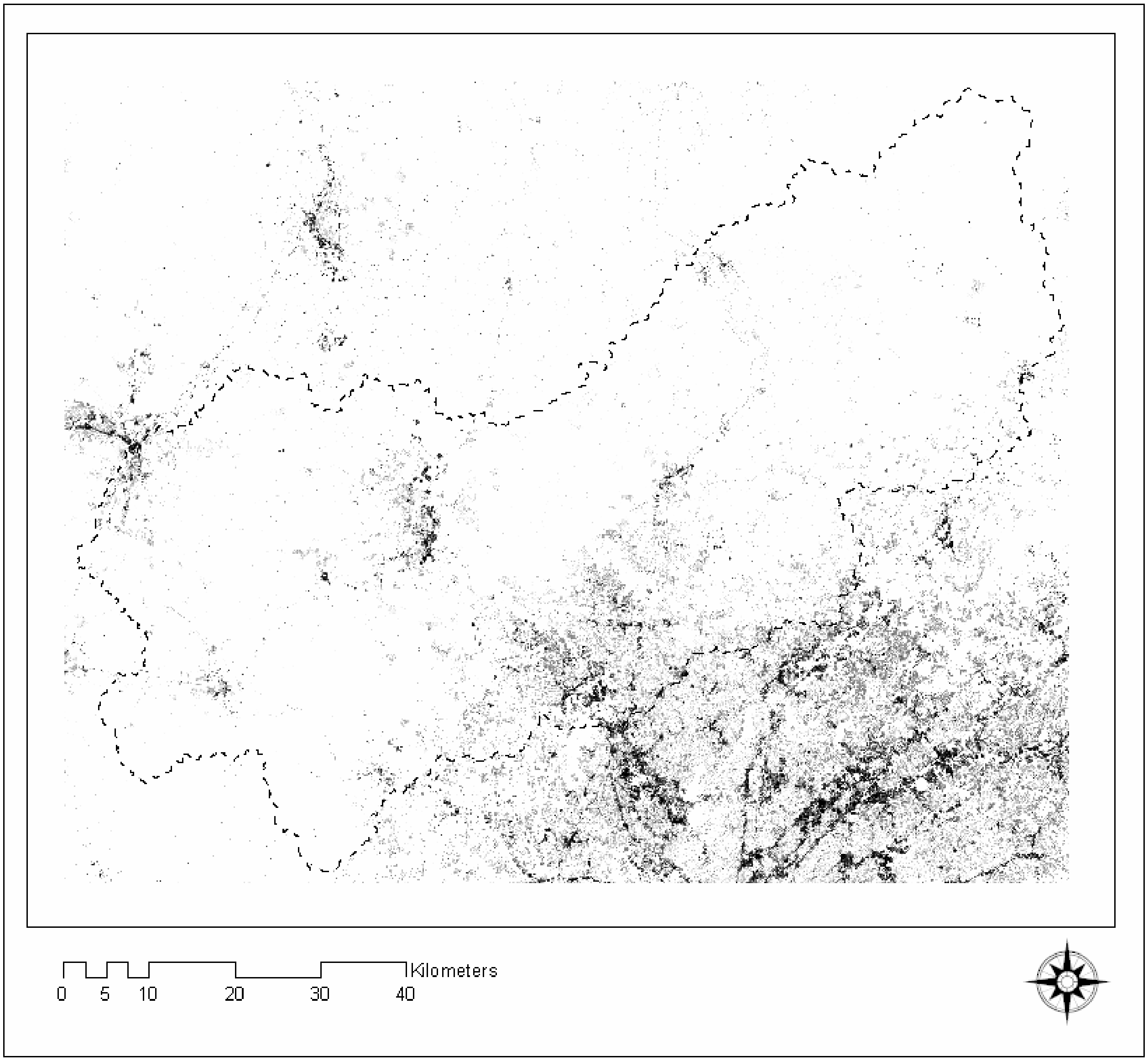


Figure 31. Etowah watershed percent impervious surface, 2001. Values range from zero (white) to 100 (black).

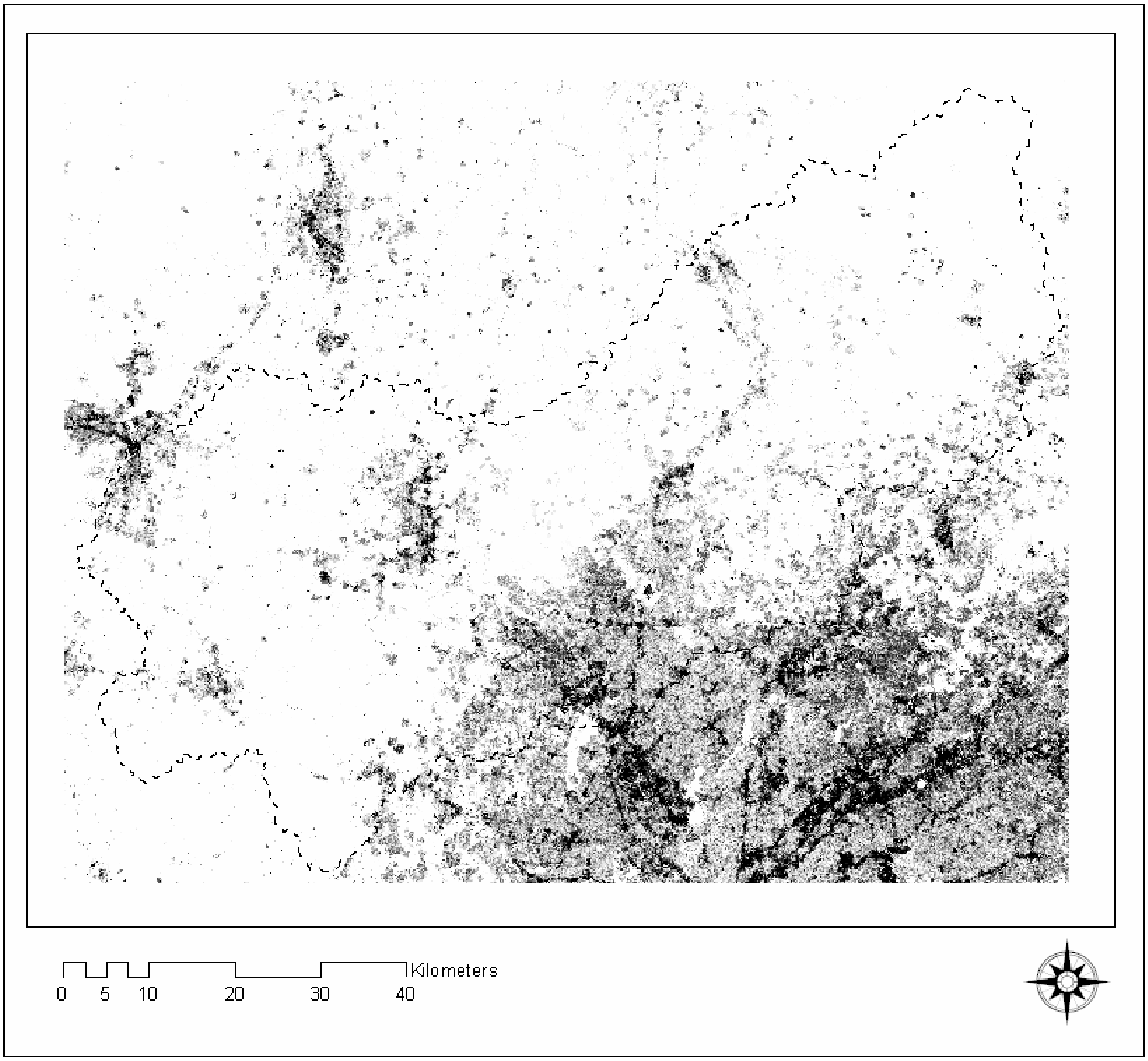


Figure 32. Etowah watershed percent impervious surface, Current Trends Scenario, 2025. Values range from zero (white) to 100 (black).

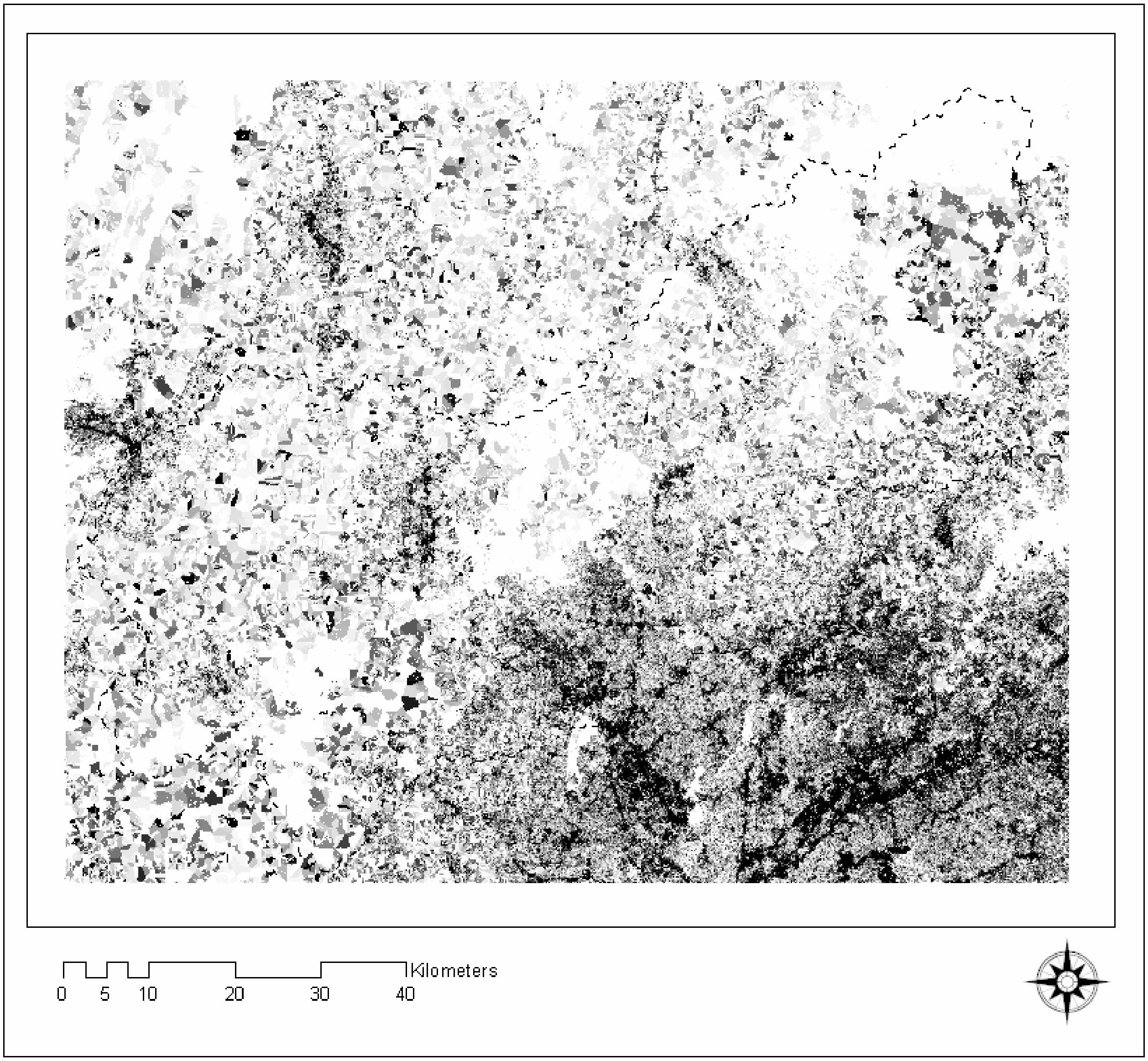


Figure 33. Etowah watershed percent impervious surface, Current Trends Scenario, 2050.

Values range from zero (white) to 100 (black).

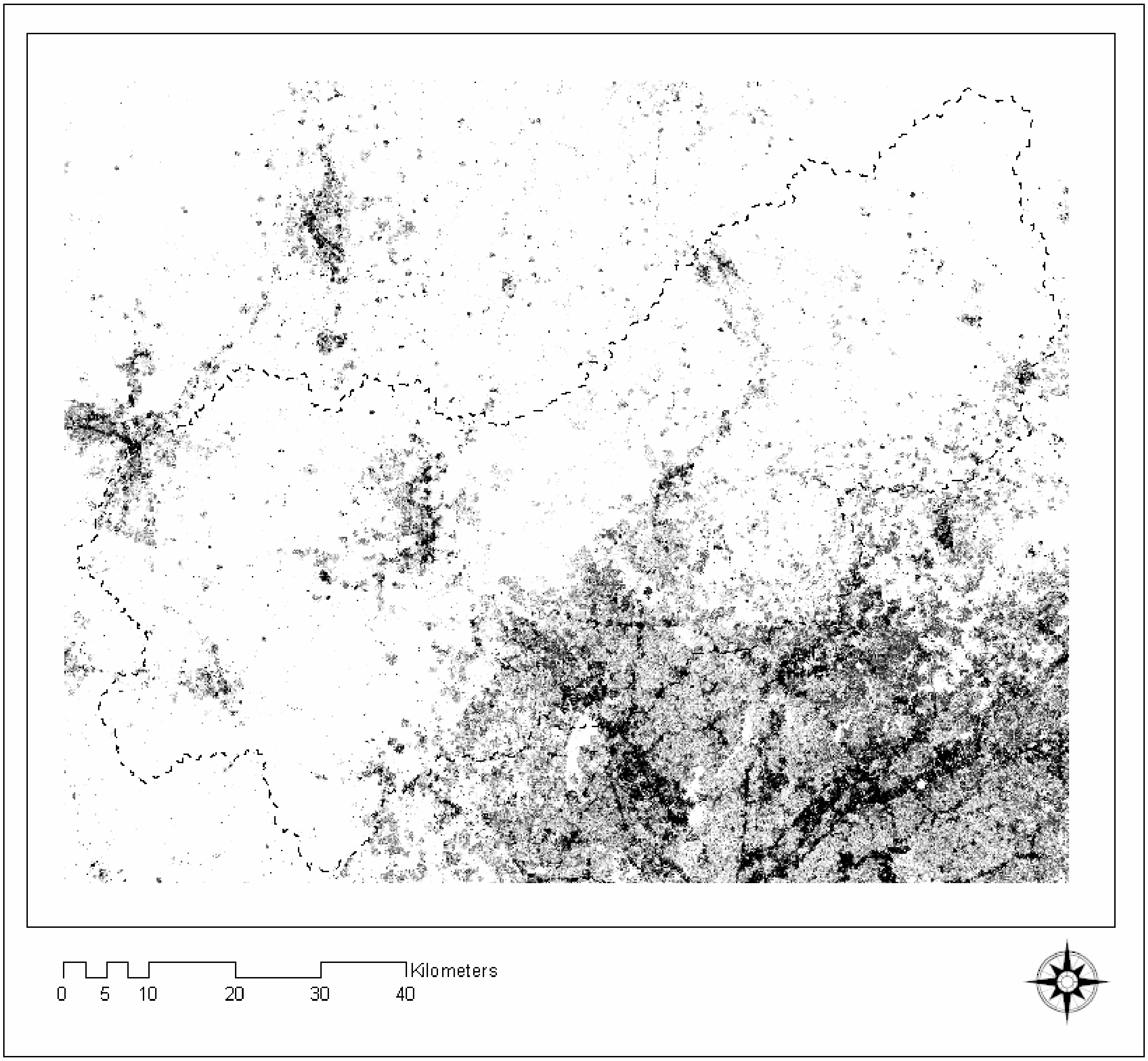


Figure 34. Etowah watershed percent impervious surface, Alternative Scenario I, 2025. Values range from zero (white) to 100 (black).

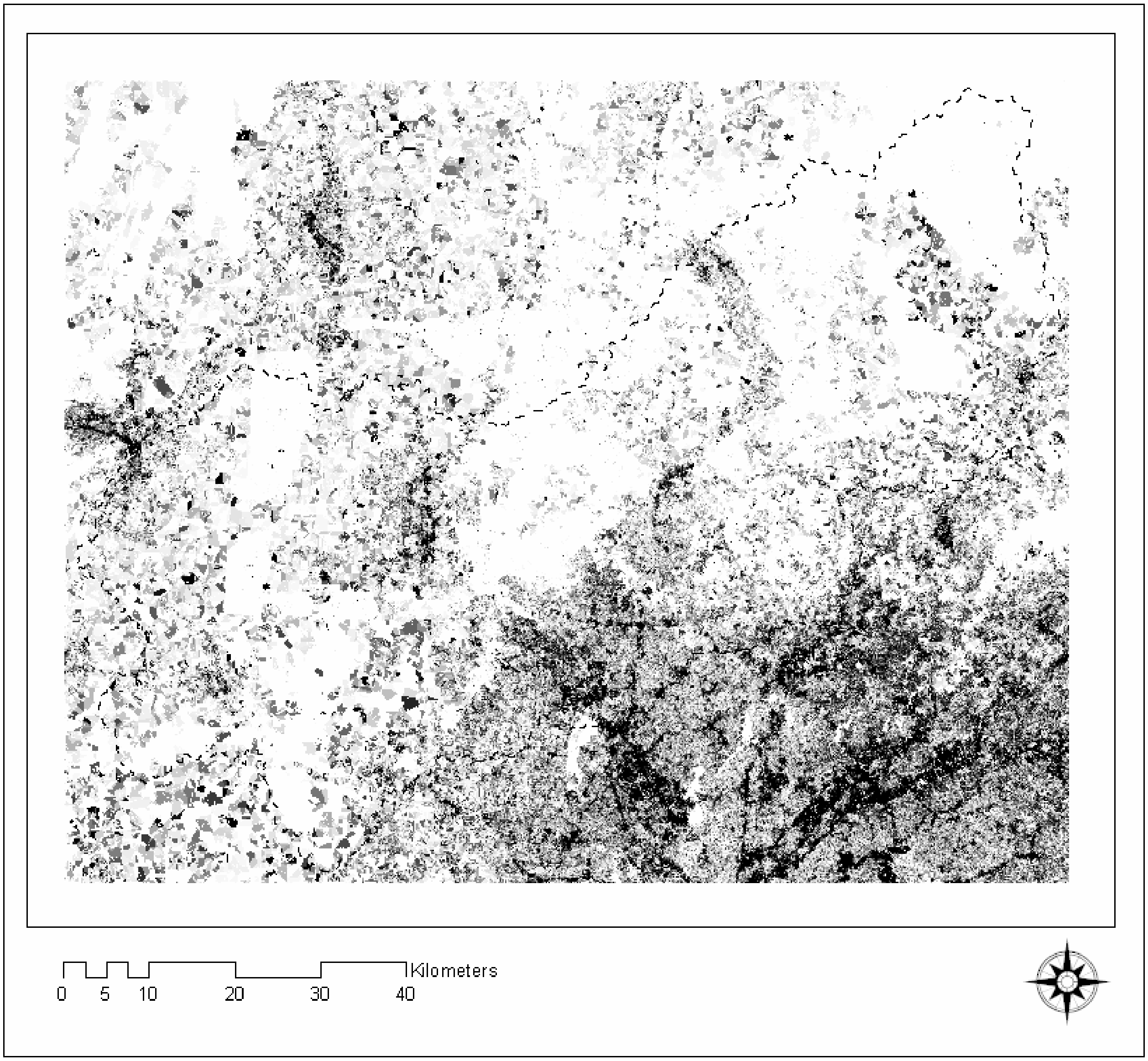


Figure 35. Etowah watershed percent impervious surface, Alternative Scenario I, 2050. Values range from zero (white) to 100 (black).

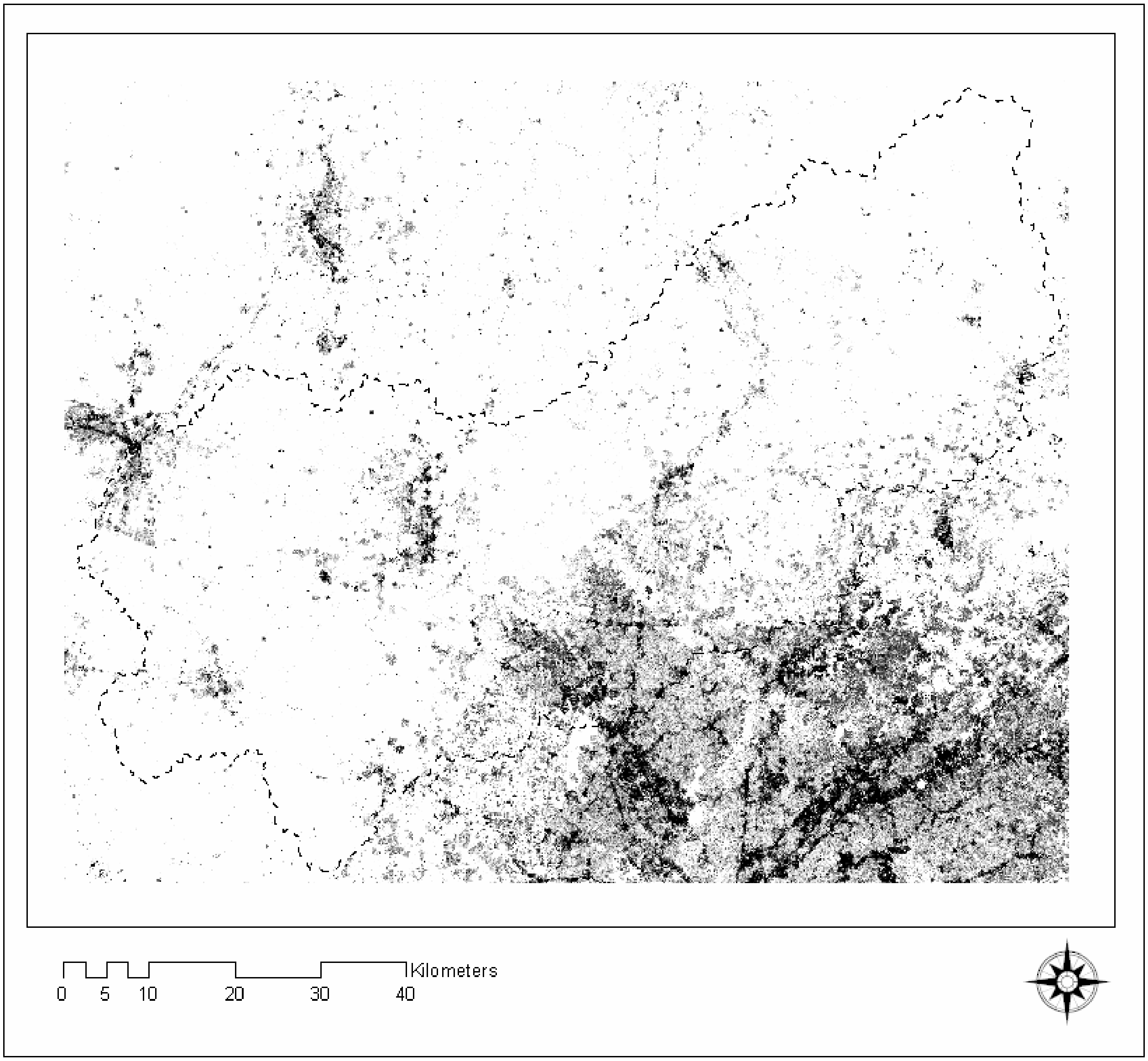


Figure 36. Etowah watershed percent impervious surface, Alternative Scenario II, 2025. Values range from zero (white) to 100 (black).

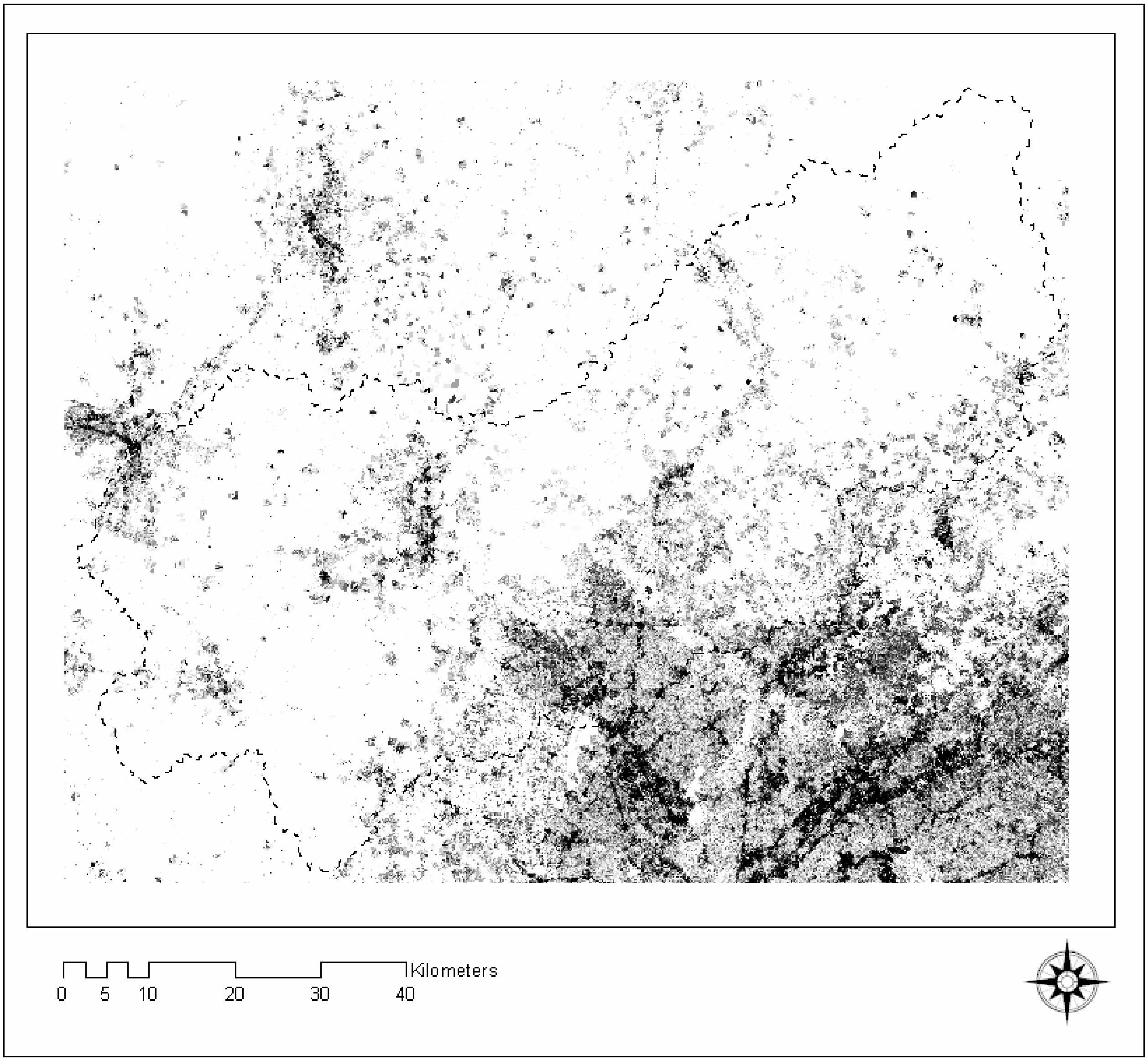


Figure 37. Etowah watershed percent impervious surface, Alternative Scenario II, 2050. Values range from zero (white) to 100 (black).

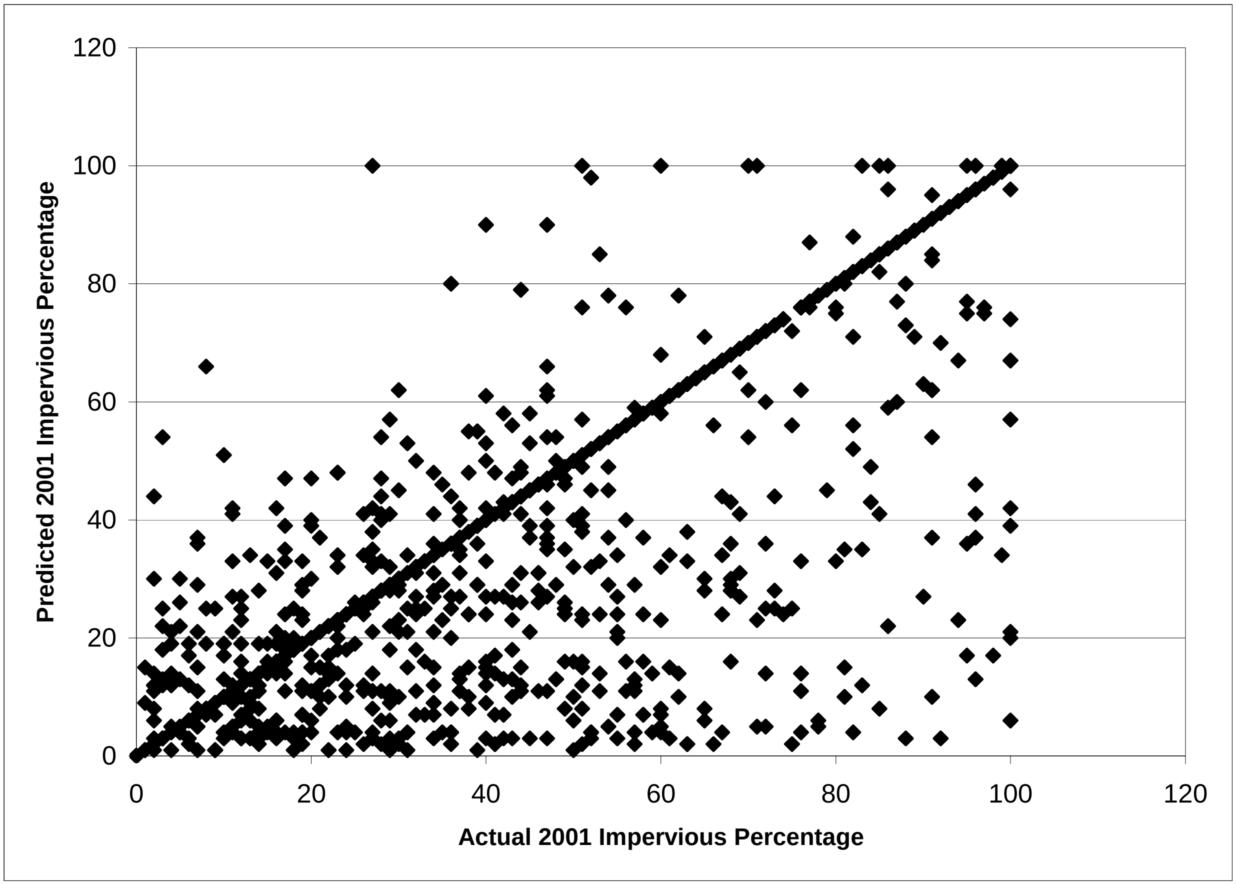


Figure 38. Predicted versus actual 2001 impervious percentage scatter plot. 0.71 overall correlation coefficient.

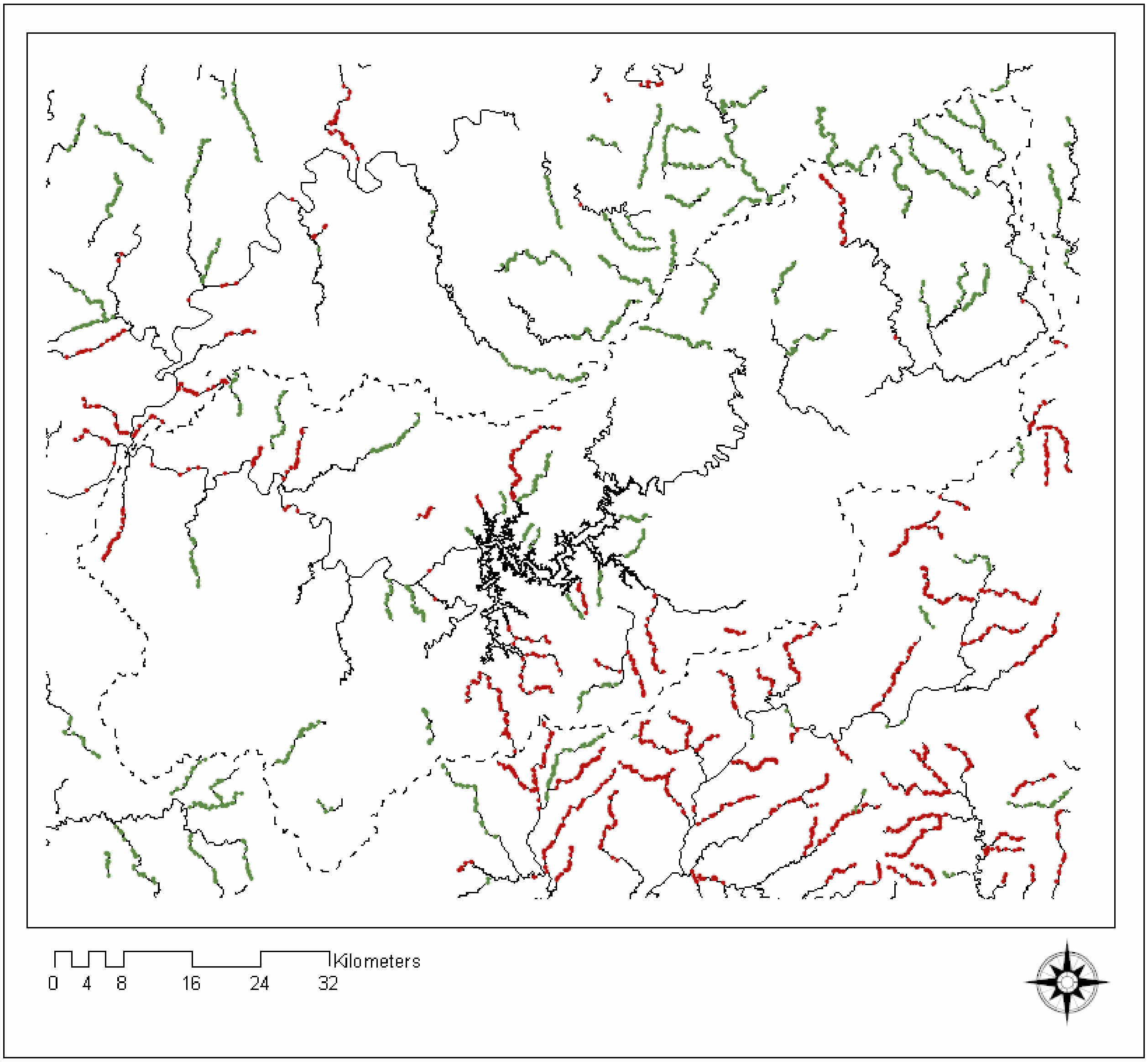


Figure 39. Sample locations of impaired (red) and non-impaired (green) streams overlaying the 2002 303d impaired and non-impaired (black line) streams. The black dashed line represents the Etowah watershed boundary.

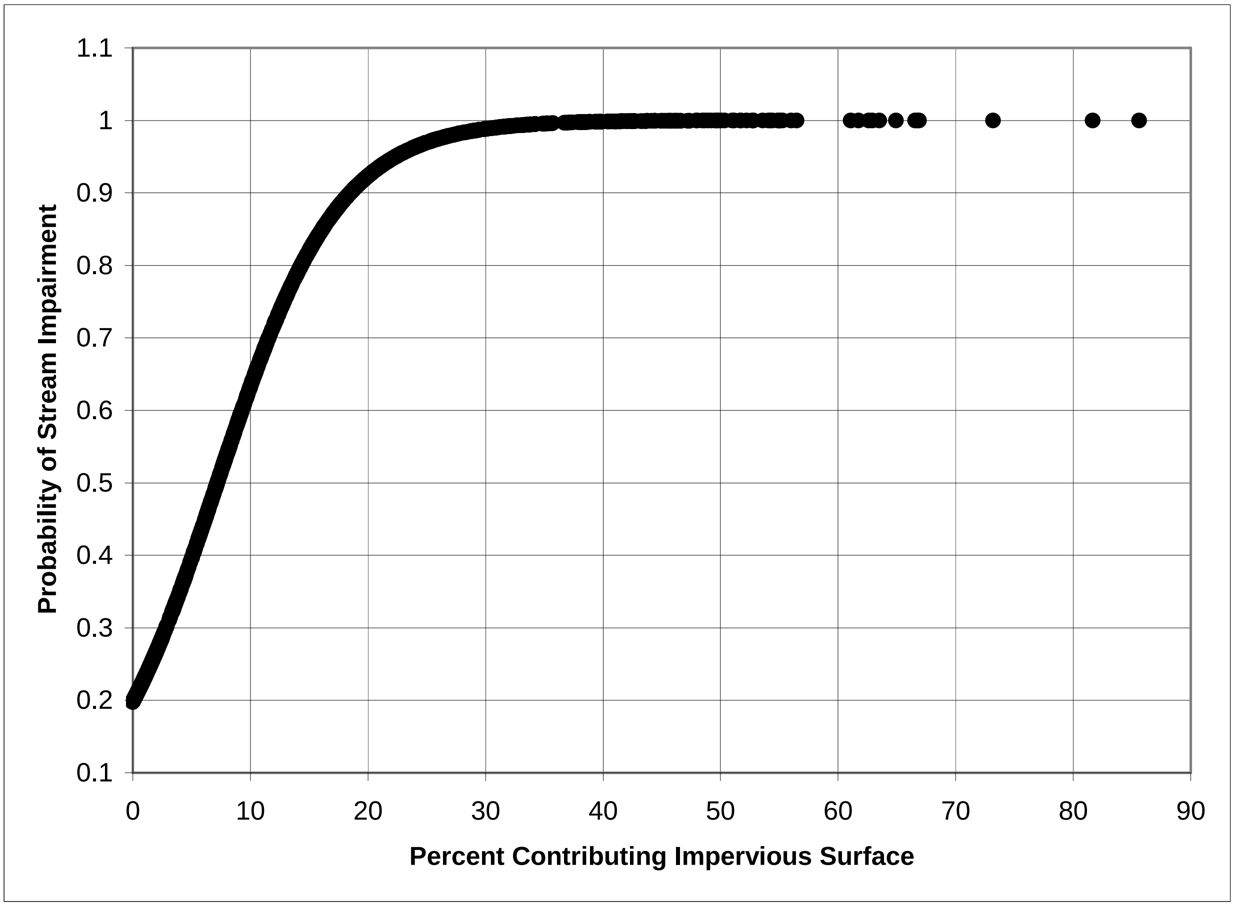


Figure 40. The probability of stream impairment based on percent contributing impervious surface.

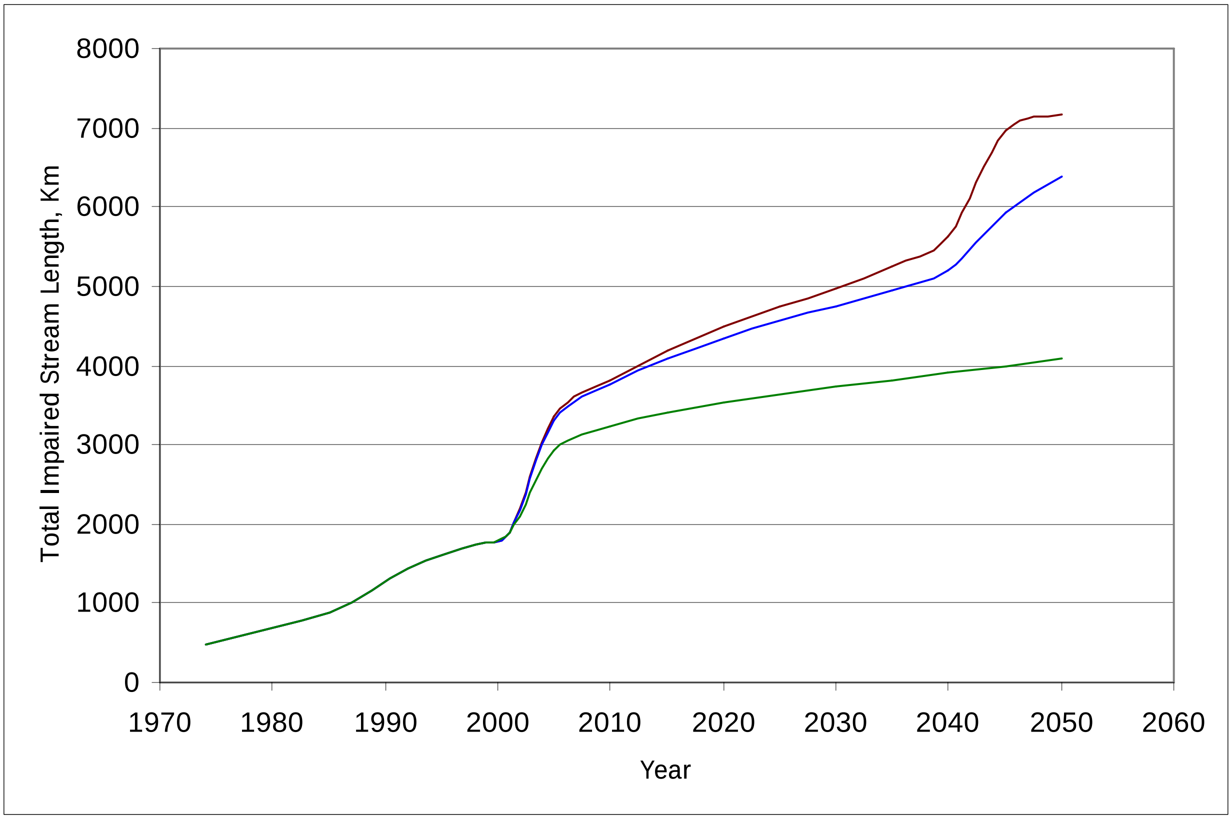


Figure 41. Estimated total impaired stream length for each future scenario, in kilometers. Current Trends Scenario is red, Alternative Scenario I is blue, and Alternative Scenario II is green.

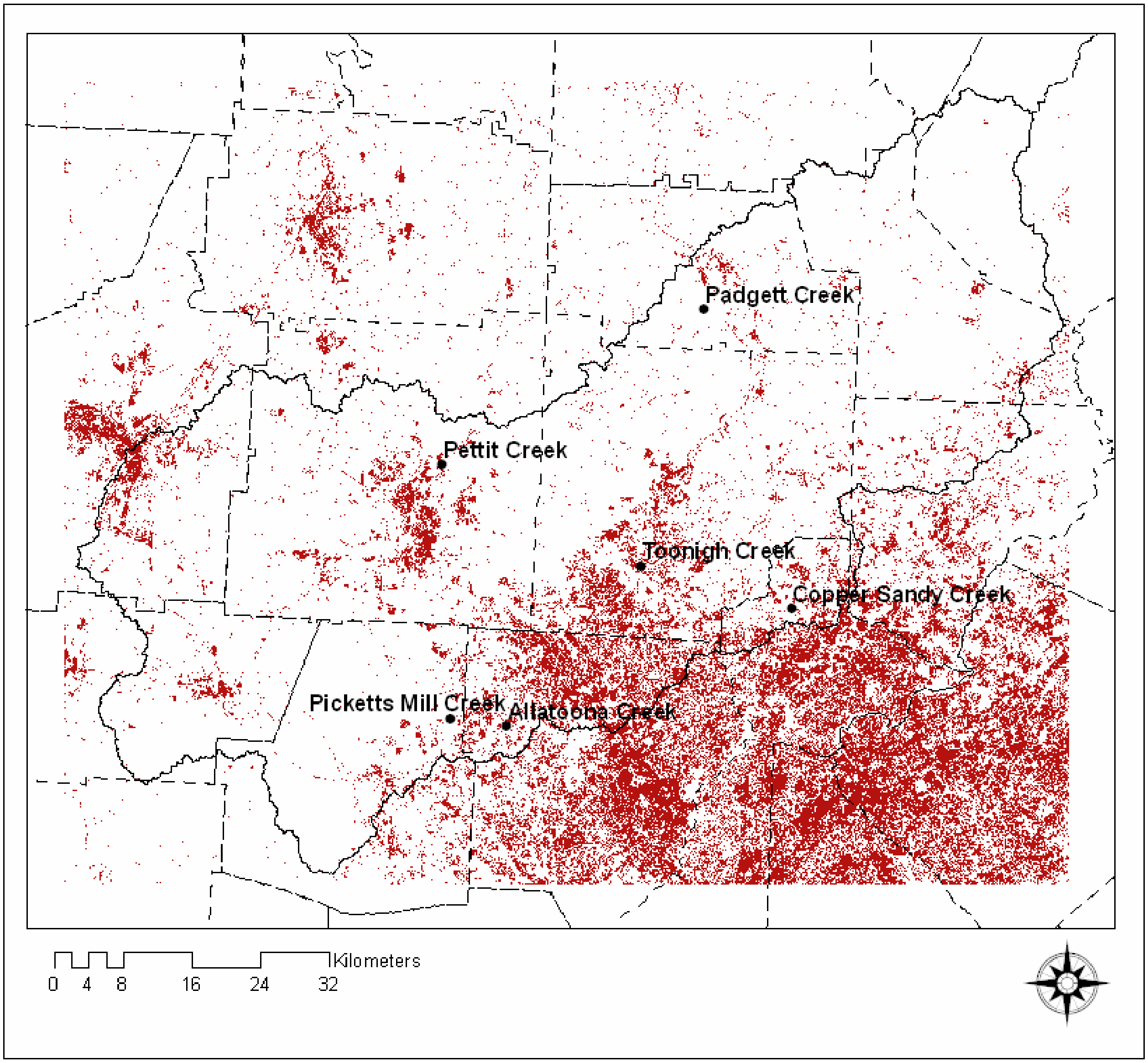


Figure 42. Selected stream locations for detailed hydrologic analysis and 2001 urban areas (red).

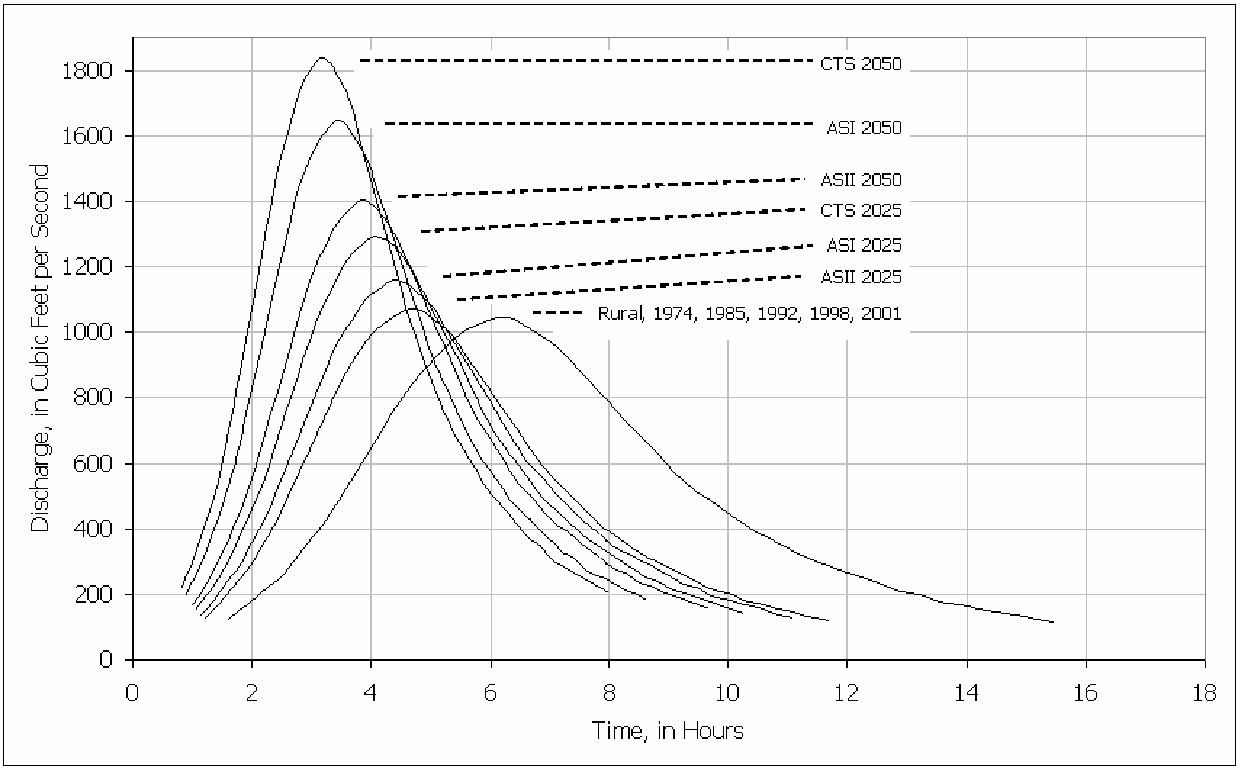


Figure 43. Pettit Creek simulated hydrograph. CTS: Current Trends Scenario; ASI: Alternative Scenario I; ASII: Alternative Scenario II.

Table 4. Two year recurrence interval discharge, in cubic feet per second and lagtime, in hours, for selected stream locations. CTS: Current Trends Scenario; ASI: Alternative Scenario I; ASII: Alternative Scenario II.

	Pettit Creek		Padgett Creek		Toonigh Creek	
Date/Scenario	**Discharge**	**Lagtime**	**Discharge**	**Lagtime**	**Discharge**	**Lagtime**
Rural	1044.82	8.40	1030.63	6.45	685.69	5.02
1974	1044.82	8.40	1030.63	6.45	685.69	5.02
1985	1044.82	7.12	1089.08	6.45	778.97	3.86
1992	1044.82	6.95	1127.33	6.45	954.20	3.34
1998	1044.82	6.73	1178.55	6.45	1001.16	3.23
2001	1044.82	6.12	1348.28	6.45	1100.09	3.02
CTS 2025	1291.79	5.13	1728.55	4.28	1401.73	2.54
CTS 2050	1838.09	4.76	1917.19	3.33	1406.60	2.54
ASI 2025	1158.56	5.23	1682.94	4.62	1379.68	2.57
ASI 2050	1646.19	4.85	1868.90	3.60	1388.57	2.56
ASII 2025	1072.54	6.09	1356.26	4.88	1082.74	3.05
ASII 2050	1402.28	5.92	1411.36	4.04	1090.85	3.04

	Copper Sandy Creek		Picketts Mill Creek		Allatoona Creek	
Date/Scenario	**Discharge**	**Lagtime**	**Discharge**	**Lagtime**	**Discharge**	**Lagtime**
Rural	669.34	4.45	654.48	4.68	791.74	7.62
1974	669.34	4.45	654.48	4.68	791.74	7.62
1985	669.34	4.45	654.48	4.68	791.74	7.62
1992	669.34	4.45	680.06	3.79	780.48	7.37
1998	727.63	3.37	740.61	3.57	840.25	6.99
2001	1058.89	2.58	871.86	3.18	1060.20	5.93
CTS 2025	1223.94	2.33	1166.43	2.58	1426.26	4.80
CTS 2050	1403.15	2.11	1290.87	2.40	1569.33	4.49
ASI 2025	1174.29	2.40	1141.25	2.62	1399.41	4.87
ASI 2050	1366.40	2.15	1262.33	2.44	1549.09	4.53
ASII 2025	942.37	2.80	875.41	3.17	1074.28	5.87
ASII 2050	1003.14	2.68	944.75	3.00	1174.62	5.51

CHAPTER 5

DISCUSSION

Urban Prediction Methods

The final results for the urban and impervious surface extents for each future model, produced using the SLEUTH cellular automata model, represents a relatively accurate picture of the ecological state of the Etowah watershed in the next 20 years. This approach can be hindered by several factors, such as the date range of the historical dataset as well as its spatial resolution, but can be used to understand the overall trends of the landscape changes that are occurring in the region. The resulting maps and hydrologic charts should not be considered as absolute results or as the literal location of the future urban extent. The methods used to produce the results should be considered by the end-user or reader, as these methods only produce probabilities and estimates of the future urban extents and impervious surface values based on the data and criteria at hand. But, even though we are dealing with an imperfect model, the generated maps and data can be a valuable tool in understanding the future effects of various landscape management practices.

Mapping future urban build-out using the SLEUTH model allows one to estimate the urban extent of an area into the future with relatively little amount of time or data. Naturally, it is impossible to access the accuracy of any of the model's results; however one can conclude that because of the nature of this urban model, the accuracy decreases the farther in time one analyzes from the source data. The results produced here suggest that the maps should be used with consideration to their overall correctness at all scales due to the generalities in urban location, extent, and impervious intensity.

Final Urbanization Predictions

The goal of this study was to generate a spatially explicit data set that accurately depicts the future distribution of urban development across the Etowah and analyze the effects on stream health. However, at the resolution that the modeling was executed (60m), the resulting urban extent along with the estimated impervious surface percentage, had a generalized appearance roughly double the minimum mapping unit. Also, the results for the urban extent and percent impervious surface for all scenarios for the year 2050 seem unlikely. The urban extent for the Current Trends Scenario and Alternative Scenario I almost encompasses the entire study area, except for the most restricted areas from the exclusion layer, while the impervious percentages remained low for these large swaths of development, perhaps offsetting the overstated developed areas. With more historical data and future road data, future urban estimates will be more accurate. However, accurate predications longer than 25 to 30 years into the future seem unlikely.

Planning Implications

Using the SLEUTH produced urbanization probability and GIS software, county, transportation, and urban planners can generate urban probability maps for specific locations, set probability thresholds to identify the most probable locations for urban development, identify potential natural resource restoration or conservation sites based on urbanization pressures, and further utilize ancillary datasets to aid in urban planning and natural resource protection. By assigning different weights for the exclusion layer, managers can tailor the SLEUTH model to their local or state environmental values and standards. For example, if a community desires a more dispersed low density approach for development in order to have a low impact to the environment as a whole, they could create an alternate exclusion layer designating pixels close to existing developments as undesirable. Other variables could also be altered in order to produce alternate outcomes, such as the type and rate of growth that was previously determined from historical data, but could be changed to accelerate or slow growth. By using SLEUTH, planners can initiate multiple scenarios in order to assess the environmental and quality-of-life impacts of zoning regulations and future development decisions.

CHAPTER 6

CONCLUSIONS

Three future urban scenarios were successfully mapped using historical land cover and impervious surface for the Etowah watershed. The probabilistic results of the SLEUTH cellular automata urban growth model can provide resource and land managers with a spatially and statistically accurate and flexible planning tool that can be modified and updated in order to assess various resource and conservation questions. In addition, a stream impairment threshold was established for the watershed that facilitates a more thorough understanding of the actual environmental state of the streams in the area. Future studies can improve upon these results by incorporating more historical land cover at shorter intervals and including more historical road datasets. The use of high resolution and coarse resolution datasets should be investigated to determine the scale and spatial limits of the urbanization model. The stream impairment threshold could also be improved by incorporating other explanatory data, such as canopy closure and riparian buffer analysis. The SLEUTH model coupled with GIS can give communities the knowledge of what effects various growth strategies may have on area streams and their watershed.

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