

**DEVELOPING A NATURAL RESOURCE DATABASE
FOR GEOGRAPHIC INFORMATION SYSTEM**

by

Khaled M. Hassouna

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APPROVED:

Dr. Richard G. Oderwald Co -Chairman
Dr. Robert H. Giles, Jr. Co -Chairman
Dr. Gerald H. Cross

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ABSTRACT

Geographic information systems (GIS) are an effective tool for land management. By studying the land formations and land cover of a site, much information about the tree and animal species inhabiting a site can be estimated. The managers of public or private lands may find the concept of a multi-layer analysis of their land useful in discriminating locations based on their many characteristics. I created a database of a small area with no previously specified objective. I produced a group of map layers emphasizing the methodology and the ability of making any number of overlays or combinations of layers. I estimated the time and cost involved in producing these layers. I produced layers of: elevation, slope, aspect, watershed-depression, watershed-flow direction, watershed-streams, and roads. I created a group of categorized data layers: elevation, slope, aspect, erosive slope, watershed-flow accumulation, buffered roads, and buffered streams. I made some combinations of different layers explaining the potential uses of such combination. I used the work of my graduate colleagues to illustrate the importance of such work when combined in natural resources management. Combinations were made of: forest cover, average temperature, solar radiation, and slope position.

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I thank my father and mother for their total support of my studies. I thank my wife who played the most important role in inspiring and supporting me throughout this project.

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Chapter 1: Introduction and Justification

Introduction

This paper describes how it is feasible to develop the database for a geographic information system (hereinafter GIS), a system that is potentially useful in forestry and other related natural resource management. The paper describes a highly applied process, one of developing the proper union of hardware, software, facilities, and staff all along with data to create a meaningful, lasting system for producing products from a GIS. The context of this paper is primarily that for an hypothetical company or agency that operates within a large region and anticipates many different but yet-un-named projects and applications to be made over many years.

I shall briefly describe the uses and potentials of the GIS, then the process, giving emphasis to the time and costs involved. This report is not about research conducted to

study some new phenomena, or to report the latest technology in resource management, but about developing major part of a system.

Objective

The objective of the project was to apply available GIS components and to develop a small database with applications that may be useful in natural resource education and environmental and rural decision making. Part of the objective was to develop cost estimates that may be helpful in deciding on whether such work is useful and practical, typically a judgment about cost effectiveness. A data set was created for learning, making demonstrations, and measuring costs. No particular project or specific use was assigned or selected at the beginning of the project. The premise was that a GIS database might be created for a typical environment in which there are no clear objectives and a long list of unranked potential projects with which a GIS might be useful. One objective was to suggest whether a GIS may be feasible for development and use in institutions and governments of the world. Linking scientific ecological studies and the on-site field applications of results of such studies is one of my fundamental objectives.

Justification

Many authors have written about the importance of learning about nature and the environment and working with it (e.g., Odum 1963,1971,1993, 1996; Fathy 1969, 1973,1986; McHarg 1969; Van der Ryn 1996). Using alternative epistemological bases, involving GIS with site-specific knowledge, noting the limited funding, and accepting lower confidence level for conclusions and subsequent actions are some paradigms integrating science and economics in land management (Giles et al. 1993). This report shows how feasible it is to build a database for use in a GIS. This database could be used on projects on large areas (such as federal or public land) or on small private land ownerships. It appears that GIS is applicable in long term planning as well as in day-to-day management.

Previous Functions

There are many functions and benefits that are likely from GIS. In the early 1990's, spatial information was used by public land managers to estimate the forest types and forest distribution in the US (Graetz 1990, Lannom 1995). It was also used to produce thematic mapped data (Evans 1994) and mapped forest density (Zhu 1994). The global community has depended heavily on GIS for tropical forest assessment

and its relation to the global warming (Gillespie 1994). The systems were used to identify and map areas of different social groups in some social studies (Lee and Culhane 1995). It was also used to monitor and solve some urban problems of over population (De Wit 1992, Baha et al. 1994). They were also used in medical and public health applications, for example to trace wide-spread medical problems (Glass et al. 1992, Beck et al. 1995, Rushton et al. 1995) and to coordinate planners and public health personnel (Werner and Hedland 1995). GIS also was of great use in routing traffic and traffic control in the US and around the world (Schnicker 1993, Genrich and Cooper 1993, Cipolloni 1994, Krakiwsky 1996).

GIS has proved to be a success in Environmental Impact Assessment, a procedure becoming mandatory for any large project in many places in the world (Johnston et al. 1994). It has been used in a wide variety of natural resource management practices (Schreier and Brown 1992). It has been used in evaluating damage from natural disasters (Anonymous 1992, Tsuji et al. 1996), and in monitoring pollution contamination of various types (Runyon et al. 1994). GIS have been integrated with knowledge bases to produce expert systems for natural resource management (Ji et al. 1992). It was widely used for National Parks and wildland protection, management, and planning (Wilcox 1984, Spear and Cottrill 1993, Murphy and Smith 1995, Niemann and Niemann 1996).

The GIS has been used in watershed-related studies and decision-support systems for management (Pickus and Hewitt 1992, James and Hewitt 1992, Angermeier and

Bailey 1992, Frye and Denning 1995). It has been used widely in environmental monitoring (Ramsey et al. 1994, Johnston and Ji 1994), e.g., monitoring land degradation and soil loss (Roehl 1962, Wischmeier and Smith 1968,1978; Wade and Wickham 1995). Additional GIS use has been as a tool for data collection about habitats and forming a habitat data bank (McGarile 1994, Thompson 1996).

GIS were used in landscape architecture, urban and regional planning, and studying regional growth (Ehlers et al. 1990, Bou-Saab and Steingraber 1992, Treitz et al. 1992, Genrich and Cooper 1993, Azar et al. 1994, Bocco and Sanchez 1995). GIS were used also in finding different alternatives for projects planning and in visualizing the future state of a study area (Versenyi et al. 1994, Batty and Howes 1996).

The military have intensively used GIS for 30 years (Kish 1995, Shank 1996). Lately the military has used GIS to find other uses for military lands (Sherman 1995). GIS has been used in archeological studies around the world, revealing hidden cultural and historical sites (Lopata et al. 1992, Murphy and Smith 1995).

GIS has now entered many businesses, connecting information bases with branches on regional, national, and international scales (Corbley 1995, Longdom and Barnes 1995, Chalmers 1996, Chisholm and Brown 1996). The planning of some businesses has now became dependent on GIS applications (Benoit 1995, Thrall 1996:1, Thompson 1996, Stone 1996).

A Brief Description of a GIS

Aronoff (1989) defined the GIS as any computer-based procedures to capture and manipulate geographically referenced data (spatial data). Dueker and Kjerne (1989) defined GIS as “ a system of hardware, software, data, people, organizations, and institutional arrangements for collecting, storing, analyzing, and disseminating information about areas of the earth.”

The basic function within a GIS is to divide a map into a group of small single-factor units. McHarg (1969) in *Design with Nature* was one of the first to popularize overlay mapping in the context of land use planning. His book appeared when the early computer mapping became readily available. Overlay mapping with physical map products has been widely used; it can now be used in many ways and has new expanded practical scope due to computer and printer advances. The entire matrix of values about one topic or factor on a map is a “layer.” By putting the layers together, the original map can be re-created. Each single-factor map may be revised to be more (or less) precise depending on the project or use. In raster-based works, the smaller the cell, the more precise will be the details. Very frequently, 30 x 30 m is used for a cell size. I used 30 x

30m cells in my demonstration. This scale has the same size as the Landsat Thematic Mapper sensor resolution, a resolution used for the land-use classification described later.

For every land feature there must be within a GIS the name, exactly where it is, and how it relates to other features. This information about the recorded features include position, topographical information and spatial relationship, and feature attributes.

Acquiring and maintaining the data sets are the most expensive component of any GIS.

Between 60% and 90% of the investment in a GIS relates to data sets. The data about land features are entered by scan digitizing, manual digitizing, manual keyboard data entry, and by using procedures available with hardware used with the global positioning satellite system (hereinafter GPS).

The spatial data recorded for a feature could be in the form of vector or raster layers. Vector data are representations of polygons. Raster data, in the form of a matrix of values, describe conditions or features at points, typically the center of the cells of a matrix. The GPS may be used to determine and record the exact position of a feature or observation relative to a global division. About 50 years ago, world map makers devised the Universal Transverse Mercator grid (hereinafter UTM). Using the UTM coordinates with the GPS seemed best suited to overcome the confusion in using many coordinate systems. Using maps without relating to a UTM grid system becomes like using a street map without streets names (Neri 1996).

GIS is an accumulative system which can be used to satisfy human needs to know what exists at a particular site, what conditions have changed over time, where it changed, and what might happen if the existing use is altered. Any quantifiable social, economic, or environmental impacts due to altering some of the conditions or uses, potentially may be monitored for a specific site using the GIS (Walker and Miller 1990).

A GIS is often used to produce a visual image of an area of study. The graphic side of a colorful spectrum of raster and vector layers of GIS may have more impact on viewers than other kinds of automation or modeling (Parr 1992). An advantage of using a GIS lies in the ability to use visual layers that then may be overlain or combined in several ways with other aspects of the study area (Giles 1962,1985). Images from satellites, infrared photos, and radar were widely used in remote sensing mapping (Collwell 1973). GIS application followed such use in producing images of layers, many of which were intended to be helpful in planning (Fuller 1994).

In the beginning of the 1900's, many problem faced those who tried to draw an accurate, reliable map. The most complicated problem was to collect the needed information from different maps having different scales. A group of bays and fjords of a coast line may be represented by a straight line in a less detailed or bigger scale map. That lead scientists and mathematicians worked hard on finding a process by which detailed relations may stay undistorted throughout scale changes. Some mathematicians called this process scale-linking procedure. That procedure consist of direct consequence of

identical processes shaping land form across many scales. The process is also known as “fractal scaling” which is widely used by geologists, landscape architects, and ecologists.

(Van der Ryn and Cowan 1996) claimed that unless people start working with nature’s own finely-tuned, scale-linking systems, they will be endangering the stability of the planet. Although this statement may be frightening, I agree that a link will have to be established to use previous efforts that were under taken in ecology at different scales. Another concept to be considered is one of not focusing on a single scale but finding an interactive link between different scales. Failing to find this link leads managers to miss the opportunities to work across different scales in a unified method to address a problem. GIS could be our way to this kind of interactive link, a pathway for studying an area as a group of adjacent cells. By unifying the size, shape, and scale of the cells, GIS users can then study an area on different scales depending on the number of cells to be considered as a study area.

By judicious use of available software, it is possible to relate information in a map or matrix of cells to factors in adjacent or nearby cells. Juxtaposition is a very important factor in ecological studies. It mainly depends on the quality of relations between adjacent areas. To study the ecological system of any area we have to know the answer to some important questions, such as, how far the site is from water; how close an area or point is to edge; how near a site is to a road; or how far a site is from another site of a

specific property. GIS can answer these questions on a visual map. At that point we can see the relations between our study units (cells) clearly.

In some types of analyses, relations between overlaid cells may be studied. By overlaying cells, site can be studied to develop an equation, for example,

$$b_{x,y} = a + c Z_{xy}$$

where some value for variable “ b” at each location, coordinates x and y, may be estimated from the coefficients a and c used with Z at that same site. Once there is an equation, a new value for each cell may be computed. When some value, b is related to several factors, each of which is a map layer, then an equation such as

$$b_{x,y} = a + c P_{xy} + d Q_{xy} + e R_{xy}$$

can be used with there being three factors, P, Q, and R, each a map layer, and a new map created showing the computed value of b at every site in the map.

One important function of a GIS is displaying and quantifying the relative nearness-to and distance-from a certain feature. Each cell will have a different distance - from that feature, affecting how suitable that cell is for some purpose. The combination of these functions will be illustrated later in a map. Fig. 1 shows the relation between two layers as a simple equation. Fig. 2 illustrates the possibility of using a large number of layers to study different variables in these layers having the same geographic location.

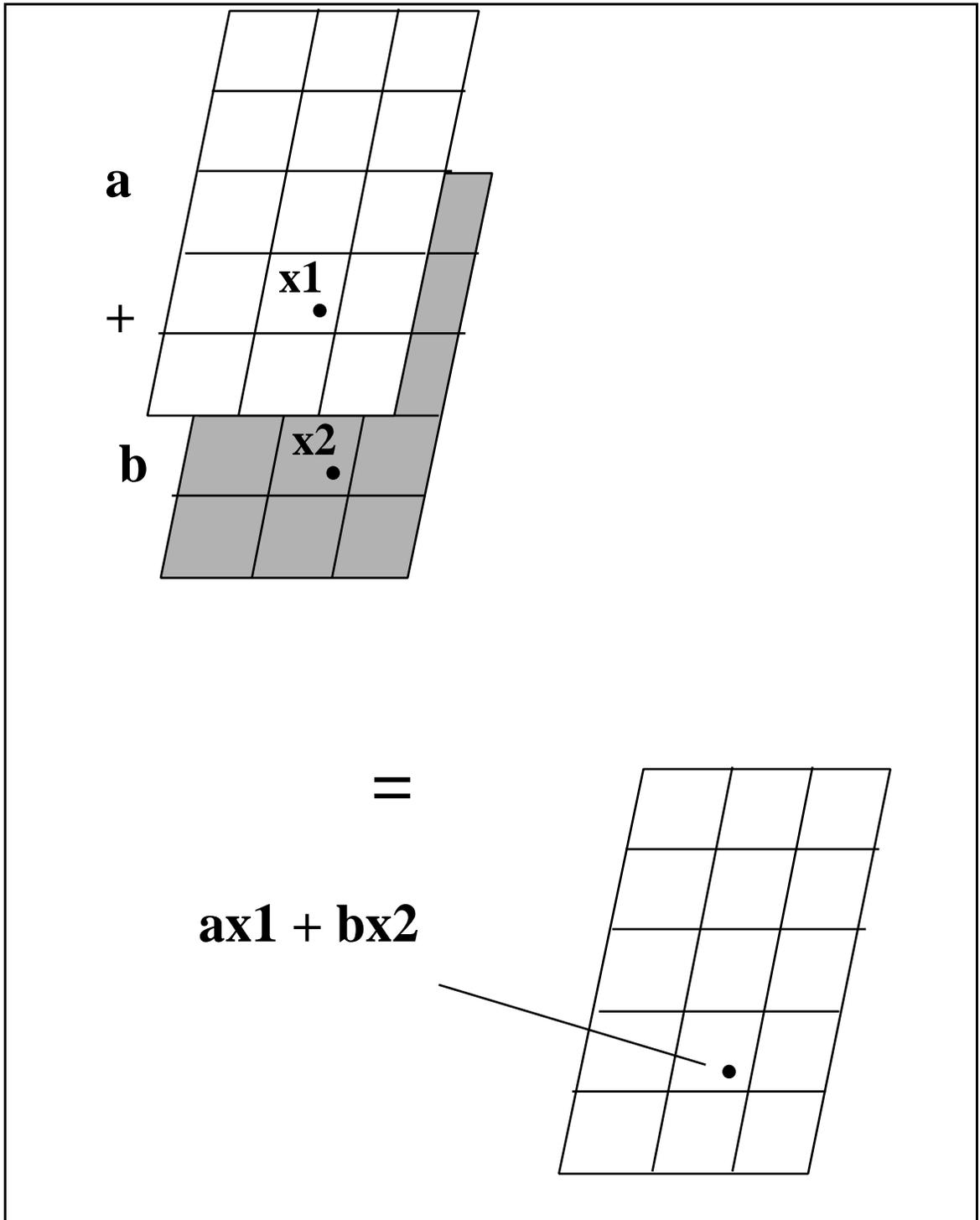


Fig. 1. The relation between different factors of the same geographic location.

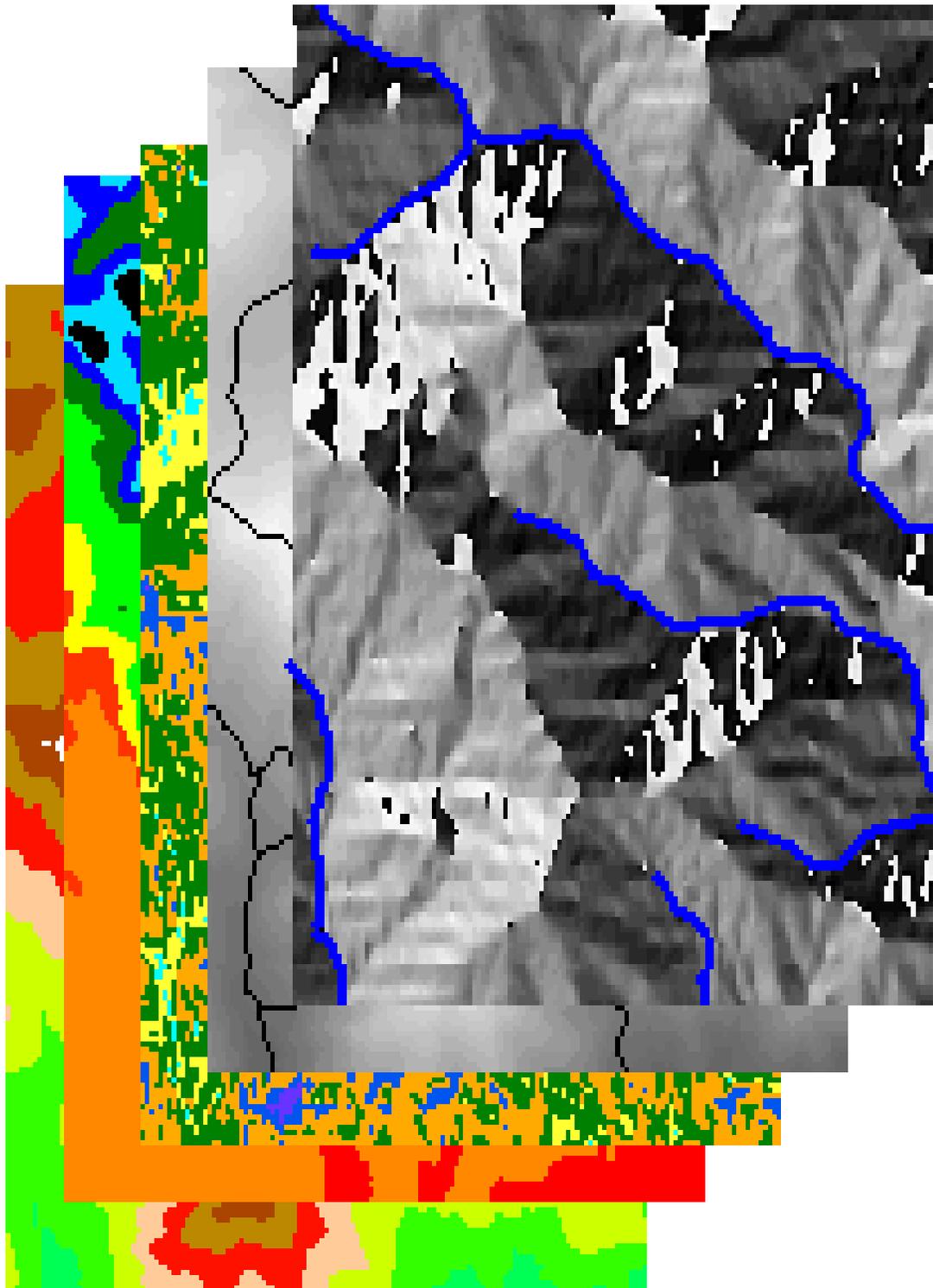


Fig. 2. Different map layers of the same geographic area.

Chapter 2: Procedures and Results

Hardware

The list of hardware used in achieving the objectives of this project is presented in Table 1.

Software

PCI was the software used for importing the digital elevation model (hereinafter DEM), producing most of the raster layers, and doing watershed analysis (PCI, 50 West Wilmot street, Suite 200E, Richmond Hill, Ontario, Canada L4B 1M5.). TNT MIPS v:5.2 was used for manipulating output and producing bitmap files (MIPS, MicroImages, Inc. , 201 North 8th street, Suite 15, Lincoln, Nebraska 68508-1347).

Table 1. Specification and price estimates for the hardware used in this project suggesting characteristics of a minimum and slightly expanded system for the work described in this paper.

Hardware	Minimum specification	Price	Recommended specification	Price
Processor	Pentium 90MHz		Pentium 150 + MHz	
Hard Drive	2 GB		4 GB	
RAM	16 MB		32 MB	
Video card	1 MB		2 MB	
	Computer Subtotal	\$ 1300		\$ 2150
Monitor	15" SVGA 1024*768	\$ 360	17" SVGA 1280*1024	\$ 830
			or 21" SVGA 1280*1024	\$ 1790
Printer	HP Design jet 350	\$ 3500	HP Design jet 350	\$ 3500
	Total	\$ 5160		\$ 6480 or \$7440*

* Considering the 21" monitor.

Microsoft Office was used for integrating bitmap files into printed document (Microsoft Corporation 1995). Some specialty programs (which will be discussed later) were written in the PCI special programming language and were used in the PCI software to produce custom-made maps. The emphasis in this project is on products and on the outputs of the GIS, but these are intimately related to hardware available, the software, the staff, and my graduate student colleagues. It is almost impossible to separate the components. The following emphasizes outputs or maps; the total system is the essential production unit.

The Window

A GIS study or project is typically conducted for (1) some large mapped area, or (2) some part of a map such as an ownership, an agency area, or a land ownership. I selected a large area for operation and demonstration. There was no specific problem, no specific analysis to be performed. It was selected exclusively for demonstration, for achieving the objectives of this project. The available software (PCI) allows a user to cast a rectangle over an area for which data are available. By selecting appropriate corner coordinates, a set of data can be “boxed in” or included within a window. The window is the area to be analyzed, the subset of data from a large data base common in most GISs.

A database was available at the Fish and Wildlife Information Exchange (Department of Fisheries and Wildlife Sciences, Virginia Tech, 205B Washington St.,

Blacksburg, VA 24060). I assembled some of it, simply used part of the existing data, and created other parts or layers.

I progressively limited data needed by geographic categories:

U.S.A.

Virginia

Madison County

Regional Planning District (a multi-county region)

The Fletcher 7.5 minute quadrangle topographic maps

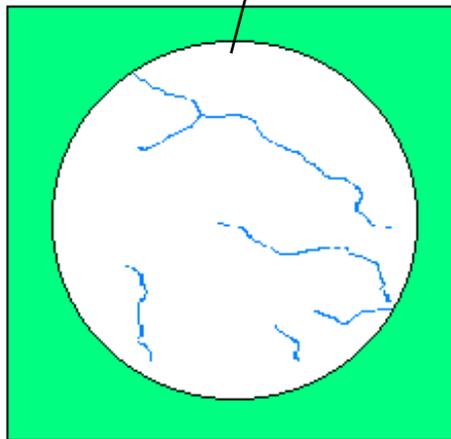
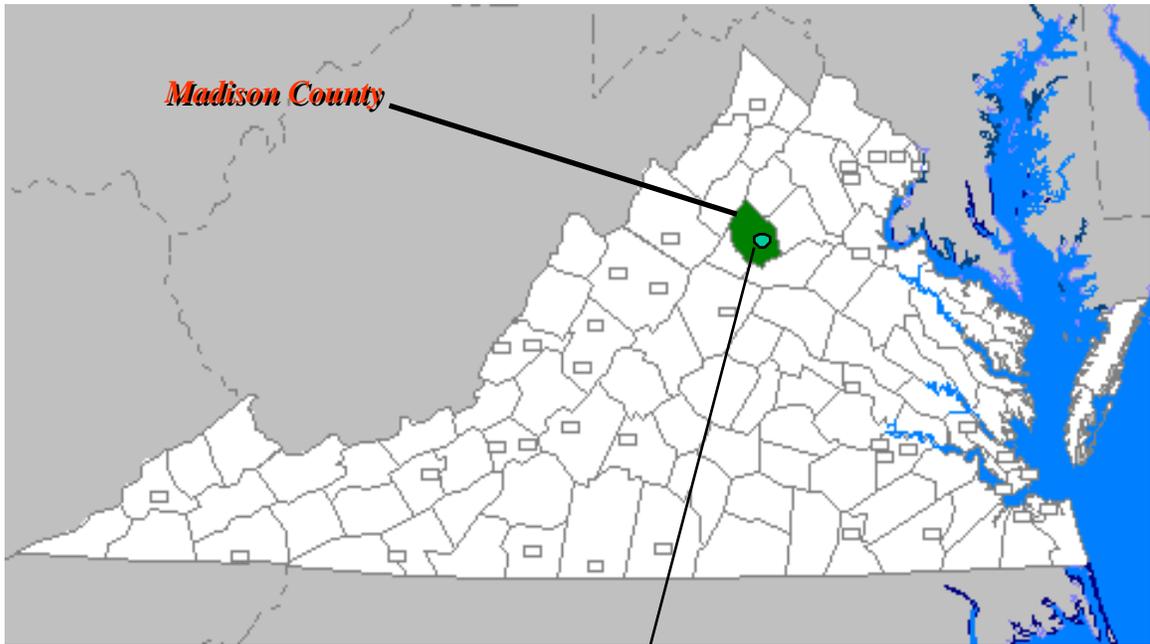
The Staunton - Rapidan River Watershed. (See Fig. 1 and Fig. 2.)

I created a window, the study area, with the coordinates between ($38^{\circ} 25' 26''$ and $38^{\circ} 27' 35''$ lat. and $78^{\circ} 22' 30''$ and $78^{\circ} 26' 00''$ long.). See Fig. 3. All data outside the window were ignored or excluded.

I then transformed the boundaries (using PCI software package) into the Universal Transverse Mercator projection coordinates between (4256940.0 and 4264350.0 N And 723450.0 and 728850.0 W). The area was thus composed of 180 by 247 pixels of dimension 30 by 30 meters each. The window had a size of 44460 pixels, 40 square kilometers (or 3996 hectares, 15.6 square miles, or 9990 acres). No boundaries (e.g., an ownership) were added; a variety of maps for the entire window were provided as part of this exploratory and demonstration project.



Fig. 3. Commonwealth of Virginia, USA, where the study area was located.



Staunton River - Rapidan River Watershed

Fig. 2. Madison County and the location of the study area.

Boundary

A window uses a boundary. Its border is the outer edge of an area. I could have digitized the boundary for an area. Boundary maps are of great importance in designating relevant areas, narrowing the work, and allowing questions to be made specific.

In this report I present maps. I shall not attempt to discuss the full meaning and implications of each map developed within the project. Such comments are relevant only within the context of a specific area, time, administration, policy, and problem or decision to be reached.

Elevation

An important map or data layer in almost any GIS is that for elevation (Fig. 5). The elevation at the center of every pixel is provided on magnetic tapes. I prepared a data matrix for the elevation at the center of each of my 44,460 pixels. I got data from the DEM of the US Geological Survey, (MS 804 National Center, Reston, VA 20192, hereinafter USGS). I used an Import command of the software PCI to import the data from DEM into PCI, simultaneously specifying the size and location of my window. I created a data base of unsigned 16 bit channels to accommodate the elevation data and other data to be produced for my layers using the create database (CIM) command of the Database Utilities package of PCI. From these raw data I could create an elevation map. I also created a linear relative elevation map. To do so I scaled the elevation data. My elevations within the window ranged between 1,267 feet (380 m) and 3,943 feet (1183

m). I divided the elevations into 10 equal categories. I assigned colors to each of the 10 categories using a Pseudo Color Table (PCT) within the PCI. I used the edit PCT in the Image Works PCI program. The result was then transformed into an ERDAS file using the ERDAS write command of PCI. The file was then imported into the software package (MIPS) using the commands Prepare, Import, Raster, ERDAS file. The elevation layer was then printed onto a plotter. It was also sent to a DOS file where it could be used by any printer. The raw elevation-data layer map is shown in Fig. 5. The relative elevation layer is shown in Fig. 6. These figures demonstrate that two or more layers (an almost unlimited number) can be produced from the same data by only changing the category and color (Fig. 7).

From one perspective, an elevation map layer is of little more use than a conventional contour map. From another perspective, it can provide more information readily than a map, for example to emphasize the highest or lowest areas or shown at a glance proportions of an area that are high or low. Fig. 6 shows 10 classes or elevation in categories but it is equally easy to produce two classes, for example, to show where a plant disease or range of animals is limited. Elevation is an important factor in many chemical, physical, biological, and ecological phenomena, so such maps are of wide potential interest.

Data may be categorized in different ways as shown in Fig. 6. The data may also be transformed (e.g., all elevations squared) to fit a known or hypothesized relationship, one that is non-linear. To emphasize the high-elevation areas - colder temperature, lower

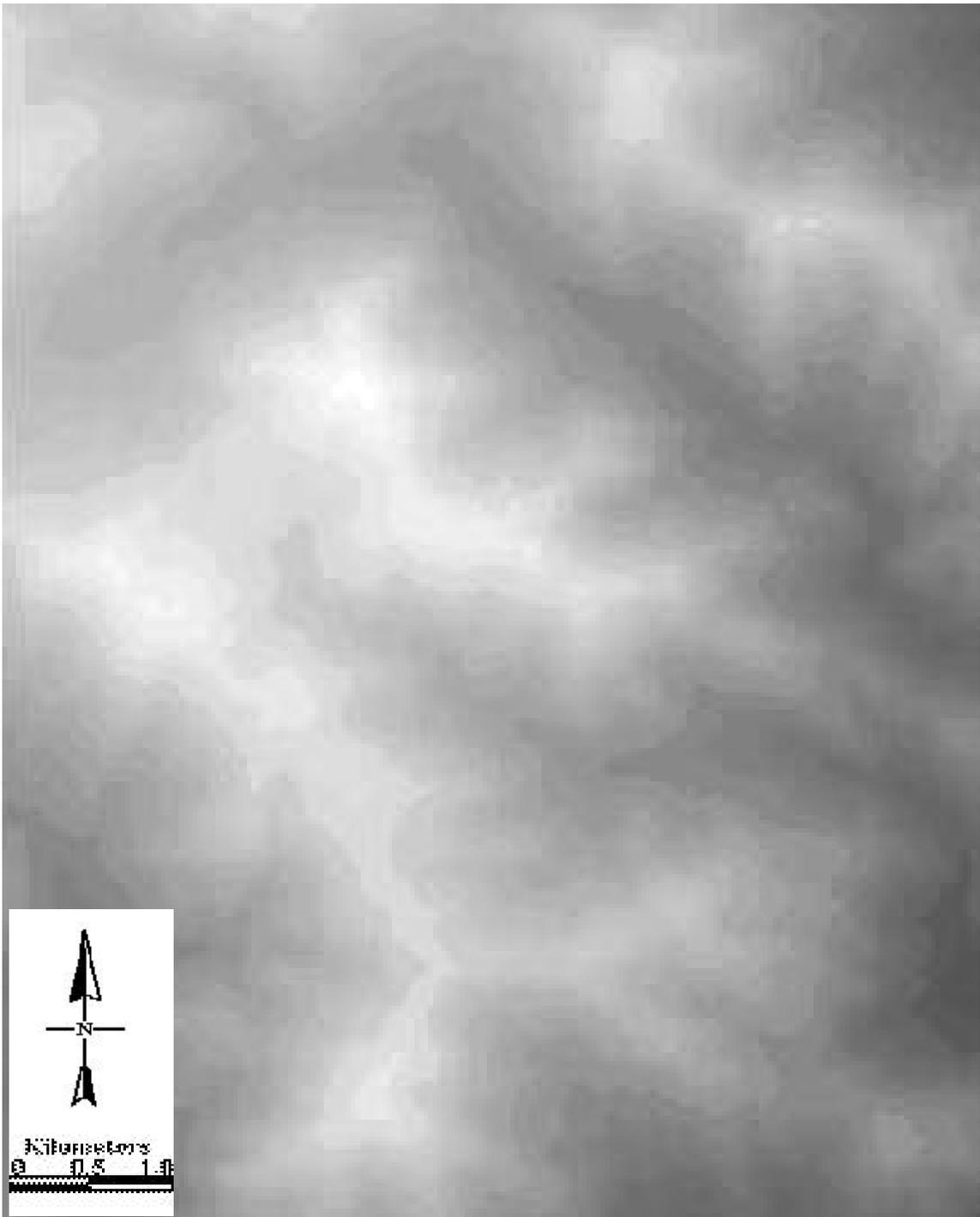


Fig. 5. A display of raw elevation data for the study area from (DEM). Light areas are of high elevation.

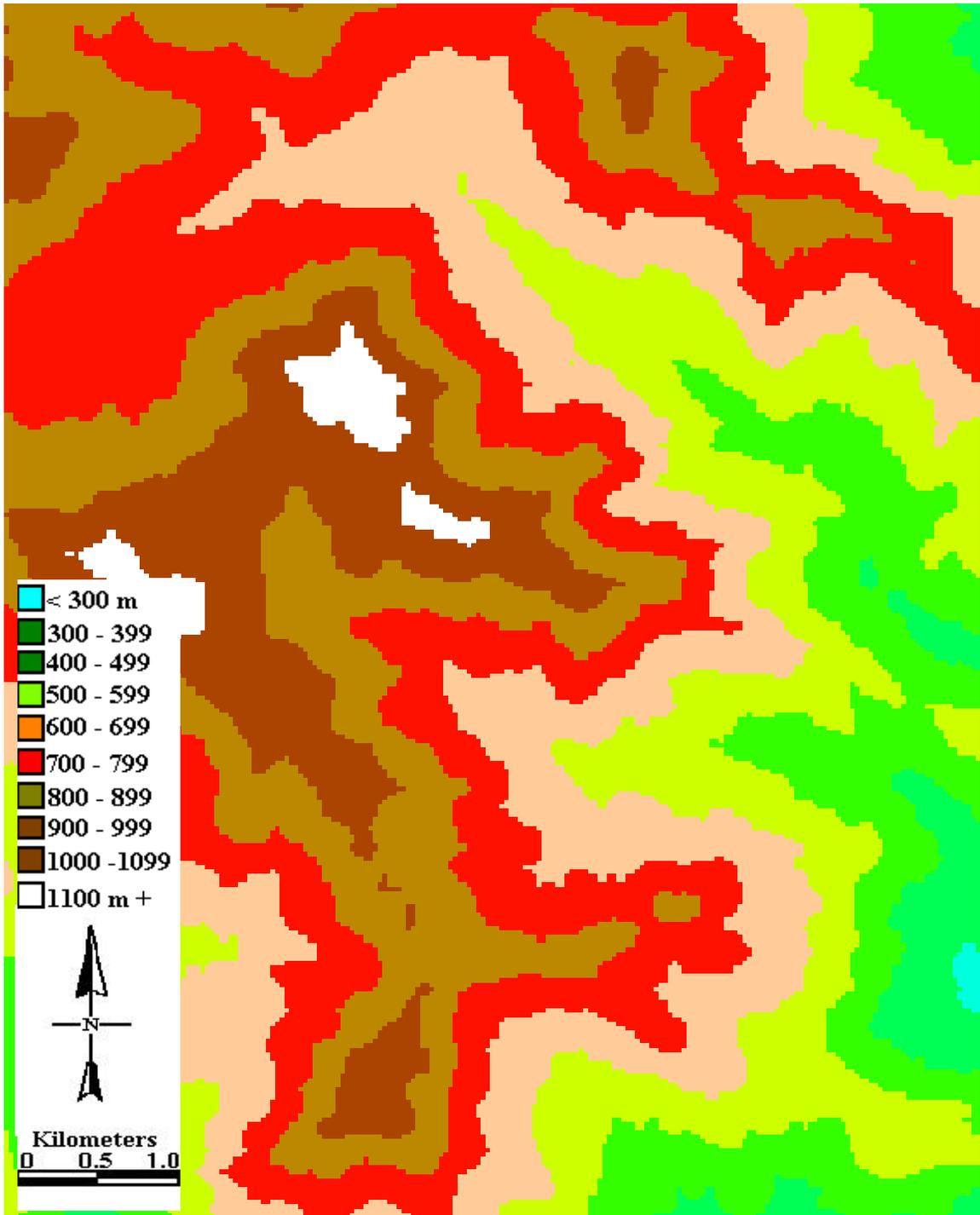


Fig. 6. Elevation data shown in 100 m categories for the study area (see legend).

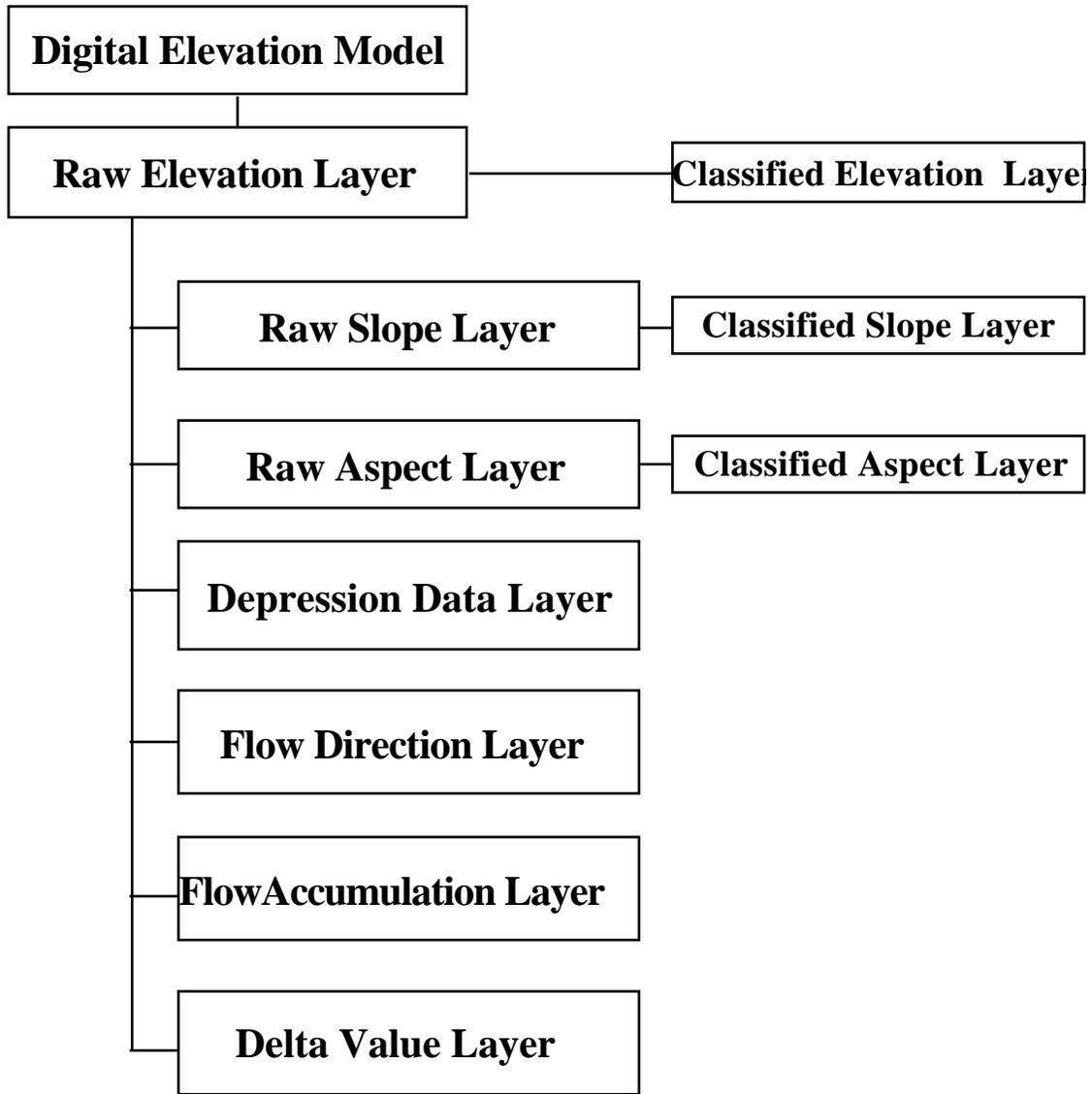


Fig. 7. Flow diagram showing layers derived from DEMs.

pressures, shorter growing seasons, all singly or in combination – an alternative map may be created for interest or for hypothesis testing. The maps related to elevation, shown above, present one of the difficulties in discussing GIS development. From one data set (elevation) I have demonstrated several maps. Each can be viewed as a “layer” and can be used with other layers, like slope, to overlay and study combinations, or as the basis for creating new layers. Slope may also be created from elevation data. See Fig. 7.

Slope

I created a slope layer based on the elevation data reported above. I used the Slp command of the Terrain Analysis package of PCI . A raw slope image was developed in gray scale shown in Fig. 8. I wrote a program in the DOS package of PCI to categorize the slope data to different categories. Using the 7 land classes of the Natural Resource Conservation Service (formerly the U.S. Soil Conservation Service) shown in Table 2. I created a land class map, Fig. 9. This simple map used with other factors can make more precise classes suggesting suitability for major types of landuse.

In Fig. 10 is a 2-category slope map. All slopes above 20% rarely can be worked safely or economically with conventional logging equipment. The area in green is the maximum area feasible for forestry. This is 53% of the area of the window. Data and statistics are valuable outputs, as well as maps, of GIS. All of the area in red is also

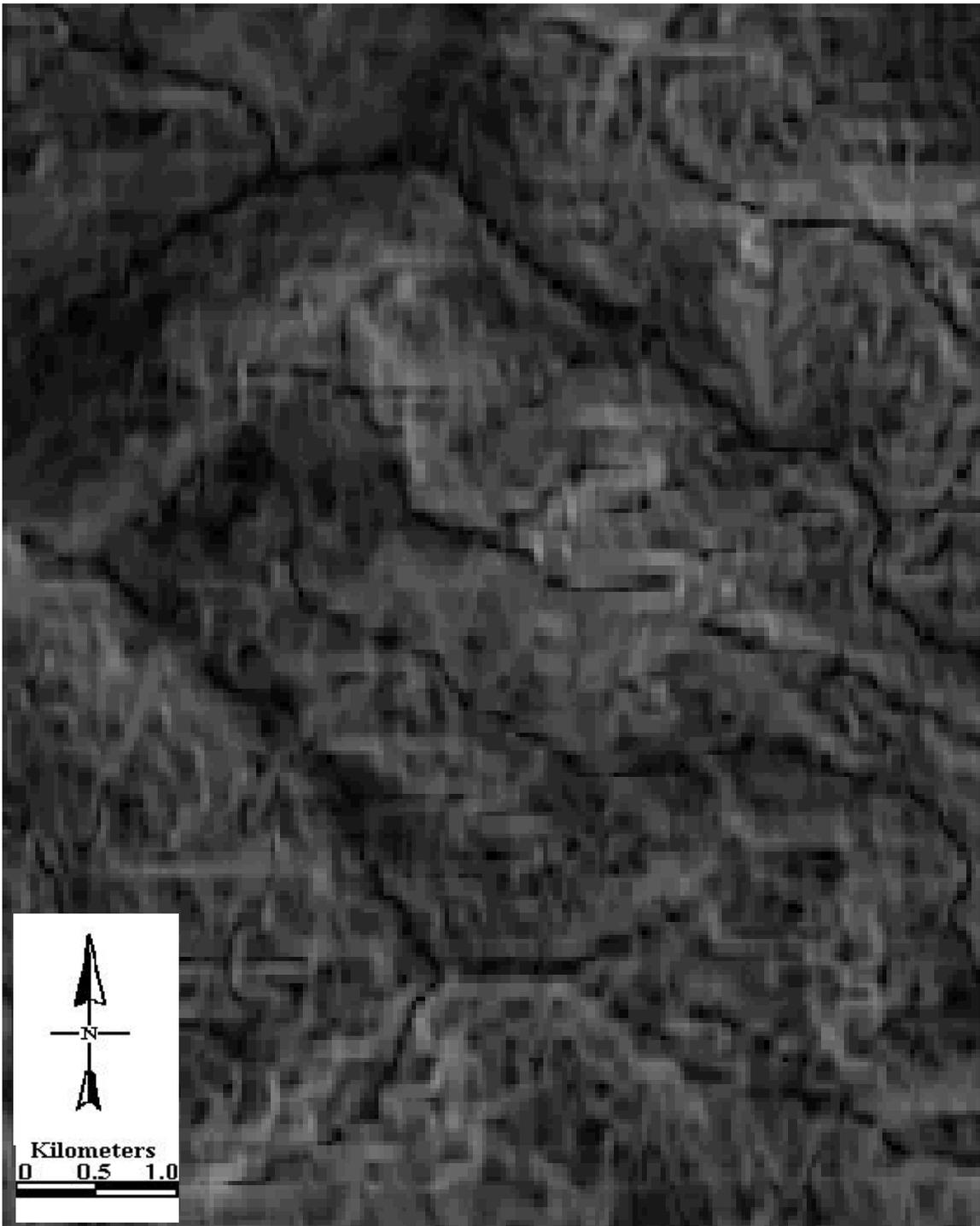


Fig. 8. Raw slope derived from elevation data for the study area. Slope range from 0 to 47. Lightest cells are steepest.

Table 2. Seven land slope classes in categories used by the Natural Resource Conservation Service (Smalley 1983).

Slope classes	Slope (in percent) in each class	Percentage of area in each class
1	0 - 2	0.96
2	> 2 - 6	2.26
3	> 6 - 10	7.51
4	> 10 - 15	17.17
5	> 15 - 25	47.47
6	> 25 - 45	23.82
7	> 45	0.88

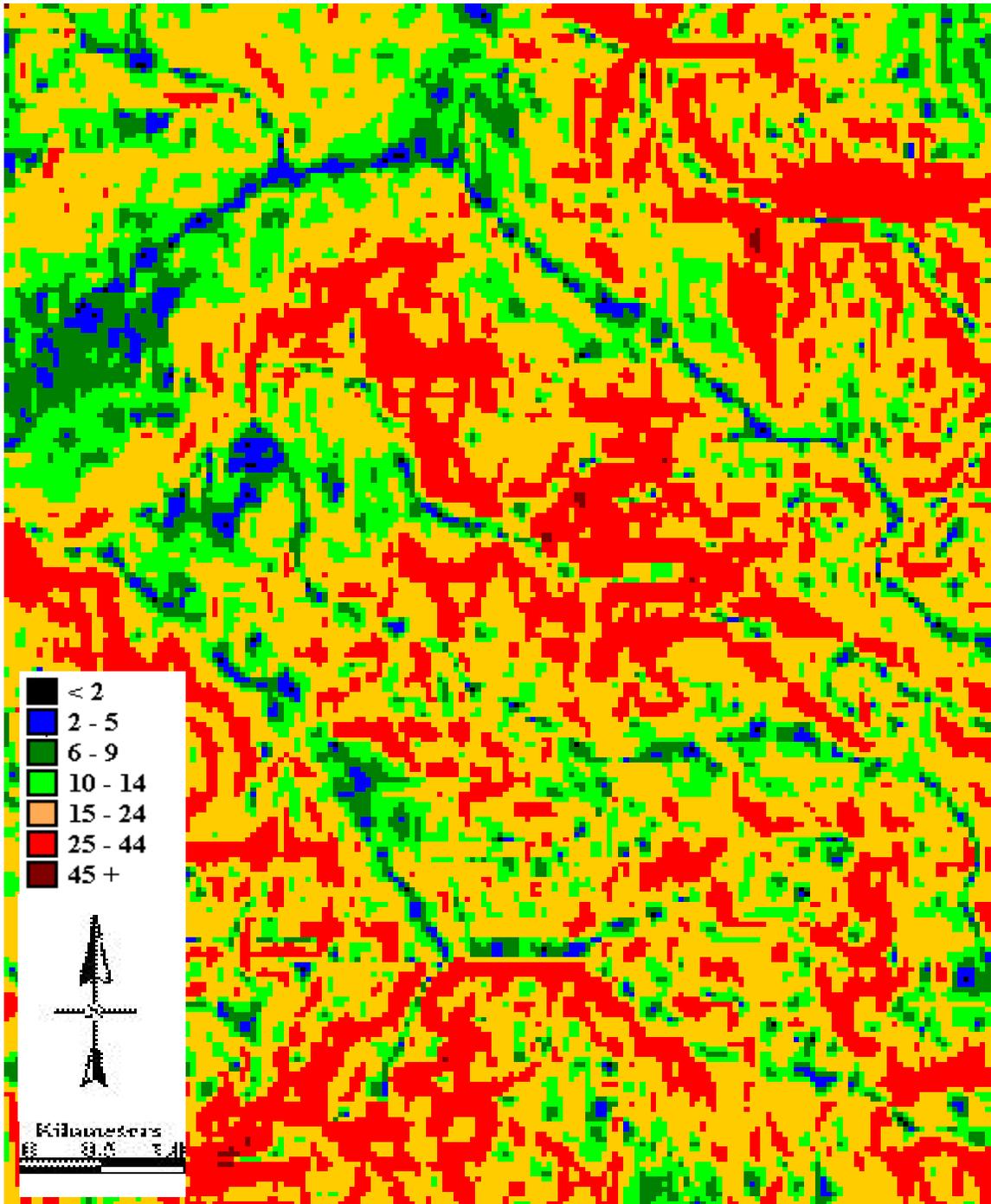


Fig. 9. Slopes of the study area in 7 classes (see legend).

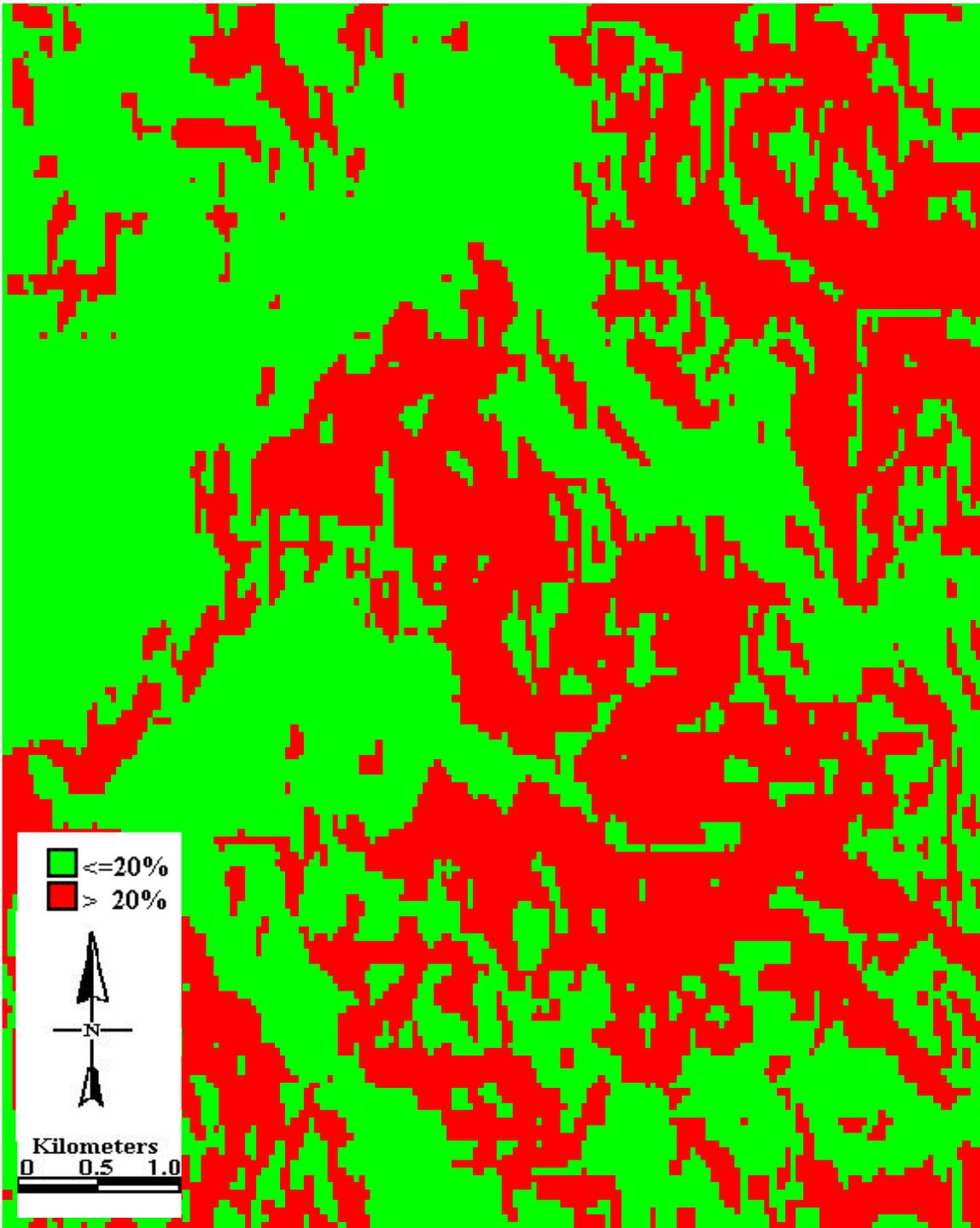


Fig. 10. Two slope classes are shown for the study area. Slopes equal to or greater than 20 % are perceived to be inoperative or inefficient with most logging equipment.

feasible to hold as an area for forest fauna. It will eventually (if it is not already) be “old growth” for it is land unsuitable for conventional logging.

In combination with a forest cover layer (described later) the proportion of land in forest that may be harvested at some time may be known. I developed a paired combination for slope and elevation, three categories of each. Fig. 11 shows the 9 categories on a map of the study area. Table 3 provides information on the categories. A layer combining slope and elevation may be very important for ecologists or others.

Forest Land Cover

David D. Morton is currently preparing a MS thesis describing how he has developed a vegetation map of Virginia. He is developing a map from Landsat and other means to display land use types. Using a land-cover layer for the window in combination with the less-than-20% -slope layer, a map can be produced to show the percentage of the window which is in forests (of unknown age) and which has a slope that may be harvested. Later, other layers may exclude those areas that are protected from harvest because they are within a National Park (i.e., excluding the “park” layer). Fig. 12 shows the combined forest cover map overlaid with roads and streams (Anderson et al. 1976).

Table 3. Information in the study area about elevation and slope combinations into 9 classes.

Elevation	Slope	Categories	Area in acres	Percent of window
High	Steep	1	123.5	1.21
	Moderate	2	72.47	0.71
	Flat	3	49	0.48
Medium	Steep	4	136.45	12.8
	Moderate	5	2561.86	25.1
	Flat	6	1276.85	12.51
Low	Steep	7	919.62	9.01
	Moderate	8	2621.06	25.68
	Flat	9	1274.48	12.49

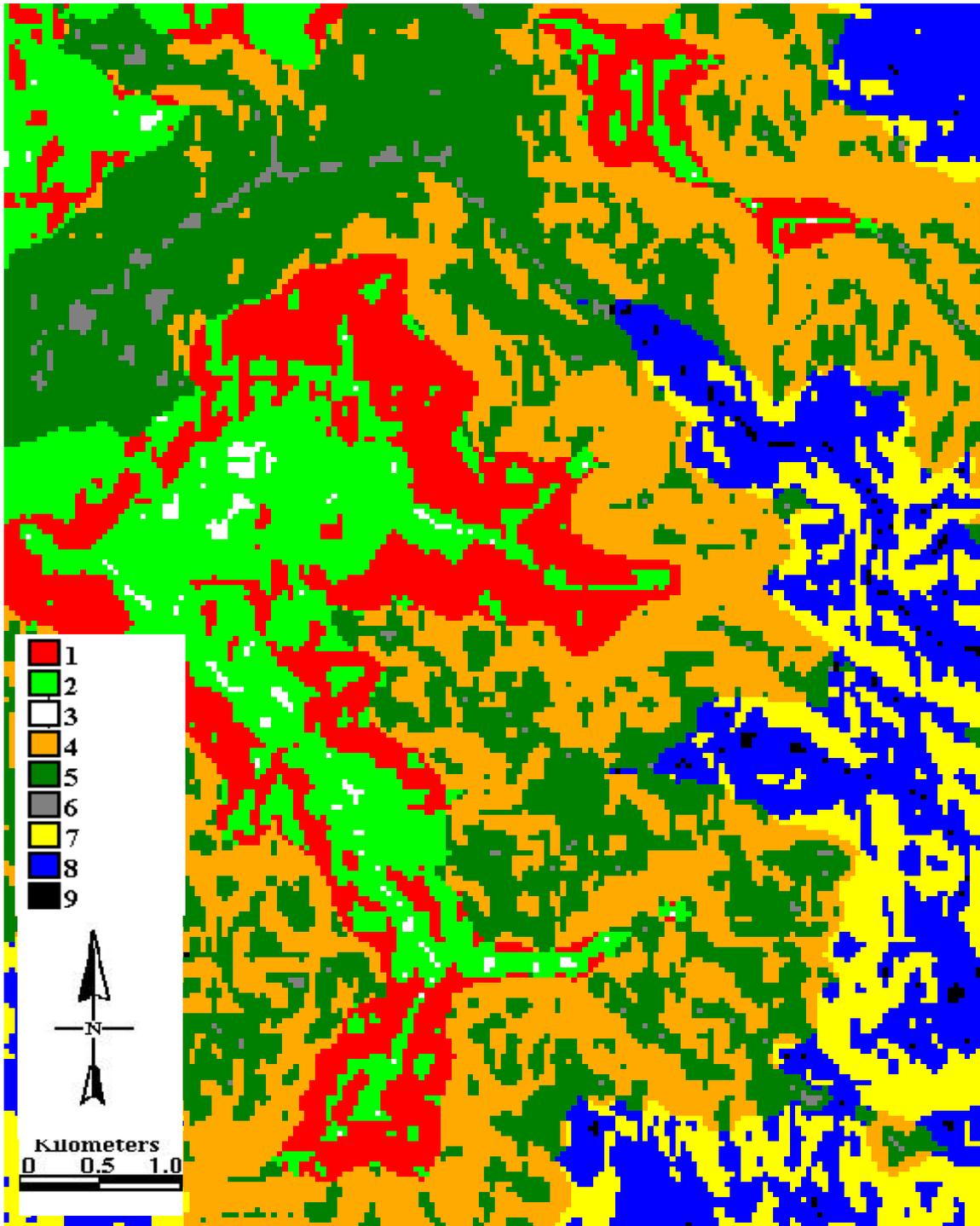


Fig. 11. Combinations of slope and elevation for the study area into 9 different classes described in Table 3.

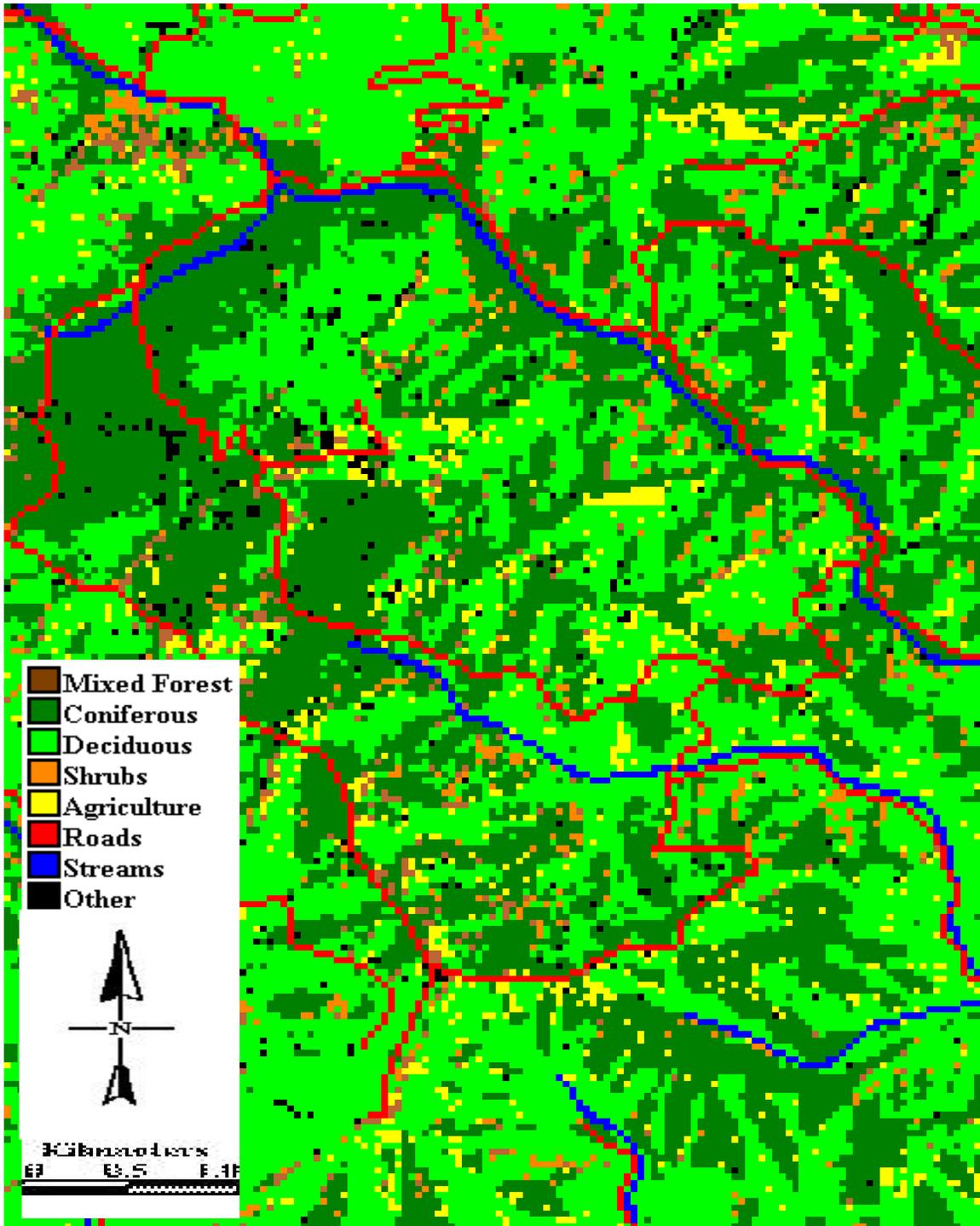


Fig. 12. Land cover (in modified Anderson classes) within the study area shown with roads and streams.

Soil Erosion

As another application, I have extracted one element from the universal soil loss equation for soil conservation planning (Wischmeier and Smith 1978).

The equation is:

$$A = R \cdot K \cdot L \cdot S \cdot CP$$

where:

A = predicted soil loss (tons / acre / year)

R = rainfall energy factor

K = basic soil erosion rate

L = slope length (feet)

S = slope (percent)

CP = cover factor

The component LS is :

$$LS = (0.43 + 0.3s + 0.043s^2 / 6.613) (/72.6)^m (\text{Cos}^2 (\text{Tan}^{-1} (s/100)))$$

where s is slope steepness in percent; L is slope length in feet; m is an exponent, the value of which depends on slope steepness (Farmer and Fletcher 1976). The equation also has been applied to construction sites and highway construction activity. The universal soil loss equation uses groups of factors affecting the soil erosion, one of which is the factor S depending on the slope, seen above but isolated as follows :

$$S = (0.43 + 0.3 s + 0.043 s^2) / 6.613$$

I produced a layer for the factor S, the erosive slope. Erosive slope is related to natural slope shown in Fig. 8. I wrote a model in the PCI programming language changing slope degrees to percent. I then wrote a program to run the formula stated above. I then presented the values of S in 6 categories in a map elaborating on the most stable or the most unstable areas. I then used the PCT edit routine in PCI to produce a map with visual quality, for example: cold colors for the stable areas and hot colors for the unstable areas. Fig. 13 shows the erosive slope (S factor) layer for the study area.

The map of erosive slope values is one step toward a potential future effort to create a Universal Soil Loss estimate. Fig. 13 expresses the role of slope as a single component of this multi-factored phenomenon. I evaluated the S - factor map with its overlaid roads and streams (Fig. 13). Dr. A. Doloff pointed out recent areas of land slippage and major erosion. These coincided with the high S values of the map. Several areas were noted where there was a high S value at a road. These may be hazardous spots and may suggest need for alternative studies, prevention, warnings, or another action to avoid consequences of massive erosion such as described within the area by Dr. Doloff.

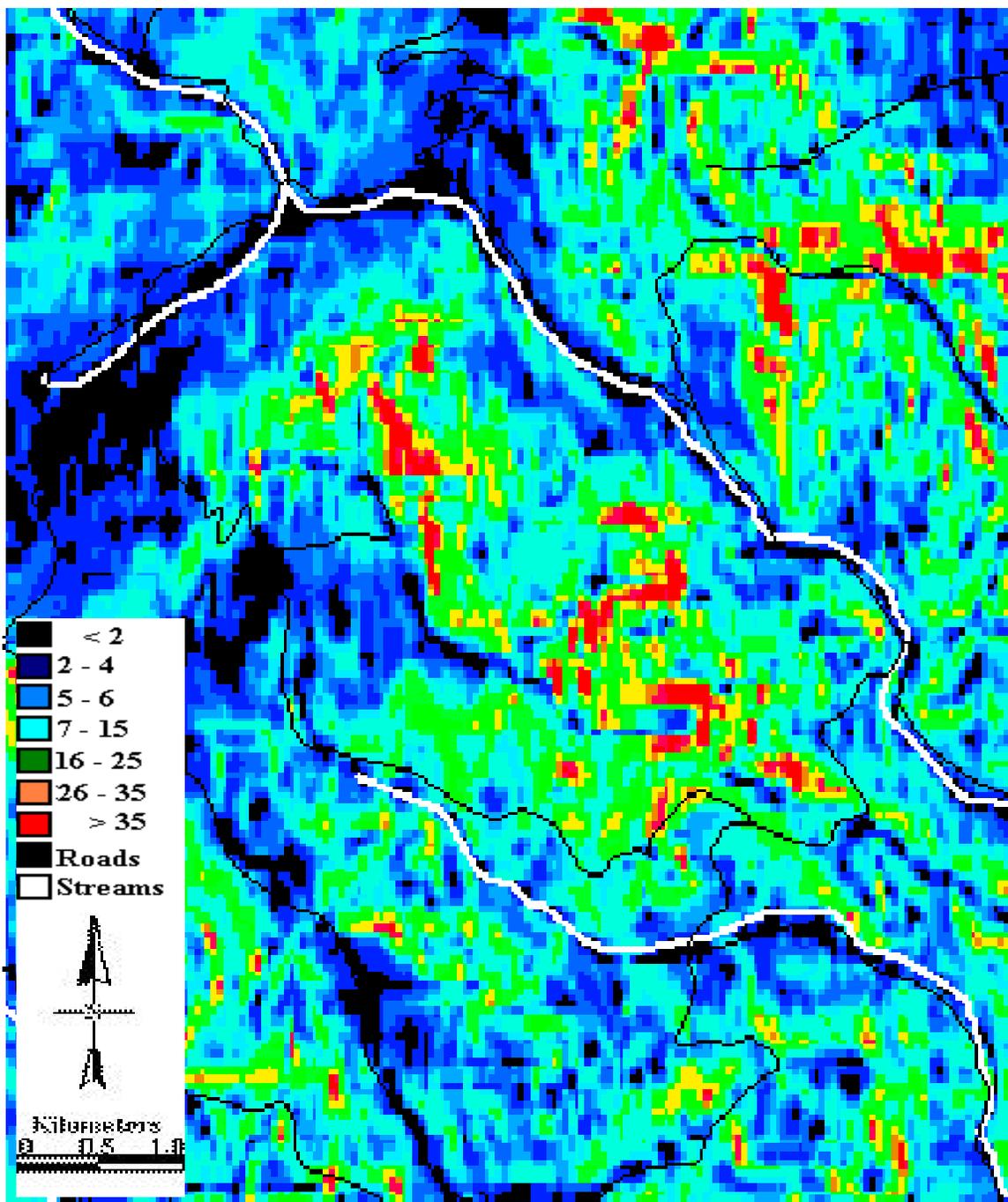


Fig. 13. Erosive slope (S) throughout the study area shown with roads and streams (see legend).

Aspect

Aspect is the direction faced by a land slope; it is the compass direction downhill from a point. I created an aspect data set using the subroutine ASP in the Terrain Analysis package of PCI software. The program computed an estimated aspect (in compass degrees) based on the elevation data of a pixel in relation to its surrounding pixels. Fig. 14 shows the aspect data for the study area between 0 and 360 degrees. I created a program in the PCI programming language to group the 360 degrees into 8 classes representing the major compass directions, N, NE, E, SE, etc. Fig 15 shows aspect data classified into these 8 directions. I assumed there are three aspects of special significance to ecologists and those interested in primary production. These are north-facing (the cool, low radiation sites); south-west-facing (the xeric, high afternoon-radiation and evapotranspiration sites), and all other aspects. I wrote a program in PCI programming language classifying these cells: category 1, 292.5 to 13 N; category 2, 202.5 to 247.5 SW; and category 3, all others. The three categories are shown in Fig. 16 .

Since south-west-facing slopes are generally poor timber-growing sites, we may hypothesize this to be the case within the study window and exclude them. By overlaying the (1) forest vegetation layer, (2) the slope-less-than-20% layer, (3) the non-southwest layer, and (4) an S-value less-than-25, we obtain a potential commercial forest map. On the other hand, another map is also obtained which can potentially be manipulated for forest, wildlife, and outdoor recreation on a sustained basis. Fig. 17 shows the first and second choices for sustained wildlife or wilderness recreation area on the bases of its

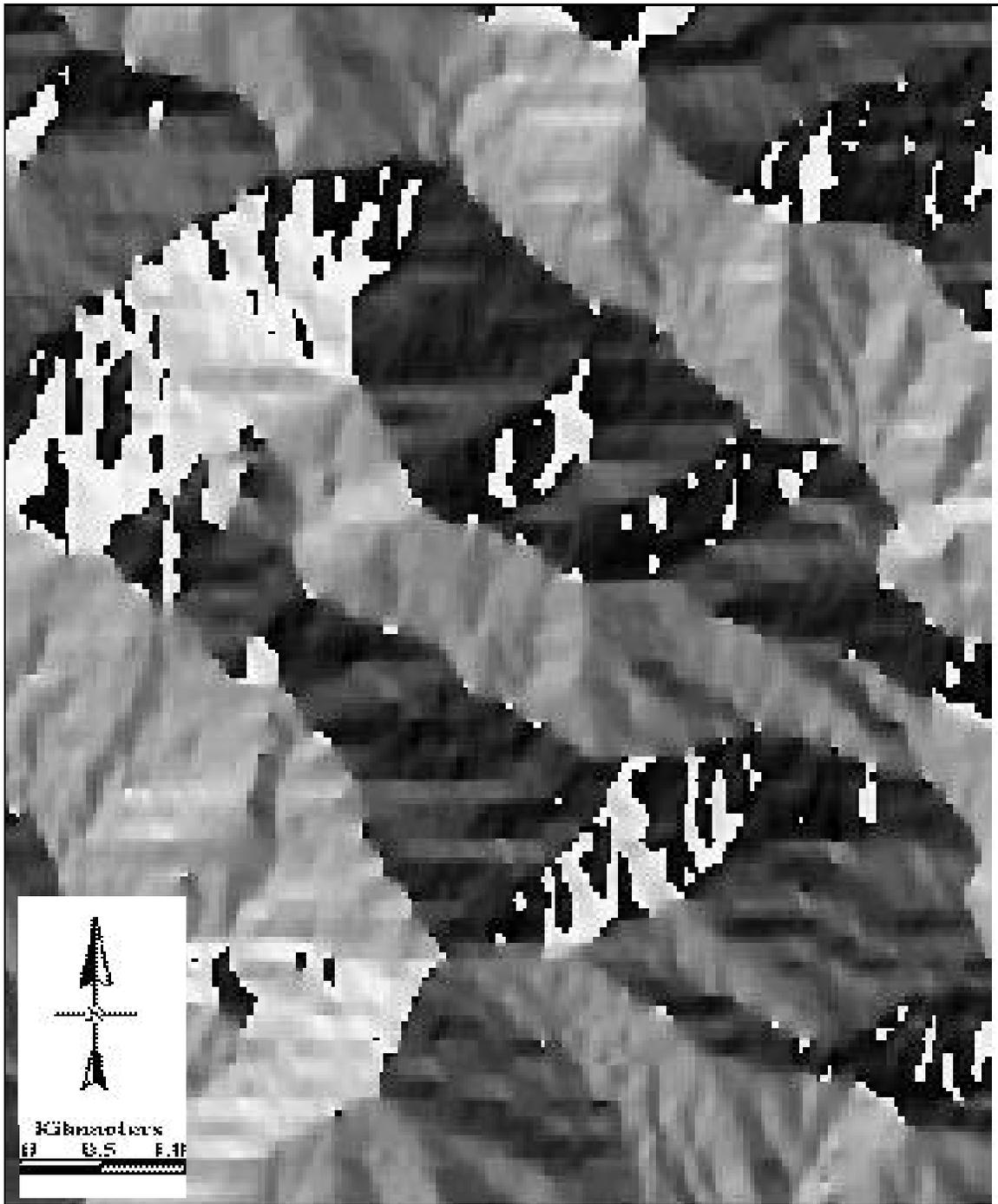


Fig. 14. Raw aspect derived from elevation data for the study area (values from 0 to 360, black = 0; white = 360 degrees).

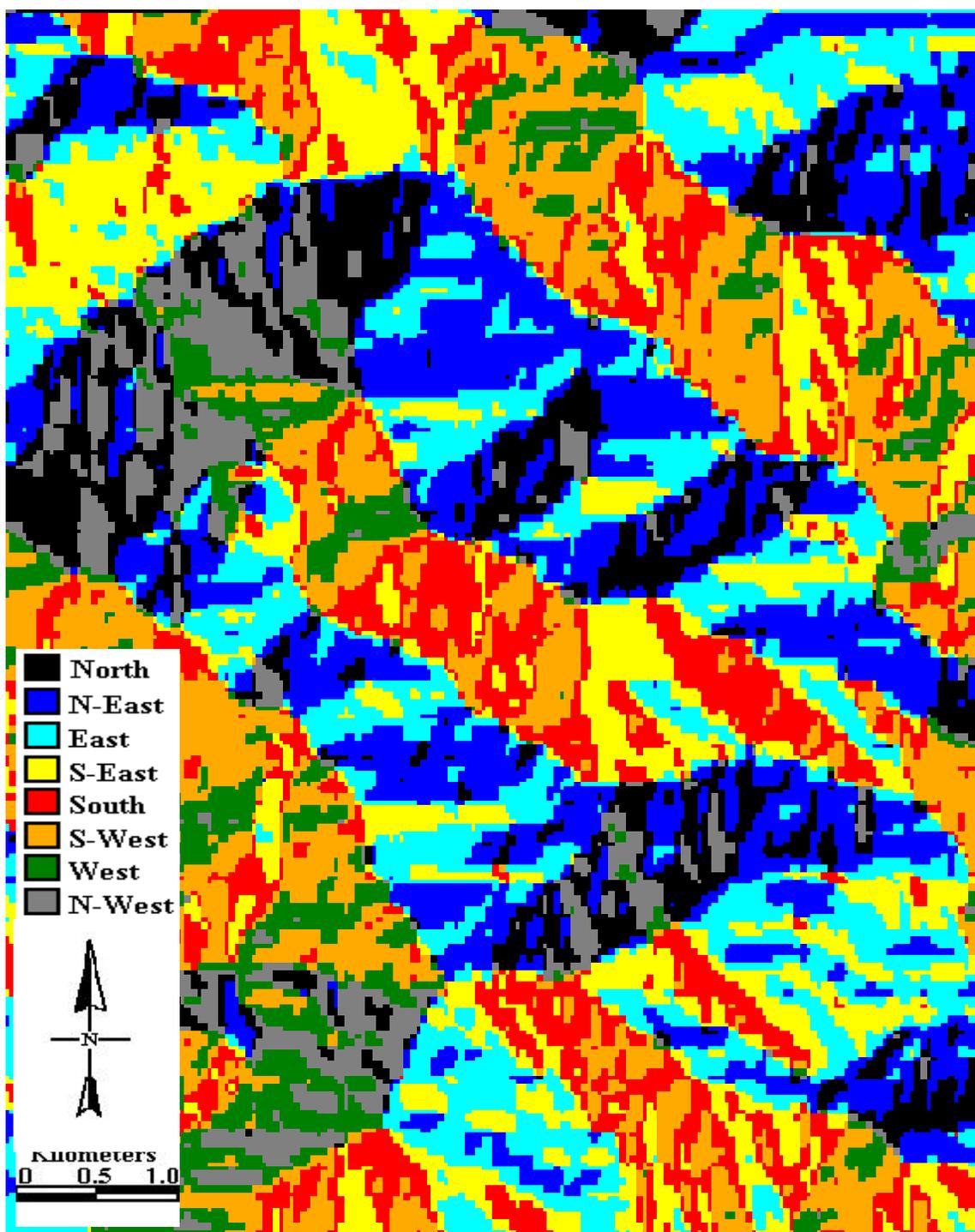


Fig. 15. Aspect of all cells of the study area shown in 8 directions (see legend).

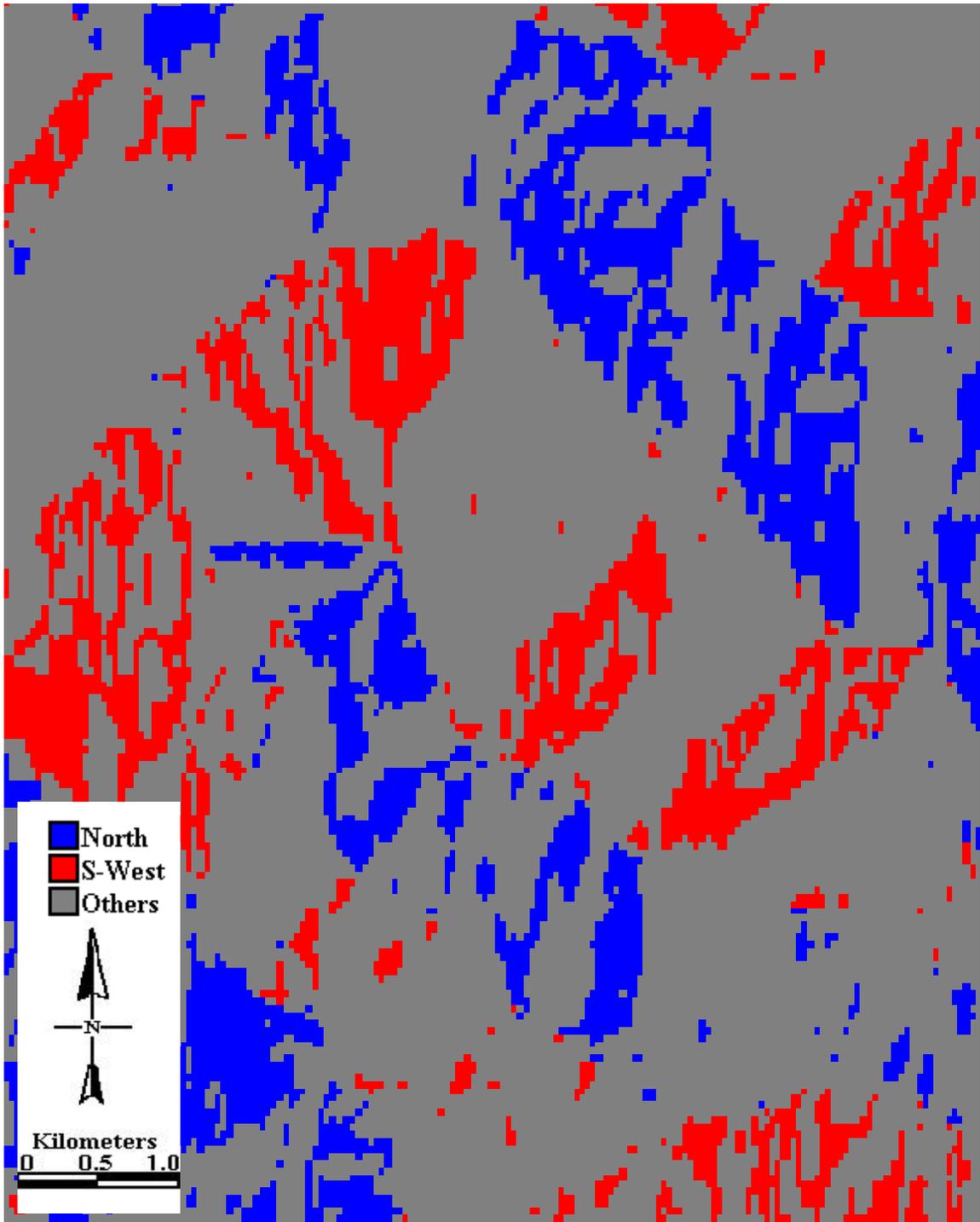


Fig. 16. Aspects of all slopes in the area shown as 3 ecologically-relevant classes (see legend).

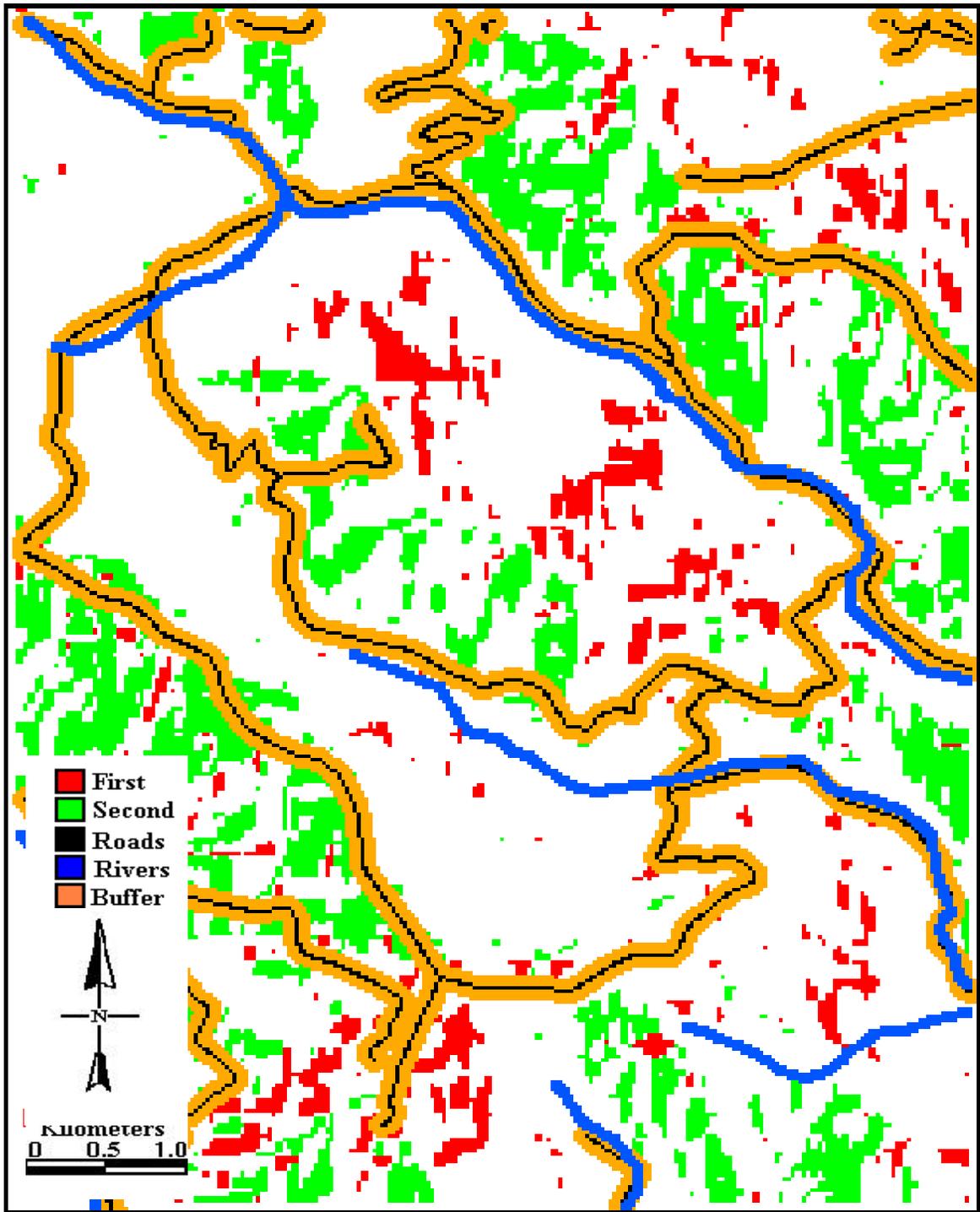


Fig. 17. First and second preferences for suggested wildlife and wilderness areas overlaid by rivers, roads, and 100m adjacent zone.

unsuitability for logging. The first choice would be: (1) area that are forested (all of the study area is forested), (2) slope-more-than 20%, (3) southwest facing slopes, and (4) S-value greater-than-25. The second-choice sites include these factors but relaxes the erosive slope criterion to include all erosive slope values, the equivalent of not including it. This combination of raster layers was overlaid by 3 vector layers which are the roads, the adjacent 100 meters buffer to the roads, and the rivers in the study area. This group of combined 7 layers can help in studying different options to guide a decision making process.

Watersheds - Depression Data

Using the same steps, I produced a group of watershed analysis layers illustrating drainage-related data. These layers were generated from elevation data using the WTRSHED command of PCI's Terrain Analysis software package. I started by creating a layer indicating the depressions in the window for the watershed. This is shown in Fig. 18. The layer, in retrospect, is identical to the Elevation layer.

Watersheds - Flow Direction

Flow direction is another layer that calculates from elevation data the direction of flow of water in the study area. Fig. 19 shows the flow-direction layer. The layer is identical to the aspect layer.

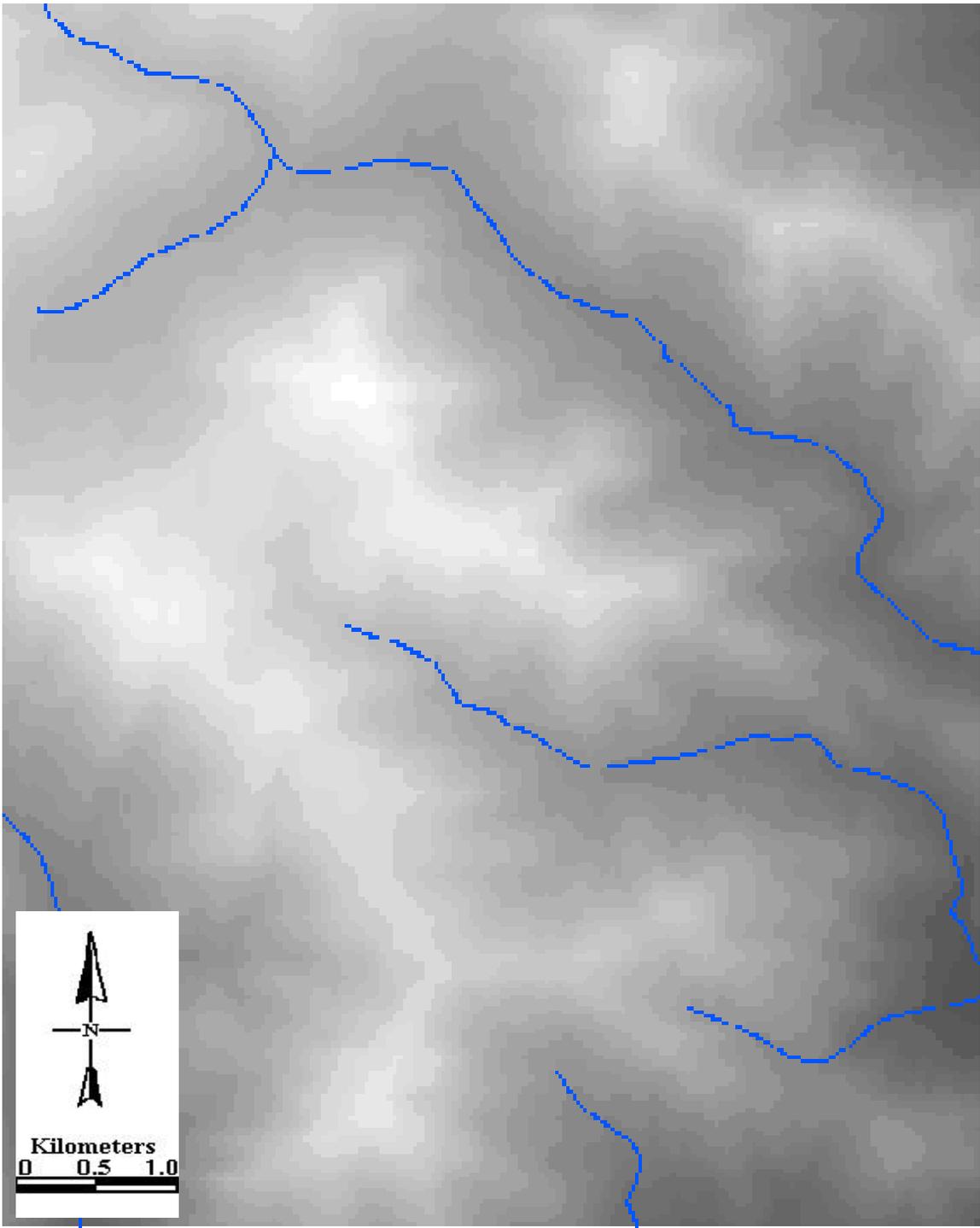


Fig. 18. Depressions derived from elevation data. The map is overlaid with streams. Light areas have high elevations.

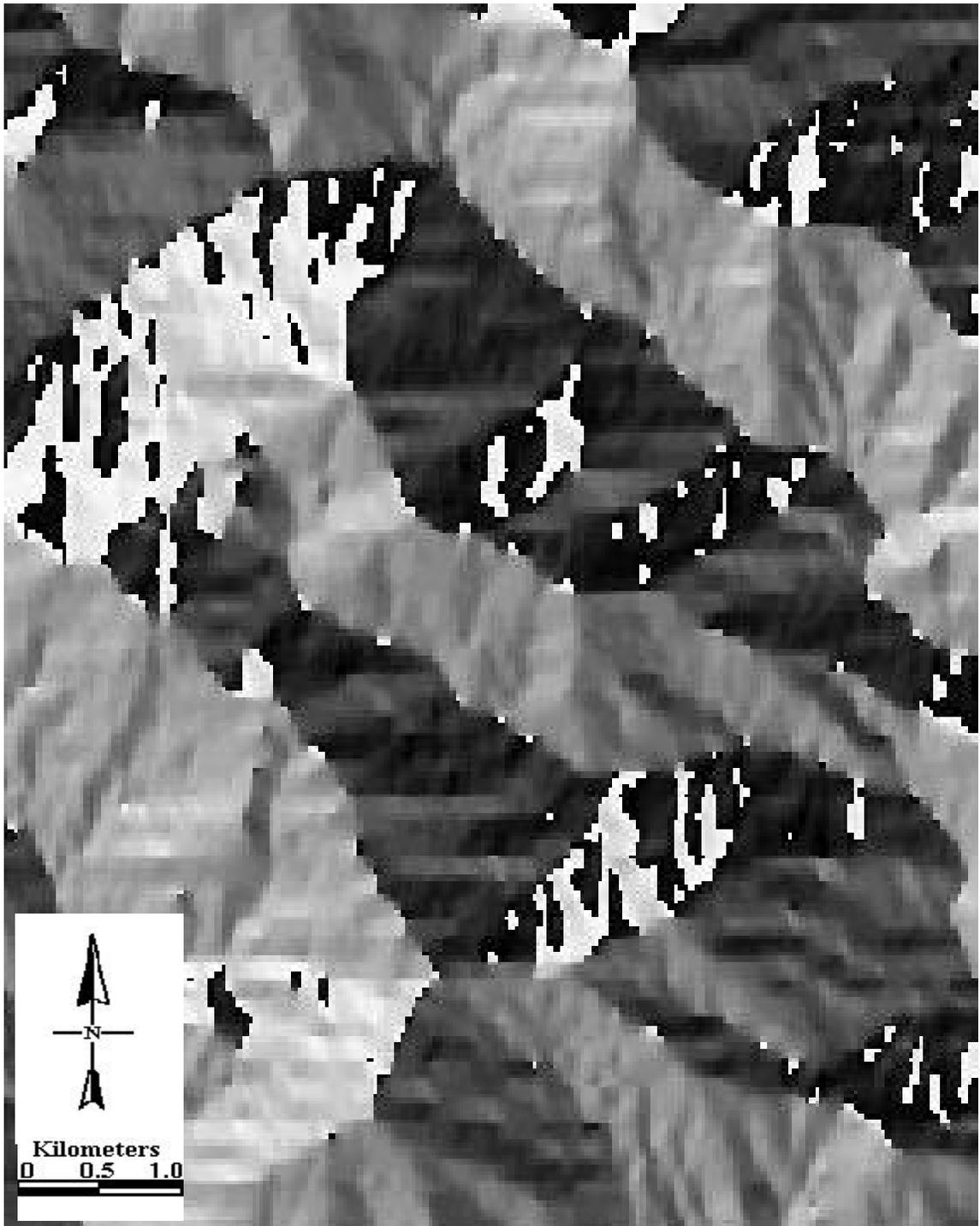


Fig. 19. Estimated direction of stream flow derived from elevation data for the study area. This map is identical to that of “aspect” although described as separate algorithm in the software.

Watersheds - Flow Accumulation

Flow accumulation is a layer mapping the expected result of water flow in the potential streams calculated from the elevation data. The map layer illustrates the relative accumulative water in potential streams. Some of these potential streams could be full of water in reality and others could be dry. Overlaying the vector layer of the streams in Madison county, with flow accumulation layer, shows a congruency between the pixels of high flow accumulation and the exact position of the Staunton River and the Rapidan River. Fig. 20 shows the flow accumulation layer, overlaid with roads and tracks. As shown in Fig. 20 , the hotter the color (the more red) the greater the value of the accumulation. Having produced a layer showing the roads, tracks, or planned bridges overlaying the flow accumulation data, planners may evaluate hazard potentials and emergency service needs. A layer of the flow accumulation overlaid with roads can be of extreme importance in case of floods for rescue personal to recognize the depth and strength of flow in different locations of the streams and to predict which roads may be damaged or blocked and to estimate the people at risk.

Watersheds - Delta Value Change-in-flow

The delta value is a parameter used to identify the differences in the value of probable change in the flow in a cell. This change is due to accumulative flow of water from all surrounding cells. Fig. 21 shows the delta value layer. The change in flow from

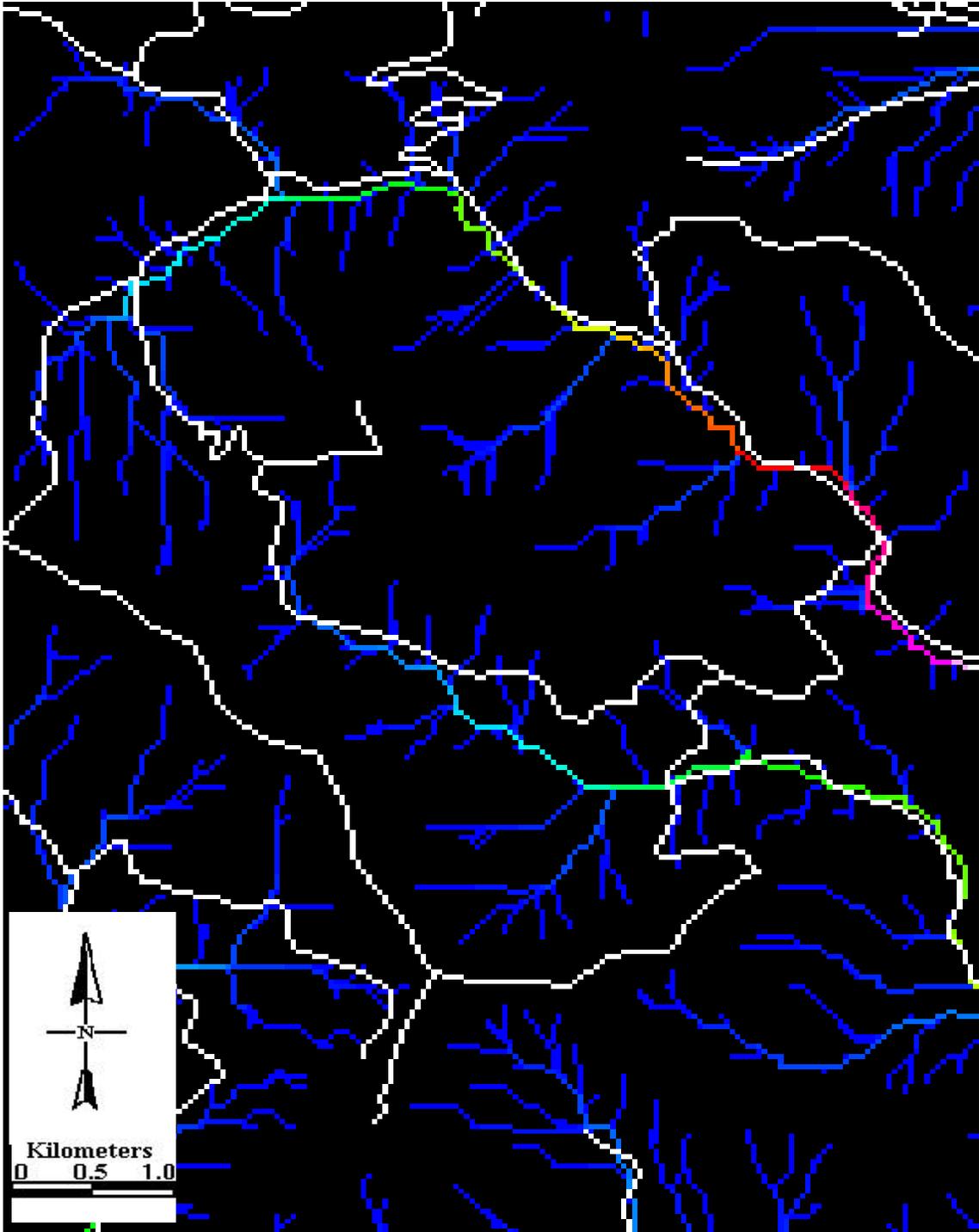


Fig. 20. The flow accumulation (that from all areas above a point) over laid with roads. Darker cells have higher likely accumulation potentials due to topography.

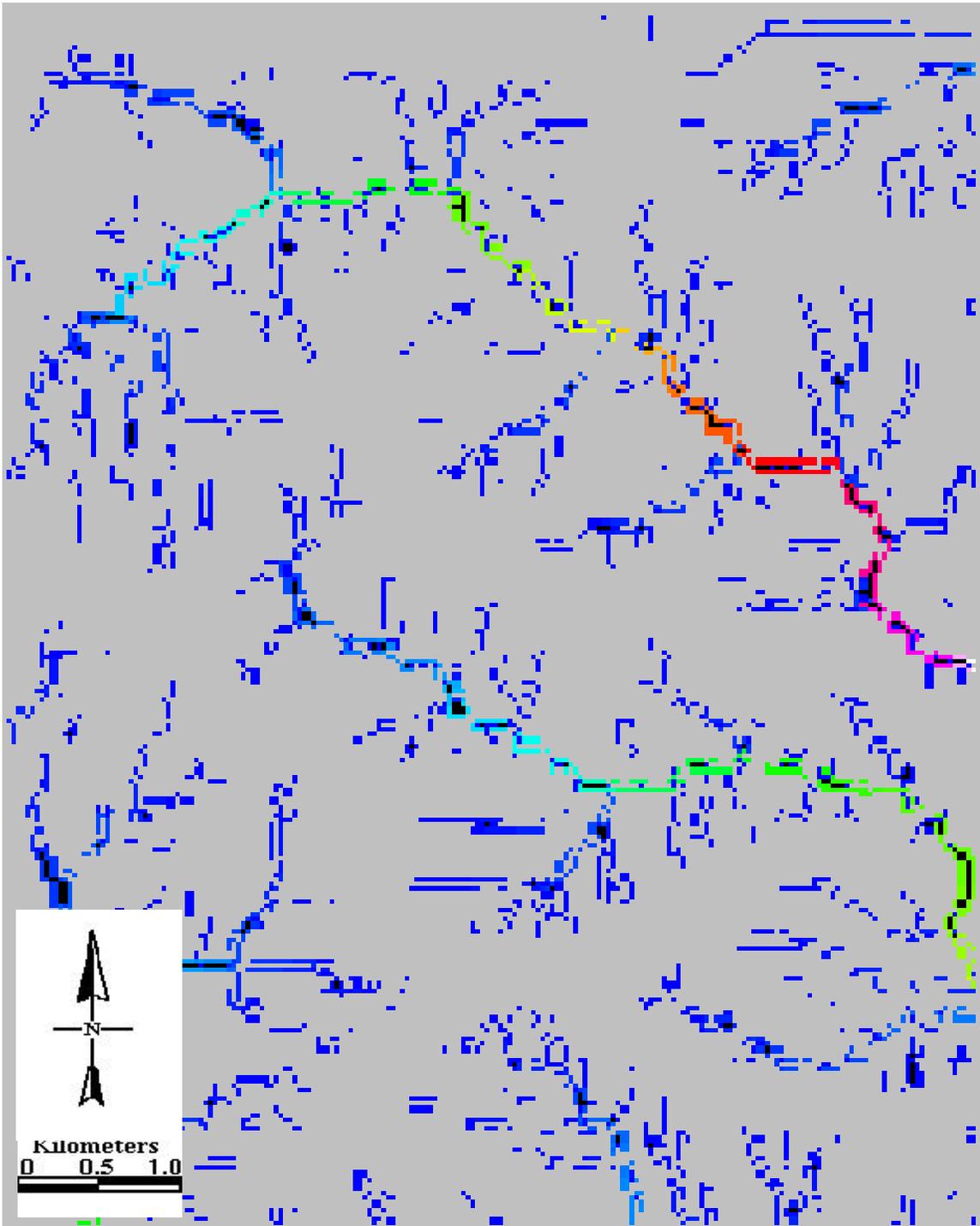


Fig. 21. Flow accumulation (delta value) throughout the study area. Hot color cells have more potential increase in accumulation; cold cells have less accumulation.

one pixel to the other is important in studying the hydraulic power of a stream or a river. This map may express relations of potential velocities that influence fish and aquatic life.

Watersheds - Streams

I created a map of all the rivers and main streams in the study area. The vectors of the country rivers and streams of Madison county were obtained from the Tiger files at the Fish and Wildlife Information Exchange (obtained from digitized maps provided from Tiger files bought by the GAP project in Virginia). Fig. 22 shows map of the major rivers and streams for the study area. Using the Make Buffer command of Prepare in the MIPS software package, I created a map of the streams with an additional 100 meters buffer or adjacent zone (200 meters total width).

Roads

I created a map of all major roads in the study area. The vector of the country roads of Madison county was obtained from the Tiger files at the Fish and Wildlife Information Exchange (obtained from the digitized maps provided by the Shenandoah National Park management). I imported the vectors into MIPS software package. Fig. 23 shows the map of the roads. Using the Make Buffer command of Prepare in the MIPS

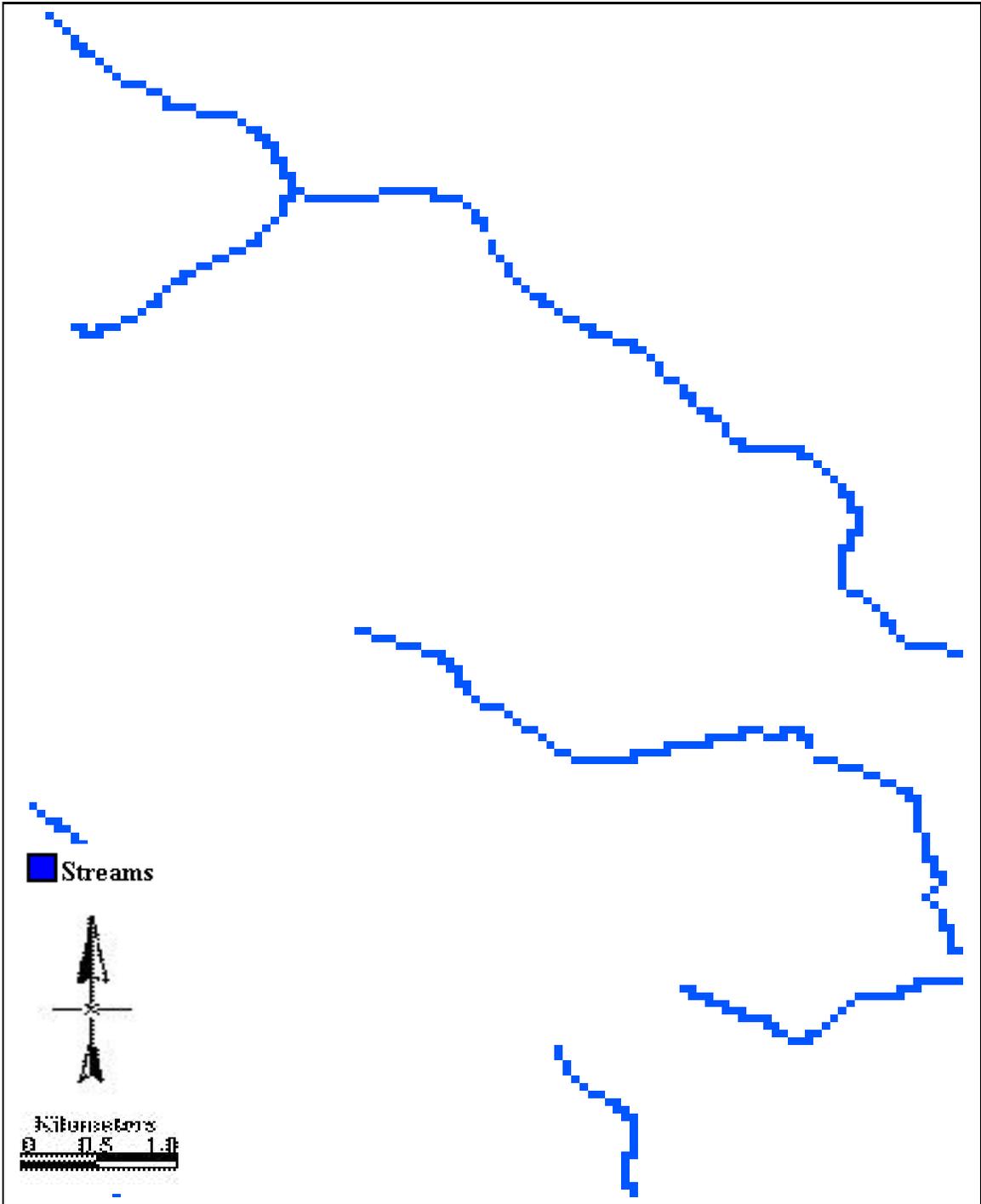


Fig. 22. Major rivers and streams in the study area of Madison County, Va.

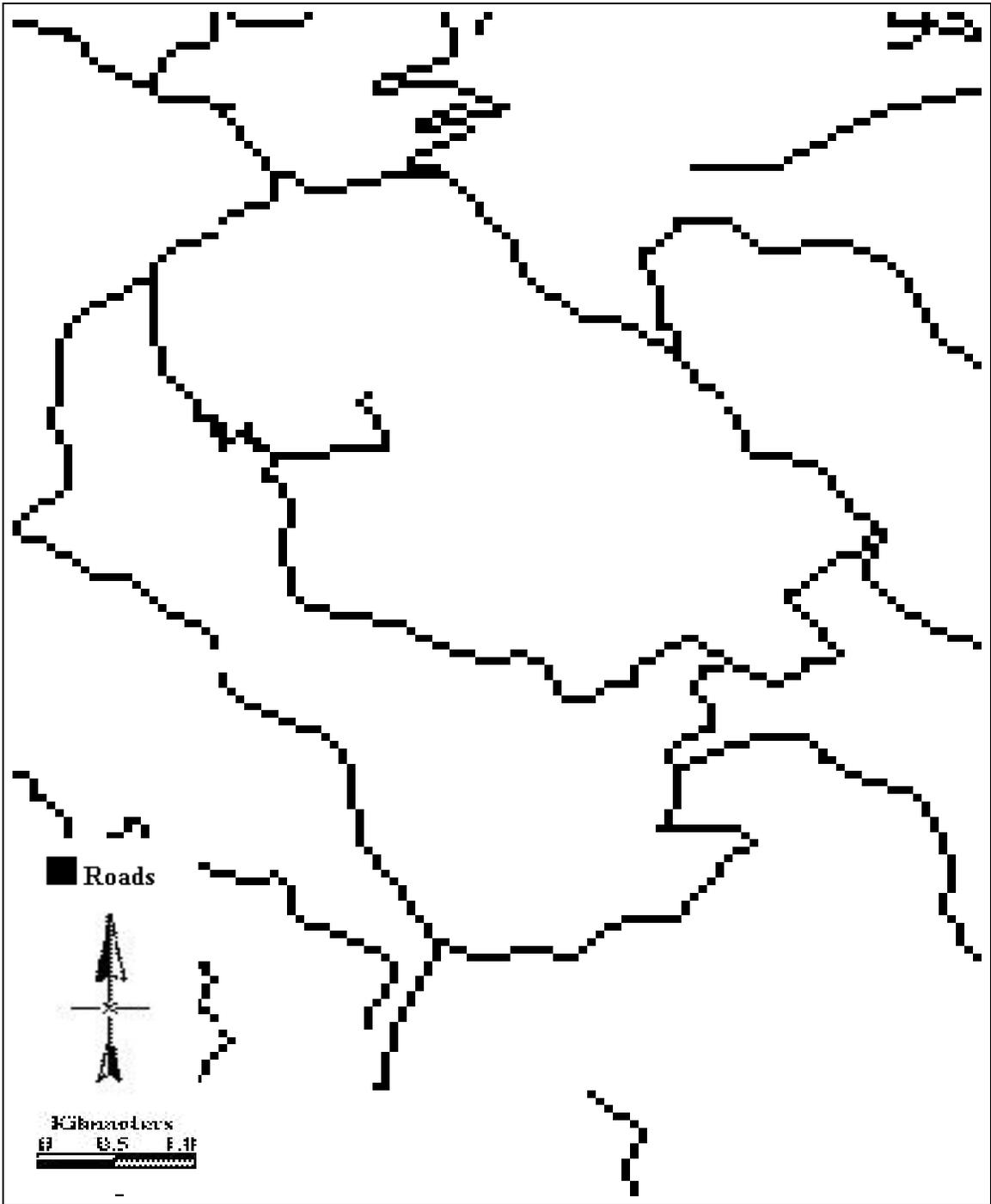


Fig. 23. Country roads of the study area.

software package, I created a map of the roads with additional 100 meters buffer or adjacent zone overlain on a map of the forested land with appropriate slopes previously shown (Figure. 17). This buffer zone map (Fig. 24) suggests the suitable areas for logging. Fig. 24 shows a combination of the roads and their adjacent zone overlaying the streams and their adjacent zone.

Climatic Changes

Climate has a great influence on the ecological systems of any area. The differences occur in temperature, precipitation, solar-radiation, etc. The National Climate Data Center, hereinafter NCDC, has records of climatic data over many years.

Climate-Temperature

Scott Kloppfer (personal communication), a graduate student colleague, used the data from the NCDC to produce an average monthly temperature layer and average solar radiation layer. I cut a window of my study area elaborating the differences in temperature. The data of 30 years(1960 - 1991) were used to obtain the average temperature of September as a demonstration. Other months, seasons, or annual values may also be mapped. Fig. 25 shows the average temperature in °F for each pixel in September.

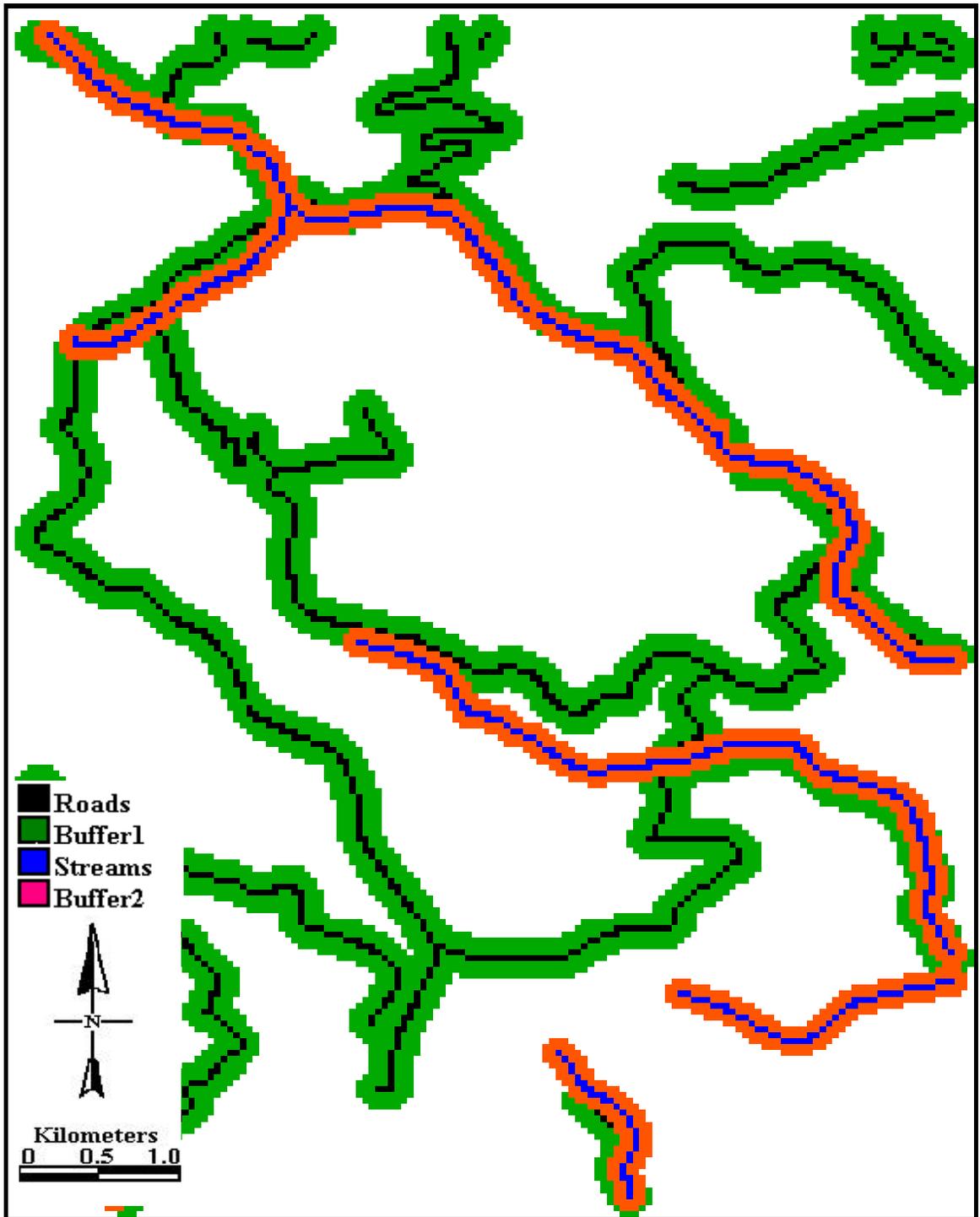


Fig. 24. Roads and streams of the study area shown with a 100 meters zone on each side of streams; 100 meters zone on each side of a road.

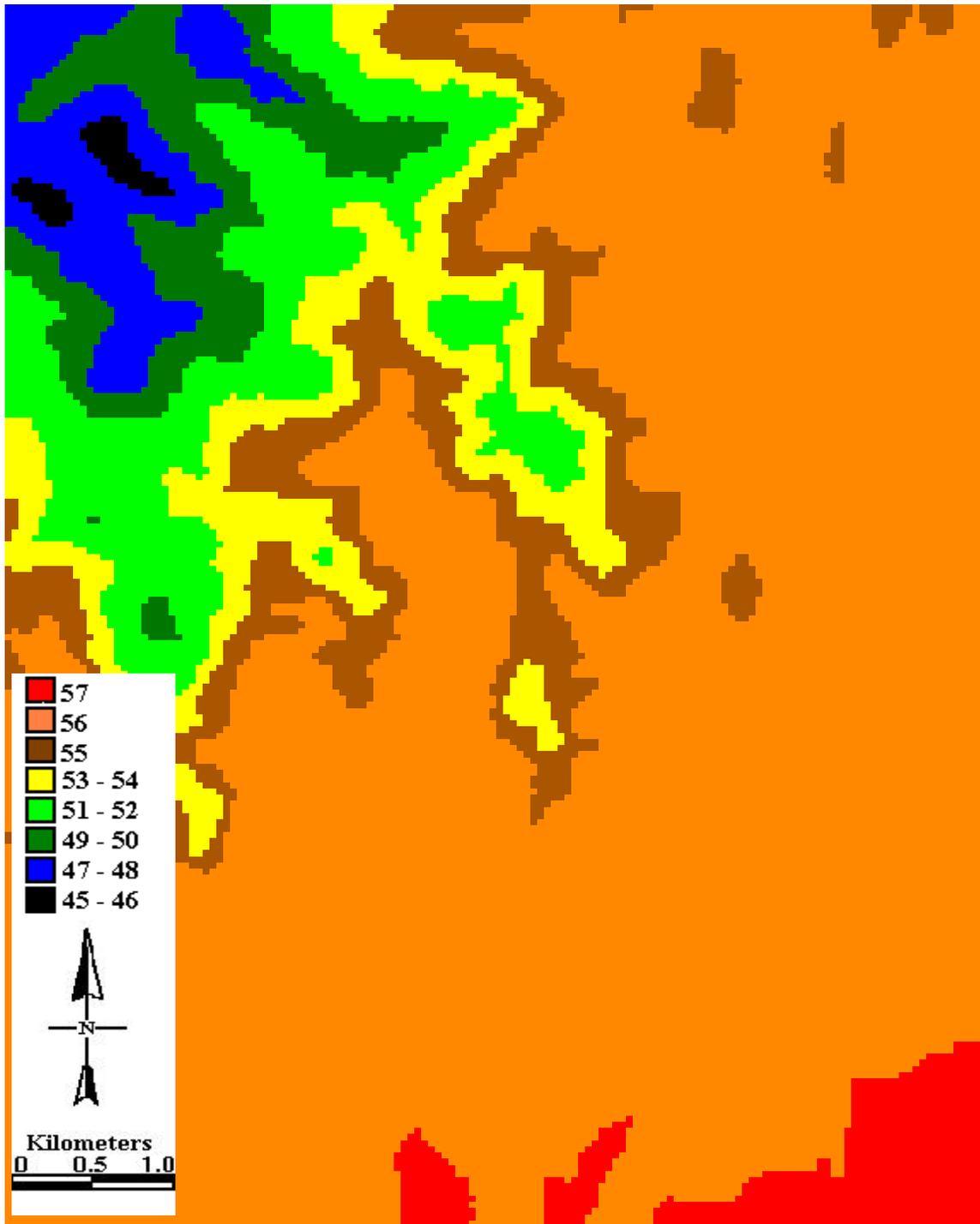


Fig. 25. Average temperature of September within the study area over 30 years (1960 - 1991) (see legend), showing an unexpected range in an important ecological variable in a single month.

Climate-Solar Radiation

I created another window using Kloppfer's work for the average solar radiation in the study area. Fig. 26 shows the solar radiation in Kcal / cm² / month. Future use of this layer is anticipated for shadow analyses, adjustments in temperature models, inclusion in potential evapotranspiration models, and in basic ecosystem modeling.

Slope - Position

Fig. 27 shows slope positions. There are 6 named categories found by John McCombs currently studying the landscape morphology of Virginia for a master of science degree at Virginia Tech. McCombs names the positions as: crest, shoulder, side slope, toe slope, and valley bottom. The positions have been mapped using a program that discriminates among these areas. The slope position has been found to be highly correlated with forest site index (dominant tree height at 50 years of age) and other relations are likely to be found (e.g., forest type occurrence). Site suitability for certain plants is correlated with position as are some characteristics of available soil moisture.

Time Involved in Data Base Construction

Trying to estimate the exact time producing of every layer was very difficult. Considering that I started to learn about GIS, its software, and its applications when I

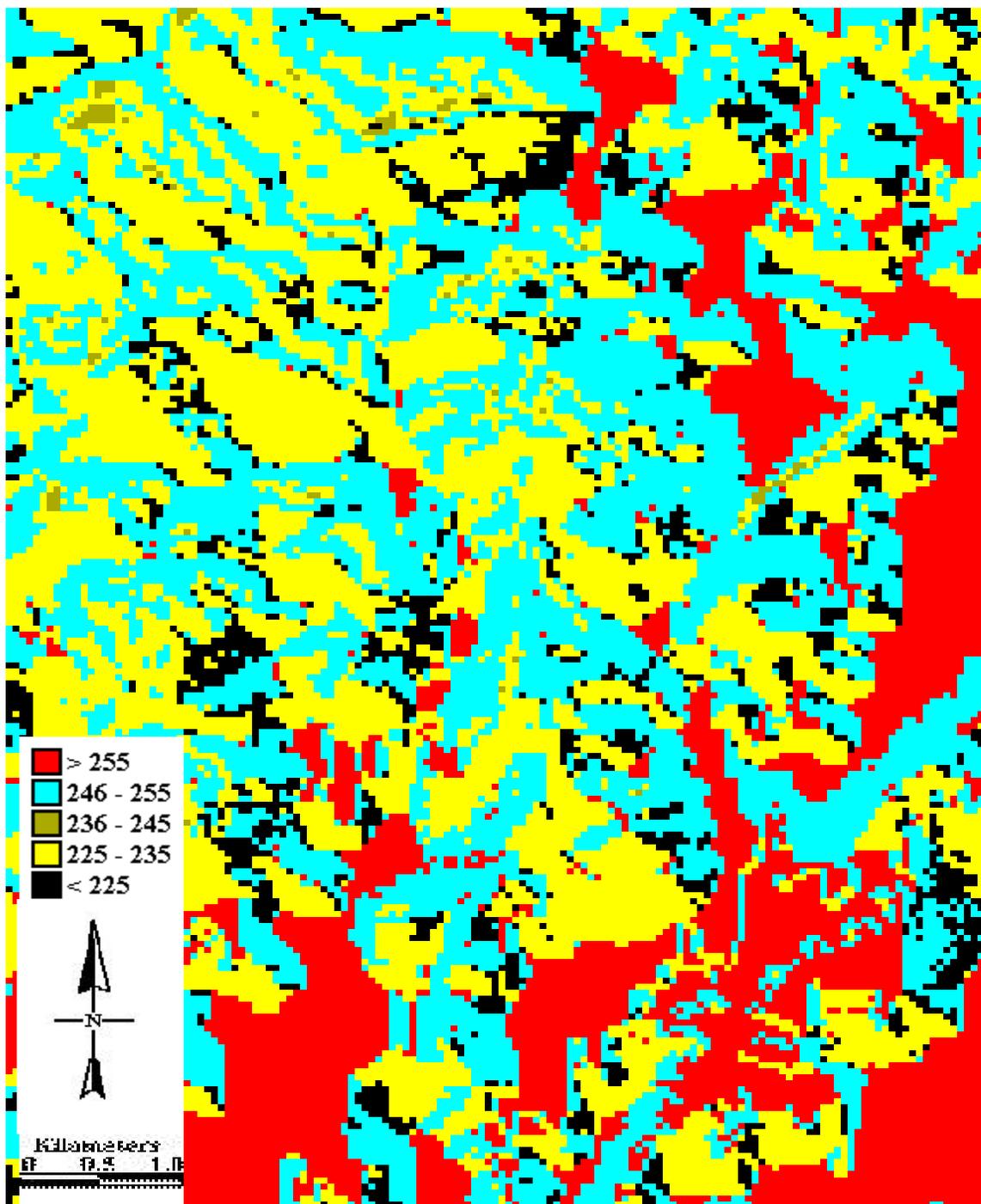


Fig. 26. Solar radiation throughout the study area in Kcal/cm²/month (see legend).

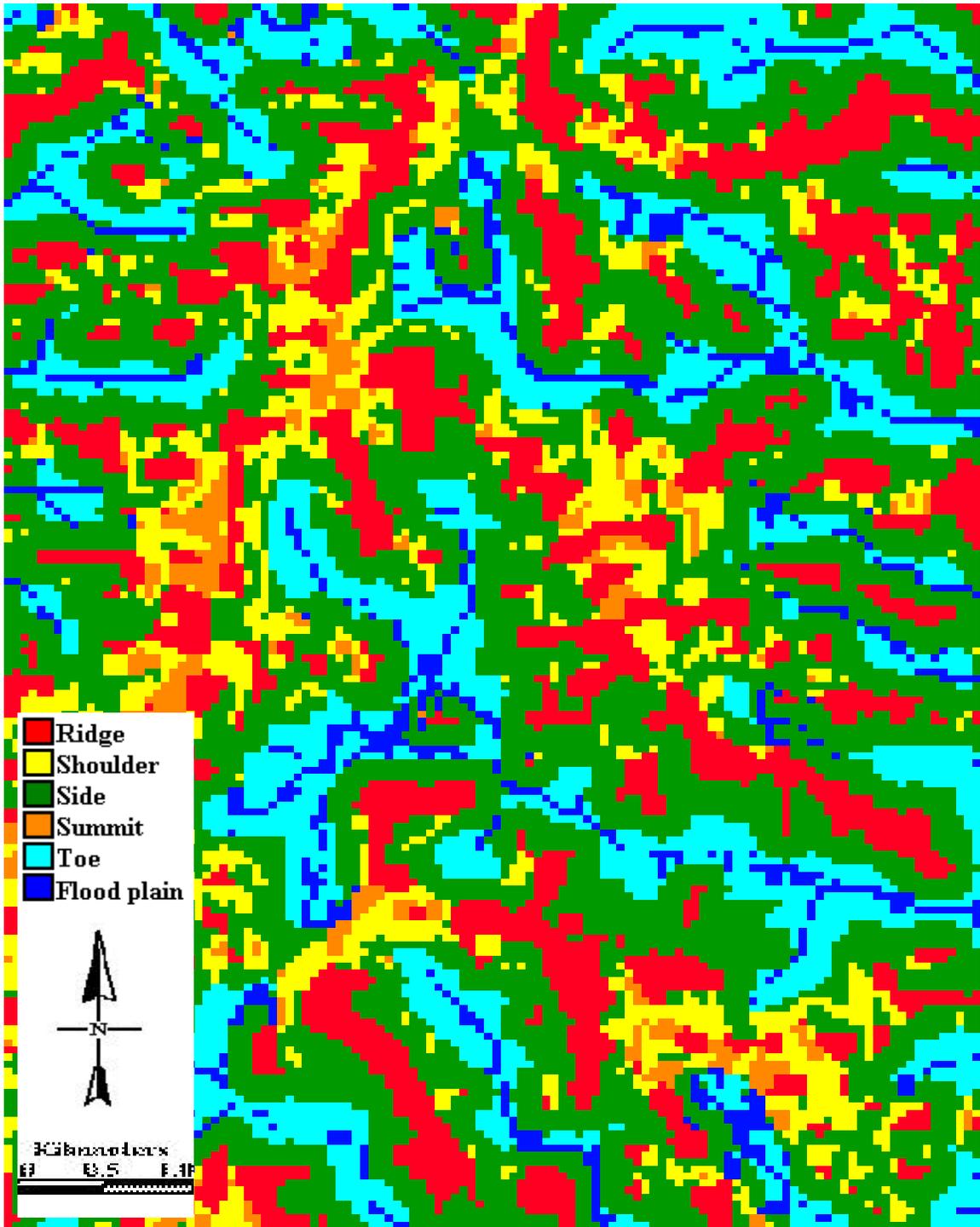


Fig. 27. Slope position of each 30m x 30m pixel within the study area (see legend).

started this project, the learning process was integrated into the production time. I tried to record the average running time of the programs and the time spent to prepare each sub-routine for running. Not having a single designated computer for my work helped me to learn about different systems, but it reduced my efficiency.

The average running time used by the software to process an operation depended heavily on the speed of the computer processor. For my small study area, the computer running time to produce any map did not exceed 2 minutes.

The time to prepare for every operation averaged between 5 to 15 minutes, depending on the kind of operation. It is important to note that the overall speed of production considerably increased over time. Safely, I can estimate the production time of each layer, those having the same area as my study area, to be 4 to 5 hours. Color classifications and visual manipulations can consume a big portion of the overall production time.

About 50 hours of production was invested in this project. The training time on using the software was estimated to be 200 hours, a period which could be cut short by a condensed training course.

Cost of Processing

If the same map layers were to be produced commercially, the cost will be a function of the hardware, software, publishing expenses, and personnel fees. Time of

operation will be the controlling factor for any production. I calculated the fixed costs of the GIS used to produce my project.

Cost - Hardware

Table 1 illustrates the required hardware for processing and publishing map layers such as those shown previously. For use with larger study areas, more storage memory is required and using a server / network system is advisable.

Cost - Software

The main software packages used were PCI, TNT MIPS, and Microsoft Office. I estimated the present prices of this software as advertised. The software used was priced as follows:

PCI = \$ 11,000 packages containing the used subroutines, Appendix A has the full price list and applicable discounts.

TNT MIPS = \$ 5,500

Microsoft Office 6 = \$ 495 (students price = \$ 199).

Cost - Publishing expenses

I was able to manipulate the final products (the maps or terrain pictures) to be printable in a variety of forms. The final map layer from a project can typically be printed directly from the print command of map and poster layout subroutine of TNT MIPS to different kinds of plotters or printers. The prices of colored printers vary from \$200 ink-jet personal printer (used in producing the maps previously shown), to multi-thousand dollar plotters depending on the desired size of the product. Table 1 shows the estimated price of a suitable suggested plotter.

The products can also be published as projector slides. One of the final steps in the production is saving the map files as presentation files. These files are printable as slides at a cost of about \$4 per slide and \$0.75 for each duplicate. Such slides are printable in most of the photographic services shops.

The maps can be also produced as a document file printable on any kind of printer and viewable on most types of computers. This process was used to produce the maps previously shown. An advantage of this method is the low expense of a printout or a small memory document. All the map layers produced in my project are saved as 5.2 MG bites.

Chapter 3: Conclusion

The two biggest problems facing most of the application of geographical information systems are time and cost. It may be interesting to explore the time and costs required to obtain data for the GIS units of Virginia with conventional or previous field methods. Consider a state like Virginia with an area of about 44,000 square miles, which has been divided into 30m x 30m cells. There are 126,622,222 such cells. Assume that an average of 3 hours is needed to make all necessary land feature observations in each cell. Also assume an that average of 1 hour is needed for transportation into and out of each cell. With a simple calculation, we find that we need 506,488,888 hours to do the work. Considering 8 working hours per day, 5 working days per week, and 250 working days per year, one needs 2,025,955 years to perform the needed work over the state of Virginia. If having unlimited financial resources and a time frame of 5 years to finish that coverage, 405,191 technicians should be employed throughout the project. Assuming a technician earns \$12,000 annually, the 81,038 technician employed every year will cost

the project \$972,458,665 annually. Excluding cars, fuel, equipment, overhead, administration and other expenses, grossly \$4,862,293,325 will be needed to be allocated for field technicians' salaries alone to accomplish the 5-year project.

Comparing the 4,862 million dollars and the 5 years duration to the cost of a GIS covering the whole state of Virginia, GIS proves to be much less expensive and much faster than manual work. In the extreme, GIS is much more efficient and effective. Even for smaller coverage, the costs of field work are high; potential savings from GIS use are very great.

On the other hand, it would be totally cost ineffective to consider such application for a private land ownership of small size. It is also unexpected that all land owners or their managers will find GIS to be applicable in their case.

Individually, few people can afford a GIS and not everyone needs one. This is why a corporation or cooperative database collection and management unit and large scale work is essential for a GIS to be feasible. Many institutions and governmental organizations around the United States have successfully adapted GIS to their needs. The U.S. Fish and Wildlife Service is undertaking an ambitious national biodiversity mapping project known as " gap analysis " (Van Der Ryn and Cowan 1996). The gap analysis project works from GIS layers of geographical and vegetation data. Knowing the geographic data and the species-vegetation associations, the gap analysis specialists can

identify under-represented ecosystem types within protected areas, habitat for various species, and faunal and floral diversity (Noss and Cooperrider 1994).

As a result of my study I have found that GIS is a large, complex system and that it is expensive. It can, however be very profitable or useful in situations with high risks where the scale is suitable, where there is creativity, and where identical procedures are used repeatedly.

Maybe the most efficient process for private land owners is to develop management firms that would manage their land collectively. Maybe it is time for land owners to identify their management objectives and group their efforts in managerial units having the same interest. At some point, GIS can become very cost effective

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**Appendix A. Estimates of PCI Software Packages
(EASI/PACE v5.3) prices (1996).**

Estimates of PCI Software Packages (EASI/PACE v5.3) prices (1996).

Package's name	Price in dollars*
EASI/PACE Image Processing Kit	2,995
Image Mapping	1,000
Multispectral Analysis	1,000
Multi-Layer Modeling GIS	1,000
Terrain Analysis	1,000
Frequency Transforms	1,000
Radar Analysis	1,000
Polarimetric Radar	1,000
Airphoto Ortho	2,000
Satellite Ortho	2,000
Atmospheric Correction	1,000
Neural Network Classification	2,000
Hyperspectral	1,000
Tape I/O	500

* 25% Federal Government discount available and 50% Educational discount applies.

Appendix B. Programs written in PCI programming language

Programs written in PCI programming language used as subroutines for modeling or classifications reported in this paper.

A program written to change slope from degrees to percent:

```
! slope degrees to slope percent

    input "Which channel has slope degrees?" %slp;

    input "Which channel for slope output (percent)?" %out;

    #num = rad(%slp);

        %out = tan(#num)*100;
```

A program to classify aspect data into 3 categories:

```
input "Which channel has aspect data ?" %asp;

input "Which channel for output ?" %out;

if ( %asp >= 337.5 ) and ( %asp < 0 )

    then %out = 10;

    extrif ( %asp >= 0 ) and ( %asp < 22.5 )

    then %out = 10;

    extrif ( %asp >= 202.5 ) and ( %asp < 247.5 )

    then %out = 30;

else %out = 20;
```

endif;

A program written to classify the elevation data of the study area into 10 categories:

```
input "Which channel has elevation data ?" %elev;
```

```
input "Which channel for output of elevation along 100m intervals ?" %out;
```

```
if ( %elev >= 1100 )
```

```
    then %out = 10;
```

```
    extrif ( %elev >= 1000 ) and ( %elev <= 1099 )
```

```
    then %out = 9;
```

```
    extrif ( %elev >= 900 ) and ( %elev <= 999 )
```

```
    then %out = 8;
```

```
    extrif ( %elev >= 800 ) and ( %elev <= 899 )
```

```
    then %out = 7;
```

```
    extrif ( %elev >= 700 ) and ( %elev <= 799 )
```

```
    then %out = 6;
```

```
    extrif ( %elev >= 600 ) and ( %elev <= 699 )
```

```
    then %out = 5;
```

```
    extrif ( %elev >= 500 ) and ( %elev <= 599 )
```

```
    then %out = 4;
```

```
    extrif ( %elev >= 400 ) and ( %elev <= 499 )
```

```
    then %out = 3;
```

```
    extrif ( %elev >= 300 ) and ( %elev <= 399 )

    then %out = 2;

    extrif ( %elev < 300 )

    then %out = 1;

endif;
```

A program written to classify slope into 7 categories:

```
input "Which channel has slope data ?" %slp;

input "Which channel for output ?" %out;

if ( %slp >= 45 )

    then %out = 70;

    extrif ( %slp >= 25 ) and ( %slp < 45 )

    then %out = 60;

    extrif ( %slp >= 15 ) and ( %slp < 25 )

    then %out = 50;

    extrif ( %slp >= 10 ) and ( %slp < 15 )

    then %out = 40;

    extrif ( %slp >= 6 ) and ( %slp < 10 )

    then %out = 30;

    extrif ( %slp >= 2 ) and ( %slp < 6 )

    then %out = 20;
```

```
    extrif ( %slp < 2 )  
  
    then %out = 10;  
  
endif;
```

A program written to classify aspect data to the 8 main compass directions:

```
input "Which channel has aspect data ?" %asp;  
  
input "Which channel for output ?" %out;  
  
if ( %asp >= 337.5 ) and ( %asp < 360 )  
  
    then %out = 10;  
  
    extrif ( %asp >= 0 ) and ( %asp < 22.5 )  
  
    then %out = 10;  
  
    extrif ( %asp >= 22.5 ) and ( %asp < 67.5 )  
  
    then %out = 20;  
  
    extrif ( %asp >= 67.5 ) and ( %asp < 112.5 )  
  
    then %out = 30;  
  
    extrif ( %asp >= 112.5 ) and ( %asp < 157.5 )  
  
    then %out = 40;  
  
    extrif ( %asp >= 157.5 ) and ( %asp < 202.5 )  
  
    then %out = 50;  
  
    extrif ( %asp >= 202.5 ) and ( %asp < 247.5 )  
  
    then %out = 60;
```

```

    extrif ( %asp >= 247.5 ) and ( %asp < 292.5 )

    then %out = 70;

    extrif ( %asp >= 292.5 ) and ( %asp < 337.5 )

    then %out = 80;

    extrif ( %asp > 360 )

    then %out = 90;

endif;

```

A program written to combine a classified elevation layer with a classified slope layer:

```

input "Which channel has elevation data ?" %elev;

input "Which channel has slope data ?" %slp;

input "Which channel for output ?" %out;

    %out = %elev + %slp;

```

A program written to classify the existing elevation data into 3 equal categories:

```

input "Which channel has elevation data ?" %elev;

input "Which channel for output ?" %out;

if ( %elev >= 912 )

    then %out = 1;

    extrif ( %elev >= 646 ) and ( %elev < 912 )

    then %out = 2;

```

```

    extrif ( %elev < 646 )

    then %out = 3;

endif;

```

A program written to calculate the erosive slope “S” multiplied by 100 to overcome fraction approximation problems:

```

input “Which channel has slope data in percent?” %slp;

input “Which channel for S_factor output ?” %out;

    %out = ((0.43) + (0.3 * (%slp)) + (0.043 * (%slp) ^2)) / 0.06613;

```

A program written to classify slope data into 3 equal categories:

```

input “What is the max slope ?” #emax;

input “Which channel has slope data?” %slp;

input “Which channel for output of slope in thirds ?” %out;

if ( %slp >= ( 0.6667* #emax ))

    then %out = 3;

    extrif ( %slp <( 0.6667* #emax )) and ( %slp >= ( 0.3333* #emax ))

    then %out = 2;

    extrif ( %slp < ( 0.3333* #emax ))

    then %out = 1;

```

```
endif;
```

A program written to classify slope into 2 categories ($\leq 20\%$ & $> 20\%$):

```
input "Which channel has slope data ?" %slp;
```

```
input "Which channel for output ?" %out;
```

```
if ( %slp > 20 )
```

```
    then %out = 1;
```

```
    else %out = 0;
```

```
endif;
```

A program written to classify erosive slope into two categories, i.e., less than 25 and 25 and more:

!S_factor in two categories, <25 & $25+$

```
input "which channel has s-factor data?" %sf;
```

```
input "which channel for the output?" %out;
```

```
if (%sf $\geq$  25)
```

```
    then %out=100;
```

```
    else %out=200;
```

```
endif;
```

Program written to combine aspect data, S_factor data, and slope:

```

input "which channel has aspect data? " %asp;

input "which channel has S-factor data? " %sf;

input "which channel has slope data?" %slp;

input "which channel for the output?" %out;

%out=%asp + %slp + %sf;

```

Program written to classify erosive slope into 12 categories (presented as 6 categories on the map layer for the visual constrains of colors):

```

input " which channel has S_factor data?" %Sfact;

input "which channel for output?" %out;

if (%Sfact >= 4000)

    then%out=40;

    extrif (%Sfact >= 3500) and (%Sfact < 4000)

    then%out=35;

    extrif (%Sfact >= 3000) and (%Sfact < 3500)

    then%out=30;

    extrif (%Sfact >= 2500) and (%Sfact < 3000)

    then%out=25;

    extrif (%Sfact >= 2000) and (%Sfact < 2500)

    then%out=20;

    extrif (%Sfact >= 1500) and (%Sfact < 2000)

```

```
then%out=15;

extrif (%Sfact >= 1000) and (%Sfact < 1500)

then%out=10;

extrif (%Sfact >= 800) and (%Sfact < 1000)

then%out=8;

extrif (%Sfact >= 600) and (%Sfact < 800)

then%out=6;

extrif (%Sfact >= 400) and (%Sfact < 600)

then%out=4;

extrif (%Sfact >= 200) and (%Sfact < 400)

then%out=2;

extrif (%Sfact< 200)

then%out=1;

endif;
```

Vita

Khaled M. Hassouna was born in Alexandria, Egypt on August 22, 1965, the son of Mohamed G. Hassouna and Soad E. Hammouda. He graduated from Alexandria University in June, 1987 with a Bachelor of Science Degree in Civil Engineering. While completing his undergraduate education he spent the summer months working as a trainee engineer in many companies and governmental authorities along the north-west Egyptian coast and in the western desert of Egypt. He worked in planning and managing work sites. In January 1990 he became the first National Park Ranger in Egypt working for the Ras Mohammed National Parks System, Egyptian National Parks Service, Egyptian Environmental Affairs Agency. He was gradually promoted to work in the federal office of the National Protectorates and Bio-diversity Unit of the EEAA. Since January, 1996, he has been enrolled in the graduate program in the College of Forestry and Wildlife Resources at Virginia Polytechnic Institute and State University.