THE LANGUAGE OF GIS:

AN INTRODUCTION FOR LANDSCAPE ARCHITECTS TO THE VOCABULARY OF GIS

by

JAMES BARRIE COLLINS II

(Under the Direction of Marianne Cramer)

ABSTRACT

This thesis provides a vocabulary of GIS for landscape architects through the use of history, definitions and applications. This thesis is based on the hypothesis that the lack of an introduction to the vocabulary and language of GIS is a current major stumbling block for landscape architects who wish to adopt GIS.

INDEX WORDS: GIS, geographic information systems, landscape architecture, language, maps, spatial relationships, information, management, local government

THE LANGUAGE OF GIS:

AN INTRODUCTION FOR LANDSCAPE ARCHITECTS TO THE VOCABULARY OF GIS

by

JAMES BARRIE COLLINS II

B.L.A., The University of Georgia, 1990

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial
Fulfillment of the Requirements for the Degree

MASTER OF LANDSCAPE ARCHITECTURE

ATHENS, GEORGIA

2006

©2006

James Barrie Collins II

All Rights Reserved

THE LANGUAGE OF GIS

AN INTRODUCTION FOR LANDSCAPE ARCHITECTS TO THE VOCABULARY OF GIS

by

JAMES BARRIE COLLINS II

Major Professor:	Marianne Cramer
Committee:	Ted L. Gragson Mary Martin R. Alfred Vick

Electronic Version Approved:
Maureen Grasso
Dean of the Graduate School
The University of Georgia
May 2006

DEDICATION

To John Linley, Allen Stovall and Spencer Tunnell

ACKNOWLEDGMENTS

Deepest thanks to Marianne Cramer, Dr. Ted Gragson, Mary Martin, Alfie Vick, and with love to my mother, Dr. Sandra L. Collins.

TABLE OF CONTENTS

Page

CHAPTER 1

INTRODUCTION

> “These rules have been developed and agreed upon by the language users and must be learned by new language users.”
> (Emmitt and Pollock, 1997, 11).

Hypothesis and Goals of the Thesis

This thesis is based on the hypothesis that the lack of an introduction to the vocabulary and language of GIS is a current major stumbling block for landscape architects who wish to adopt GIS. Furthermore, this thesis sets out to prove that GIS is needed by landscape architects. A goal of this thesis is to introduce landscape architects to the potential of GIS and challenge the long held beliefs of many landscape architects that GIS has an insurmountable learning curve for little gain in knowledge.

This thesis offers historical background and research as a preamble to the goal of providing a workable GIS vocabulary for landscape architects. For many landscape architects, familiarity with the vocabulary and basic principles of GIS will provide enough knowledge to effectively interact with local and regional agencies. There are different levels of GIS knowledge required in landscape architecture, and schools of landscape architecture should understand that the majority of landscape architect students will benefit in their future careers from exposure to GIS in the form of introductory training. We must eliminate the idea that one either uses GIS or not. For the majority of landscape architects, understanding the concepts and potential will be sufficient to access information through GIS.

Challenges

In their book *Ecology and Design*, Bart Johnson and Kristina Hill acknowledged the impact the profession of landscape architecture had on GIS (Geographic Information Systems) when they wrote: "The GIS paradigm tsunami that eventually swept up geography, and much of planning, forestry, wildlife biology, and ecology had its contemporary roots in landscape architecture (Johnson 2002, 220)." The roots Johnson and Hill were referring to spanned technological and philosophical contributions by landscape architects who adapted new applications to their needs, even before the term 'GIS' was part of our vocabulary. Johnson and Hill also provide a sobering analysis of the subsequent slowness of the landscape architecture profession to fully adopt GIS:

> Computer-aided mapping lived but languished in landscape architecture programs that were uncertain what it had to do with design….For some, making maps describing the implications of ecology remained an alternative to design, not a part of it (Johnson 2002, 220).

Johnson and Hill's commentary is apt, but as an avenue to decision making, which design surely is, GIS offers unparalleled opportunities for landscape architects. Among the legendary figures of GIS are landscape architects Ian McHarg, Lawrie Jordan, Bruce Rado, Jack Dangermond, and Carl Steinitz. I have known each of these landscape architects, and worked for two of them for almost a decade (Jordan, Rado). This thesis is designed to help landscape architects become aware of a rich legacy that was constructed through the vision and will of some of the greatest landscape architects of our time. Directly relating to any school of landscape architecture, and most especially to one such as the University of Georgia's School of Environmental Design, considering the recent merger with the Institute of Ecology, Johnson and Hill words may be applied:

> In the design professions today, the relationship between ecological analysis and ecological design, and the relationship between region and site is more apparent than a decade ago; but the essential ambivalence that kept landscape architecture from seizing the moment of intellectual, entrepreneurial, and design opportunities may continue to predispose design to a related kind of blindness to its relationship with ecology (Johnson 2002, 220).

This is an even more important issue for the University of Georgia's School of Environmental Design since both the School and the Institute of Ecology joined to form the College of Environment and Design in 2001. One of the ways the College's members can communicate or share data is through the information collected with GIS. The challenge is for landscape architects to first learn and understand the history and language of GIS in order to understand what it does best. This thesis will provide a better understanding of GIS through the use of history, vocabulary and applications.

Landscape architects have made substantial contributions to the field of geographic information systems (GIS). For example, Ian McHarg, one of the foremost landscape architects of the twentieth century, is considered one of the giants of GIS, primarily due to the overlay analysis techniques he documented in *Design with Nature.* In 1969 landscape architect Jack Dangermond founded ESRI, the preeminent (and largest) GIS firm in the world; sales currently approach $490 million dollars a year (Geospatial Solutions 2004). Notwithstanding the notable achievements of a few visionary individuals in our field, landscape architecture as a profession has been almost exclusively a follower rather than a leader in GIS. Where computer aided design (CAD) software has become the de facto architectural drafting platform of the twenty-first century, landscape architecture has been slow to adopt GIS. Today the market has competent software, low-priced hardware, readily available data, and jobs waiting for landscape architects with GIS experience. Landscape architecture has not followed in the footsteps of early landscape architects who contributed so much to GIS. A question this thesis addresses is: Why are we as a profession under-represented in a field that we helped pioneer? After working for sixteen years as a landscape architect using GIS on a daily basis, and examining the perceptions of many of my peers and colleagues in landscape architecture, it is clear that most landscape architects do not understand the potential of GIS, and further, are clearly intimidated by the technology. What is the greatest obstacle to landscape architecture and GIS finally finding each other? By providing a compilation and synthesis of the history of GIS in landscape architecture, the opportunity to offer evidence that landscape architecture's GIS roots are still valid today will be developed. A case study will be offered that demonstrates that GIS is a mandatory skill for landscape architects working in local and regional governments and for those firms dependent on GIS for landscape and regulatory information from government agencies. An introduction to the vocabulary and language of GIS offers the ability to translate fundamental concepts, ideas and terms in context to the landscape architect.

The United States Geological Survey defines 'controlled vocabulary' as a "consistent collection of terms chosen for specific purposes with explicitly stated logical constraints on their intended meanings and relationships" (USGS 2004). GIS has an extremely controlled vocabulary, but the concepts and definitions contained within are substantial and can easily overwhelm a beginner. This thesis is constructed around the idea that landscape architects need help in the form of an introduction to the language of GIS and should be offered the opportunity to learn GIS at several different skill levels.

Chapter Descriptions

Chapter Two covers the history of GIS with a focus on how it relates to landscape architecture. Contributions of landscape architects to the field of GIS will be presented. It is important for landscape architects to understand their professional legacy. It is safe to say that many landscape architects have not heard of Lawrie Jordan, Bruce Rado, Jack Dangermond or Carl Steinitz. While most of us are familiar with the legacy of landscape architect Ian McHarg, few landscape architects are aware that he is considered one of the great pioneers of GIS. By understanding our past, we can move forward to embrace what GIS has to offer. It is a fact that landscape architecture of the 20th Century adopted analysis techniques that are eminently suited to what GIS has to offer. In the framework of Chapter Two I have a second important goal. This goal is to provide an introduction into the essential philosophy that drives GIS by providing the reader with a solid comprehension of the structure and function of GIS.

Chapters Three and Four will build a vocabulary of GIS for landscape architects, focusing on important concepts and outlining the fundamentals of GIS. By providing a framework that speaks directly to landscape architects, these chapters will attempt to identify the critical elements of knowledge required of any landscape architect considering GIS. Just as medical prescriptions are based on a vocabulary and language that allow physician and pharmacist to communicate, the goal is to connect landscape architects to GIS by focusing on the concepts and terms that are most directly related to their profession.

Chapter Five takes a look at a variety of subtle knowledge points in GIS that every competent GIS professional should know. Chapter Five’s content in relation to the rest of the thesis might seem indirect. Chapter Five is in fact a very important part of this thesis because it focuses on nuances of the language of GIS by addressing a variety of terms and applications that are often misunderstood even by GIS professionals. This chapter is an opportunity to communicate subtleties in GIS that it took me many years to learn.

Chapter Six is a case study using GIS in local government to demonstrate how GIS impacts the everyday work of a landscape architect. This example provides support for the idea that landscape architects should be familiar with the basic concepts of GIS. Both the case study in this chapter and the application example in Chapter Seven support a key point of this thesis by demonstrating that a basic understanding of GIS is essential to modern landscape architects.

Chapter Seven will provide an application example focusing on GIS in local government. Landscape architects who have mastered basic GIS skills should be able to perform the tasks outlined in Chapter Seven. I have selected local government as the subject for three reasons: 1) Local and county governments are currently the most likely employers that will require GIS expertise of landscape architects. 2) Many of the concepts and data sets covered can be easily applied to other large-scale, public, or regional organizations. 3) Many private landscape design firms are dependent on GIS information for their work. This is where Ian McHarg paved the way for both GIS and landscape architecture, and thus, is an appropriate way to connect the past and present, in terms of landscape architecture and the subject matter of this thesis.

Chapter 8 is the conclusion of the thesis. Appendix A is a glossary of GIS terms. The definitions contained in the glossary have been culled from thousands of GIS terms, and they have been selected as a resource directed specifically to landscape architects involved in GIS. These terms are the foundation of the vocabulary of GIS. When a GIS term is introduced in the body of this thesis, the term will be provided in **bold** text format, and can be found in the glossary found in Appendix A.

I will complete this introduction with an indirect reference from photography: In the photographer's darkroom, there are details which are important and there are details that are not so important; a little under or over time in the stop bath is not disastrous, but proper development and fixing times must be rigorously followed in order to maintain any minimal claim of competency. The successful photographer knows these things, what matters and what does not. It is the goal of this thesis to separate the important from the unimportant in GIS for landscape architects.

CHAPTER 2

A HISTORICAL OVERVIEW OF GIS

Note: GIS terms are highlighted in bold text format and can be found in the Glossary of GIS Terms (Appendix A, Page 105).

This chapter initiates the language of geographic information systems (GIS) through a history of its development around the essential components: maps, information, geographic projection, and spatial relationships. The latter part of the chapter shifts focus to the landscape architects who combined the essential components of GIS and advanced the technology. The history of GIS will supply the framework for the communication of the fundamentals of a geographic information system within this chapter's goal of leaving the reader with a solid understanding of the crucial components and character of GIS.

Figure 2-1. Landscape architecture's language is visual.

(Southport Cottage Point n.d.)

(Southport Cottage Point n.d.)

The language of GIS is based upon analysis of the information that lies beneath the visual.
Key components are maps, information, geographic projection, and spatial relationships.

Maps

Maps form the visual core of GIS and are excellent tools for the visual representation of locations and spatial relationships between locations (Star and Estes 1990, 15). However, due to space constraints, maps are limited in the amount of information that can be presented; there is finite space for lines, symbols, and annotation. The problem is exacerbated when the map represents extensive geographic areas: the larger the area covered the smaller the amount of information available for any one location on the map (Figure 2-2). North arrows and scale are not normally shown in GIS display. In GIS, figures are oriented to true North, and scale refers to the resolution of the data as opposed to the view. In this thesis, display will follow GIS convention and neither scale nor north arrows will be displayed with graphics.

Figure 2-2. Map of Jerusalem city center (Cook 1924).
Maps provide excellent visual records of locations, but offer limited physical space for detailed information. Analysis is limited to area and distance measurements.

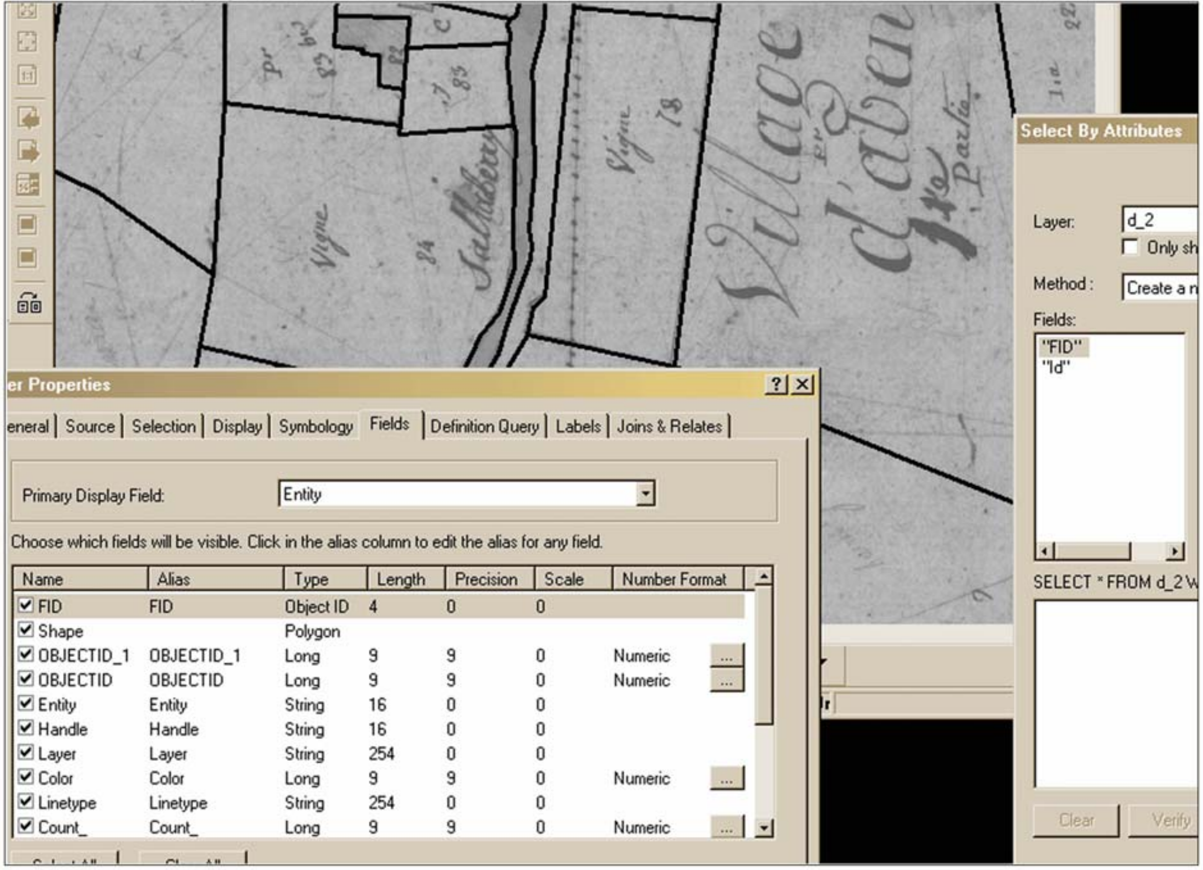
Landscape architecture's language is visual by its nature, communicating ideas and concepts through plans, construction drawings, process graphics, and renderings. The spatial limits imposed by the traditional medium are the force behind finding value in GIS. The power of GIS is the amount of information that can be attached to the visual representation, the map, of the area being studied. This is the beginning of our development of a definition of GIS.

Information

Tor Bernhardsen writes in his book *Geographic Information Systems: An Introduction*, "Geographic information systems evolved from centuries of map making and the compilation of registers (Bernhardsen 2002, 27)." The most famous land register, the **Domesday Book**, was a registry of land ownership for England developed in 1086 for William the Conqueror. The Domesday Book included property values, livestock records, and a history of ownership as well as incomes earned and taxes paid (Bernhardsen 2002, 28). Property registry for taxation purposes was the primary role of the Domesday Book. Modern scholars recognize the Domesday Book as an invaluable record and one of the earliest **demographic** tools of the development of European societies and economies (Erskine and Williams 1987, 23). Considering the space limitations inherent on paper maps, recording detailed land records on a map of England would have been impossible. While maps of the Domesday Book were developed centuries after it was written, the scope and magnitude of the registry is indicative of the problems faced when handling large amounts of data that have significant ties to geographic location.

One solution to the inherent space limitations of maps involves relating tabular information to **spatial data** in the form of reference points. Among the first to relate information to location were the Romans, who needed a method of establishing property ownership, including the documentation of property boundaries in order to tax property owners. The Romans developed data-driven mapping systems to record property ownership (Bernhardsen 2002, 27). By tying data registries to map locations, the Romans found a solution to the space limitations inherent in traditional maps. In doing so, they created the first **cadastral maps**. A cadastral map shows the boundaries of the subdivisions of land for purposes of describing and recording ownership or taxation (*ERDAS Field Guide, Fifth Edition* 1999, 593).

Figure 2-3. Cadastral Map, Viodose, France. Year: 1811.
A scanned cadastral map displayed in ArcView GIS sofware.
Note the underlying tabular information field definitions that relate to each land record.



Primary Display Field: Entity

Choose which fields will be visible. Click in the alias column to edit the alias for any field.

Name	Alias	Type	Length	Precision	Scale	Number Format
☑ FID	FID	Object ID	4	0	0	
☑ Shape		Polygon				
☑ OBJECTID_1	OBJECTID_1	Long	9	9	0	Numeric
☑ OBJECTID	OBJECTID	Long	9	9	0	Numeric
☑ Entity	Entity	String	16	0	0	
☑ Handle	Handle	String	16	0	0	
☑ Layer	Layer	String	254	0	0	
☑ Color	Color	Long	9	9	0	Numeric
☑ Linetype	Linetype	String	254	0	0	
☑ Count_	Count_	Long	9	9	0	Numeric

Layer: d_2
☐ Only sh
Method: Create a n
Fields:
"FID"
"Id"
SELECT * FROM d_2 W

Figure 2-3 shows a scanned cadastral map displayed in ArcView GIS software. The original paper map is from 1811 and the accompanying database shows the information attached to the map in tabular records (Fig. 2-3). A crucial component of GIS is evident in the example provided by cadastral maps: in traditional **cartography** the important information is the location of a feature; cadastral maps are driven by the data that are tied to features. While a visual representation of property division may be important, the points themselves have little or no meaning without the underlying ownership and taxation records. Tabular information attached to geographic locations is one key to GIS and location is only one piece of the information available for any piece of data.

Geographic Projection

Geographic map projections portray the rounded surface of the earth or a portion of the earth on a flat surface. The Greeks developed the first map projections, and Claudius Ptolemy, around 150 A.D., created the first map of the world projected to two-dimensional form (Bernhardsen 2002, 27).

The ability to reference maps to map projections is a key asset of geographic information systems, as well as a primary distinguisher from other computer aided design (CAD) and graphics software programs. Projection systems solve an immense challenge in overlay analysis and design processes: how does one overlay one map over another in digital format? This is an extremely simple question, with profound ramifications. Landscape analysis is dependent upon relationships between geographic locations that must be mapped accurately to each other. **Scale** is the ratio of distance on a map as related to the true distance on the ground (*ERDAS Field Guide, Fifth Edition* 1999, 627). When maps of different scale are overlain, there must be a way to adjust for the differences. Geographic map projections solve the challenge efficiently and effectively. If a user can project the maps to standard geographic projections (**georeferencing**), the GIS software can successfully overlay **images**, maps, and **vector** graphics, even when they have vastly different scales. For example, as long as the maps are projected correctly, one can display and analyze a map at 1:100 scale on top of a map of 1:250000 scale. Figure 2-3 is an example of a one meter **aerial photograph** superimposed over thirty meter imagery (Fig. 2-3).

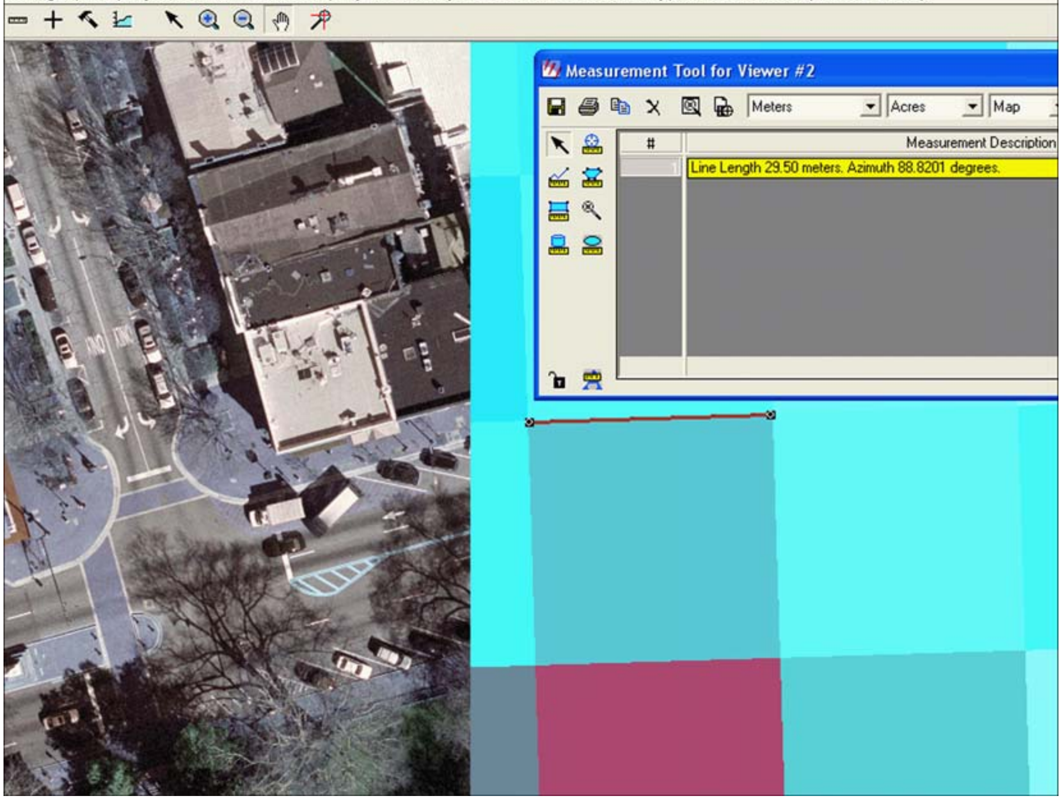


Figure 2-4.   Athens, Georgia.
1 meter digital aerial photograph (left) superimposed over 30 meter satellite imagery (right).
Geographic projections allow the display and analysis of data of different types and scales (USGS 2003).

Line Length 29.50 meters. Azimuth 88.8201 degrees.

Each **pixel** on the image on the right represents a square thirty meters by thirty meters on the ground; the display is zoomed to optimize viewing of the one meter image, leaving the display of the thirty meter imagery as visually meaningless blocks.

Spatial Relationships

A crucial step in the evolution of GIS can be found in landscape architecture's utilization of maps as analysis, design, and decision-making tools. The technique of overlay mapping involves using maps drawn to the same scale, overlaying them, and conducting comparative **spatial analysis** (Steinitz, Parker, and Jordan 1976, 444). Criteria can be applied that includes or excludes geographic area from human activity or further development; spatial analysis is used by almost every landscape architect in the analysis phase of design; GIS simply moves this analysis to the computer realm, and offers the ability to incorporate more information into the process. Overlaying methods of spatial analysis date back to the 17th and 18th centuries (Star and Estes 1990, 18). These methods can be traced through Frederick Law Olmsted's practice, in the 1890's work of partner Charles Eliot. Eliot embraced a scientific approach to design, most notably evident in his classic work, *Scenery and Vegetation of the Boston Metropolitan Parks*. Eliot used transparent overlays of site boundaries, paths, streams, ponds, vegetation, and topography for analysis (Miller 1999, 58).

In the early 20th century, landscape architects and planners began more extensive use of overlay mapping as a standard methodology for planning (Forseman 1998, 4). Data overlay techniques were used extensively in the 1912 study conducted by landscape architect Warren Manning, a one-time associate of Frederick Law Olmsted's firm (Steinitz, Parker, and Jordan 1976, 444). In a planning study for the city of Billerica, Massachusetts, Manning created maps that included soil, vegetation, topography, and their combined relationship to land use. Manning's overlay process streamlined inventory and analysis of a site to guide design decisions and was very similar to the methods used by many practicing landscape architects today (Steinitz, Parker, and Jordan 1976, 445). In these overlay analysis methodologies used by 20th century landscape architects, we see the roots of modern GIS. In the next section of this thesis, the example of Ian McHarg will be used to more fully examine the types of criteria that can be introduced into the design process.

Ian McHarg

The 1969 introduction of the book *Design with Nature* formalized land suitability analysis (Star and Estes 1990, 21), establishing Ian McHarg as not only one of the foremost landscape architects of the twentieth century, but also as a pioneer in GIS. "Ian McHarg, while trained professionally as a town planner and a landscape architect, might better be described as an inspired ecologist" observed Lewis Mumford in the preface to McHarg's book *Design with Nature* (Mumford 1969, vii). By examining the values of how human beings shape the land, McHarg was supported by a growing community of ecologists who were concerned with the impact of human activity on ecosystems. McHarg introduced the critical components of ecology to the analysis process.

While McHarg's considerable impact on the value systems of planners was revolutionary, his development of methods for successfully analyzing the large criteria sets and data inputs involved in his planning was just as critical to the advancement of the planning profession. Management and design decisions are most effective when useful information is applied to solving the problem at hand. It follows that the more useful information that is available and can be applied effectively, the more informed and competent a decision will be. Reams of information are of little value if the decision system cannot effectively process the data available. This issue confronted landscape architects in the 1950s and 1960s, as the rapidly expanding ability to generate data for large areas of land made finding new analysis methods a priority.

McHarg had to find a way to incorporate a large number of variables in order to reach a conclusion. "We need, not only a better view of man and nature, but a working method by which the least of us can ensure that the product of his works is not more despoliation (McHarg

1969, 5)." McHarg's method of managing the challenges he outlined was based upon the overlay of a variety of maps to subtract or add areas with accompanying criteria to the equation. The methods he pioneered form the basis of modern GIS.

Ian McHarg's inclusion of social and natural criteria offered an expanded number of variables (Table 1 McHarg 1969, 33) for consideration. Following are three examples of criteria that McHarg used.

> Example 1, Economic Criteria:
> A soil map can be used to identify different rock structures, with values assigned to those soils that have better compressive strength. This is an example of economically based criteria where land is considered or removed from consideration due to the cost of building over a specific soil structure (McHarg 1969, 33).
>
> Example 2, Natural Criteria:
> An example of ecological criteria could be found in an evaluation of forest or marsh quality, ranking land cover with regards to its ecological benefit to natural communities. Criteria could include wildlife habitats, species, species distribution, species health, age, proximity to urban, number of endangered species (McHarg 1969, 33).
>
> Example 3, Social Criteria
> Hierarchical values may be established for land and buildings, both in price and social significance. Price valuation is the worth of land in monetary terms; social significance is factored in with regards to, for example, the density of human population in the proposed building areas. Human density can have both positive and negative weightings in the design matrix, as there are advantages to the economy of many areas to have new development in or adjacent to population centers. Conversely, the displacement of communities to accommodate a new development can adversely change the character of neighborhoods and towns for decades. In this example, both social and economic criteria are found, and in fact, may be at odds with each other (McHarg 1969, 33).

Introducing an increased number of considerations to the design process led to an explosion of information available, much of it geographic in nature. McHarg considered factors such as slope, geology, sun angle, land cover, building values, climate, drainage, erosion, wildlife habitats, hydrology, physiography, demographics, historical value, and human population in his planning phase of the design. Each of these factors could have a number of sub-categories, thus compounding the available information that had to be managed in a way that allowed for effective use. Further, the introduction of a number of variables for consideration in design allowed for weighting of values in criteria.

McHarg compiled information in a series of maps containing information that might affect the usability of locations for the design purpose. The exploded view in Figure 2.5 shows soil drainage, an important factor in many building applications.

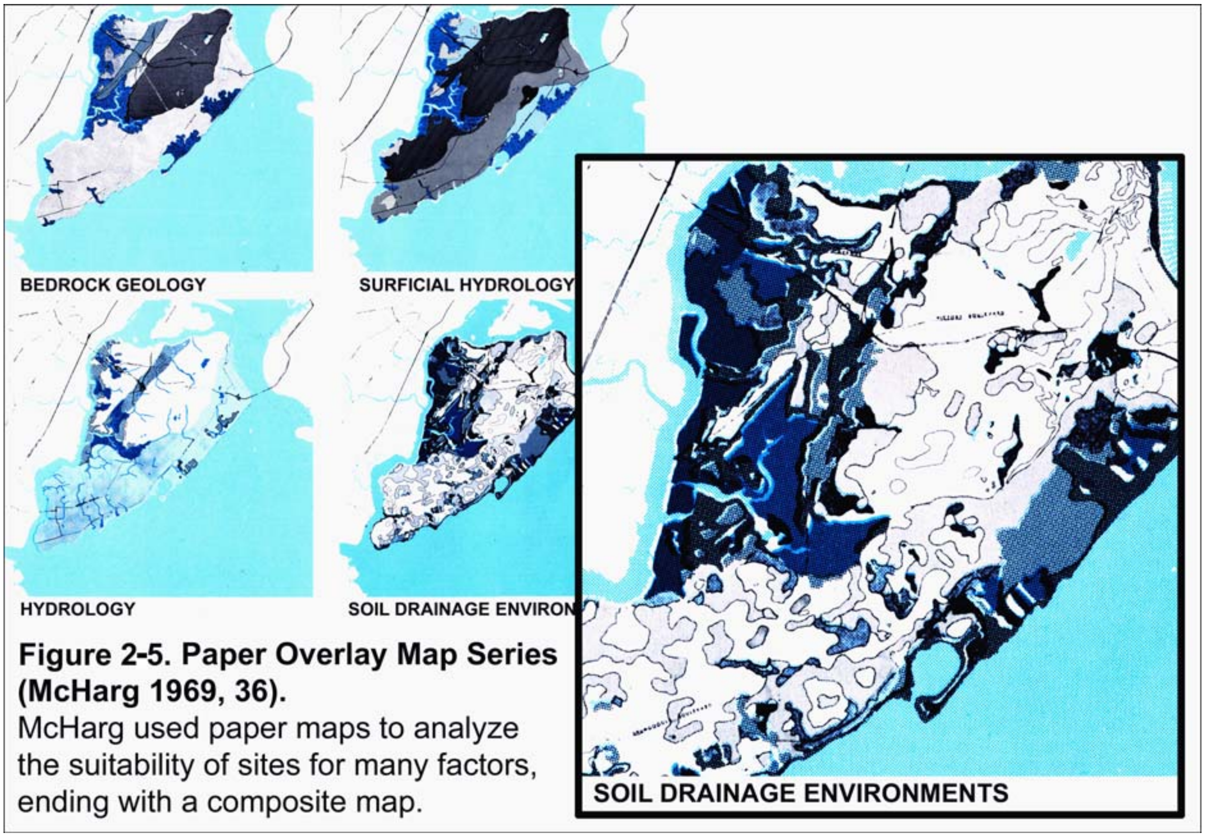


Figure 2-5. Paper Overlay Map Series (McHarg 1969, 36).
McHarg used paper maps to analyze the suitability of sites for many factors, ending with a composite map.

In 1998, McHarg provided his own assessment of the contribution of landscape architecture to GIS when he wrote, “The rapid transformation of GIS relies on the foundation of landscape architecture and ecology for much of its theoretical and practical underpinnings” (McHarg 1998).

A Definition of GIS

Previous sections of this chapter have outlined the essential components of geographic information systems: *maps, information, geographic projection, and spatial relationships*. What is the essential difference between a map and a geographic information system? A map has a point where a feature lies. The feature is a gold mine or a river or a military encampment. A GIS has a point where *information* lies. The tabular information stored in the database is often the most important component of a GIS **layer** or **theme**. A layer is a spatial dataset containing a common feature type. The terms layer and theme are used interchangeably by many GIS users. The spatial confines of a digital or hardcopy map will never be able to compete with the ability of GIS to store and model an almost infinite amount of information, indexed through *geographic projection* to its location and its relationship to other locations. Once locations are projected geographically, layers can be overlaid in order to conduct *spatial analysis*. GIS can be described concisely: *GIS is information tied to geographic location, and those locations are geographically projected.* Functionally this translates into a location tied to georeferenced data contained in a database. The location is a geographic rendering of a potentially unlimited amount of data. By the 1960's, all the functional components of a GIS had been developed, but it was the advent of the computer age that finally realized the promise of GIS.

It is useful to provide Ian McHarg's definition of GIS: "The systematic introduction of numerous different disciplinary data, connected by their shared location on the planet, which can be used to record an inventory of the environment, document observations of change and constituent processes, and permit predictions based on current practices and management planes" (McHarg 1998, ix). Included in McHarg's description is the backbone of a geographic information system: information (different disciplinary data, documentation), geographic projection (shared location on the planet), inventory and analysis (observation and prediction).

The Birth of GIS

Computers were being used during the 1950s at the University of Washington to run qualitative transportation studies. By 1958 a team at the University of Pennsylvania working for landscape architect Ian McHarg digitized natural resource data using punch cards, creating area calculations for environmental parameters that were used to assist with the Metropolitan Open Space Study (McHarg 1998). These initial rudimentary computer processing and analyses are considered one of the first true applications of GIS. By the early 1960s mainframe computers were coming online (Coppock and Rhind 1991, 26). Designed primarily for data management and scientific computations, mainframe computers had made a quantum leap in processing speed and power. They offered the raw number crunching speed required for large applications

In 1962 the Canadian Land Inventory, created in response to the 1961 passing of the Agricultural Rehabilitation and Development Act, was tasked with the creation of an inventory of land use and land capability study across Canada (Tomlinson 1998, 24). Scales ranged from 1:50,000 to 1:250,000, and would show agriculture, forestry, wildlife, recreation, and census boundaries. The area of coverage was close to 2.7 million square kilometers (Forest 1998, 332). Estimates of a hardcopy manual creation of the Canadian inventory ran in the millions of dollars and would require over five hundred technicians working for three years (Coppock and Rhind 1991, 23). The exorbitant costs and physical size of the project led the project managers to consider other alternatives. Besides costs there were other problems associated with mapping large geographic areas to the detail called for in this inventory. The *Atlas of Great Britain and*

Northern Ireland (Bickmore and Shaw 1963), unwieldy and already considered out of date when published, convinced researchers that computers might be the only viable option for creating, editing, and analyzing data (Coppock and Rhind 1991, 23).

Geographer Dr. Roger Tomlinson was consulted to help develop a plan for the Canadian Land Inventory that would allow the mapping and analysis of the continent-wide system. His response in November 1962, was the paper, *Computer Mapping: An Introduction to the Use of Electronic Computers in the Storage, Compilation and Assessment of Natural and Economic Data for the Evaluation of Marginal Land* (Foresman 1998, 24). The report clearly outlined the functional requirements of a computer-based system that would analyze geographic data, including statistical form in tabular databases. The birth of the Canada Geographic Information System marked the introduction of the term “geographic information system” and introduced a number of significant contributions to GIS, including the creation of **drum scanning** for fast **digitization** of maps, data indexing, and **topology**. Drum scanners are used to reproduce analog images as very high resolution digital files and have a cylinder that spins while a focused light source on a track shines through or on it and onto the image sensors. Drum scanners produce large extremely high quality images with fine dynamic range and resolutions as high as 12000 dots per inch (Johnson 2003, 86). While not completed until 1971, the Canada GIS is still considered one of the largest geographic land surveys ever conducted, now containing a digital archive of approximately 10,000 digital maps (Coppock and Rhind 1991, 29).

Disappointments

Even with the success of the Canada GIS, some of the inevitable disappointments of this pioneering system add insight. At the time the high cost of hardware placed the digital Canada

GIS in an early disadvantage to manual systems. Comparisons made by the Ordnance Survey of Britain determined that digital approaches to mapping were not yet cost effective (Coppock and Rhind 1991, 29). There is a parallel in landscape architecture's slowness to adopt digital technologies, including CAD and GIS. The benefits of designers adopting new methods are usually always mitigated when there are exorbitant costs associated with hardware. Considering that only in recent years have landscape architecture schools offered formal training in digital drafting techniques (CAD), finding trained personnel to run digital softwares has been difficult. Even today, for many applications, especially at site level planning, hand drawn trace overlays are a more effective and faster means of analysis. As the amount of analysis area expands and the amount of information increases the power of GIS begins to makes sense for landscape architects. Even with the understandable reluctance of landscape architecture to adopt digital processing methods, some of the most significant achievements of the mid-1960s and 1970s were driven by landscape architects, most notably at the Harvard Graduate School of Design.

The Harvard Graduate School of Design

In the mid-1960s, architect Howard Fisher was endowed by the Ford Foundation to set up a geospatial laboratory (Chrisman 1998, 36). After being turned down for support from two Chicago universities, Fisher approached his alma mater, the Graduate School of Design at Harvard University, and the Laboratory for Computer Graphics and Spatial Analysis was born (Chrisman 1998, 37). Ironically, the nucleus of one of the most productive software development labs in history both inside and outside of GIS was formed at a university with no geography department by an architect in a school most noted for turning out classically trained architects and landscape architects.

Fisher formed a team of programmers and hired a staff geographer, but it was a third group, the landscape architects, who gravitated towards the software packages being developed. Carl Steinitz, a landscape architect on faculty, was working on applied planning projects including power plant siting, transportation corridors, and suburban expansion (Stinton 1998, 37). In landscape architecture during the 1950s and 1960s, landscape architects had begun to focus on large-scale projects. At the University of Wisconsin-Madison landscape architect Phillip Lewis was working on huge projects on a statewide coverage that required analysis of a large number of spatial and non-spatial variables (Stinton 1998, 37). Steinitz understood the demand for an analytical method to analysis of the landscape (Chrisman 1998, 34) and was an early adopter of the basic computer programs originating out of Fisher's lab. Over the next decade and a half, Carl Steinitz and his students focused on analytical projects while continuing to contribute to the improvement of GIS software.

Figure 2-6. Harvard Graduate School of Design, 1960's (ESRI).
Left to Right: Carl Steinitz, Peter Rogers, Jack Dangermond

It is important to note that the emphasis at the Harvard lab at the time was the development of tools for spatial analysis and so there was a heavy focus on both development and use of software. Today almost every GIS user in the world is using software that had its roots in the Harvard lab of the 1970s. Jack Dangermond, founder of Environmental Systems

Research Institute (ESRI), Lawrie Jordan and his co-founder of ERDAS, Bruce Rado, are all landscape architects who graduated from the Harvard School of Design and were students of Carl Steinitz. ERDAS is the leading remote sensing software in use today, and ESRI produces the most widely used GIS software in the world. Landscape architect Jack Dangermond is still owner of privately held ESRI whose sales approach half a billion dollars per year (Geospatial Solutions 2004).

From a technological standpoint, a strong case can be made that the landscape architects that came out of the Harvard Graduate School of Design over the decade from 1970-1980 were the most crucial innovators in GIS. The last twenty five years of GIS development and maturation saw the corporation take over and the large software developers drove GIS as we see it today. Advances in usability, better **graphical user interfaces**, and development of GIS databases were all geared towards making GIS easier to use and more accessible to a broader range of users. A user from the 1970s, the 1980s and the 1990s had to be a “GIS person” - someone trained, often formally, in the operation of geographic information software. Today GIS is more accessible to everyone, including landscape architects.

CHAPTER 3

THE HEART OF GIS: DATA

Note: GIS terms are highlighted in bold text format and can be found in the
Glossary of GIS Terms (Appendix A, Page 105).

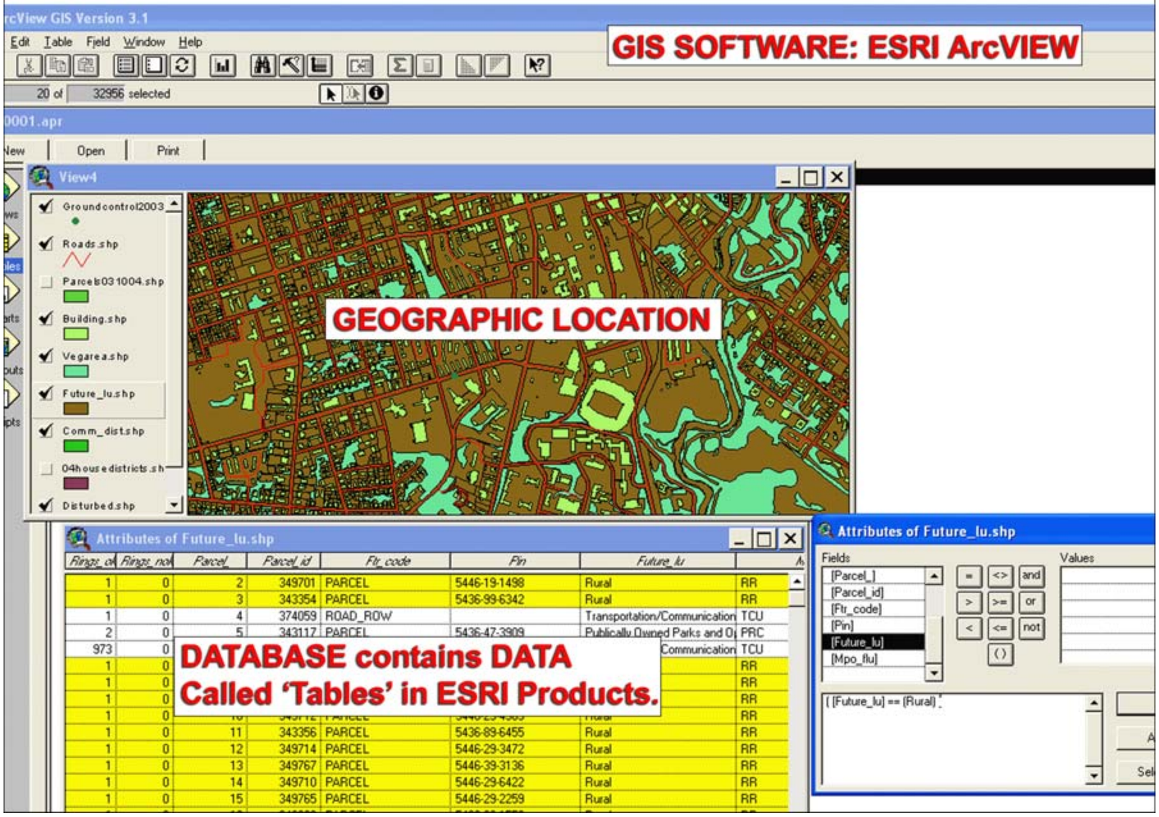
It is important to understand that the term “GIS” often has different connotations depending upon the context in which it is used. A GIS can be considered software. A GIS can be considered a combination of software and hardware or even a collection of software, hardware, and data (Malczewski 1999, 16). GIS can also be considered a discipline or a profession (Pickles 1995, 4). As was noted in Chapter Two of this thesis Ian McHarg referred to GIS as an “…inventory of the environment” (McHarg 1998, ix). This thesis has provided a working definition of GIS: GIS is information tied to geographic location, and those locations are geographically projected. It is worthwhile to note that each of the preceding descriptions may be used appropriately according to what one desires to communicate; these are the inevitable nuances in any language, and these nuances will be explored more fully in Chapter Five of this thesis. All accurate descriptions of GIS focus on information attached to geographic location. This chapter will explore and explain the vocabulary of GIS data. Understanding the concepts provided here is the absolute backbone of the language of GIS.

A Definition of Data

The term ‘**data**’ is used extensively in GIS. What exactly is data? A number of authors define data as a “collection of facts” (Purba 2000, 14). For example, David R. Green, in his book *GIS: A Sourcebook for Schools*, defines data as, "A collection of facts, concepts or instructions in a formalized manner suitable for communication or processing by human beings or by automatic means" (Green 2001, 192). Green's definition is an attempt to describe in succinct terms a word that has a wide scope of possible meanings; it is this type of definition, found most often in technical guides written by technical authors, that does not really succeed in getting to the essence of the matter. There is a dangerous assumption involved in defining data as a collection of facts, in that facts are things that are known to be true. If the data is incorrect, then it is not a collection of facts (Johns and Hill 2002, 253). The point is not to appear pedantic, but to emphasize the need to provide a vocabulary defined in a language that is truly useful for the landscape architect approaching GIS for the first time. Is it possible to define the term 'data' in a way that provides a reasonable, perhaps not perfect, but understandable definition?

So, what is data? Data contains information. Data is information and I am quite happy with this as a working definition. The data itself may be accurate or inaccurate, but it is still data. This is an important point, since the results of analysis or decisions made on the basis of incorrect data will be flawed (Hewitt, Stone, and Slonecker 1992, 47). GIS data is normally considered information contained in a database or a digital spreadsheet. The information in the database is attached to a geographic location that may be viewed on a computer screen (Figure 3-1). A definition of data for GIS for landscape architects thus follows: Data is information contained in a database tied to geographic location.

Figure 3-1. GIS: DATA, DATABASE, GEOGRAPHIC LOCATION (MAP). (Athens-Clarke County 2005).



GIS SOFTWARE: ESRI ArcVIEW

GEOGRAPHIC LOCATION

DATABASE contains DATA Called 'Tables' in ESRI Products.

Rings_ok	Rings_nok	Parcel_	Parcel_id	Ftr_code	Pin	Future_lu	
1	0	2	349701	PARCEL	5446-19-1498	Rural	RR
1	0	3	343354	PARCEL	5436-99-6342	Rural	RR
1	0	4	374059	ROAD_ROW		Transportation/Communication	TCU
2	0	5	343117	PARCEL	5436-47-3909	Publically Owned Parks and O	PRC
973	0					Communication	TCU
1	0						RR
1	0						RR
1	0						RR
1	0						RR
1	0	11	343356	PARCEL	5436-89-6455	Rural	RR
1	0	12	349714	PARCEL	5446-29-3472	Rural	RR
1	0	13	349767	PARCEL	5446-39-3136	Rural	RR
1	0	14	349710	PARCEL	5446-29-6422	Rural	RR
1	0	15	349765	PARCEL	5446-29-2259	Rural	RR

([Future_lu] == [Rural])

A Definition of Database

This thesis has developed a definition of data that includes of data in a database. What is a **database**? A workable definition for landscape architects is "A database is a collection of related data" (McTaggart 2000, 9). A database is not just a random collection of information; a database is organized related data (McTaggart 2000, 10). Constructing a definition for a database around GIS involves understanding that the data is organized logically and that it pertains to a set of geographic locations. These geographic locations are displayed on a digital map, and provide the basis for visual organization, as well as **spatial modeling**. The key here is not an exhaustive examination into what a database is or is not, but to drive the point home that the database is the backend of the system. The data contained in the database is tied to and directly accessible from geographic locations. The data contained in the database and the ability to analyze, display, and model it is at the heart of GIS. This is a crucial point that will be discussed more fully throughout the rest of this chapter. Figure 3-1 is a representation of the typical display of data, database, and map in ESRI's GIS software package (Athens-Clarke County 2005).

The Differences Between CAD and GIS: Data and Applications

Many landscape architects adopting GIS have previous exposure to **Computer Aided Design (CAD)** softwares (Bernstein 2003, 407). It is useful to draw a distinction between the two similar computer technologies in order to assist landscape architects in understanding whether CAD or GIS is the correct application for a specific project. CAD software is a computer drafting tool that is used in the creation, display, and editing of design. CAD is used in fields such as landscape architecture, architecture, engineering, and industrial design for construction drawings (Coticchia 1993, 415). CAD software typically provides excellent tools to emulate traditional hardcopy drafting techniques in a digital format (Lock 2003, 53). The strength of CAD is that it allows an increase in the speed from design to implementation (Downey 1998, 39). Accuracy can also be more successfully controlled. In addition to the ability to draft documents in a digital format, many CAD softwares include the ability to analyze data such as the compiling of installation and maintenance costs (Haniva and Hanna 2003, 11). It might be a safe bet to hypothesize that all of us who use computers, whether for balancing budgets in a digital spreadsheet, typing novels in a word processor, or merely browsing the Internet, rarely think about why we migrated from paper analog processing to digital applications. The reason for our migration is efficiency. The strength of CAD is that it currently represents the most efficient means of drafting design documents.

The comparison between CAD and GIS emphasizes the definitive qualities of GIS. Both CAD and GIS softwares can **georeference** data, but it is the analytical capability that is the strength of GIS. Gary Lock wrote in his book, *Using Computers in Archaeology*:

> While the strengths of CAD lie in precision vector drawing, those of GIS are based around analytical functionality which can take several forms. GIS are designed to integrate the spatial data with an attribute database so that spatial data elements can have large amounts of text (and image) data associated with them. This is a sophisticated two-way link so that the results of standard database queries can be displayed and, conversely, various map-based spatial queries will produce database querying. This gives rise to one of the main strengths of GIS which is that of data integration and management (Lock 2003, 54).

Lock describes the essential differences between CAD and GIS, as well as highlighting the key strengths of GIS, the ability to tie information to location and analyze that information quickly and effectively. It is the accessibility to data through integrated databases and the analytical capability of GIS that distinguishes GIS from CAD.

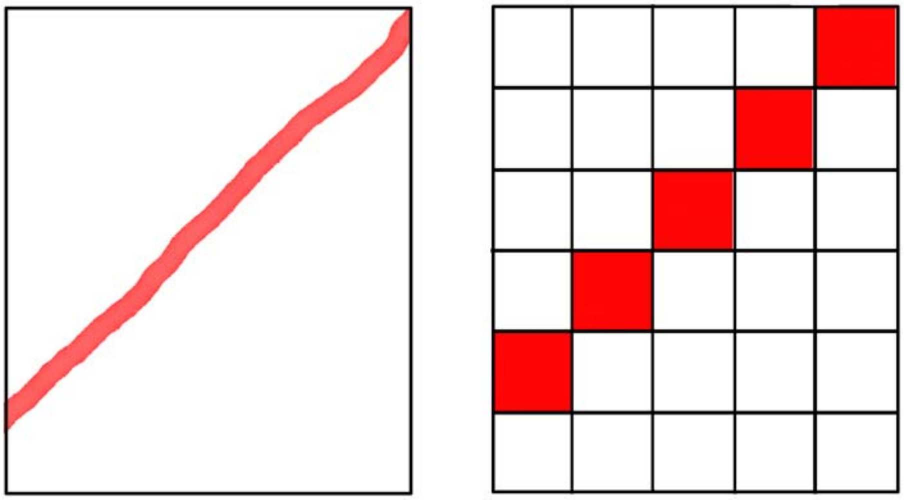
When one considers the potential benefits of combining CAD and GIS into one software package, this is a story worth briefly examining in order to help landscape architects understand some of the factors that affect the tools they use. The largest CAD and GIS software developers, Autodesk and ESRI respectively, both offer the ability to **import** and **export** other manufacturers' file formats, including both CAD and GIS. For the **AutoCad** (Autodesk) user, there is even an add-on GIS software called AutoCad Map 3D. The following, rather infamous quote from the Autodesk website, reports that, "In fact, joint Autodesk and ESRI customers claim that Autodesk GIS software is a better editing tool for ESRI (GIS) SHP files than ESRI's own software" (Autodesk 2005). Despite Autodesk's claims, packages dedicated to either GIS or CAD should be acquired for use according to the landscape architect's specific needs. In the early 1990's, ESRI and Autodesk offered a product called ArcCad that was promoted as offering a link between GIS and CAD. Unfortunately, for reasons not germane to this thesis, the product never developed fully and is no longer offered by the companies. While landscape architects and other design/research professions might understandably view the need for access to tools that allow them to access complimentary technologies, market forces may preclude the offering of products that would benefit our profession.

Introduction to Raster and Vector Data Structures

GIS data are typically **raster** or **vector** format (Sayre, Roca, Young, and Sedaghatkish 2000, 53). Understanding the difference between raster and vector data allows the user to take advantage of each data type according to application. Raster and vector data structures will be defined in detail in the subsequent sections of this chapter, but an introductory comparison is provided here. Vector data structures organize information geometrically in the form of **points**, **lines**, and **polygons**. Raster data structures present data in the form of uniform, systematically organized **cells** (Bernhardsen 2002, 55) (Figure 3-2). Typical uses for vector data include any feature that is presented most effectively through the use of lines or points or irregular polygons. For example GPS locations, rivers, boundaries, roads, contour lines, zoning maps, demographics, and parcel maps are most often used in vector format. Raster data structures are normally used where the source of the data collects information in cells. Satellite imagery and digital elevation models are derived from cell (**pixel**) based sensors.

Raster and vector data may be translated from one data type to the other. The conversion of raster data to vector data is called '**vectorization**', and the conversion of vector data to raster data is called '**rasterization**' (Worboys and Duckham 2004, 16-17). Rarely will the practicing landscape architect have the need to vectorize or rasterize data, because automated methods can be problematic with regards to maintaining accuracy.

Figure 3-2. Vector and Raster Data Simple Comparison.
Vector and raster formats are the two primary GIS formats in use today. Vectors are line-based and, for example, are often used for features such as roads, boundaries, and rivers. Raster are cell-based, and, for example, are often used for imagery, photography, digital topographic maps, and elevation models (Seppelt 2003, 71).



Vector Data.
Vector data are stored as coordinates, and form points, lines, or polygons.

Raster Data.
Raster data are stored as cells.

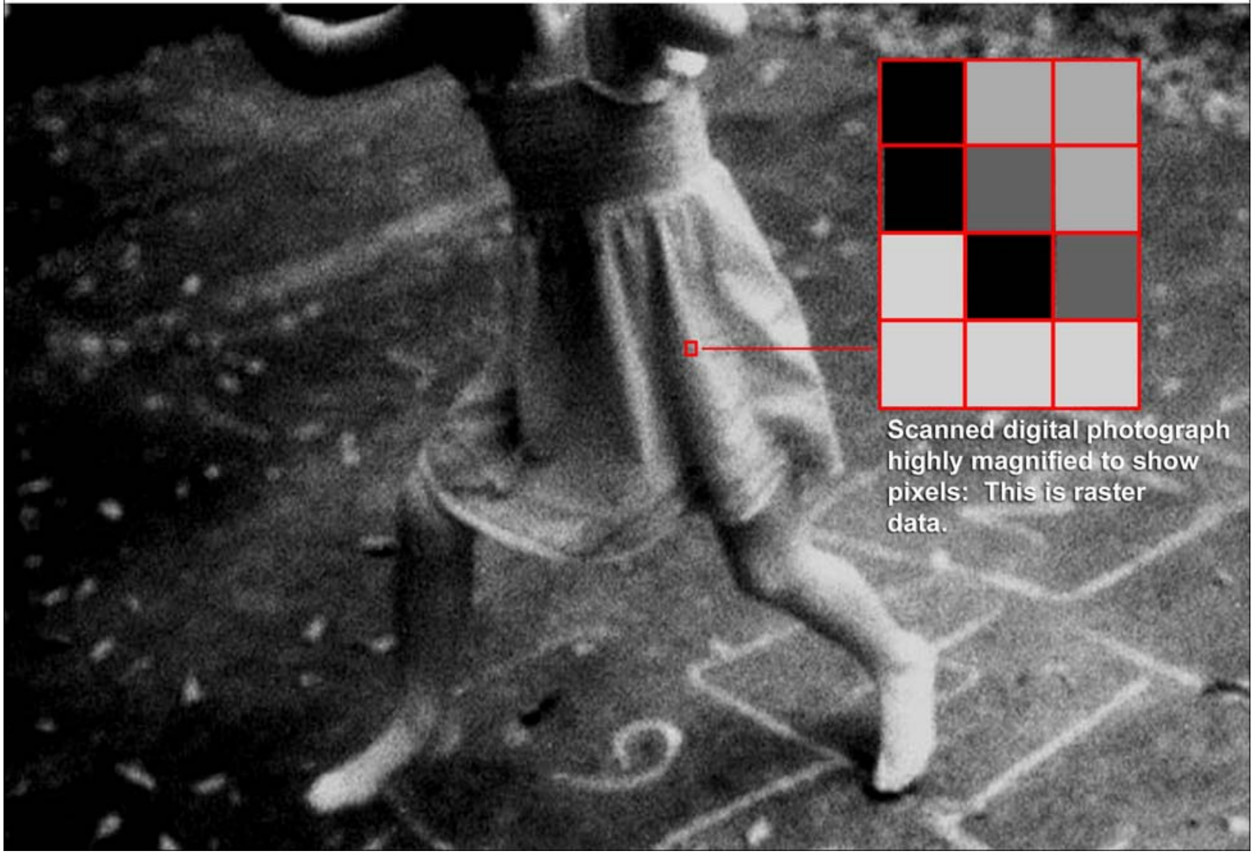
However, there is one example of data that is derived, as opposed to directly converted, with which landscape architects should be familiar with. **DEMs** (**digital elevation models**) are raster-based contour maps, with each pixel representing a specific elevation for a specific point (Garbrecht, Jurgen, and Martz 2000, 3). DEMs offer an excellent example of the context of translation and derivation of products between raster and vector. Vector contour maps are often derived from DEMs through automated processing means. While contour lines can certainly be **digitized** manually, the contour line data (**DLGs**) that are offered by the **USGS (United States Geological Survey)** are generally excellent and easily acquired through the USGS (Goodchild, Steyaert, and Parks 1993, 203). The only real potential limitation of using DEMs or DLGs is **resolution**. DEMS currently available in the United States are either 30 meters or 10 meters resolution; even in the more accurate 10-meter data, there are still 30 foot increments in horizontal distance. Thus even with manual **interpolation** of contours, there is potential for a high degree of error.

Raster Data

A raster data structure is composed of a grid or array of **pixels**, each with a value that corresponds to a specific geographic location (Faust 1998, 60). **Spatial resolution** is the measure of the smallest object that can be resolved by the sensor, or the area on the ground represented by each pixel (*ERDAS Field Guide, Fifth Edition* 1999, 630). The spatial resolution is described in terms of the representation of the length of one side of a pixel. For example, each pixel in **Landsat TM satellite imagery** contains sides of 30 meters and a total area of 900 meters. The pixel would be described as having a **spatial resolution** of 30 meters. The final pixel resolution in terms of ground units is a function of either the scale of the hardcopy source or the resolution of the **sensor**. A sensor is a device that gathers energy, converts it to a digital value, and presents it in a form suitable for obtaining information about the environment (*ERDAS Field Guide, Fifth Edition* 1999, 628). This sensor could be as sophisticated as a satellite-based camera or as simple as a digital thermometer measuring air temperature; a sensor is simply a device that collects data.

The simple data structure and geometry of raster data cells is excellent for computation of **attributes** (Millington, Walsh, and Osborne 2001, 217). Figure 3.3 shows the essential character of raster data, evident even in a digital or scanned photograph that is directly accessible as an example to anyone who has taken or viewed a digital photograph.

Figure 3-3. Raster Data Example.
GIS raster data has the same format as digital photography. The raster cells, or pixels, are the smallest unit of a digitized image (Freeman 2003, 220) (Photograph: Collins, 2003).



Every pixel has a numerical value assigned to it, for both visualization and analysis purposes; for example a road may be assigned a value of 1 and everything that is not a road may be assigned a value of 0. In this simple example, the user can then create a **buffer zone** around all of the roads. A buffer zone is a specific area around a feature that is isolated for or from further analysis. For example, buffer zones are often generated around streams in site assessment studies so that further analyses exclude these areas that are often unsuitable for development (*ERDAS Field Guide, Fifth Edition* 1999, 593). It is worth noting that raster processing and analysis tends to place focus on the values of the pixels themselves, whereas vector processing and analysis tends to place focus on data contained in the database tables attached to map features.

The primary types of raster data are **aerial photography** (Figure 3-4), **land cover classifications** (Figure 3-5), **satellite imagery** (Figure 3-6), **digital elevation models**, and **digital topographic maps** (Figure 3-7). Figure 3-4 shows aerial photography as a companion piece to the photograph in Figure 3-3. The only real difference between the two examples is that the satellite imagery was captured from orbit and has subsequently been georeferenced to a **projection system**. They are both raster images.

Figure 3-4. Raster Data Example, University of Georgia Main Library and North Campus. A companion piece to Figure 3-3., this aerial photograph also features a magnified portion of the image (outlined in red) that shows the cells that are the individual elements of the data. (Photograph: Athens-Clarke County 2003).

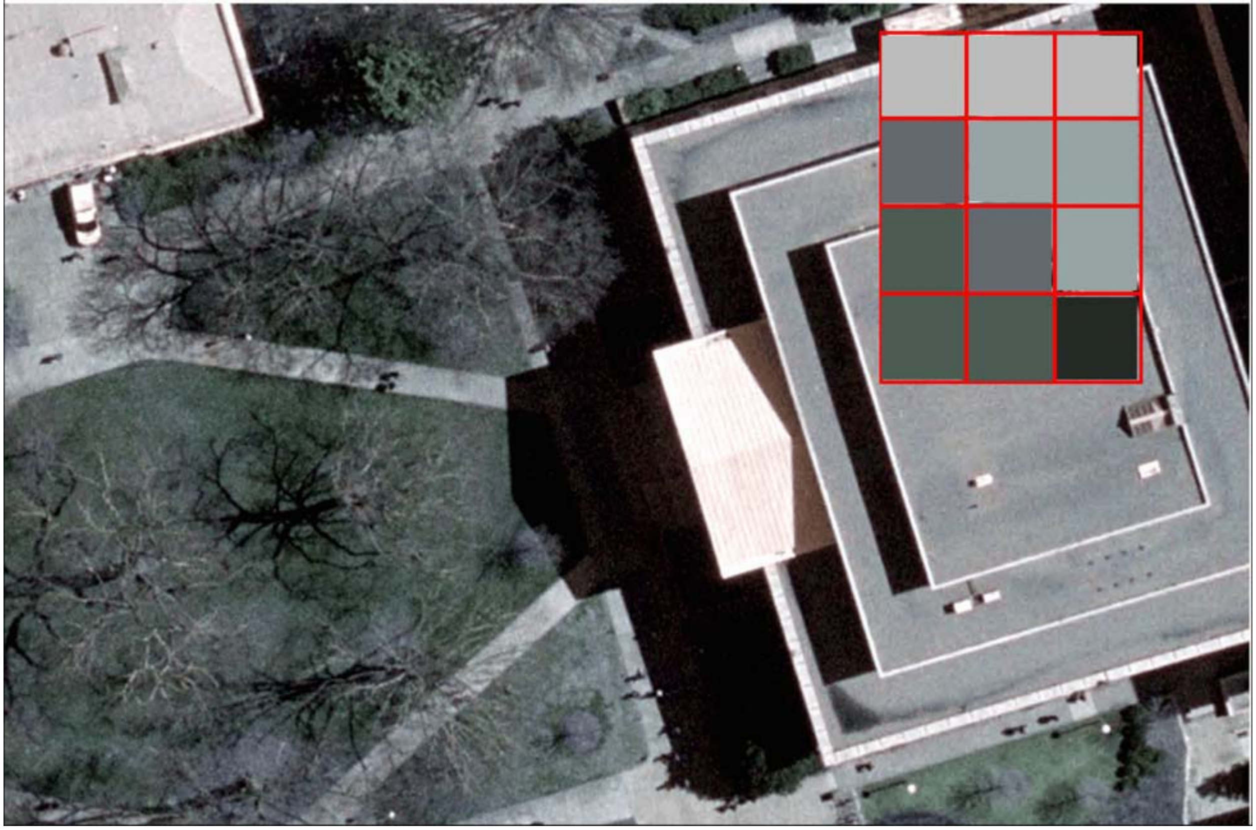


Figure 3-5. Raster Data Example: Land Cover Classification.
One of the primary products of satellite imagery, land cover classification is useful in evaluating the physical characteristcs of a landscape. In this classification of the Kishwaukee River Basin, cover is designated urban, crops, grassland, upland forest, water, marsh, and bottomland forest (Illinois Department of Natural Resources 1997).

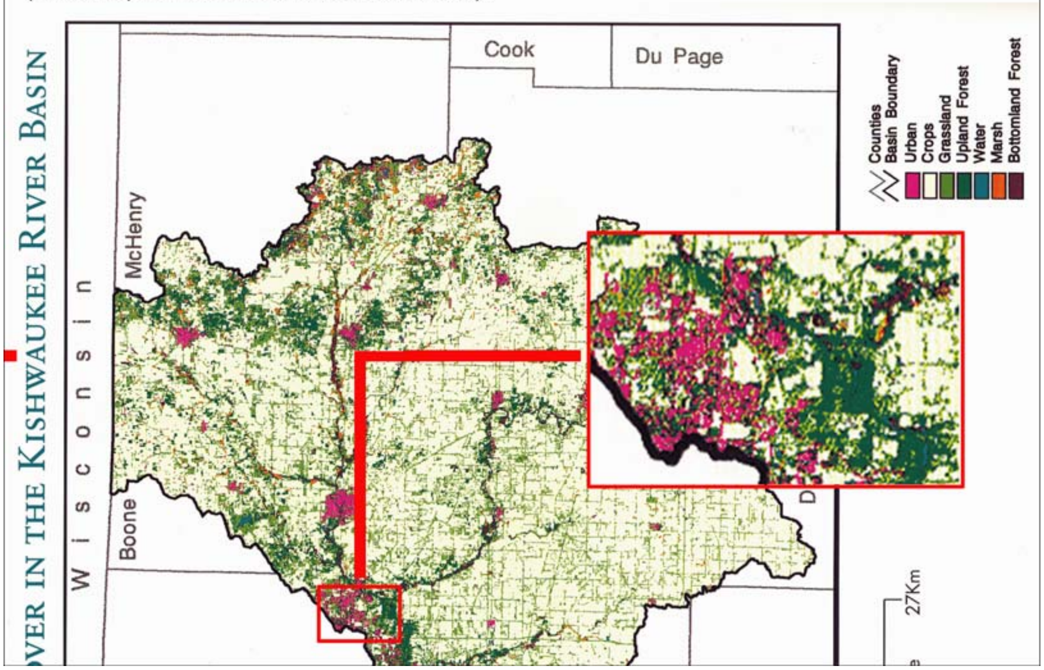
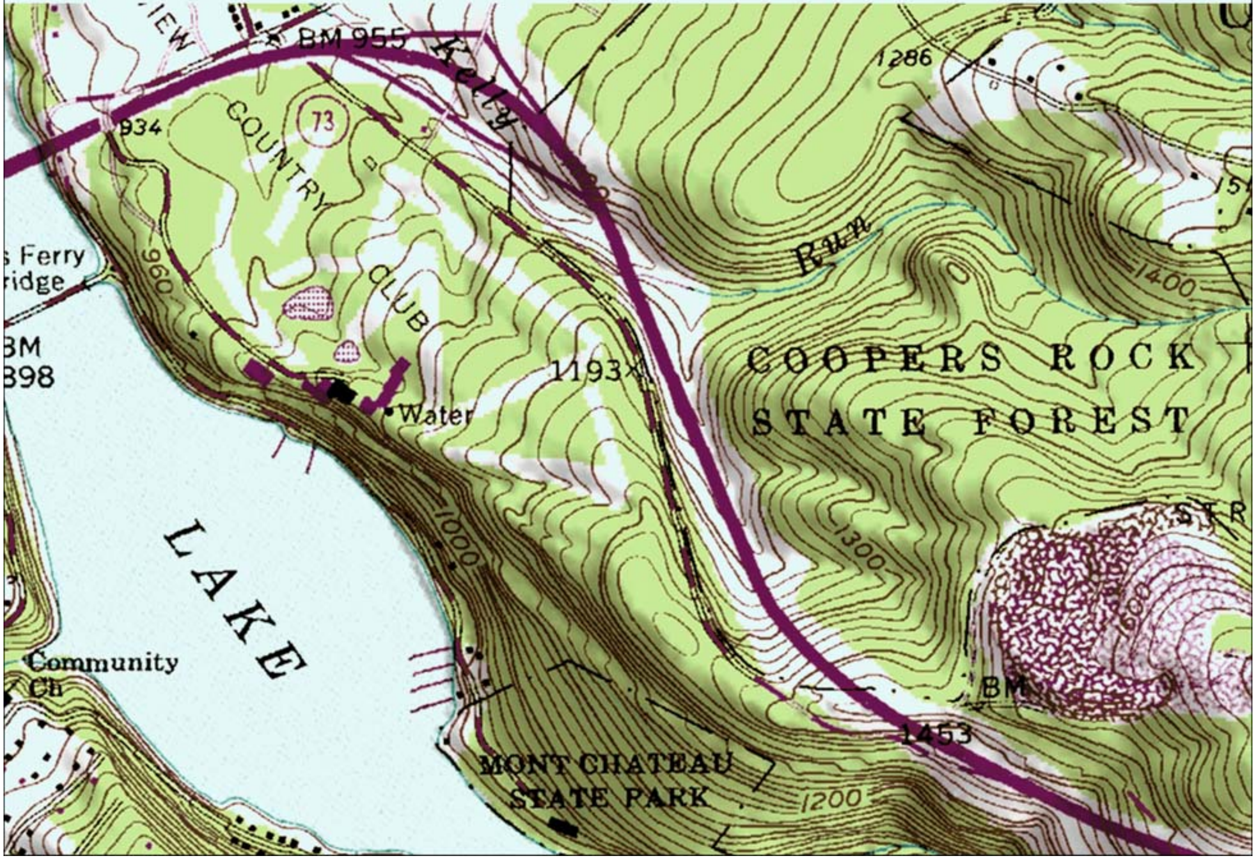


Figure 3-6. Raster Data Example: Satellite Imagery - September 2001, Manhattan.
One meter resolution satellite imagery shows the site of the terrorist attack on the World Trade Center in Manhattan (Space Imaging Corporation 2001).

Figure 3-7. Raster Data Example: Digital Topographic Map.
Digital Topographic Maps, often referred to as Digital Raster Graphics (DRGs), are digital versions of standard USGS topographic map series (United States Geological Survey 2006).

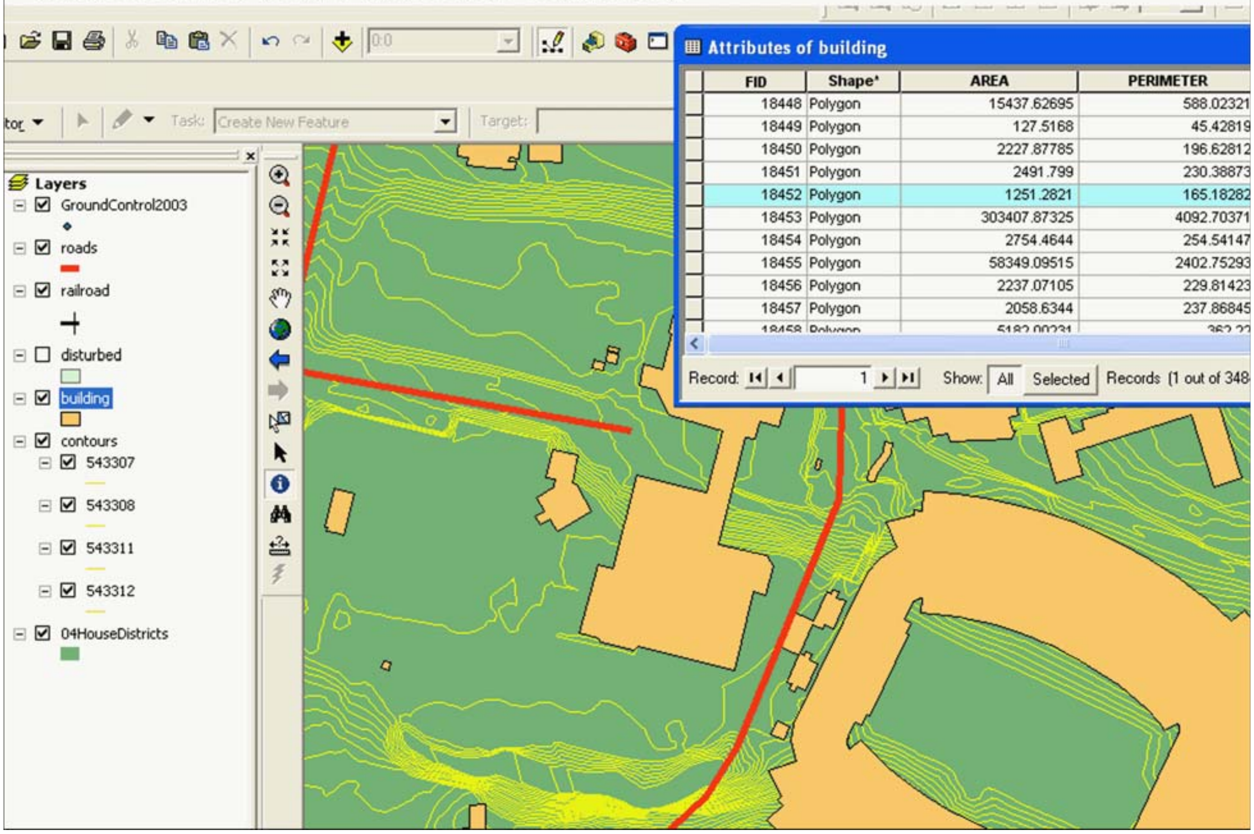


<u>Vector Data</u>

A vector data structure is composed of **points**, **lines**, and **polygons**. Vector data is especially well suited for boundaries and locations. In order to define the shape of a feature with the vector data model, x,y coordinates are used (Hutchinson and Daniel 2004, 6). Vector data has very high resolution, as compared to traditional raster imaging sources. Magnification does not degrade the display quality of vector data (Davis 2001, 89); whereas the quality of the visualization of raster data is severely diminished as the image is magnified. This extensive visual degradation is evident in the magnified areas in both Figures 3-3 and 3-4. A further benefit to the high resolution potential of vector data is that it supports high spatial accuracy

(Davis 2001, 89). Figure 3-8 shows vector data displayed in ESRI's ArcMap software. The attribute **table** at the top right of the graphic is a portion of the attributes attached to the building **layer**. As evidence of the tremendous potential for analysis, modeling and display capabilities of GIS, the layer displayed in Figure 3-8 contains over 19,000 records.

Figure 3-8. Vector Data Example, University of Georgia Sanford Stadium.
Vector data displayed in ESRI ArcMap software. Displayed layers are roads (red) and buildings, including Sanford Stadium at bottom right (gold). Note attribute table at top right, containing data referenced to displayed features. (Data: Athens-Clarke County 2003).



Attributes of building

FID	Shape*	AREA	PERIMETER
18448	Polygon	15437.62695	588.02321
18449	Polygon	127.5168	45.42819
18450	Polygon	2227.87785	196.62812
18451	Polygon	2491.799	230.38873
18452	Polygon	1251.2821	165.18282
18453	Polygon	303407.87325	4092.70371
18454	Polygon	2754.4644	254.54147
18455	Polygon	58349.09515	2402.75293
18456	Polygon	2237.07105	229.81423
18457	Polygon	2058.6344	237.86845

Record: 1 Show: All Selected Records (1 out of 348

Summary of Raster and Vector Comparison

Many theses could be written on the subject of vector and raster GIS data. However, much of the subject matter of those theses would be outside of the needs of most landscape architects. Software developers have done an excellent job of making GIS more accessible to professionals not formally trained in GIS. There are a number of key points regarding data that have been presented in this chapter, and these key points are summarized below in bulleted form:

1. Most of the data used today by landscape architects and other professionals will not be created in-house. Thus, most of us will not have to actually choose whether to use vector or raster data; it will be provided in the best available format by the source.
2. The strength of GIS lies in the access to attributed data that underlies the actual features mapped in the data.
3. Most of the modeling and analysis of raster data is performed on the pixels themselves, whereas most of the modeling and analysis of vector data is performed on the underlying attribute data, found in the database.
4. A vector data structure is composed of points, lines, and polygons.
5. A raster data structure is composed of cells (pixels) in a grid format.

Raster vs. Vector Controversies

A very common misconception regarding the use of vector and raster data structures is worth exploring. There have been endless debates about which data structure, vector or raster, is superior for GIS (Davis 2001, 85.). Typical of software designers, users and published authorities is a mindset that creates a "vector vs. raster" dialectic. Star and Estes, acknowledged authorities on GIS, wrote in the book *Geographic Information Systems: An Introduction*, "The choice of a particular spatial data structure is one of the important early decisions in designing a geographic information system" (Star and Estes 1990, 33). Star's and Estes' words are typical of a belief that one must choose between vector and raster. Nicolas Faust, writing about early GIS, noted: "The battle between the proponents of raster and vector has been raging since the earliest days of GIS development. Advocates and detractors of both raster and vector GIS have exhibited an almost evangelical fervor concerning the correct form for the analysis of spatial data" (Faust 1998, 61). One of the crucial messages of this thesis is that the vector vs. raster debate is a waste of time and energy. Rather than debating this subject, the sophisticated GIS user knows that vector and raster data structures are indeed suited for different applications and that a competent GIS contains both raster and vector data. When Star and Estes wrote that one must choose a particular spatial data structure in 1990 there was truth within their statement. Certainly, the type of data that is generated will be most useful in either a vector or raster format according to the application of that data. Many people believe that the argument is based upon technological advantages of one data structure over another, when in fact, the ongoing debate about the virtues of raster and vector data has been almost completely a marketing issue driven by ESRI and ERDAS, the leading software companies of the time.

CHAPTER 4

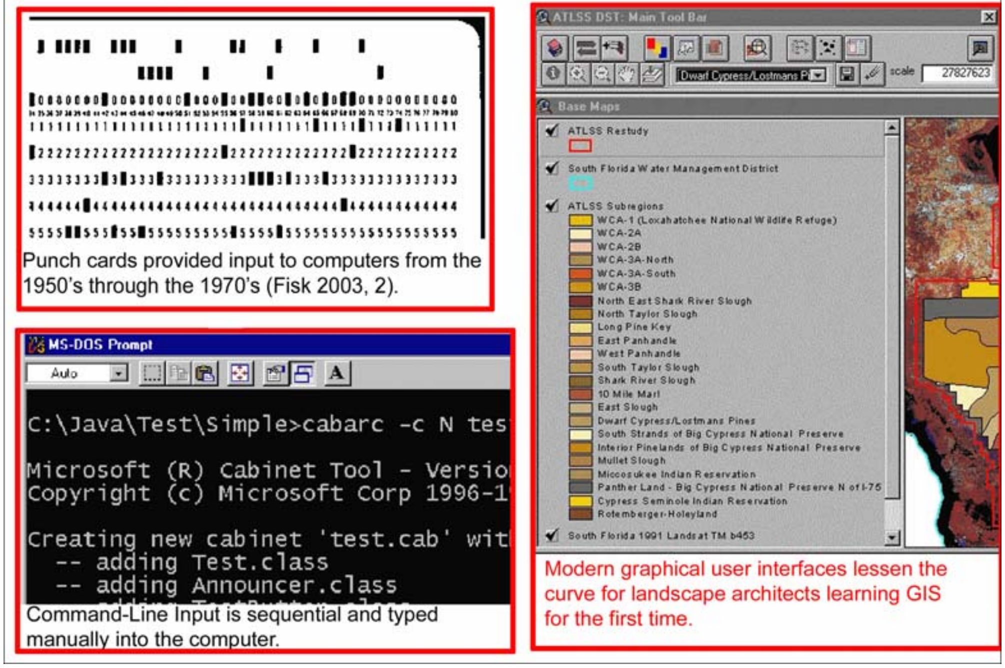
PROCESSING DATA: PRACTICAL DEFINITIONS

Note: GIS terms are highlighted in bold text format and can be found in the Glossary of GIS Terms (Appendix A, Page 105).

Introduction

GIS is more available to landscape architects today for a number of reasons. GIS software has become more user-friendly and intuitive to use, with **graphical user interfaces** having for the most part replaced **command-line** operations (Figure 4-0). Many university programs have added GIS training to their curriculum so that students have opportunities to

Figure 4-0. Punch Cards to Command Line to Graphical User Interfaces.
Early computers used punch cards to input instructions. During the 1980's, command line processes were typed into the computer sequentially. Today's computer software programs are based upon more intuitive graphical user interaces that frequently feature push button operation.



Punch cards provided input to computers from the 1950's through the 1970's (Fisk 2003, 2).

```
C:\Java\Test\Simple>cabarc -c N tes

Microsoft (R) Cabinet Tool - Versio
Copyright (c) Microsoft Corp 1996-1

Creating new cabinet 'test.cab' wit
  -- adding Test.class
  -- adding Announcer.class
```

Command-Line Input is sequential and typed manually into the computer.

Modern graphical user interfaces lessen the curve for landscape architects learning GIS for the first time.

learn the fundamentals of GIS while still in school. The widespread application of GIS throughout so many parts of our professional and personal lives has mandated at least a familiarity with geographic information systems. Perhaps most importantly to landscape architects today is that data is much more freely available. During the early years of GIS the investment required to create and acquire data was enormous. Every organization considering adopting GIS had to consider the very serious financial ramifications of data acquisition and/or data creation. During the 1980s and 1990s the overall cost of implementing a GIS system involved much heavier spending in data acquisition and editing than in hardware or software (Tomlinson 2003, 186). While the costs of data acquisition can still be considerable, the current environment for GIS use often requires much less of a financial investment in the acquisition of GIS than in the past. Commercial data providers have been in business long enough to recoup the original cost of investment in the creation and acquisition of data and they are now able to resell data at much lower prices. Fierce competition within the data provider market has driven down prices further (Shamsi 2002, 86). The landscape architect using GIS should explore options of acquiring data that have already been created by other government and private organizations as considerable savings can be realized in the initial GIS implementation. Data can normally be acquired from local and state governments, as well as from the USGS (www.usgs.gov). A phone call local planning office can yield tremendous amounts of data that is available free or for little cost.

Notwithstanding the significant improvements in cost and availability of GIS data, there are times when data must be created or edited in-house. Creating or editing GIS data prior to actual use in a GIS for analysis, display, or modeling is called **preprocessing**. Preprocessing of data is normally the most expensive part of GIS (Tomlinson 2003, 186).

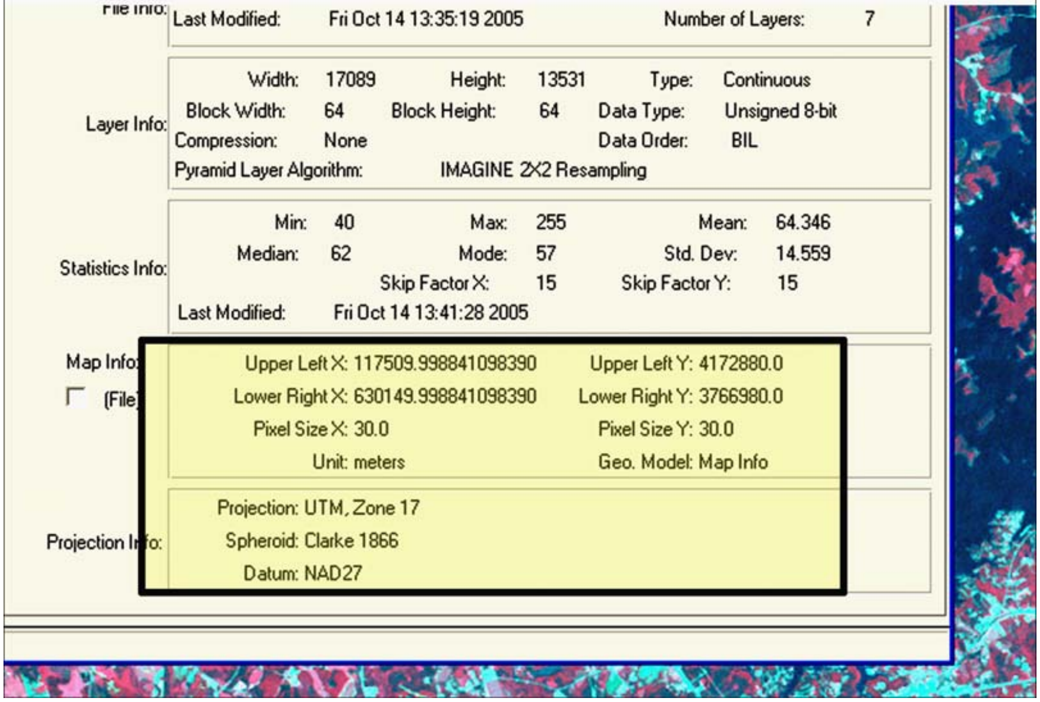
Georeferencing and Rectification of Data

Georeferencing is the process of assigning map coordinates to (geographic) data and resampling the pixels of the image to conform to a map projection. (*ERDAS Field Guide, Fifth Edition* 1999, 606). **Rectification** is the process of making image data conform to a **map projection** system. (*ERDAS Field Guide, Fifth Edition* 1999, 624). For the purposes of the landscape architect, the terms 'georeference' and 'rectification' may be viewed as interchangeable, and for the rest of this section the term 'georeferencing' will be used to describe a process that can be accurately termed either georeferencing or rectification. A description of georeferencing follows:

> Rectification or georeferencing is the process of assigning real-world coordinates to geographic data to tie it to the Earth. When data are collected by cameras or digital sensors, they have inherent forms of distortion from the sensor and terrain. These various forms of distortion must be removed before images will spatially match other geographically referenced data sets. Once the distortion is removed and real-world coordinates are assigned, the data should accurately represent a given portion of the Earth, allowing for analysis with other properly referenced themes, layers, and images (NOAA Coastal Services Center 1997).

An important part of the NOAA description of georeferencing is the statement that data must be georeferenced in order for it to be displayed with other layers of data in GIS software. This is a critical point. It may seem simple, but how is it that GIS software is able to locate the same location from multiple files? The answer lies in georeferencing, one of the distinguishing features of GIS and GIS files. Files georeferenced to known **projection systems** allow the software to display and **model** layers of data, correctly assigning the proper location attributes to the same pixel for each file. A **projection** is a mathematical model that transforms the locations of features on the Earth's surface to locations on a two-dimensional surface. Some projections preserve the integrity of shape; others preserve accuracy of area, distance, or direction (*ESRI* 1990, xxxiii).

Figure 4-1. Georeferencing Information.
The boxed area of this graphic shows the projection information for a GIS file, indicating that the file is georeferenced and can be displayed with other layers in GIS software (Software: ERDAS IMAGINE).



File Info:
Last Modified: Fri Oct 14 13:35:19 2005
Number of Layers: 7

Layer Info:
Width: 17089
Height: 13531
Type: Continuous
Block Width: 64
Block Height: 64
Data Type: Unsigned 8-bit
Compression: None
Data Order: BIL
Pyramid Layer Algorithm: IMAGINE 2X2 Resampling

Statistics Info:
Min: 40
Max: 255
Mean: 64.346
Median: 62
Mode: 57
Std. Dev: 14.559
Skip Factor X: 15
Skip Factor Y: 15
Last Modified: Fri Oct 14 13:41:28 2005

Map Info:
☐ (File)
Upper Left X: 117509.998841098390
Upper Left Y: 4172880.0
Lower Right X: 630149.998841098390
Lower Right Y: 3766980.0
Pixel Size X: 30.0
Pixel Size Y: 30.0
Unit: meters
Geo. Model: Map Info

Projection Info:
Projection: UTM, Zone 17
Spheroid: Clarke 1866
Datum: NAD27

A format that most landscape architects are aware of is **Tagged Image File Format** (**TIFF**). This format is widely used in image editing softwares such as Adobe Photoshop. TIFF file format is not a native GIS format in that it is neither proprietary to any GIS software manufacturer nor capable of holding georeferencing attributes. The TIFF file a landscape architect loads into Adobe Photoshop is not georeferenced; thus it cannot be displayed correctly over other map layers according to geographic location. Researchers at NASA's **Jet Propulsion Laboratory** developed tags that allowed TIFF files to be georeferenced (Ritter 2000). The standard, known as **GeoTIFF**, involves a supporting file placed in the same directory as the TIFF file. The supporting files, called World Files, include the necessary projection and map information to allow a file to be viewed and manipulated in GIS software packages. The TIFF file itself remains viewable in any software that supports the display of TIFF.

Landscape architects should be familiar with the terms ‘file coordinates’ and ‘map coordinates’. **Map coordinates** express the locations of the Earth’s surface using a particular map projection, such as UTM, State Plane, or Polyconic (*ERDAS Field Guide, Fifth Edition* 1999, 614). **File coordinates** express the location of a pixel within the file in x,y coordinates. The upper left file coordinate is usually 0,0 (*ERDAS Field Guide*, *Fifth Edition* 1999, 605). Files that have map coordinates are georeferenced. GIS software is capable of displaying and modeling files that do not have map coordinates (are not georeferenced) by assigning pixel location through file coordinates. However, GIS software cannot correctly align files that only have file coordinates because there is no way to draw a correlation between the exact locations of specific points without having those points assigned to a projection system. For example, using a projected file, a point identified as having a specific **latitude** and **longitude** has context in the GIS because a second file that is georeferenced to latitude and longitude can be displayed as a layer with the original file. If there is a point in the second file that has the exact same latitude and longitude as a point in the first file, those two points can be directly overlaid. The connection between the two points is the latitude and longitude, and GIS softwares are designed to make this connection.

Reprojecting Data

Georeferenced data conforms to a specific projection, such as Universal Tranverse Mercator, State Plane, or Albers Conical. The **reprojection** of data is the transfer of the data from one **projection** to another. In the 1980s and 1990s, many GIS software packages would not correctly display layers of GIS data unless the files were georeferenced to the same projection. Reprojecting data was one of the most common processing steps in GIS. Most of the leading GIS software packages today reproject on the fly which means that the software automatically reprojects the data and displays it accurately on the computer screen. Still it is good practice to project all GIS layers of data into the same projection. Especially if the data will be supplied to customers who may not be savvy GIS users, potential problems can be avoided by ensuring that all of the data supplied is georeferenced to the same projection. In addition, while software packages may be able to display data that has different projections, the software may not be able to correctly analyze or model the data.

There are many map projections available and each projection has its own particular strengths and weaknesses. For example **Albers Conical Equal Area** projection is good for large land masses whose greatest dimension is east to west, such as the continental United States. However, for a land mass such as the South American continent that runs north to south, Albers Conical Equal Area would be a poor choice for data projection. For a smaller area, **Universal Tranverse Mercator** (**UTM**) or **State Plane** might be more useful. Reprojecting geographic data is merely the means of transferring it into the most appropriate projection for the task intended.

Choosing a Map Projection

There are entire books and university courses dedicated to the subject of map projection. The text in this section is dedicated to help a landscape architect narrow the choices of projection or coordinate system to the most likely candidates. A definition of map projection follows:

> The curved, three-dimensional surface of the earth is difficult to represent on a flat, two-dimensional map. A map projection defines the spatial relationship between features on the earth's surface (3D) and their representations on a map (2D). It is a mathematical expression based on a sphere or spheroid, (conic,

> cylindrical, or planar) which transforms the earth's curved terrain to a flat surface. Map projections cause distortion to one or more map properties, such as scale, shape, area, distance, or direction. A map projection is selected based on scale and which map property must be preserved (Georgia GIS Data Clearinghouse 2005).

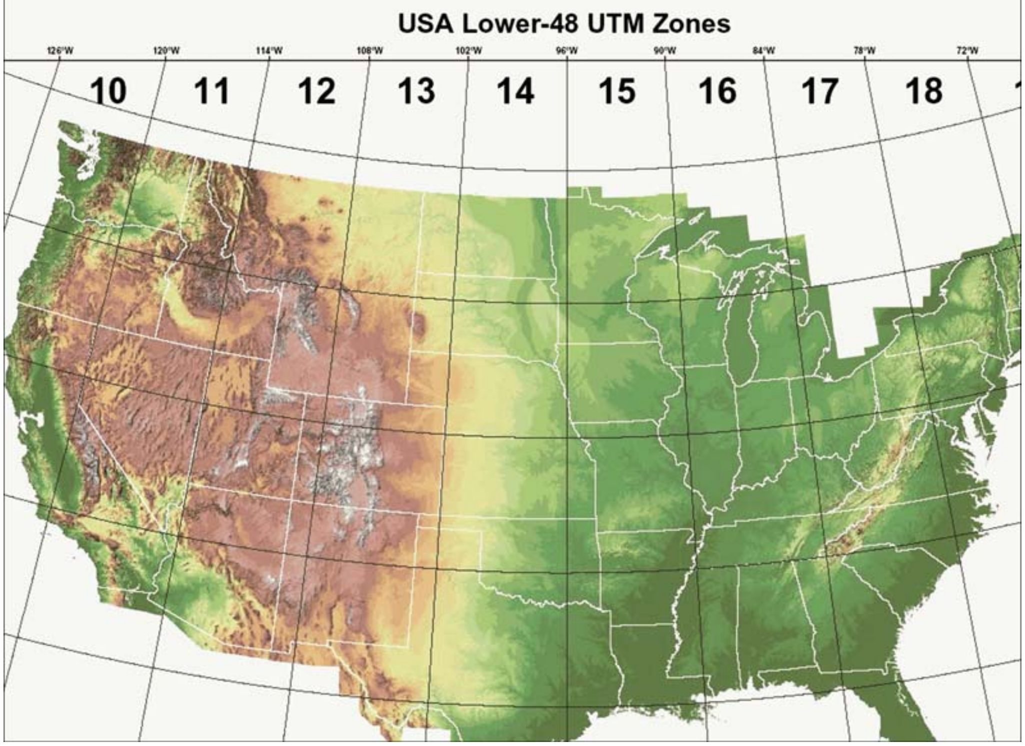
When choosing the map projection, often a **datum** must be chosen as well. The datum provides a base reference for measuring location on the Earth's surface, as well as defining the origin and orientation of latitude and longitude of lines (Tomlinson 2003, 111). The two most commonly used datums in the United States are NAD 83, based upon the GRS80 spheroid, and NAD 27, based upon the Clarke Ellipsoid 1866. Another datum that is used extensively is WGS 84. The landscape architect new to GIS should select a projection and datum that conforms to existing data, consult with a more experienced GIS professional or study many of the excellent books available regarding projection and datum systems. The *ERDAS Field Guide* and the book *Understanding Map Projections* by Melita Kennedy and Steve Kopp offer more exhaustive insight into map projection. An overview of the most prevalent projection and coordinate systems is discussed in the following paragraphs so that designers can make a more informed decision. A landscape architect working in the United States will almost always be able to choose between the choices that follow.

1. **UTM (Universal Tranverse Mercator)** is a coordinate system used extensively at the state and regional level. I have used UTM for virtually my entire career, and it is considered a standard by many organizations at all levels. UTM is used extensively, both in America and internationally, and is a safe and wise choice for landscape architects working on a statewide or regional basis. A definition of UTM follows:

> An international plane (rectangular) coordinate system developed by the US Army that extends around the world from 84 Degrees North to 80 Degrees South. The world is divided into 60 zones each covering six degrees longitude. Each zone extends three degrees eastward and three degrees westward from its central

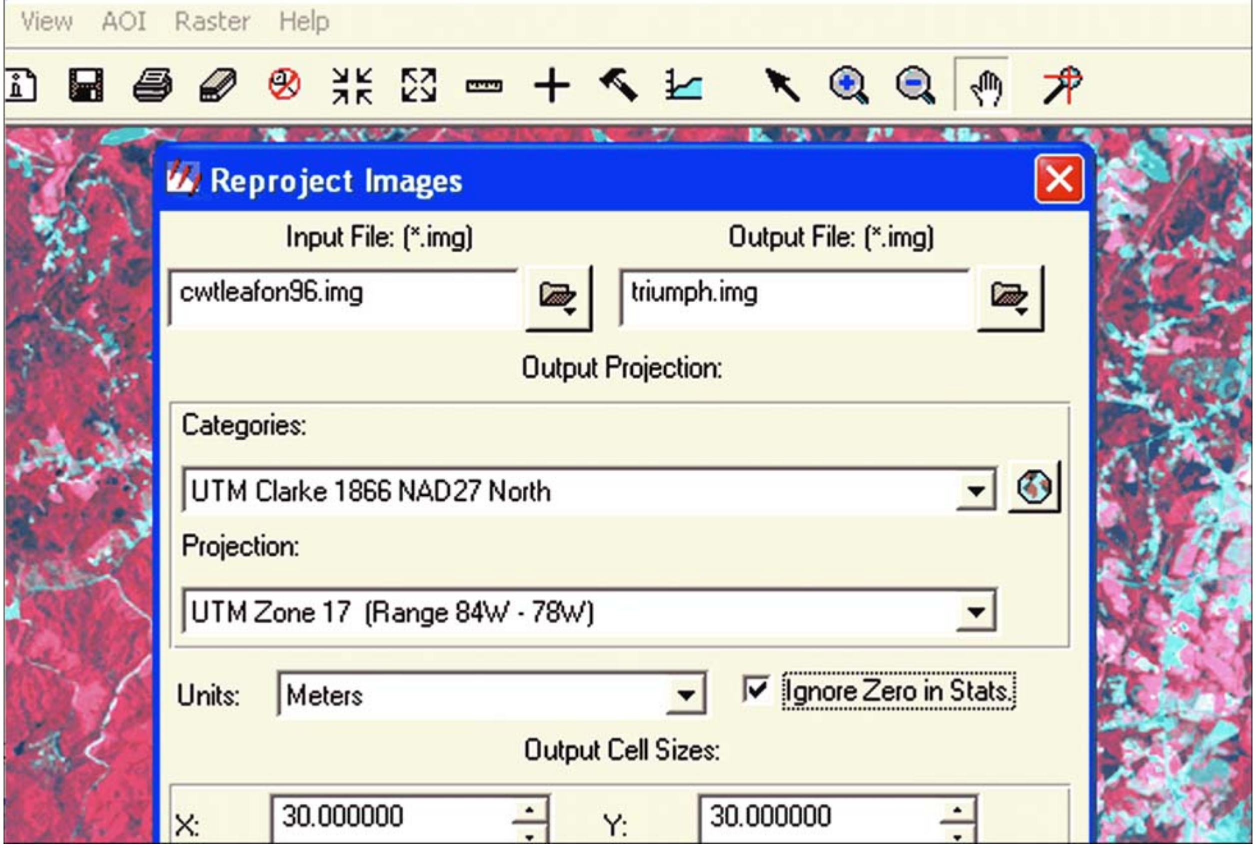
meridian. (*ERDAS Field Guide, Fifth Edition* 1999, 635).

Figure 4-2. UTM (Universal Transverse Mercator) Zone Map (USGS 2005).



UTM is divided into zones and it is important that the data is projected to the appropriate zone for the location (Figure 4-2). There are sixty zones covering the Earth east to west, each six degrees longitude in width; each zone measures approximately 900,000 meters at its widest point. The state of Georgia falls into UTM zones 16 and 17 (*ERDAS Field Guide, Fifth Edition* 1999, 570) and consequently any data that covers Georgia should be projected to either zone 16 or 17, depending upon which part of the state the area is located. GIS software programs offer standard menus for accessing standardized projections (Figure 4-3). In the example provided in Figure 4.3, the projection categories (Projection, Units) are standard options that may be filled in with pull-down menus.

Figure 4-3. Reprojecting to UTM, Zone 17.
An example of a reprojection menu. In this case the output projection is set to UTM, Zone 17. (Software: ERDAS IMAGINE).



Input File: (*.img) cwtleafon96.img

Output File: (*.img) triumph.img

Output Projection:

Categories: UTM Clarke 1866 NAD27 North

Projection: UTM Zone 17 (Range 84W - 78W)

Units: Meters

☑ Ignore Zero in Stats.

Output Cell Sizes:

X: 30.000000

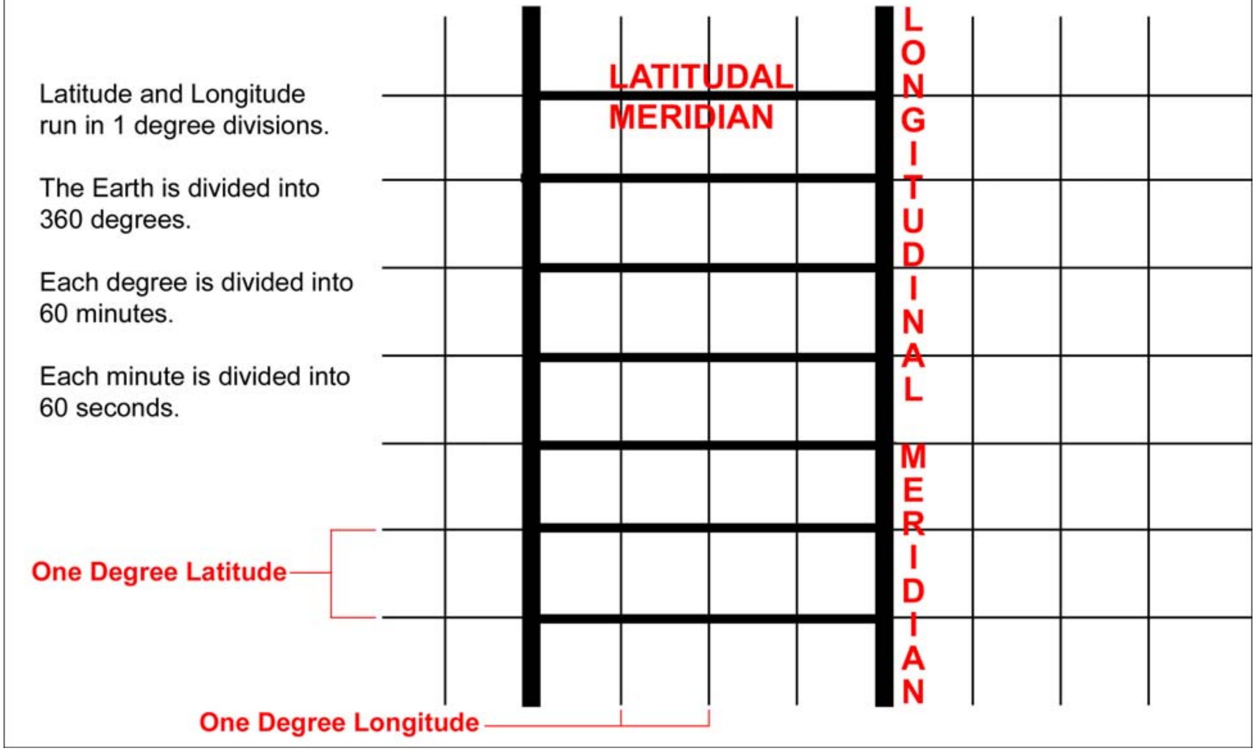
Y: 30.000000

2. **Geographic** is a coordinate system representing latitude and longitude (Hutchinson and Daniel 2004, 317). An easy way to remember the direction of the **meridians** is to remember to think of a ladder (Figure 4-4). Latitude is the rungs of the ladder and longitude is the poles to which the rungs are attached. Thus, latitude runs east to west, and longitude runs north to south. More information is located in the following definition:

> Latitude - Longitude is a coordinate system that treats the globe as if it were a sphere or spheroid. The sphere is divided into 360 equal parts called degrees. Each degree can be further subdivided into 60 minutes, each composed of 60 seconds. The standard origin is where the Greenwich Prime Meridian meets the Equator. All points north of the Equator and east of the Prime Meridian are positive. The origin divides the globe into four quadrants; northwest, northeast, southwest and southeast. Each line of longitude runs north and south and measures the number of degrees east or west of the Prime Meridian. Values range from positive 180 to negative 180 degrees. Lines of latitude run from east to west

and measure the number of degrees north or south of Equator. Values range from the North Pole, at positive 90 degrees, to the South Pole, located at negative 90 degrees (Georgia Clearinghouse 2005).

Figure 4-4. Latitude and Longitude: The Rungs of a Ladder.
Latitude runs the same direction as the rungs of a ladder: East to West.
Longitude runs the same direction as the poles of the ladder: North to South.



Latitude and Longitude run in 1 degree divisions.

The Earth is divided into 360 degrees.

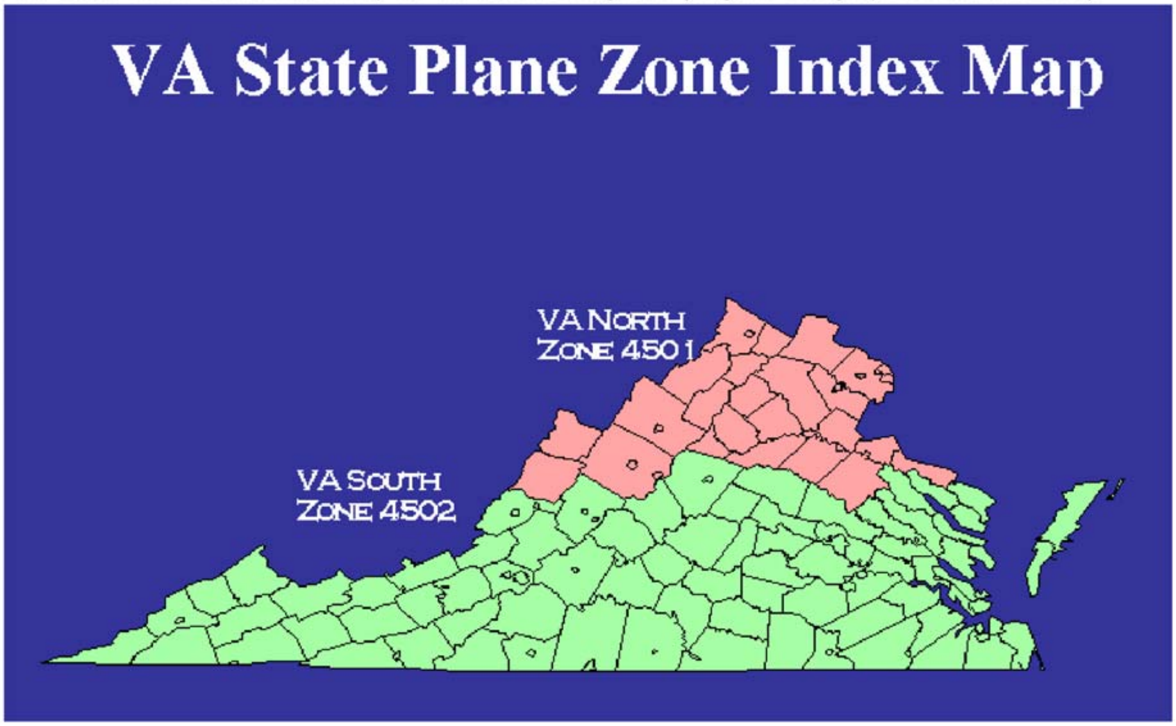
Each degree is divided into 60 minutes.

Each minute is divided into 60 seconds.

3. **State Plane**, used by many local governments, is a coordinate system that divides the United States into 130 sections, each with its own projection surface and grid network (ERDAS 1999, 553). Designed for large-scale (small-area), State Plane uses Lambert Conformal Conic projection for states that are longer in the east-west direction and Transverse Mercator projection for states that are longer in the north-south direction (Kennedy 2004, 45). Only used in the United States, State Plane, which is based upon NAD 27, is recognized by all states for definition of legal boundaries. Thus, landscape architects working in local or state government will most likely be using data projected to State Plane. Zone boundaries are small and follow

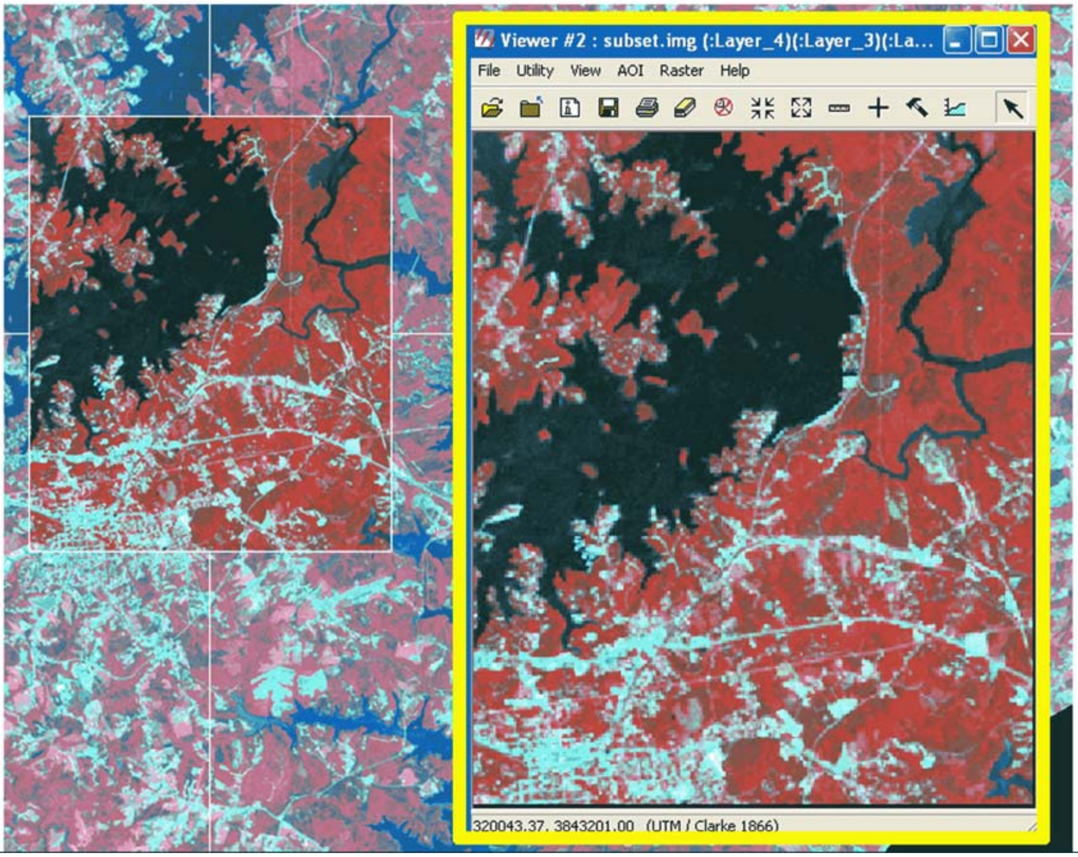
state and county lines (Figure 4-5). Due to the small boundaries, accuracy is excellent, and State Plane is an excellent choice as a projection system for local governments.

Figure 4-5. State Plane Projection.
Comprised of smaller geographic areas than Universal Transverse Mercator, State Plane is the most likely projection system that landscape architects working in public works will use. The example provided is the State Plane Zone Index Map for the state of Virginia. (Virginia Geographic Network 2003).



4. **Albers Conical Equal Area** is a projection that produces accurate area and distance measurements in the middle latitudes and of geographic regions that are wider east-west then they are in the north-south direction (ERDAS 1999, 481). Albers Conical Equal Area is briefly noted in this thesis because it is the best projection system for a continent-wide projection for uninterrupted GIS data sets of North America. If the data set covers North America, but will be offered in subsets, then UTM is a better choice, because UTM offers a higher level of accuracy at state and regional levels.

Figure 4-6. Subsetting/Clipping
The process of extracting data from one file to another, the highlighted box (Viewer 2) is a subset taken from the larger underlying image (Software: ERDAS IMAGINE) (Imagery: Landsat TM 1996).



Subsetting/Clipping

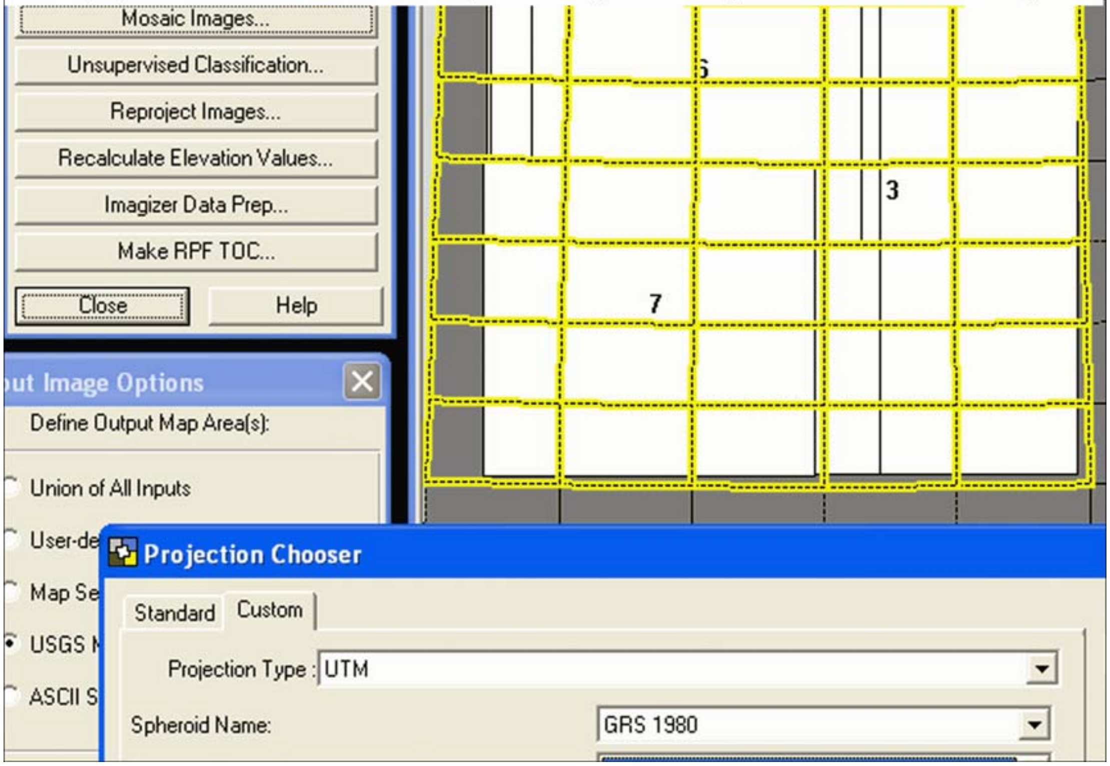
Subsetting, or **clipping,** is "the process of breaking out a portion of a large image file into one or more smaller files" (*ERDAS Field Guide*, *Fifth Edition* 1999, 631). Subsetting is normally the term used in raster operations, whereas clipping is normally the term used in vector. Subsetting is useful in the initial compilation of GIS data, especially with regards to analysis and modeling of data where the geographic **extents** must match exactly. For example, if a GIS professional conducts change **detection**, it will be important that the boundaries of the data are identical. Change detection, which is a form of statistical analysis, compares **land**

cover classifications from different time periods to examine changes in the environment, for example, seeking to answer whether there is an increase or decrease in the amount of a specific type of vegetation.

Mosaicing

Whereas subsetting/clipping involves the creation of smaller GIS files from larger ones, **mosaicing** is the process of piecing together images side by side to create a larger image (*ERDAS Field Guide, Fifth Edition* 1999, 616). For many GIS software programs the input files must all be georeferenced to the same projection prior to running the mosaic.

Figure 4-7. Mosaic Operation.
Setting up a mosaic, this dialog box shows the input files to be stitched together into a larger file. Note the reprojection choice that will also be completed during the mosaic (Software: ERDAS IMAGINE).



Projection Type : UTM

Spheroid Name: GRS 1980

CHAPTER 5

NUANCES OF THE GIS VOCABULARY

Note: GIS terms are highlighted in bold text format and can be found in the Glossary of GIS Terms (Appendix A, Page 105).

There are fundamental terms and concepts discussed in GIS. Often these terms and concepts are incompletely understood, even by senior GIS operators. Explanations through documentation and/or teaching are often offered at a level that more technical than needed for those whose goals are to effectively apply the technology to their work. The following chapter provides examples of commonly misunderstood facets of GIS, with a goal of providing concise descriptions of various components of GIS technology. Whereas exhaustive explanations of these technologies can be intimidating, the goal of this chapter is to connect the user to the technology by providing a working vocabulary. Succinct descriptions applied in terms familiar to landscape architects provide an underpinning for a complete understanding at a level appropriate to successfully access what GIS has to offer.

Satellite Imagery is not Photography

Otherwise knowledgeable GIS professionals often refer to ‘satellite photographs’, but there is no such technology currently used in this era of satellite-based acquisition of representations of the Earth. Today’s use of digital cameras has blurred the definition of ‘photograph’. In a traditional sense photography refers to the actual reaction of light upon film and the digital sensors of modern satellites produce a product more accurately termed ‘imagery’.

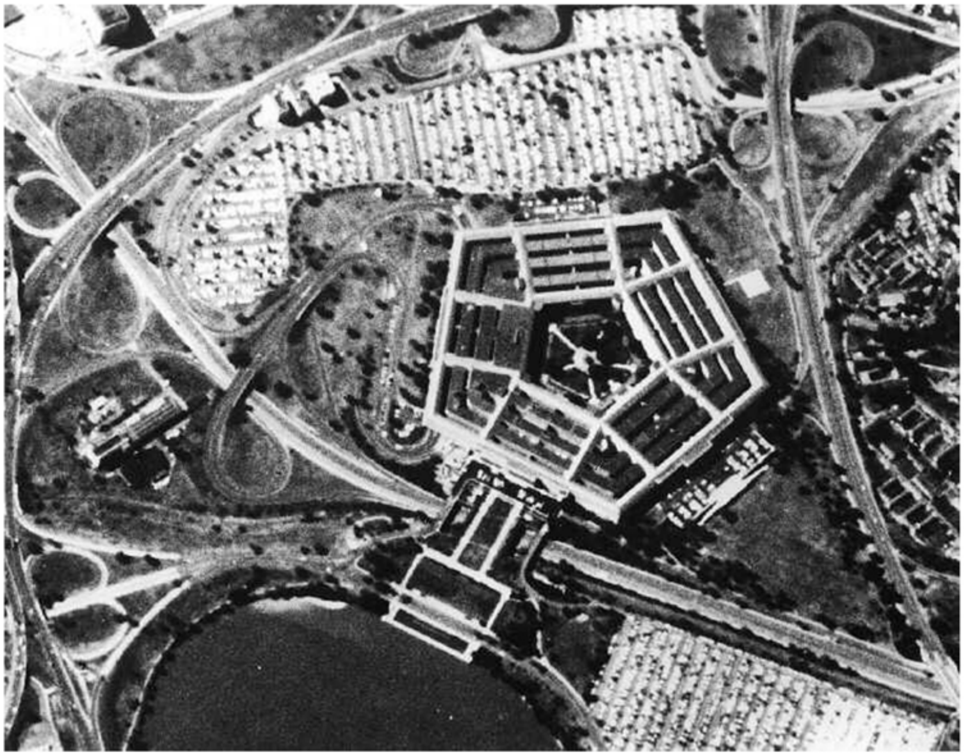
Modern satellite imagery is captured using digital sensors, based upon the same **charge-coupled devices (CCD)** used in today's consumer digital cameras. Invented in 1969 at Bell Labs, CCD chips are image sensors composed of silicon chips containing millions of photosensitive diodes called photosites. Each photosite is stored as a set of numbers that can be used to set the color and brightness of each pixel to reconstruct the image (Lucent Technologies, 2002).

Figure 5-1. Hurricane Isabel from Two Perspectives.
Hurricane Isabel, September, 2003. The larger photograph is from space; the smaller inset from Earth. Both revealing, but from a scientific perspective, modern sensors reveal more than just a photograph. Cloud height, rainfall amount, wind dispersion can all be measured.

Manned space flight photography is available through photographs captured by space shuttle astronauts, but this data is not typically used in remote sensing or GIS processing (USGS, 1997). The Soviet Union and United States used photography-based satellites for military reconnaissance from the late 1950s through the early 1970s. **Corona**, the American system, was in place from 1958 to 1972, and the first successful mission captured over 1.6 million square miles of Soviet Union territory. Once the film was exposed, it was jettisoned back to Earth near

Hawaii, in a capsule fitted with a parachute designed to be snagged by airplane as it returned to Earth (Project Corona 1999). Corona used a special polyester film base designed specifically to be used in satellite-borne cameras; this film, called Mylar, is used for drafting by landscape architects, architects and engineers.

Figure 5-2. Corona Satellite Photograph, Pentagon, Washington, D.C.
Photograph taken by satellite, and then de-orbited back to Earth for processing and development of film (Project Corona 1999).

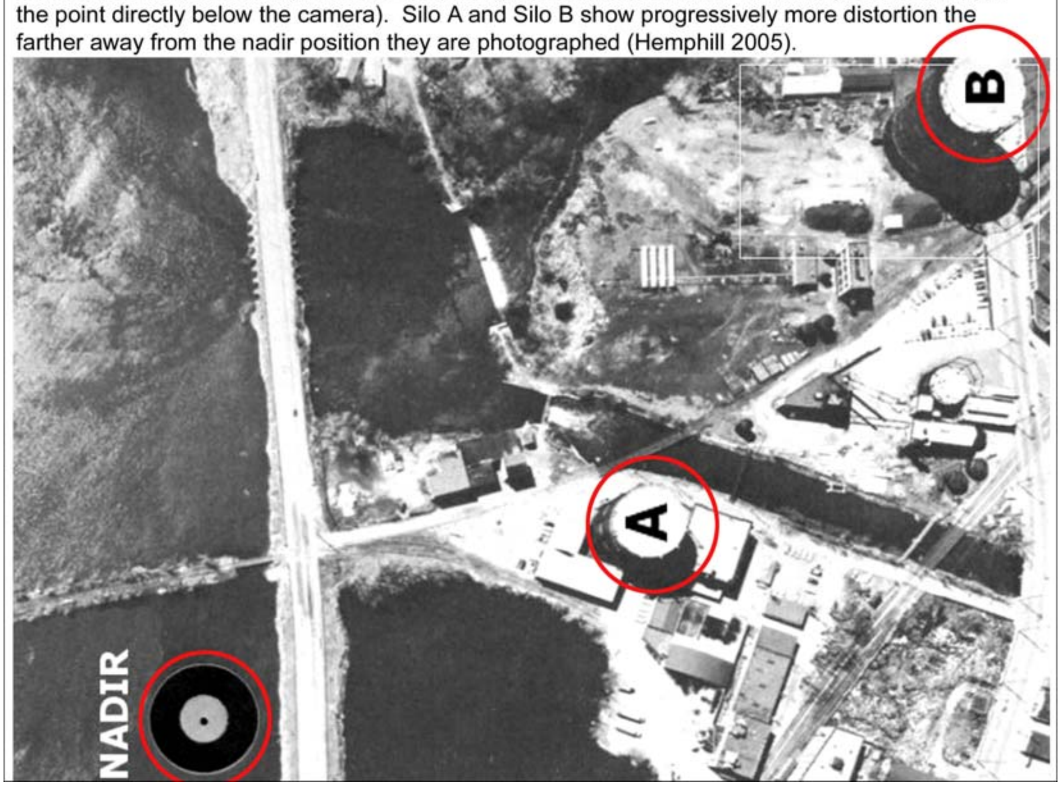


Traditional 35mm handheld cameras have moved heavily to digital offerings and the idea of photography for almost all users will include digital applications. The divide between ‘digital’ and ‘film-based’ photography in descriptive terms has or will shortly become nonexistent. Our children will certainly not consider these things as film-based photography becomes the sole domain of fine art photographers. Even with recent advances the terms ‘photography’ and ‘imagery’ in describing remote observation of the earth will continue to have very different meanings. The educated landscape architect using GIS should refer to satellite products as ‘satellite imagery’, not ‘satellite photographs.’

X, Y, & Z: What Orthorectified Imagery Offers

Orthorectification is a form of **rectification** that corrects for terrain displacement (*ERDAS Field Guide*, *Fifth Edition* 1999, 619). Imagery and products derived from imagery often suffer from **distortion** and **displacement**. Distortion is the shift in the location of an object that changes the perspective characteristics of the photo, and displacement is the shift in the location of an object in a photo between an object's image and its true plan position (Hemphill, 2005).

Figure 5-3. Distortion and Displacement.
An example of the distortion that occurs with remotely sensed data. While differences in terrain can cause distortion, this example shows the photographed areas that are off-nadir (nadir referring to the point directly below the camera). Silo A and Silo B show progressively more distortion the farther away from the nadir position they are photographed (Hemphill 2005).



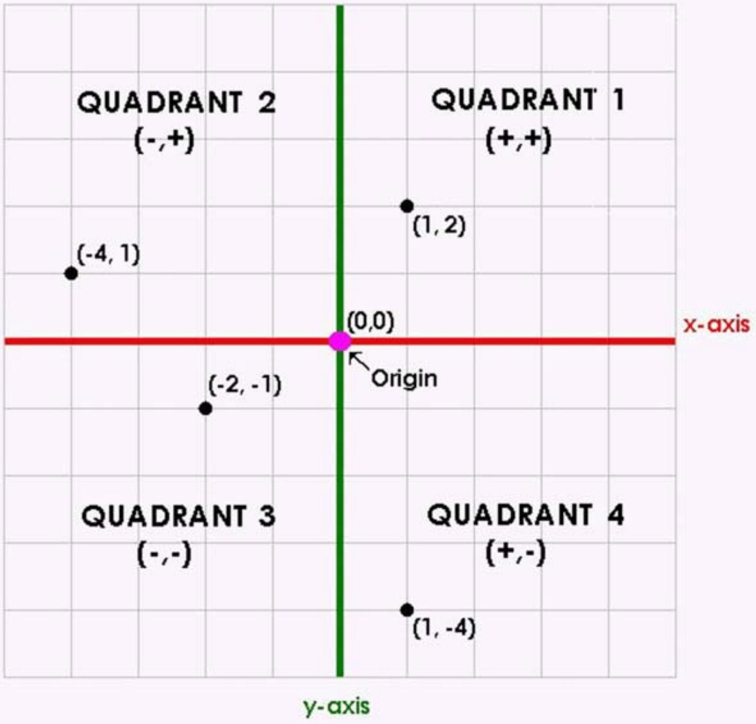
Distortion and displacement are most prevalent in areas that are mountainous or that have significant changes in elevation. Errors in the location accuracy of imagery may also be attributed to **lens distortion** (small flaws in the optical components of the sensor lens) and **tilt displacement** (images taken from oblique, rather than vertical orientations) (Hemphill, 2005). Imagery should ideally be captured directly overhead at a true ninety-degree angle between the sensor and the location. This location is referred to as **nadir**. Because of the footprint of the image, some portion of the imagery will be recorded at an oblique angle off-nadir. Orthorectification is the method of accounting for accuracy errors in imagery caused by topographic relief, lens distortion and tilt displacement.

Figure 5-4. Salt Lake City.
Created for the 2002 Winter Olympics, this view of Salt Lake City was created by draping imagery over elevation data. Orthorectification allows changes in terrain to be accounted for during processing, ensuring much higher accuracy levels (Stacy 2002).

We look at maps and imagery in two dimensions (plan view); computer representations of GIS are viewed in plan view on a computer screen. While the curvature of the earth has great effect on the accuracy of GIS maps that cover large distances, the relief of the Earth itself, in the form of mountains and hills and valleys, introduces significant errors in the accurate representation of data. This is especially critical in GIS where the importance of the work is based upon statistical calculation, rather than visual interpretation. Small errors in accuracy increase dramatically in magnitude when errors of a few feet are magnified over miles.

Maps are typically presented in flat space with an **X,Y Cartesian** system used to describe locations (Figure 4.4).

Figure 5-5. Cartesian Grid System.
The basis for map systems is the Cartesion Grid System, where locations are identified along an x,y axis of points (Math.com, 2005).



However, it is the Z factor that offers the greatest contribution to increasing location accuracy. Z is the vertical, or third dimension, and data can be corrected to account for the vertical. Orthorectification is used to correct for terrain displacement caused by changes in elevation in the Earth's surface. Often, orthorectified data will be referred to as 'ortho-corrected' or 'terrain-corrected.' These terms are interchangeable and simply refer to data that has been adjusted to account for terrain differentials when seeking the most accurate data possible.

Figure 5-6. Orthorectified Aerial Photograph.
The photograph on the left is overlain with an X,Y Cartesian Grid; the photograph on the right shows the warping of the entire image during the orthorectification process to accomodate changes in elevation. The naked eye cannot identify the subtleties of the transformation, but the grid provides a visual representation of the redistribution of points (Hemphill, 2005).

Orthorectification of aerial photography is typically computed using a **stereo pair**, two photographs having a slight overlap to record parallax of detail to make possible examination of an object or an area common to both photographs (Blinn, Queen, and Maki 2005). While satellite imagery may sometimes be orthorectified using stereo pairs, the standard method is to use image geometry provided in the form of rational polynomial coefficients to drape the image over a **digital elevation model**. Trained **photogrammetrists** (see 'photogrammetry' in Glossary of Terms) normally perform orthorectification of imagery and the practicing landscape architect will rarely have the need to orthorectify imagery or aerial photographs. Virtually all imagery and aerial photographs offered commercially may be ordered orthorectified. While the cost is higher, it is nearly always worth the extra expense, especially in mountainous or hilly regions.

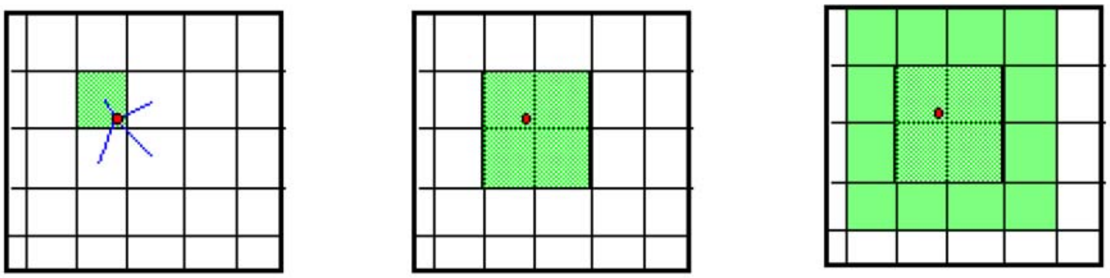
Filtering and Resampling: Nearest Neighbor is Almost Always the Choice

Whether running a **filter** or **resampling** in Adobe Photoshop or a GIS package such as ERDAS IMAGINE, the user is often confronted with making a choice between three options: **cubic convolution interpolation**, **bilinear interpolation**, and **nearest neighbor interpolation**. Each method of filtering or resampling has distinct advantages and disadvantages, but the practicing landscape architect will rarely go wrong by exclusively choosing nearest neighbor processing in GIS applications.

A digital image, whether it is has been captured with a consumer grade digital camera or the most sophisticated satellite, is an assignment of number values to pixels. Resampling and filtering alters the values of pixels. When an image is sharpened or resampled, pixels are changed. For example, resampling methods are employed when an image’s size is changed, either a reduction or an enlargement. Most landscape architects have used interpolation as a method of establishing units when scale is adjusted upward or downward, normally assigning a uniform unit measure between known points. Filtering and resampling of images use a form of interpolation to assign ‘value’ to adjacent or new pixels, as opposed to the way we might normally think of interpolation in terms of assignment of ‘distance’. Cubic convolution, bilinear interpolation and nearest neighbor processing are all methods of interpolating the ‘value’ of pixels during processing. The term ‘value’ will correspond to a ‘color’ that is assigned to pixels in order for human beings to be able to visually interpret an image.

The differences between cubic convolution, bilinear interpolation, and nearest neighbor processing can be easily described. If the value of one pixel is considered and the value of that one pixel needs to be changed via automated means, each of the three methods is different only in how it considers the pixels that surround the pixel to be changed. Nearest neighbor is the simplest method in that it considers only the pixel value next to the pixel to be changed in assigning a new value. Bilinear interpolation considers a square of four pixels adjacent to the pixel to be changed and cubic convolution considers a square of sixteen pixels adjacent to the pixel to be changed (Figure 5-7).

Figure 4-6. Image Interpolation Methods.
When an image is changed in size or a filter, for example a sharpening filter, is run, the values of pixels necessarily change. Interpolation of values, as opposed to interpolation of distance, is the goal of these methods (Sivanandam, 1998).



Nearest Neighbor. Only pixel closest to pixel value to be changed is considered.

Bilinear Interpolation. Four pixels that are around the pixel value to be changed are considered.

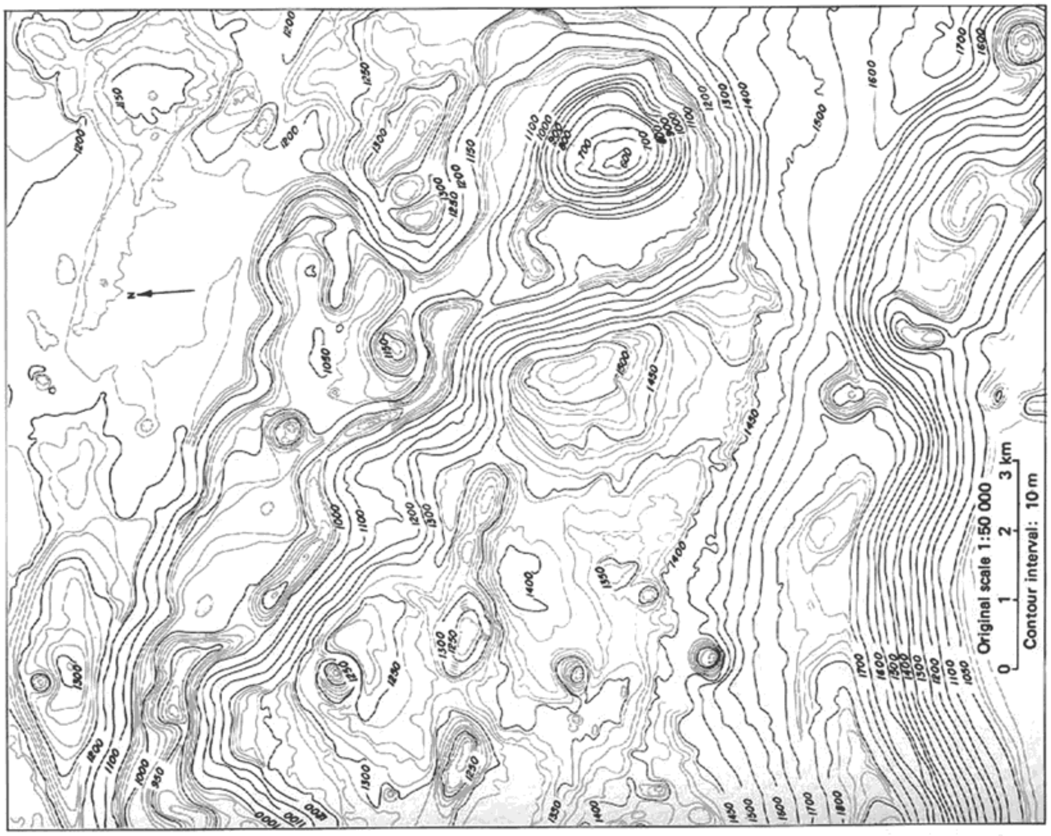
Cubic Convolution. Sixteen pixels that are around the pixel value to be changed are considered.

Cubic convolution processing is often the default choice in image manipulation software such as Adobe Photoshop because it provides the smoothest result, the one that is most pleasing to the eye. However, it is the simplicity of nearest neighbor processing that is its strength. Preserving the **radiometric** properties of an image is usually more important than enhancing the visual properties. Nearest neighbor processing provides the least amount of change to the original pixel value, because the new value is only being affected by one adjacent pixel. Where a user is provided the option of choosing between GIS interpolation methods, nearest neighbor is a safe choice. GIS is presented visually, but this thesis has established that it is the value of the data, whether it is in the number assignations of pixels or the tabular data that is attached to the visual data, that is the strength. Landscape architects new to GIS must become comfortable with the idea that the power of GIS is in the statistical possibilities inherent in the data. This is a departure from classic design training, which is almost completely dependent upon the visual analysis. When using any method that automatically alters pixel values, the logical choice is almost always the one that alters the pixels in the least intrusive way. Nearest neighbor processing is this choice.

Contours in GIS: The Difference Between DEM's and DTM's

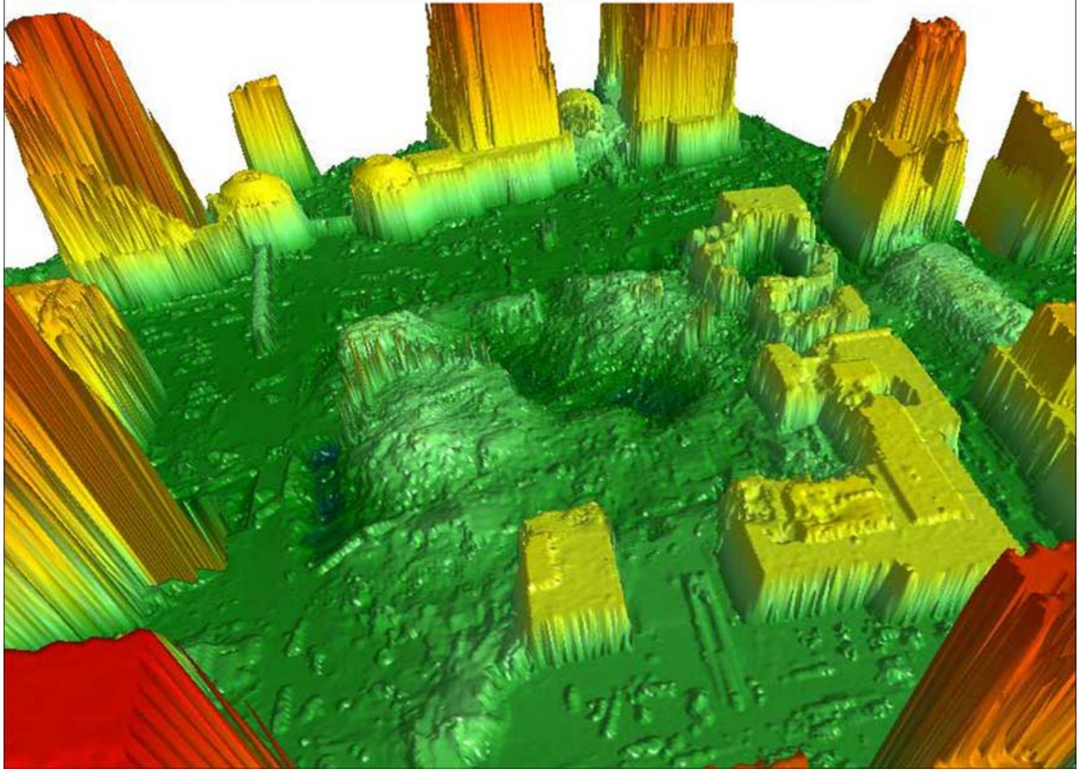
Landscape architects are intimately familiar with contour maps, using them as tools for site planning, calculating cut/fill and engineering purposes (Figure 5.8). Another example of the use of contour maps are United States Geological Survey (USGS) topographic maps. USGS topographic maps are one to twenty-four thousand (1:24,000) scale and cover the contiguous United States. Digital USGS topographic maps are called **digital raster graphics (DRGs)** and are derived from **digital elevation models (DEMs)**. Vector-based contour maps are very similar to paper representations of contour maps. Lines represent specific elevations and the space between the lines must be interpolated. Digital elevation models and **digital terrain models (DTM's)** are raster-based contour maps with each pixel representing a specific elevation for a specific point. Every pixel has an elevation attached. Depending upon the resolution of the DEM or DTM, very little interpolation is required.

Figure 5-8. Contour Map.
Familiar to all landscape architects, contour maps provide a means for graphically representing changes in elevation. (Masursky, 1978).



It is important to understand that DEM’s and DTM’s are digital raster-based representations of elevation. Most vector-based contour maps are derived from DEM’s and DTM’s. A subtlety that many GIS people do not know is the difference between a DEM and a DTM. Many people use the terms ‘DEM’ and ‘DTM’ interchangeably. A DEM is a regularly gridded pattern that represents the elevation of the Earth’s surface, while a DTM also contains the elevations of structures. A DEM is a representation of change in relief of terrain. DTM includes the relief of terrain, but also may contain the heights of buildings or bridges or any other structures that are built upon the terrain (Figure 5.9).

Figure 5-9. Digital Terrain Model - World Trade Center Site After September 11.
Derived from LIDAR, this image shows the hallmark of a digital terrain model, surface structures are included in the data. A digital elevation model would not include building heights, only ground elevation, and this is the key distinction between a DTM and DEM (NOAA, 2001).

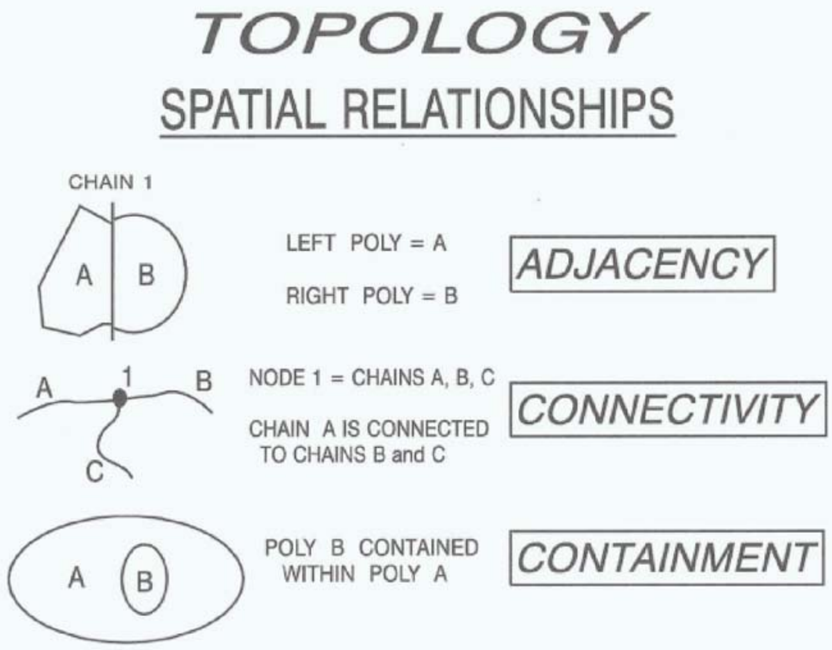


Topology Explained

The term topology is used repeatedly in discussions about GIS, and yet, in common with many of the subjects in this chapter, topology is often not understood. The UNESCO Guide to GIS provides an introduction to topology: "Topology is a mathematical approach that allows us to structure data based on the principles of feature adjacency and feature connectivity (UNESCO 1999)." Why are feature adjacency and feature connectivity important? The answer provides a foundation of knowledge that is sufficient for landscape architects using GIS. This section will include a more detailed definition of topology and an explanation of why topology is important.

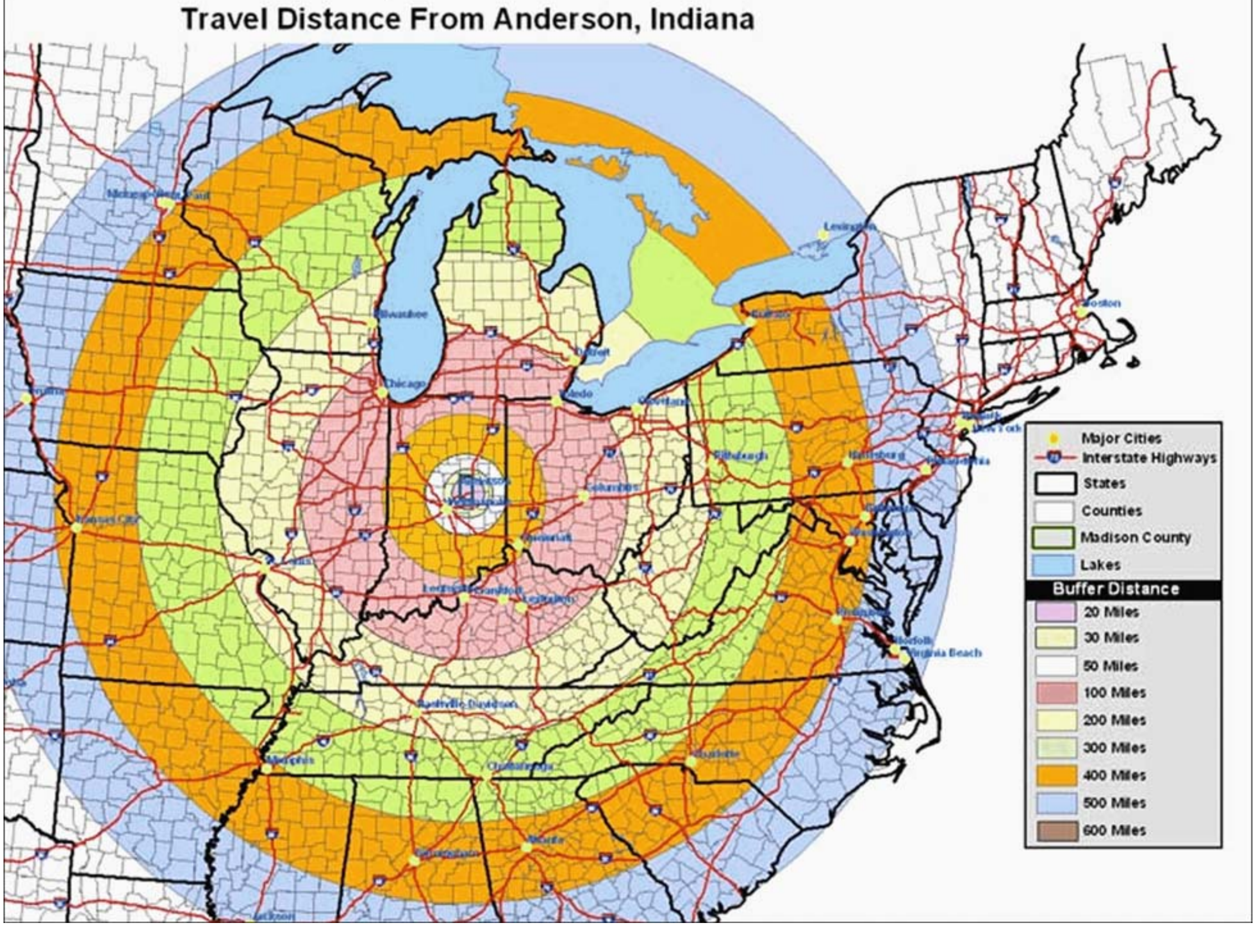
Topology is defined as the spatial relationships between features in a **vector** layer (*ERDAS Field Guide* 1999, 634). These relationships are the connections between the lines and polygons that are adjacent to each other (Hutchinson and Daniel 2004, 6). If there are two features, not only do the shapes of the polygons matter, but where these polygons are in relation to each other matters (Figure 5-10).

Figure 5-10. Topology.
Topology is the computer-based relationships between vector lines and polygons that allows human beings to execute spatial analysis. Topology may be viewed as the architecture of the GIS files that handles feature adjacency (University of Rhode Island, 2005).



Why is topology important? It is important because the context of spatial relationships is critical in analysis and topological structures are what allow the spatial relationships in vector files to be represented. Figure 5-11 shows a series of buffer zones created through simple distance equations where circles are generated according to the distance from a central point.

Figure 5-11. Buffer Operation.
Topology of data structures allows distance-based functions to be executed (Madison County Council of Governments 2002).

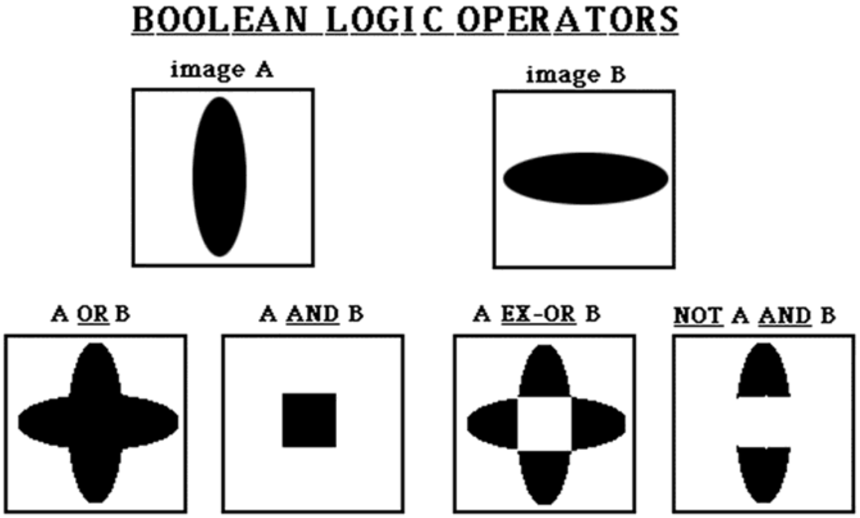


In another example geared towards landscape management or design, a buffer zone created around a stream can only include or exclude areas of interest if the context of where geographic locations lie in paper or computer space is established. This spatial relationship between features, the topology, is one differentiator between vector GIS data and all other data types. Topology may be considered the term in the landscape architect’s GIS vocabulary that acknowledges the importance of spatial relationships in GIS. The acknowledgement alone of the importance of these relationships is enough of an understanding of topology to carry a landscape architect through a career using geographic information systems.

Boolean Logic Explained

This thesis has emphasized that the power of GIS is most fully realized in the ability to analyze large amounts of data. Analysis often takes the form of **modeling** and **statistical analysis**. Modeling is the process of creating new layers from combining or operating upon existing layers (ERDAS Field Guide, Fifth Edition 1999, 616). Boolean logic is used by scientists in a seemingly infinite number of fields of research, including GIS. Boolean logic is the key to the sophistication of human decision making patterns and has been critical to our development as a species. It is a crucial component to what makes us human, and what makes human thought so powerful. It is also simple to understand.

Figure 5-12. Boolean Logic.
The diagram below shows the basis for Boolean Logic. Boolean operators provide powerful capabilities to select or eliminate areas of interest through simple 'and' 'or' statements. (Wagner, Roger C. 2000).

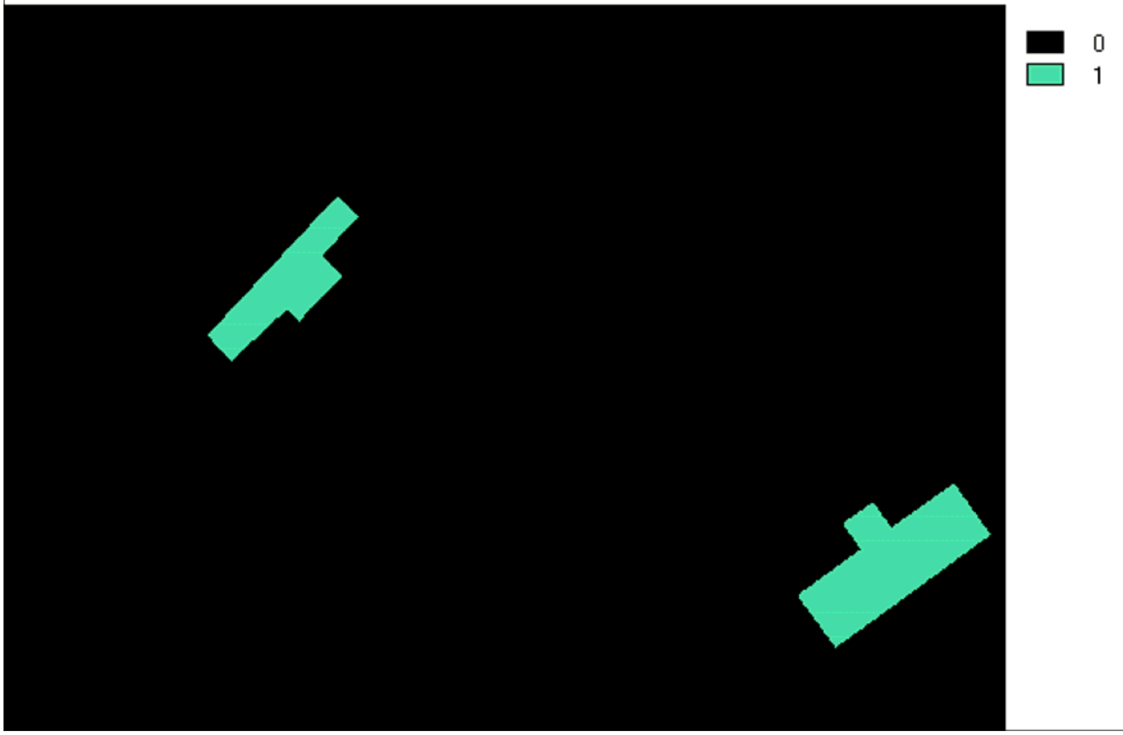


Until several decades ago human beings were the only entity that could use Boolean logic. At present there are two entities capable of Boolean logic, human beings and computers. Anyone that uses Google and other comparable internet search engines uses Boolean logic.

Boolean logic is the ability to ask a question and consider the terms ‘and’ and ‘or’ (Figure 5-12). These are called logic gates and help us to form questions that have different outcomes according to the input. Boolean logic in GIS is merely the ability to insert these “and” “or” statements into models (Figure 5-13). An example of using an “and” statement follows: “If a tree falls within fifty yards of a stream AND this tree is larger than six inches in diameter, then take x action.” Another example, using an “or” statement might be, “If a tree is growing within fifty yards of a stream OR within fifty yards of a lake, then take x action.”

Figure 5-13. Boolean Logic: GIS Example.
The simple example below demonstrates the core of boolean logic as applied to GIS. The boolean operation that generated this result can be described in boolean terms as “IF the zoning is commercial OR light industrial, display as green (and assign the value 1); all other zoned and non-zoned areas display as black (and assign the value 0) (Allen, Chris 1997).

Boolean Parcel Model: Commercial and Light Industry assigned a value of 1.



CHAPTER 6

CASE STUDY: GIS IN LOCAL GOVERNMENT

Note: GIS terms are highlighted in bold text format and can be found in the Glossary of GIS Terms (Appendix A, Page 105).

Introduction

Failure to adequately understand what GIS actually offers, combined with a lack of formal training at the university level, has led to landscape architects that are unable to make the most of the analysis and employment opportunities of GIS. The authors of the *GIS Development Guide* astutely observe that "Historically, much of the delusions and disappointment with GIS projects stems not from a failure of the technical components of the GIS but rather from a lack of understanding of the process of technology innovations and the lack of realistic expectations of all parties associated with the project" (Becker 1996, 2). The profession of landscape architecture has not typically worked at a scale that can support GIS, but in large scale planning efforts GIS is an essential tool. In endeavors that require a landscape architect to utilize GIS, we are usually ill-equipped to make use of this technology. Who are the users of GIS data? What is the role of local government and how does GIS fit in? This chapter answers these questions at a broad level by giving a top-level overview of the issues that face local government and by providing examples of how GIS is used by local government to address these issues.

The application example that follows attempts to develop context and comprehension of what GIS offers by pulling back from the more focused portions of previous sections of the thesis and encompassing a larger view. The application example provided will give a more complete understanding of how the GIS parts fit together into a cohesive whole. Whether a landscape architect works directly or indirectly with local planning offices, there is a high likelihood that practicing landscape architects will be exposed to GIS through local government organizations. Large planning departments may have formally trained GIS personnel that handle the bulk of GIS work, while in other jurisdictions, landscape architects may be required to shoulder GIS in a more direct way. Regardless of the situation, there is no doubt that exposure to and familiarity with GIS will be worthwhile.

GIS in Local Government: The Users and Beneficiaries

The primary users of geographic information in local government involve the public, the planners, and the decision makers. It is estimated that seventy to eighty percent of a local government's work involves land or geographically related tasks, and most local governments have turned to GIS as the foundation for managing these tasks (O'Looney 2000, 3). Whether it is a homeowner coming in to find out lot sizes, a developer examining zoning, an analyst editing new tree ordinances, or a commissioner considering the impact of a new subdivision, geographic information systems give all of these users the ability to access data tied to location. A more complete list of the different types of users of GIS in local government is found in Appendix B found on page 129. The need to respond to public inquiries, provide data and analysis for application reviews and permit approvals and to provide information to facilitate policy reviews made by a municipality's leadership all form the basis for the application of GIS in local government (Becker 1996, 31).

Jack Dangermond, president of ESRI, told me many years ago that he hoped that someday millions would eventually benefit from GIS. His hope has been realized. Reflecting upon the impact of GIS in the decade or so since he first voiced his hopes, Dangermond went on to write that most of the millions whose lives are touched by GIS on a daily basis are not even aware of this fact (Dangermond 1997, vii). The users and beneficiaries of GIS in local government are all of those who live in the community. From a technological standpoint, very little of what goes on in a community is not touched by GIS. Ambulances and police are routed in real-time using interactive GIS softwares from command posts (Steede-Terry 2000, 49). **Global Positioning System (GPS)** maps, whether used by police, rescue units, utility companies, or the public, are based upon GIS. GPS points are invaluable for contributing new location and corresponding information and even new layers to existing map layers (Kennedy 2002, 4). Voting districts are evaluated using census maps and **demographic data**. Demographic data offers millions of lines of data about households, earning power, race and more (Monmonier 2001, 62). Parcel maps are displayed online using interactive maps for the public to view and these maps are often updated in real-time (Figure 6.1). The number of local governments serving GIS map layers online to users has grown exponentially in recent years. In fact the distribution of GIS maps online, in the form of land use plans, zoning information, and environmental information is the current largest application of GIS (Peng 2003, 26). Zoning is edited and changed constantly, with approvals for rezoning made on the basis of community input and the data generated through the power of GIS. Slope, soil, streams, water quality, land cover and current use can be displayed, analyzed and modeled with GIS.

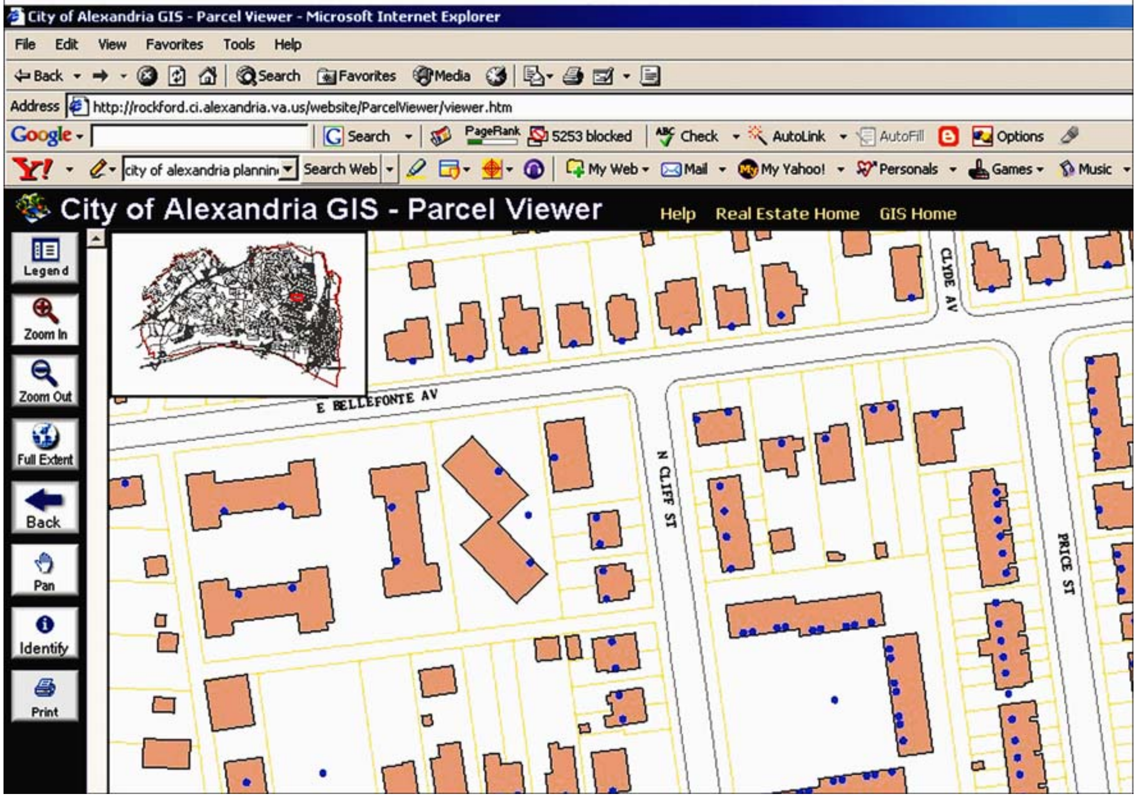


Figure 6-1. Online Parcel Viewer (City of Alexandria).
GIS serves parcels online with an interactive viewer for the public.

The Role of Local Government

The role of local government is to make decisions in the public interest (O’Looney 2000, 3). The responsibilities of local government are immense. Growth in population has exponentially increased the challenges of coordinating the well being of a community. Consider the following overview of examples that local government must address and consider in order to manage these responsibilities (Becker 1996, 37-39).

a. Tax planning…establishing and managing value of real estate;
b. Emergency dispatch…establishing the location of a person calling 911;
c. Public health…ensuring a community is safe;
d. Crime…tracking the movement of criminal activity in neighborhoods;
e. Managing growth…protecting quality of life in a community;
f. Recycling…removing, discarding, and reusing a communities trash;
g. Schools… ensuring comparable quality educations for all;
h. Transportation…moving people safely from one place to another;

i. Business…fostering a healthy business climate to attract investment;
j. Evacuation routes…removing an entire population from an unsafe environment;
k. Conservation…protecting the resources, natural and historic, in a community;
l. Voting districts…ensuring that the people's voice is heard;

GIS offers the most accurate and efficient means to manage the wide range of information local government must gather and manipulate. It is important to emphasize that accumulating information in the preceding list is a formidable task for any community. If decisions are made using faulty data or logic, these decisions will be flawed. Thus the quality and accessibility of the data that supports decisions has significant effect upon the health of a community. In addition to the ability of a community to protect the quality of its drinking water, respond quickly to an emergency or provide adequate educational opportunities all the layers of GIS accumulated by a community have direct and essential impacts upon the quality of the lives of the human beings that reside in a community.

GIS in Local Government: Inventory

In his regional study of Minnesota's Twin Cities area Ian McHarg started with an environmental inventory in which he cataloged with maps and matrixes the existing environmental conditions (Kaiser 1995, 291). The reason for McHarg's advocacy of creating such an inventory was an analysis of the potential for change by understanding the constraints already present (Randolph 2004, 112-113). McHarg's methods form the basis for modern land suitability planning and are used extensively in many planning disciplines, including local government planning (Godschalk 1986, 386-400).

Local government planning works in much the same way as McHarg's classic studies. GIS inventory in local government will almost always include code designations (zoning maps, parcel maps, building permits), natural features (flood plains, slope, land cover), infrastructure inventory (buildings, roads, street signs, utility access), and demographic data (census, population density). A more complete list is found in Appendix C on page 130.

The Primary Uses of GIS in Local Government

Ian Gilfoyle, in his book *Geographic Information Management in Local Government*, outlines the key uses of GIS in local government effectively. Gilfoyles' words may be paraphrased in the following manner (Gilfoyle 2004, 6):

1. Creation and maintenance of a digital base map of the local government area.
2. Creation and maintenance overlay maps (layers in McHargian and current GIS terminology) of information relevant to the needs of different departments (for example: land use searches, buildings, planning codes, boundaries, districts).
3. Production of digital maps for different users and user types (public, employees, decision makers).
4. Creation of links between the digital map and data held in other databases (for example: environmental health systems, housing, emergency routes).

Gilfoyle goes on to emphasize that the links between maps and information are where, in his words, the "real power of GIS technology lies" (Gilfoyle 2004, 6). This is a point that has also been emphasized in this thesis. Landscape architects must grasp the tie between the visual medium of maps, the ability to locate features geographically and the millions of pieces of data that can be attached to the maps and the locations. Gilfoyle sums up the point when he writes: "A key requirement of all local authorities is the ability to pull together information that is known about a specific plot of land or property from different departments and systems" (Gilfoyle 2004, 6-7). The following sections in this chapter's application example will show how a landscape architect or planner takes information from a number of GIS layers in order to help create a report that is useful to the public, planning colleagues, and the commissioners who will ultimately approve or reject an application to rezone property.

A Landscape Architect, GIS, and a Rezoning Review

The application example provided in this section is not based upon one specific local planning organization, but rather it is a compilation from various sources. However, the applications described herein might certainly fall within the action item set of any competent local planning office. The application example provided is a zoning review. The landscape architect would normally be on the planning department staff as a planner, and the term ‘planner’ will be used throughout the body of this section. Other participants in the process include the planning commission, the public, related departments such as the engineering or GIS departments, as well as a property owner or his designated representative which could include a landscape architect.

Prior to the zoning review, a technical review report is produced and provided to the applicant. This technical review report is created by current and long range planners as well as other specialists in other county/city departments, such as the engineering and water/sewer departments. For example, the engineering department must review the impact on transportation in the area requested to be rezoned, and the water/sewer department must review stormwater runoff impact. The planning department goes over their review with the applicant; sometimes revisions must be made before the process can move forward, in order to attempt to address any issues outlined in the technical review report. The planning commission makes its recommendation based on staff comments, as well as review of various support materials.

Finally, the application goes before the board of commissioners, who either approve or reject the proposal.

GIS is used in the technical review analysis in regards to comprehensive planning as it relates to the surrounding area, natural resources, and future land use. Specifically, GIS assists planners by providing information pertaining to natural resources including water bodies and their respective buffers, floodplains, wetlands, slope, watersheds, groundwater recharge areas, as well as roads, schools, parks, and historic resources. This information is taken into account as the site plan is reviewed. Layers that show existing and future land use, current and past rezoning applications, and tax parcels are also used to assess adjacent land uses as well as recent rezonings within the vicinity.

The property under review is located through a parcel search using GIS. A short description of the parcel based upon the underlying aerial and the street layer (Figure 6-2) is created.

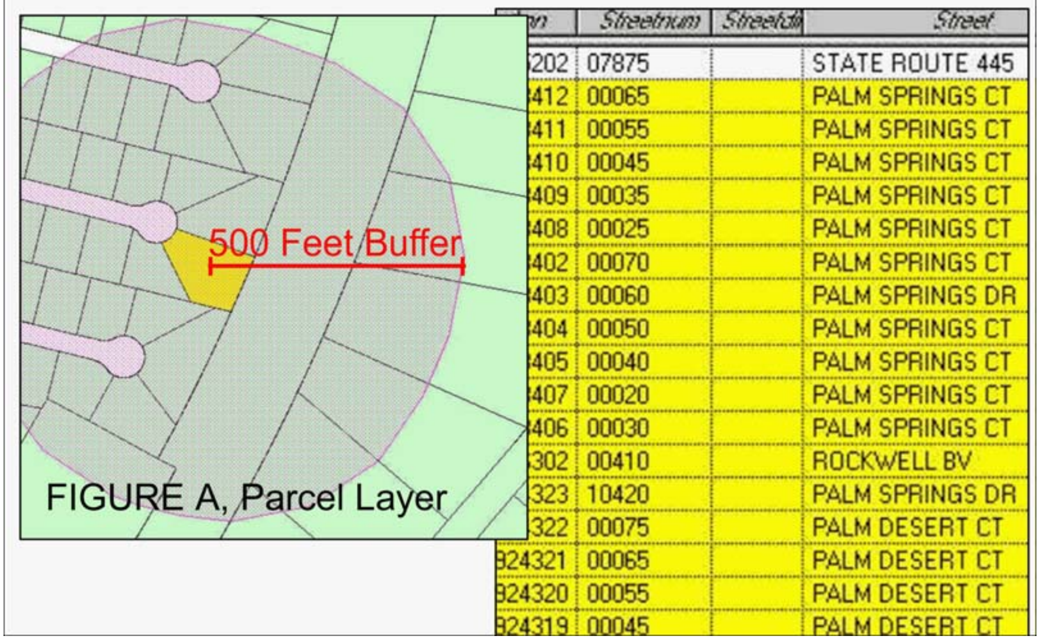
Figure 6-2. Rezoning Technical Review: Parcels and Aerial Photograph (City of Alexandria 2005).

Layers
Visible Active
☐ ○ Small Area Plan
☐ ○ Zoning
☑ ○ Address Points
☑ ○ Metrorail Station
☑ ○ Road Centerlines
☑ ○ Roads
☑ ○ Metrorail Tracks
☑ ○ Railroads
☐ ○ Buildings
☑ ● Parcels
☑ Aerial Photos

The planner will analyze the streets on which the property abuts based upon transportation reports and viewing address point, land use and comprehensive plan GIS layers to see if there are any upcoming road improvements scheduled in the state/regional transportation plan. In the GIS, the zoning application layer is used to examine whether adjacent properties went through a rezoning. The planner is looking at the current zoning of existing properties to see if the proposed rezoning application is appropriate for the area. Following an examination of recent and current zoning decisions, the analyst will then turn on the future land use layer in the GIS to determine the subject property's anticipated future land use. This will be used to determine if the proposed application conforms or does not conform to the comprehensive plan; the future land use map is part of the comprehensive plan. A comprehensive plan is a written document that identifies the goals, objectives, principles, guidelines, policies, standards, and strategies for the growth and development of the community (Pace University School of Law 1998).

The planner will use the GIS to determine whether there are neighboring schools or parks to examine whether there is a conflict of use; for example, many communities restrict the ability to operate businesses that serve alcohol within a specific distance from a school or church, typically five hundred feet. To establish the boundary within the GIS, a **buffer** operation is run (Figure 6-3). A buffer is a form of **proximity analysis,** a technique used to determine which pixels of a thematic layer are located at specified distances from pixels in a class or classes where zones of a given distance are generated around coverage features. The resulting buffer zones form polygons – areas that are inside or outside of the specified buffer distance from each feature (ERDAS 1999, 622).

Figure 6-3. Buffer Proximity Analysis (McCarthy, Fox, and Zaepfel 2002).
The table contains attributes of each parcel: address, value, zoning, and tax information for the parcels that fall within the shaded portion of Figure A, Parcel Layer. By specifying a buffer distance, the planner can evaluate the types of properties/zoning that surround the parcel being considered for building permits, business permits, or rezoning.



	Streetnum	Streetdi	Street
202	07875		STATE ROUTE 445
412	00065		PALM SPRINGS CT
411	00055		PALM SPRINGS CT
410	00045		PALM SPRINGS CT
409	00035		PALM SPRINGS CT
408	00025		PALM SPRINGS CT
402	00070		PALM SPRINGS CT
403	00060		PALM SPRINGS DR
404	00050		PALM SPRINGS CT
405	00040		PALM SPRINGS CT
407	00020		PALM SPRINGS CT
406	00030		PALM SPRINGS CT
302	00410		ROCKWELL BV
323	10420		PALM SPRINGS DR
322	00075		PALM DESERT CT
324321	00065		PALM DESERT CT
324320	00055		PALM DESERT CT
324319	00045		PALM DESERT CT

Sidebar: In 1982, the Supreme Court heard a landmark case, Larken v. Grendel's Den, with regards to rights of schools and churches to prevent issuance of alcohol permits to establishments within five hundred feet. The Court struck down the law. Although the Court recognized the importance of using zoning to protect schools and churches, the Massachusetts law in question allowed churches to decide whether an establishment that served alcohol was able to function with the five hundred foot buffer. The Supreme Court ruled that allowing the church to decide substituted religious decision-making authority for public legislative authority (Ryden 2002, 67). This sidebar has been added to further demonstrate that the issues facing local government, and planners that work for or interact with local government, have dramatic impact upon the life of a community.

Following the buffer analysis, the planner might turn on a zoning layer (Figure 6-4) in the GIS to identify which zoning the client's property is located in, and then comparing the zoning vision statements within the comprehensive plan to evaluate whether the proposed rezoning conforms or does not conform with the intended future land use of the area (Figure 6-5).

Figure 6-4. Zoning Map (Forsyth County, Georgia 2004).
Printed and derived from GIS Land Use layer.

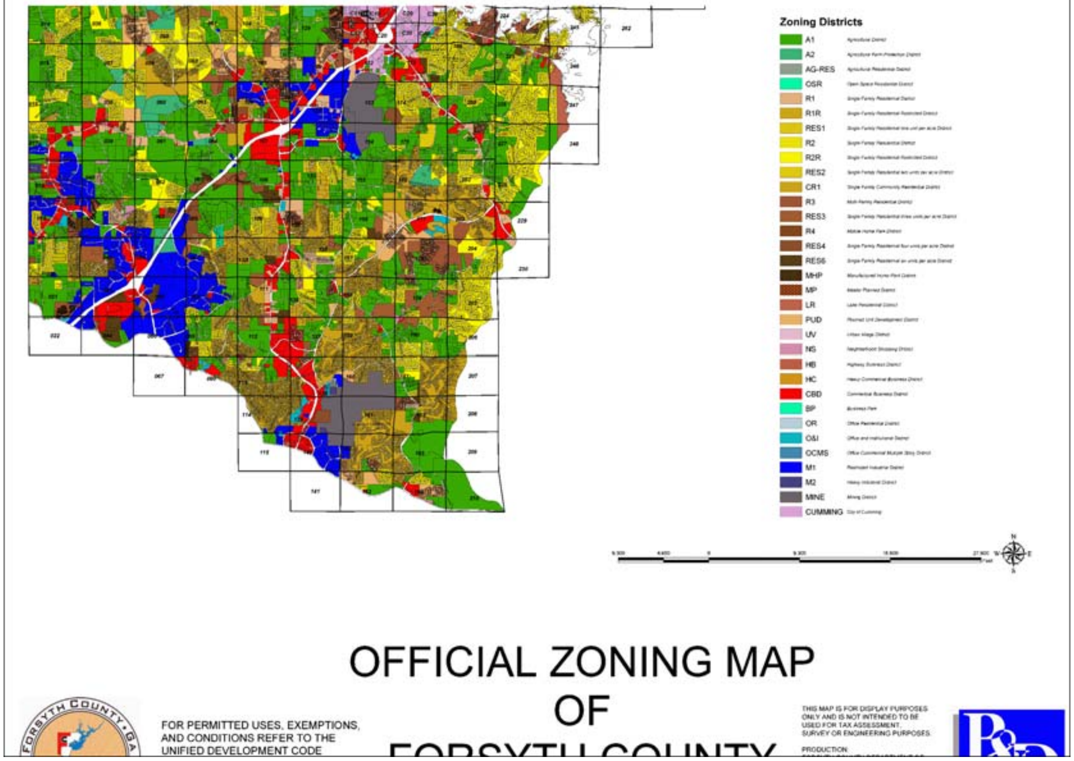
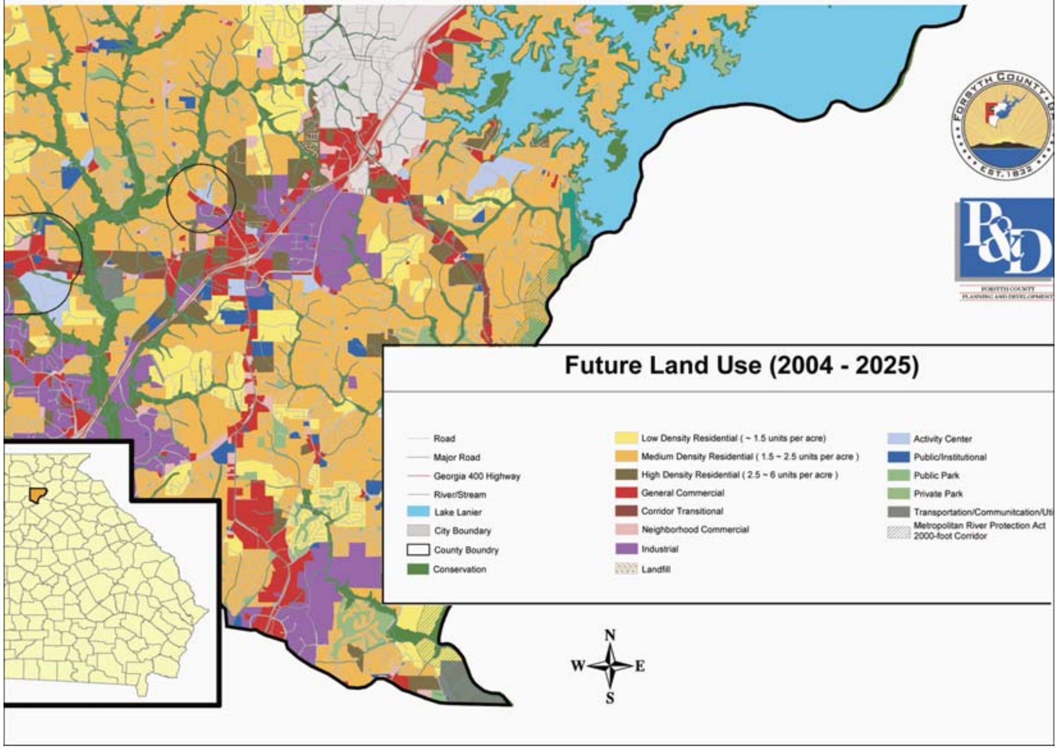


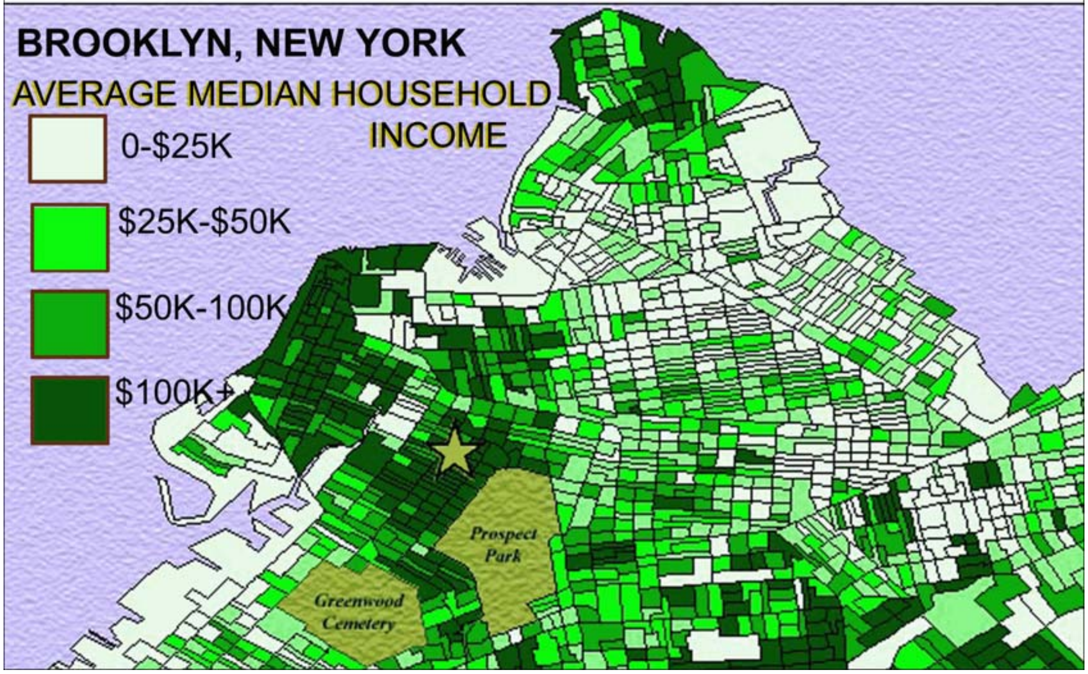
Figure 6-5. Future Land Use Map (Forsyth County, Georgia 2004).
Printed and derived from GIS Land Use layer.



Demographic data offers a tremendous amount of information to planners and decision makers in local government. It is possible to evaluate a wide range of information and the data, recorded every ten years by the U.S. Bureau of the Census, offers the ability to evaluate change over time. Planners may evaluate many human factors and create maps representing income, population densities, and growth. Demographic data is especially important in densely populated urban areas such as Brooklyn, New York (Figure 6.6) where an increase in the human population or new buildings may strain existing infrastructure. When ordering, discussing, or using U.S. Census demographic data, the user must be familiar with the term ‘block level’:

> The smallest geographic entity for which the U.S. Bureau of the Census tabulates decennial census data is called ‘block level’. Visible and/or invisible features shown on a map prepared by the U.S. Census Bureau bound its geographic area. Many blocks correspond to city blocks bounded by streets, but blocks in rural areas may include many square miles and have some boundaries that are not streets. The Census Bureau established blocks covering the entire nation for the first time in 1990. (*ESRI Online Dictionary*, 2005).

Figure 6-6. Demographic Data (United States Bureau of the Census 1990).
Derived from United States Census Data, demographic data can be imported into GIS software, and used for visual and spatial analysis. In the example below, Brooklyn, New York is shown, with correspondingly darker areas representing average median household income (Decision Support Services Incorporated 1997).



The planner might then examine the impact of the proposed zoning on resources such as rivers, creeks, lakes, ponds and marshes. **Slope** analysis is generated (Figure 6-7), which might affect or limit the grading of a potential site. The planner will interpret the slope analysis to determine if the proposed use is within the acceptable range specified by the building codes. Buffer proximity analyses are run on sensitive natural resources such as **groundwater recharge areas**, **watersheds**, floodplains, rivers and streams. The planner would evaluate a GIS layer that indicates whether or not the subject property is in a groundwater recharge area (Figure 6-7). Creation of impervious surfaces is especially harmful to groundwater recharge areas (Randolph 2004, 489).

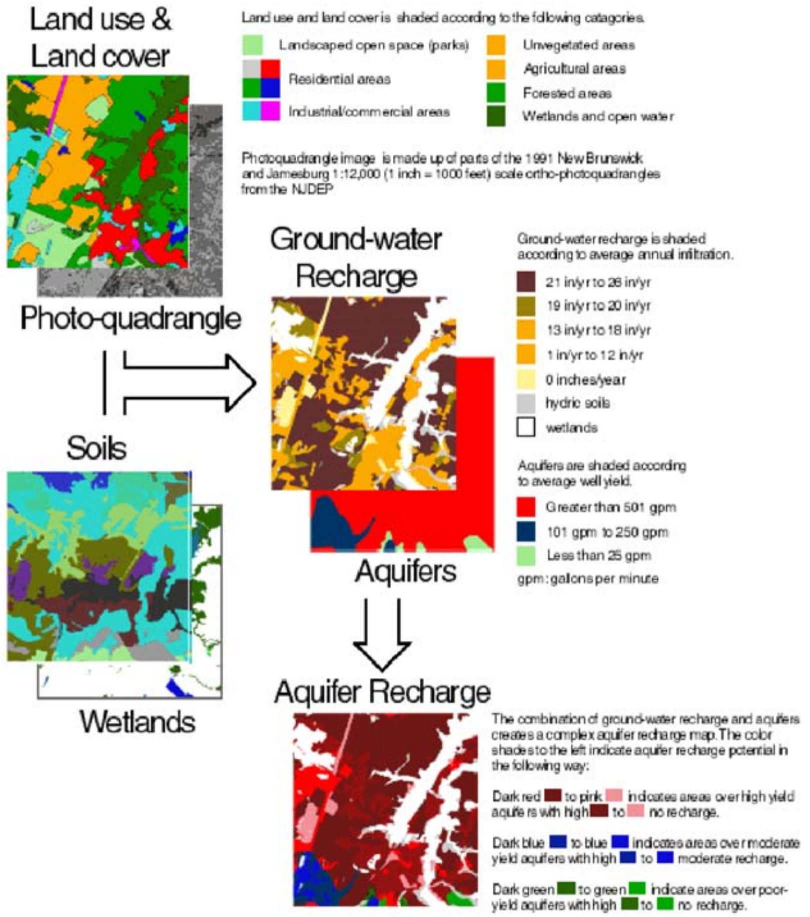
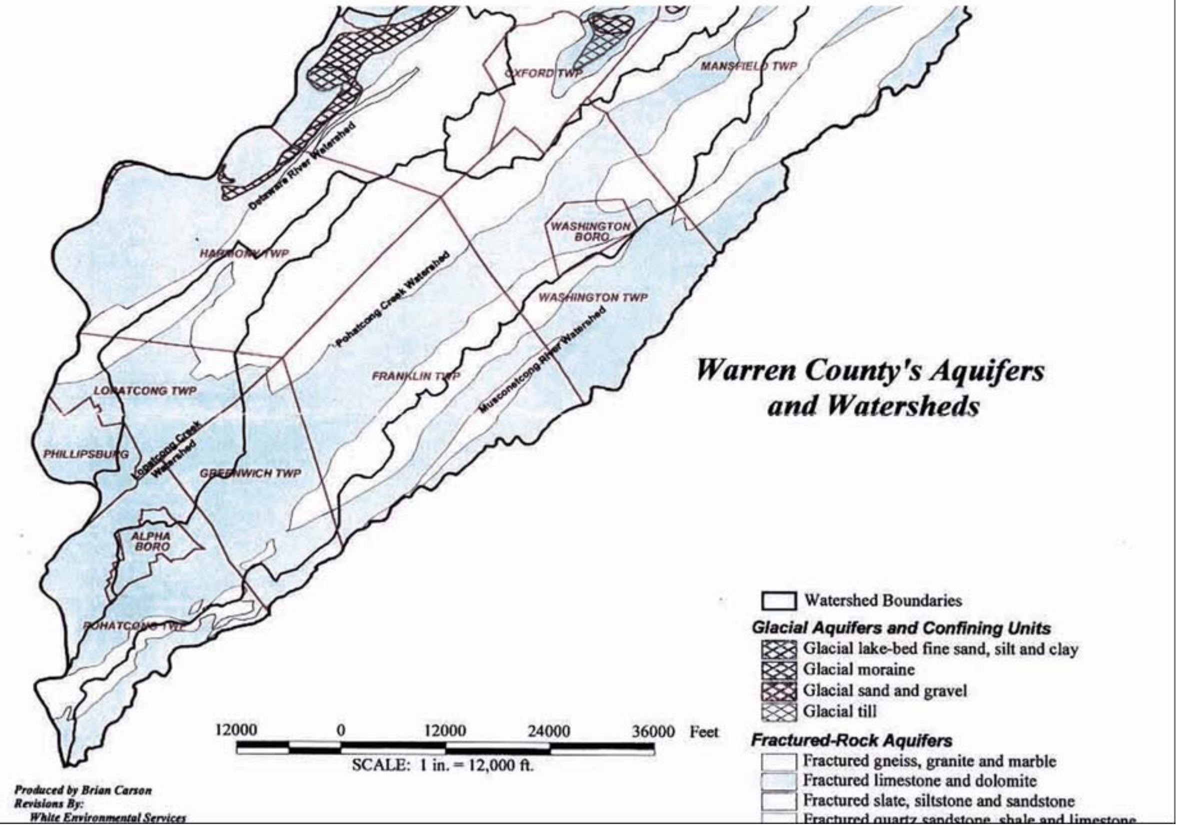


Figure 6-7. Ground Recharge Analysis (New Jersey Geological Survey 1996).

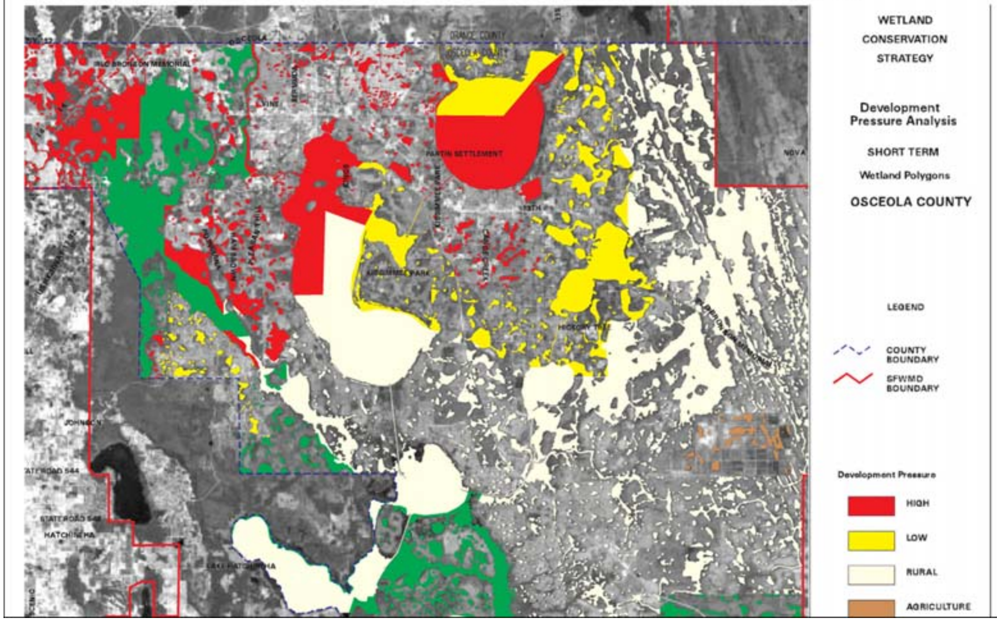
The planner will almost surely use GIS to determine which watershed the subject property is located in. An example of a typical watershed layer is provided in Figure 6-8. Industrial wastewater discharges, sewer overflows, waste dumping, accidental leaks and spills all can have devastating affects on a watershed, most especially in wetlands (Beatley 2002, 176).

Figure 6-8. Aquifer and Watershed Boundaries
Created using the GIS software program ArcView, this watershed map is part of a series of environmental resources created for Warren County and is typical of the types of watershed boundary maps found at the local government level (Warren County Environmental Commission 1999).



In addition to evaluating the watershed layer, the planner will display the wetland layer to view any areas that might be at risk. Planners may have use of wetlands analysis maps such as those created by the South Florida Water Management District (Figure 6-9). In Figure 6-9, areas are designated from high to low potential for impact from building development. Maps of this type can be created by overlaying and analyzing floodplain GIS data with satellite imagery or aerial photography. The wetland data itself, if not already in house, is normally available from the Federal Emergency Management Agency (FEMA) or the National Wetlands Inventory (NWI) (Green, R. W. 2002, 92).

Figure 6-9. Wetlands Analysis Map, Osceola County, Florida.
Individual wetlands are color-coded to reflect those areas of highest and lowest development pressure. Red indicates wetlands in areas that have the greatest potential for complete development (build-out of infrastructure). These wetlands are considered to be under the greatest pressure from development, including degradation of water quality, hydrological changes, or outright loss of the wetland itself. Yellow indicates wetlands in areas of low potential build out. Cream colored wetlands indicate those that are expected to be in rural development. Brown indicates wetlands expected to be in agricultural development. Green indicates wetlands that are or will be in areas under no pressure for development (such as parks or preserves) (South Florida Water Management District 1999).



After contributing to the technical review report, the planner will close his or her GIS for the day (or until the next report is due). After the applicant receives a copy of the report, they may come back to the planning office with questions or to request clarification. Most people want to know two things: what is the current zoning for their property and what the future land use map indicates. In the case of the GIS in Alexandria, Virginia (Figure 6.1), the public can use the Internet to interactively find their property and view a number of layers including roads, rail, and buildings and even underlay their property with an aerial photograph. The public can pull up their specific parcel and find out the existing zoning, the zoning on the future land use map and the zoning for adjacent properties. Residents looking at properties for sale or trying to sell their own property are potential users of this information. Whether they are online, using an interactive map or they visit the local planning office to get help, their answers will be derived from and presented through GIS.

CHAPTER 7

APPLICATION EXAMPLE: ASHEVILLE, NORTH CAROLINA

Note: GIS terms are highlighted in bold text format and can be found in the Glossary of GIS Terms (Appendix A, Page 105).

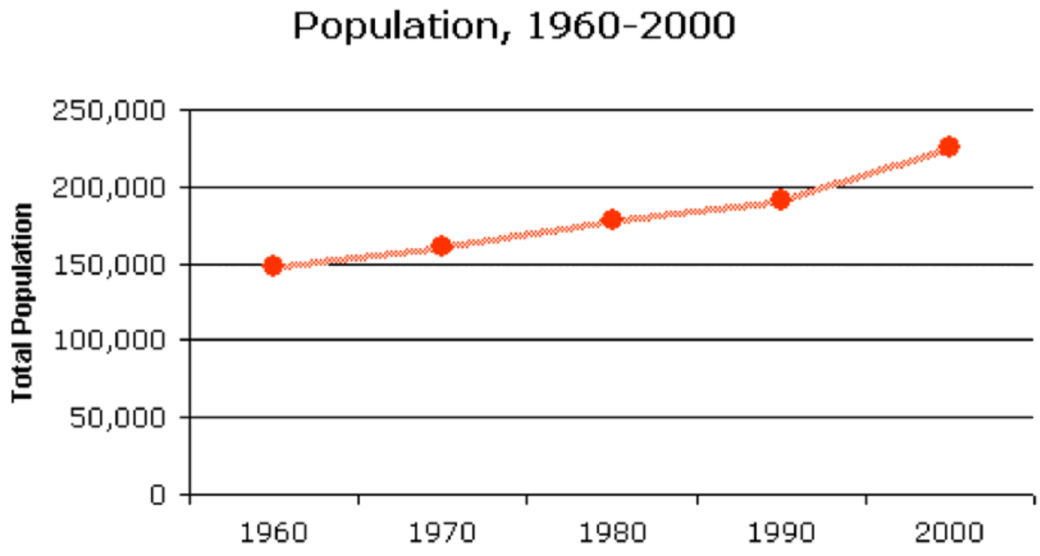
Introduction

An application example is provided in this chapter to provide exposure to the type of workflow that a landscape architect might use in GIS. The city of Asheville, in Buncombe County, North Carolina, was chosen in order to match the scale and approach to Ian McHarg's techniques outlined in his urban studies, described in "Nature in Metropolis", Chapter Five of "*Design with Nature*" (McHarg 1969, 55-77). McHarg wrote: "Urbanization proceeds by increasing the density within and extending the periphery, always at the expense of open space (McHarg 1969, 57)." In the study outlined in the chapter "Nature in Metropolis", McHarg writes that "Within the metropolitan region natural features will vary, but it is possible to select certain of these that exist throughout and determine the degree to which they allow or discourage contemplated land use (McHarg 1969, 57)." This chapter will use a representational cross-section of input data, such as slope, urban, wetlands, and land cover, using these layers to explain the sequence of techniques required to identify areas likely to come under development pressure in and around Asheville, North Carolina.

Overview of Asheville

Asheville, located in Buncombe County, North Carolina, was chosen as the subject for this chapter because it offers the opportunity to use GIS to explore the challenges that will face a rapidly growing city that has limited land available for growth. Asheville's population grew 17.83% from 1990 to 2000 (Figure 7-1). This fast growth rate is expected to continue (Buncombe County Planning and Development, 2006). The mountains that surround Asheville and provide one of the key benefits to living in and visiting Asheville are also a primary reason that this city will eventually run out of land suitable for residential development. The mountainous terrain simply will not allow a high concentration of urban development.

Figure 7-1. Population Growth for Asheville North Carolina, 1960-2000. (Censusscope.org 2006).



Population, 1960-2000

	1960	**1970**	**1980**	**1990**	**2000**
Total	147,291	161,059	177,761	191,774	225,965
Change		13,768	16,702	14,013	34,191
Percent Change		9.35%	10.37%	7.88%	17.83%

Definition of the Project

The goal is to identify potential geographic areas in and around Asheville, North Carolina that may be vulnerable to future urban and suburban development pressure. This process is geared towards providing an overview of the techniques and data available to support such a study and will be limited to GIS in scope. There are surely other resources that should be evaluated in a future land use study, such as real estate patterns and community input, but the goal is to remain focused on GIS techniques in the context of this thesis and the development of a GIS vocabulary for landscape architects. This project, like those of Ian McHarg, is based upon the inclusion or exclusion of geographic areas based upon specific criteria, and adheres to Asheville and Buncombe County regulations, as defined throughout the chapter. Data preparation will highlight some of the steps required in order to prepare the data for the analysis phase.

Areas that are under water (lakes, rivers) will not physically be able to be developed. Areas that are already heavily urbanized will be excluded from consideration as potentially vulnerable to development. While it is true that urban areas may be further developed, the basic character or nature of these existing areas is already urban. Areas that have a slope greater than twenty percent will be excluded from consideration, as the challenges associated with heavily developing heavily contoured land are barriers to construction. In addition, in keeping with McHarg's philosophies, environmental variables will be introduced to the study. The example used in this chapter will be wetlands. Based upon research into Buncombe County's development guidelines, exclusion of wetlands from further construction may be considered valid criteria in the study (Buncombe County Planning 2005). What follows is a step by step GIS implementation, focusing on data preparation, and analysis.

Input Criteria for the Project

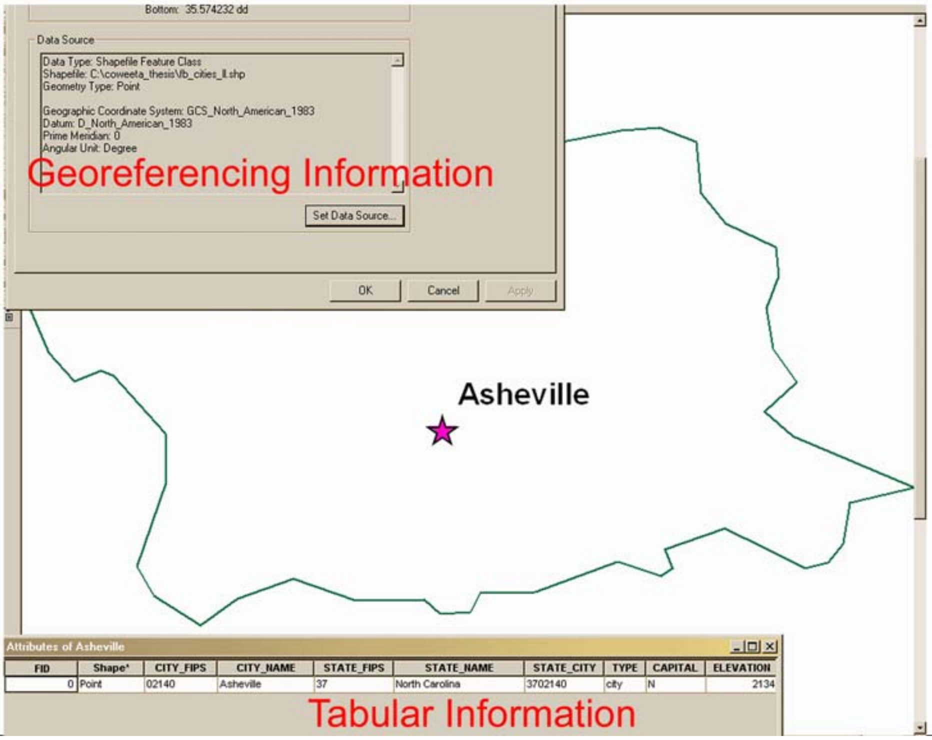
The following input criteria, represented as GIS layers, will be used for this study. These layers have been selected to represent a cross-section of the types of information that would typically be used by a landscape architect or planner. A national forest layer, Pigsah National Forest, will be used, as significant urban or suburban development in a national forest is highly unlikely. An urban land cover layer will be utilized on the basis that existing urban areas will not face the extreme change in natural systems that further development might incur. A slope layer will be included because there is a limit to urban development possibilities due to the difficulties of building on steeply contoured land. Further, slope is an appropriate choice because it will be the most direct representation of the surrounding mountains that are the primary geographically limiting factor associated with urban development in and around Asheville. A wetland layer will be introduced into the study, due to current local, state, and national restrictions on developing in these areas. A polluted sites layer will be examined, as these can be indicative of heavily industrialized areas, and might lead developers away from an area that otherwise seems suitable for building. Urban development tends to follow the existing road networks, and a roads layer will be used to help identify areas that may be open to further development (Stokes 1997, 52).

The layers will be used to paint a picture of areas under pressure of development. The addition of each layer will illustrate a different GIS concept for the landscape architect. Many of these concepts have been discussed in earlier chapters of this thesis, and all will be described in more detail when presented further on. The national forest layer introduces **clipping**. The urban layer introduces **recoding**. The slope layer will introduce vector to raster **conversion**, and subsequently be combined with the urban layer to introduce **union** processing. Polluted sites will be used to demonstrate **buffering**, and finally, roads will be used to show **proximity analysis**. All of these techniques and layers will produce a map that indicates those areas in and around Asheville, North Carolina that are most susceptible to new urban development.

Data Preparation: Georeferencing and Clipping

Figure 7-2 shows the display of two **vector layers**, a **point** layer designating the location of Asheville, North Carolina, and a **polygon** layer showing the boundary of Buncombe County, North Carolina. Both the georeferencing and tabular information for the Asheville layer are shown, confirming that this layer is **georeferenced** and may support the display and **modeling** of other layers over it. The tabular information for the Asheville point layer is basic, providing fields that include the name of the city, the state Asheville is found in, the elevation, **and FIPs code**.

Figure 7-2. Display of Point Shapefile of Asheville, North Carolina.
(SAMAB 2003). A simple point layer of Asheville is displayed, surrounded by a boundary layer for Buncombe County, North Carolina. The layer includes georeferencing information and tabular data.



Bottom: 35.574232 dd

Data Source

Data Type: Shapefile Feature Class
Shapefile: C:\coweeta_thesis\lb_cities_ll.shp
Geometry Type: Point

Geographic Coordinate System: GCS_North_American_1983
Datum: D_North_American_1983
Prime Meridian: 0
Angular Unit: Degree

Attributes of Asheville

FID	Shape*	CITY_FIPS	CITY_NAME	STATE_FIPS	STATE_NAME	STATE_CITY	TYPE	CAPITAL	ELEVATION
0	Point	02140	Asheville	37	North Carolina	3702140	city	N	2134

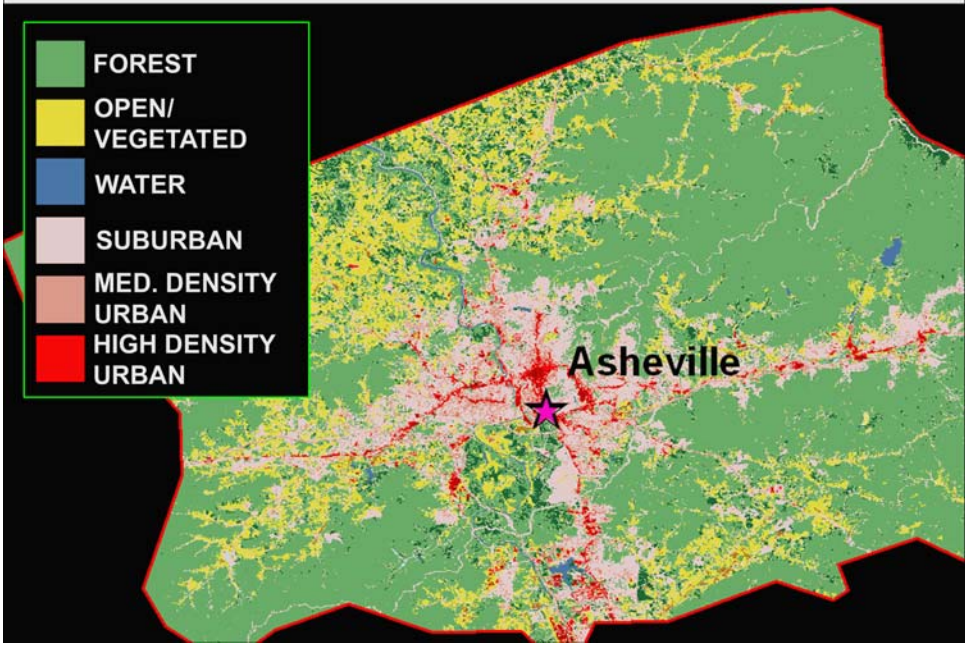
The county boundary file, in particular, will be used in the next section of this chapter, as various GIS layers are matched to each other by **clipping** their boundaries to the **extents** of the county boundary. Figure 7-3 is the display of the coverage of one of the GIS **vector** layers that will be used in the study, Pigsah National Forest, prior to clipping. Figure 7-4 shows the Pigsah National Forest layer after clipping. Figure 7-5 shows **raster** land cover that has been clipped to conform to the county boundary layer.

Figure 7-3. Pigsah National Forest, Unclipped.
(SAMAB 2003). Federal lands, such as Pigsah National Forest, would normally indicate land that would not be under pressure from development. Pigsah National Forest, shaded in green, has not yet been clipped to match the county boundary file.

Figure 7-4. Pigsah National Forest, Clipped.
(SAMAB 2003). Pigsah National Forest layer now features only coverage within the county boundary file. All layers used in this study will be clipped to conform to Buncombe County.

Land cover is often useful in planning studies because it can show where the development or changes have occurred. The graphic in Figure 7-5 shows green areas as vegetation, yellow areas as grassland or non-urban open, and the pink/red areas as urban. This

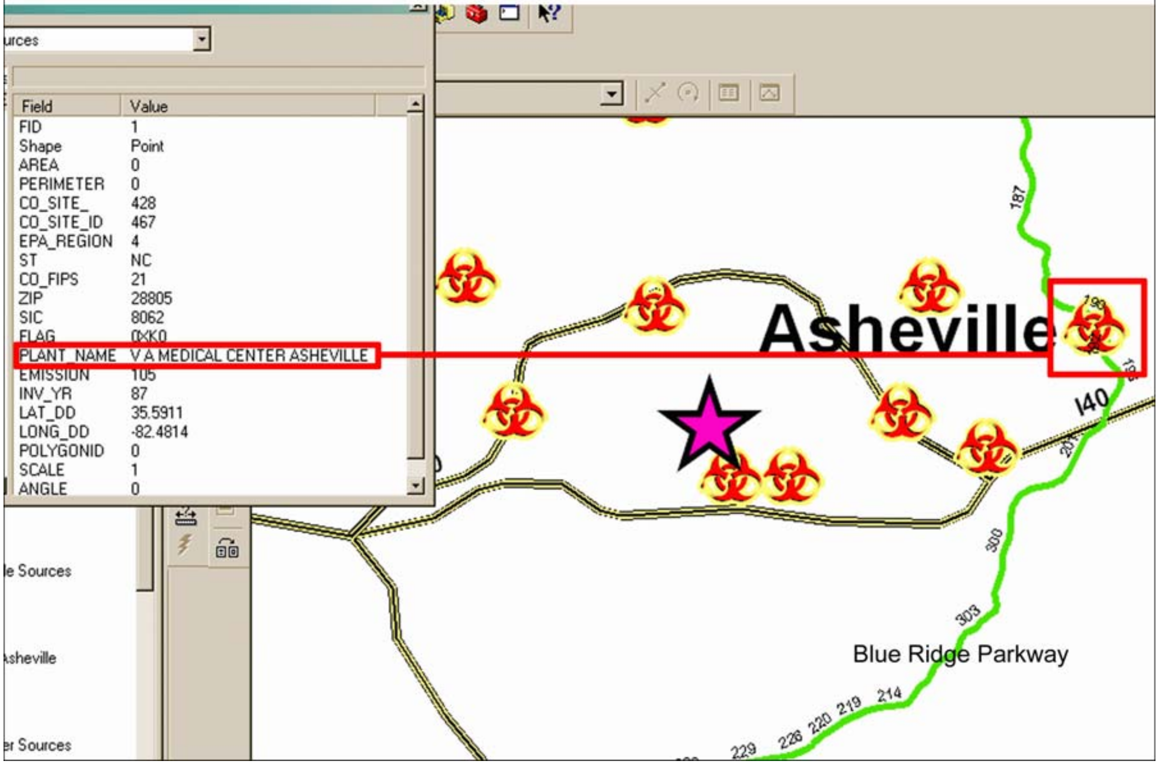
Figure 7-5. Land Cover, Clipped.
(Coweeta LTER, 2005) Raster data clipped to conform to the county boundary used as the extent of this project.



layer will be used to subtract urban layers from the potential of development pressure. An early visual interpretation of this layer would indicate that the area southwest of the city center might be a likely candidate for development.

The introduction of more layers to the GIS allows the landscape architect to begin to build a contextual picture of the issues involved in the study. For example, Figure 7-6 adds the U.S. Interstates and the Blue Ridge Parkway to the GIS display, as well as the locations of federally identified polluted sites. These layers, available through the Environmental Protection Agency, include Superfund sites, as well as those that may be sources of various pollutants such as nitrogen oxide, sulfur oxide, and carbon monoxide. The tabular data associated with the pollutant layers can provide information about the potential danger of development near a

Figure 7-6. Pollutant Sites.
(SAMAB 2003). Introduction of more layers to the project includes the Blue Ridge Parkway, U.S. Interstates, and pollutant sites. The tabular information reveals that the polluted site falling directly on the Blue Ridge Parkway is the Veterans Administration Medical Center of Asheville.



Field	Value
FID	1
Shape	Point
AREA	0
PERIMETER	0
CO_SITE_	428
CO_SITE_ID	467
EPA_REGION	4
ST	NC
CO_FIPS	21
ZIP	28805
SIC	8062
FLAG	0XK0
PLANT_NAME	V A MEDICAL CENTER ASHEVILLE
EMISSION	105
INV_YR	87
LAT_DD	35.5911
LONG_DD	-82.4814
POLYGONID	0
SCALE	1
ANGLE	0

particular site. For example, one of the sites (not identified in Figure 7-6) near Asheville produces cyanide as a bi-product of manufacturing. As shown in Figure 7-6, the site located near the Blue Ridge Parkway is the Veterans Administration Medical Center of Asheville. It is not worthwhile for the purposes of this thesis to investigate the reasons the VA Center has been identified as a source for pollutant materials. It is reasonable to expect that this site is not as potentially harmful to the environment or human inhabitants as a heavy manufacturing plant might be.

There is no question that a developer, with all of the issues being equal, would rather build near a VA hospital than a cyanide producing industrial plant. McHarg has emphasized the need to 'weight' various input data (McHarg 1969, 57), and the example provided in Figure 7-6 highlights the strength and need for weighting data during analysis. Variable weighting will not be shown in the body of this chapter. A further purpose of Figure 7-6 in the context of this

Figure 7-7. Correlation between Polluted Sites, Urban, and Roads.
(SAMAB 2003, Coweeta LTER 2005). A new layer, roads, has been added to the GIS, and they are visible as black vectors in the graphic. Visual analysis indicates a direct connection between the presence of polluted sites and their concentration in urban environments.

thesis is to demonstrate the various sources of data that might be available, as well as to demonstrate the benefit of the tabular data attached to each location.

In the data preparation stage of this project, the indicated layers have been clipped, georeferenced, and an initial visual evaluation of the data content performed by the landscape architect. Figure 7-7 shows the polluted sites displayed over the land cover, with road networks included, and there is, in most cases, a direct correlation to urban buildup and the location of polluted sites.

Data Preparation: Recoding Land Cover for Analysis

As described earlier in this chapter, this project is based upon the inclusion or exclusion of geographic areas based upon specific criteria. An essential part of this project includes the **recoding** of data in order to be able to analyze it. For example, the land cover for this project includes various classes, including water, urban, open, wetlands and forested lands. Recoding is simply the reclassification of classes into new classes. In the case of the land cover, this data will be used to exclude specific classes from further consideration as candidates for new development. Water is excluded because it cannot be developed. Urban is excluded because it is already developed. Wetlands are excluded because they are protected. Open and forested properties are included as potential development sites. All of the excluded classes (urban, water, wetlands) will be recoded from the original classes into one non-developable class, and all of the potential development sites (open and forested) will be recoded into a separate class.

Figure 7-8. Land Cover, prior to recode.
(Coweeta LTER, 2005) Analysis of areas around Asheville likely to face development pressure will include a masking out or inclusion of potential sites based upon criteria described in the thesis.

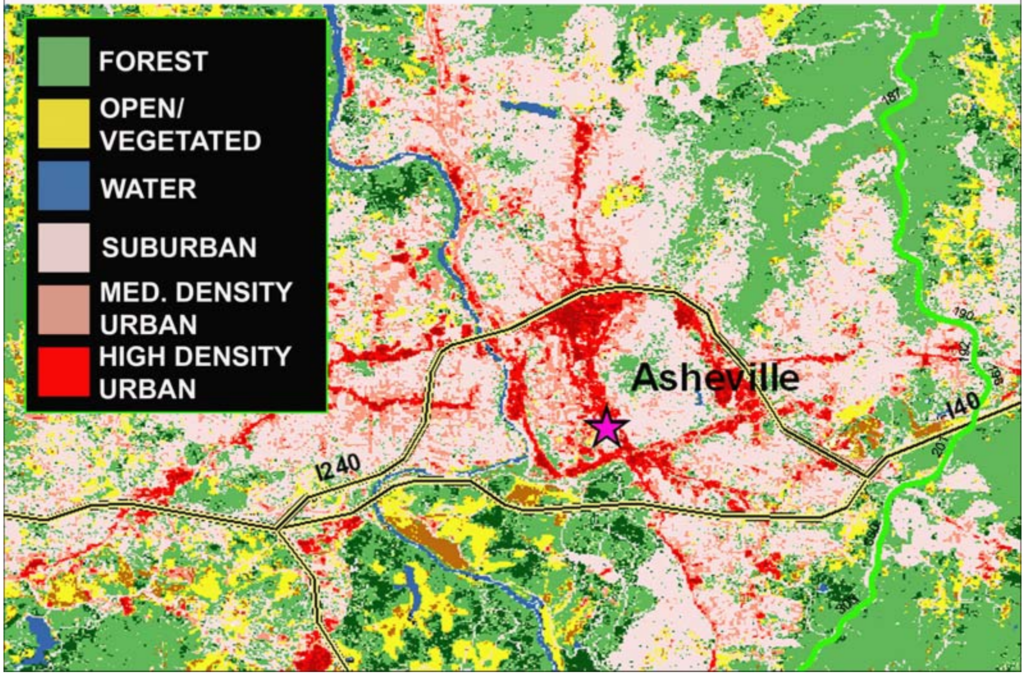
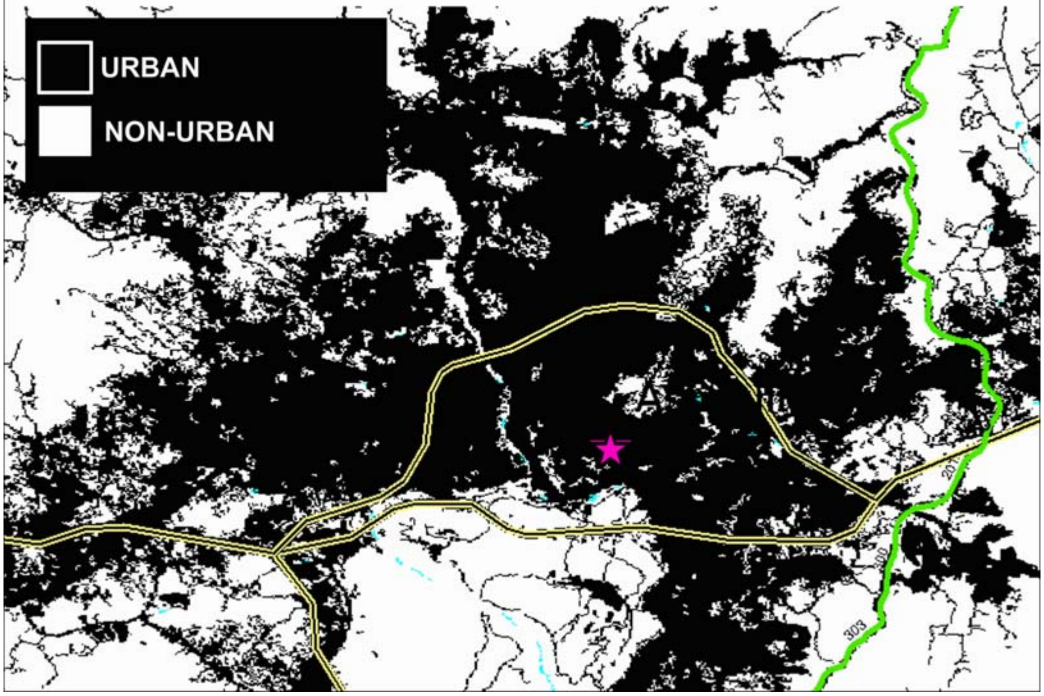


Figure 7-9. Land Cover, after recode.
(Coweeta LTER, 2005) All urban areas have been recoded to a value of 1, visualized in black in the map. Non-urban areas have a value of 2, are visualized in white on the map,and are are candidates for new development.



Data Preparation: Recoding Slope for Analysis

The example of recoding is continued, with the addition of vector to raster **conversion** added as a step (Figures 7-10 and 7-11). North Carolina has a statewide GIS database for public download (http://www.ncdot.org/it/gis/DataDistribution/default.html), and twenty foot **contours** were downloaded for use in this project. Because of the mountainous **terrain** surrounding Asheville, there is an effective limit to where new urban development can occur, based on slope percentages. Ordinances in Asheville place restrictions on construction in areas of higher than fifteen percent, with some exceptions allowed in areas of up to twenty-five percent slope (Asheville Planning Department 2005, 4). It is interesting to note that, in addition to establishing safety standards for building, these restrictions are in place due to a commitment to protect the aesthetics of the mountainous regions surrounding Asheville (Asheville Planning Department 2005, 3). For the purposes of this study, a slope of twenty percent has been established as the limit for urban development.

Figure 7-10. Contours.
(Coweeta LTER 2005). 20 Foot vector contours will be transferred into a raster slope file for modeling. Blue lines are a separate rivers layer provided to show continuity between Figures 7-10, 7-11, and 7-12.

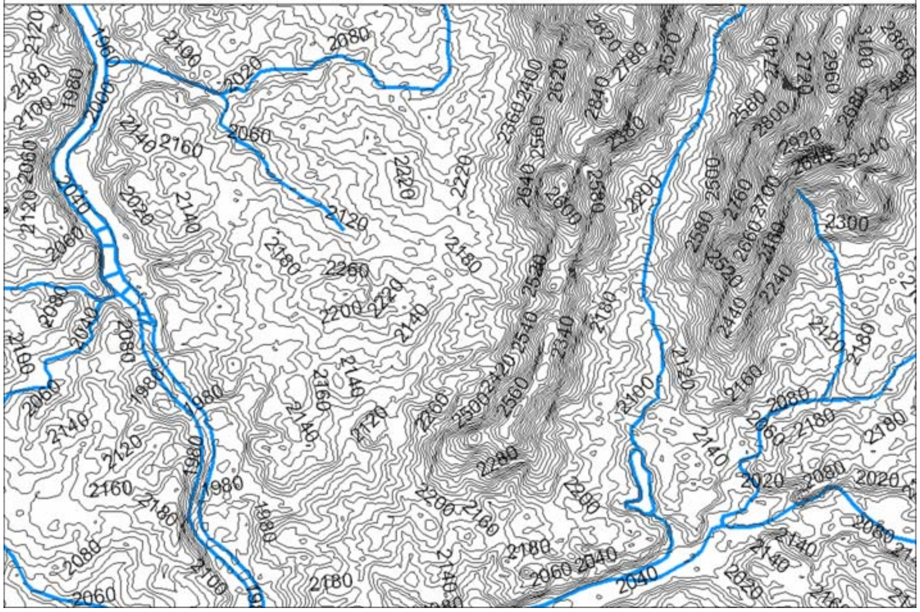


Figure 7-11. Slope.
(Coweeta LTER, 2005) Slope derived from contour layer (Figure 7-10). Lighter colors indicate less percentage slope, and darker colors indicate more percentage slope.

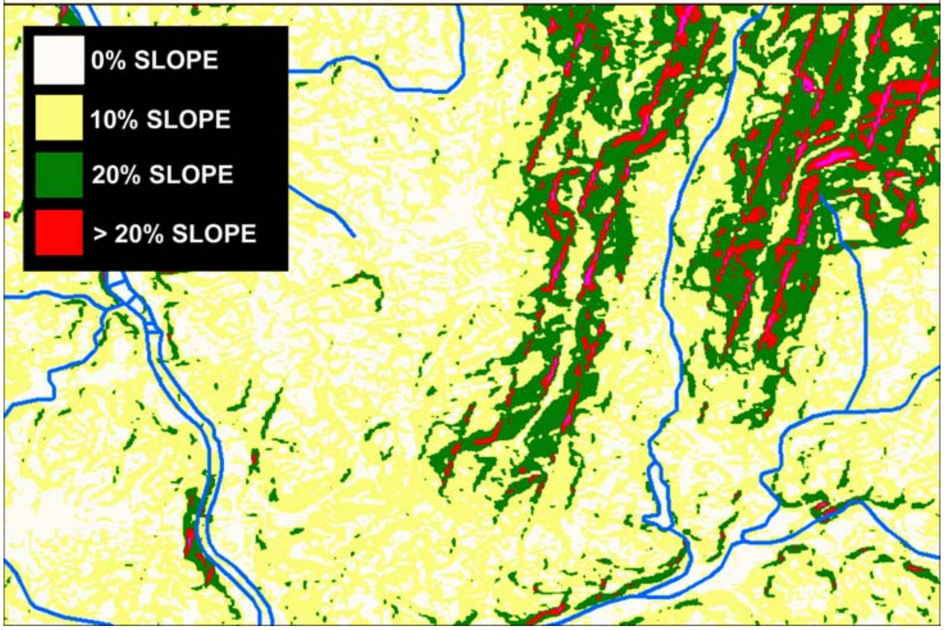
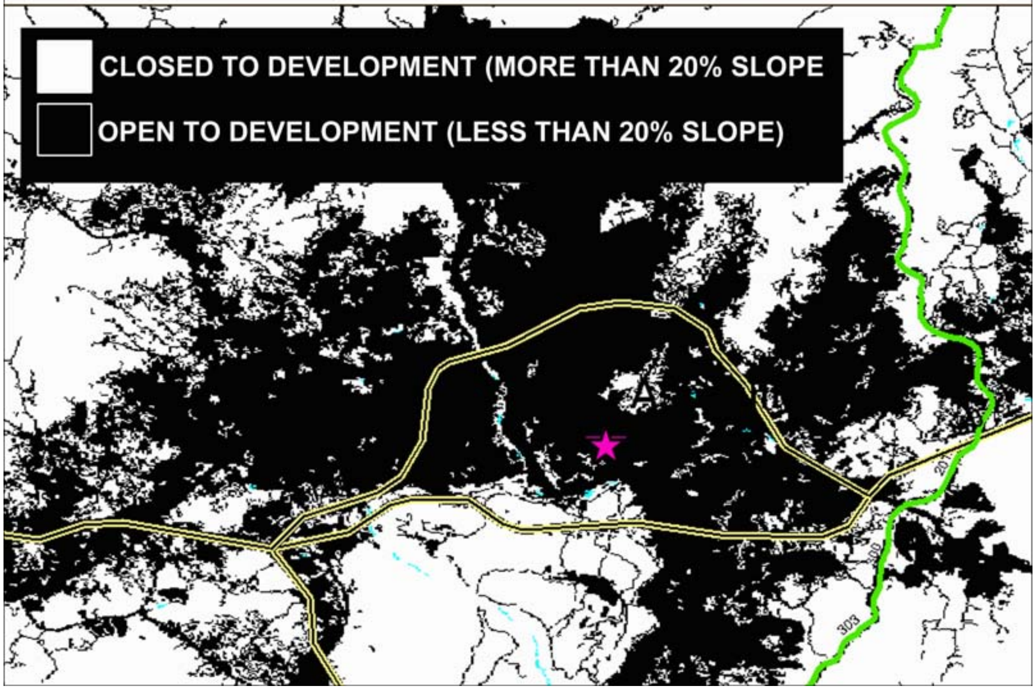


Figure 7-12. Slope recode.
(Coweeta LTER, 2005) Slope of greater than 20% is recoded to a value of 2 (black) and represents areas that are not precluded from development.



Data Analysis: Introduction

Previous sections of this chapter have outlined some of the key steps involved with preparing GIS data for use. The goal of the data preparation for this study has focused upon recoding various data layers into an on/off decision rule, where pixels that have a value of one are considered ‘on’, or under consideration as candidates for future urban development pressures, and pixels that have a value of two are considered ‘off’, or excluded from consideration as candidates for future urban development pressure. It is possible to create a range of values that correspond to a gradient range. By way of revisiting a previous example, terrain with a slope of less than twenty percent has all been assigned a value of one, and all terrain with a slope of twenty percent or more had been assigned a value of two (Figure 7-12).

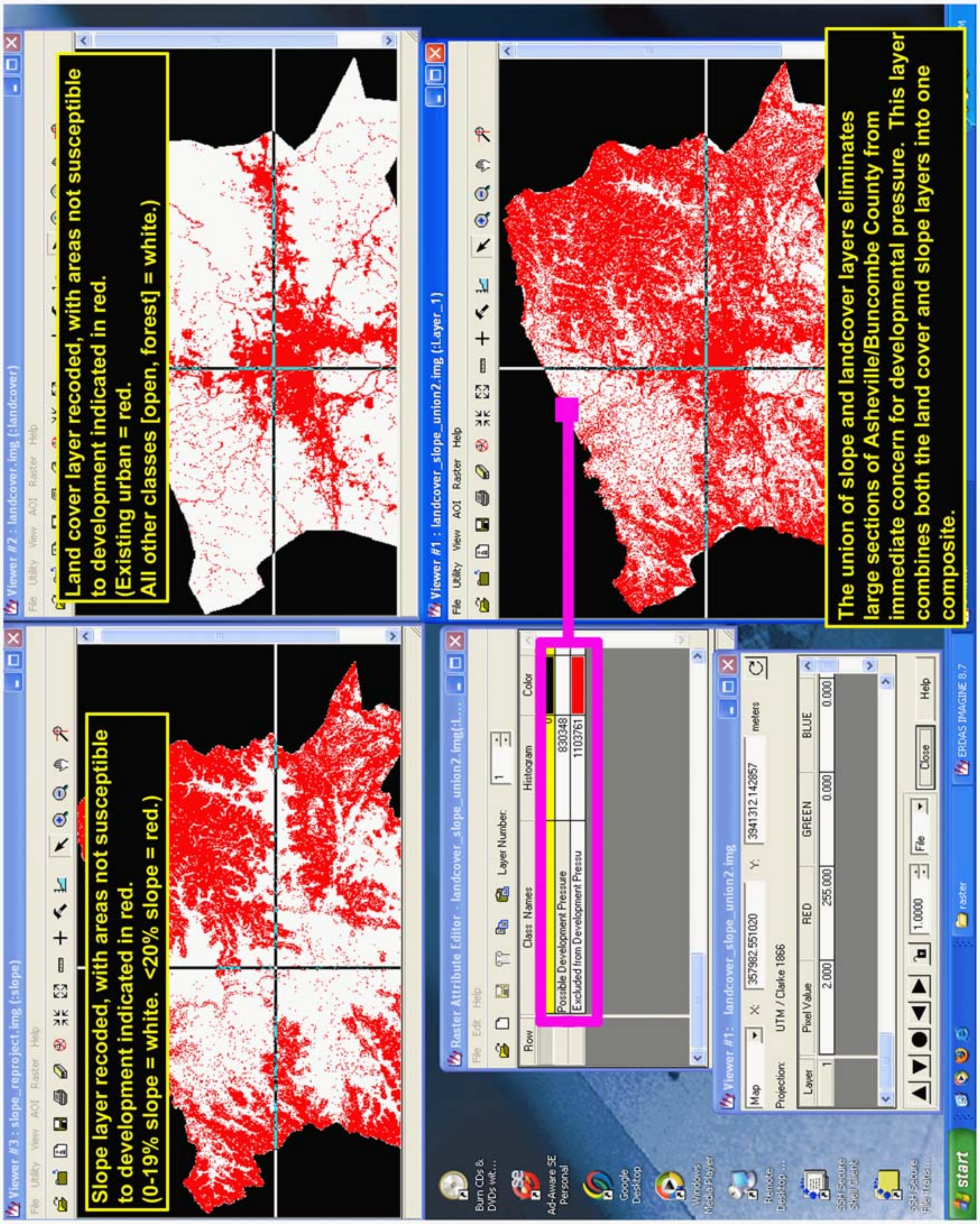
This section of this chapter will provide examples of how the various recoded data layers may be combined to include or exclude geographic areas from likelihood of future urban development. The process is identical to that used by Ian McHarg in the studies outlined in his book *Design with Nature* and described in Chapter Two of this thesis.

Data Analysis: Union

In the preceding section of this chapter, urban and slope layers were clipped to the Buncombe County layer and recoded into discrete classes, representing either exclusion from further development pressure or as being susceptible to further development pressure. The analysis phase of this study begins, and is centered around the **union** of input layers to form a composite map. Figure 7-13 shows the union of the slope and urban layers into a composite map that either includes or excludes areas from the likelihood of urban developmental pressure. Union will be used again later in this application example to create the final composite.

Figure 7-13. Union of Layers.

(Coweeta LTER 2005). Although subsequent layers of information will be added to refine the study, this example provides an example of the analysis technique. Two layers, slope and land cover, were recoded in the data preparation section of this chapter. The recoded layers contain only two values, the first, indicated in red, corresponding to land excluded from danger of further development, and the second, indicated in white, still open to development. The union of the two layers provides a composite.



Slope layer recoded, with areas not susceptible to development indicated in red.
(0-19% slope = white. <20% slope = red.)

Land cover layer recoded, with areas not susceptible to development indicated in red.
(Existing urban = red.
All other classes [open, forest] = white.)

The union of slope and landcover layers eliminates large sections of Asheville/Buncombe County from immediate concern for developmental pressure. This layer combines both the land cover and slope layers into one composite.

Row	Class Names	Histogram	Color
		0	
	Possible Development Pressure	830348	
	Excluded from Development Pressu	1103761	🟥

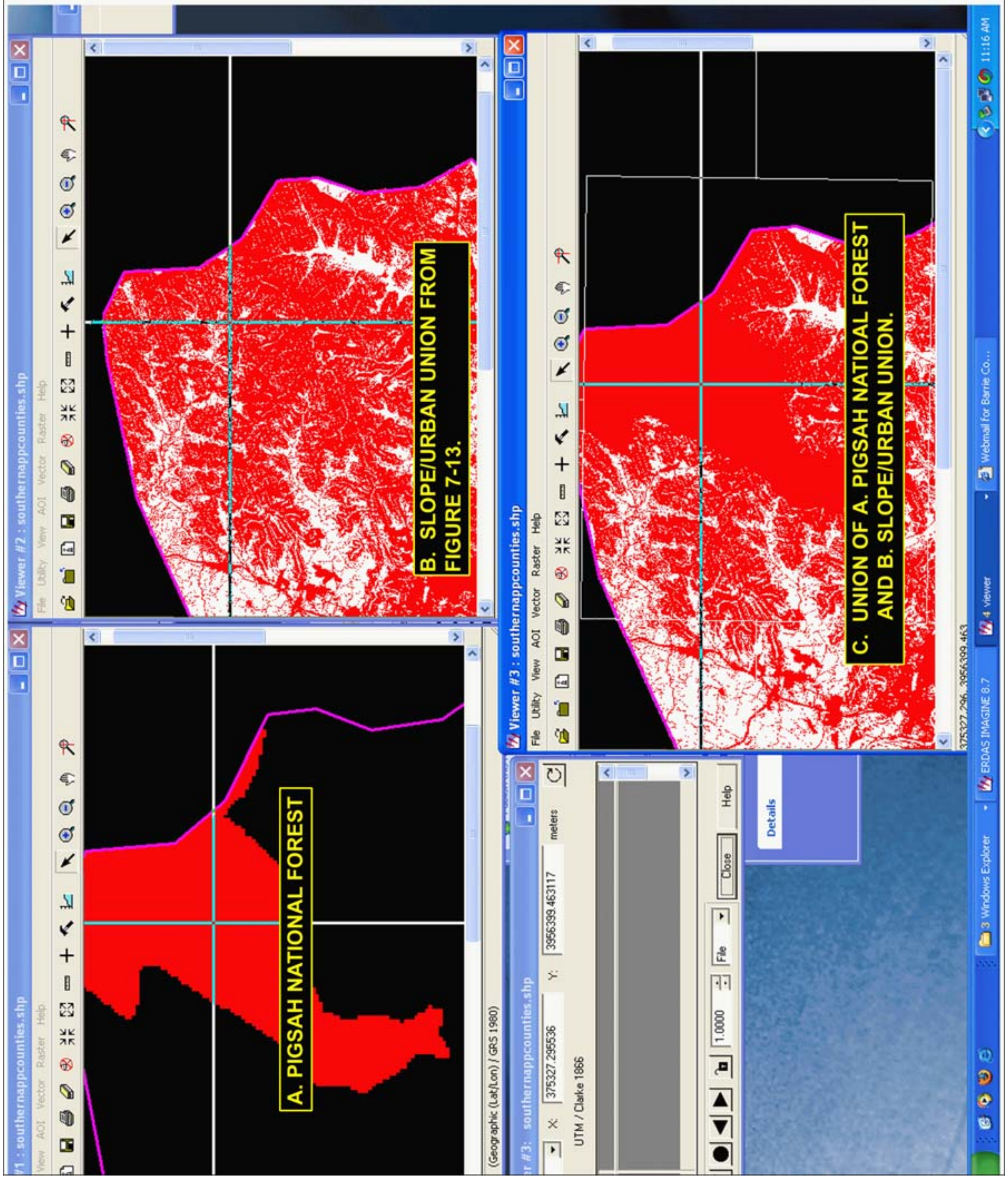
Map X: 357982.551020 Y: 3941312.142857 meters

Projection: UTM / Clarke 1866

Layer	Pixel Value	RED	GREEN	BLUE
1	2.000	255.000	0.000	0.000

Figure 7-14. Union of Layers, Second Example.
(Coweeta LTER 2005). This example shows the addition of Federal Lands (Pigsah National Forest) to the composite of the Slope and Urban union shown in Figure 7-13. Pigsah National Forest would not be considered a likely candidate for urban development pressure.

Pigsah National Forest occupies land that is highly sloped and mountainous, thus the union further illustrates that these areas are not in danger of development, short of a change in National Forest regulations and Buncombe County ordinances.

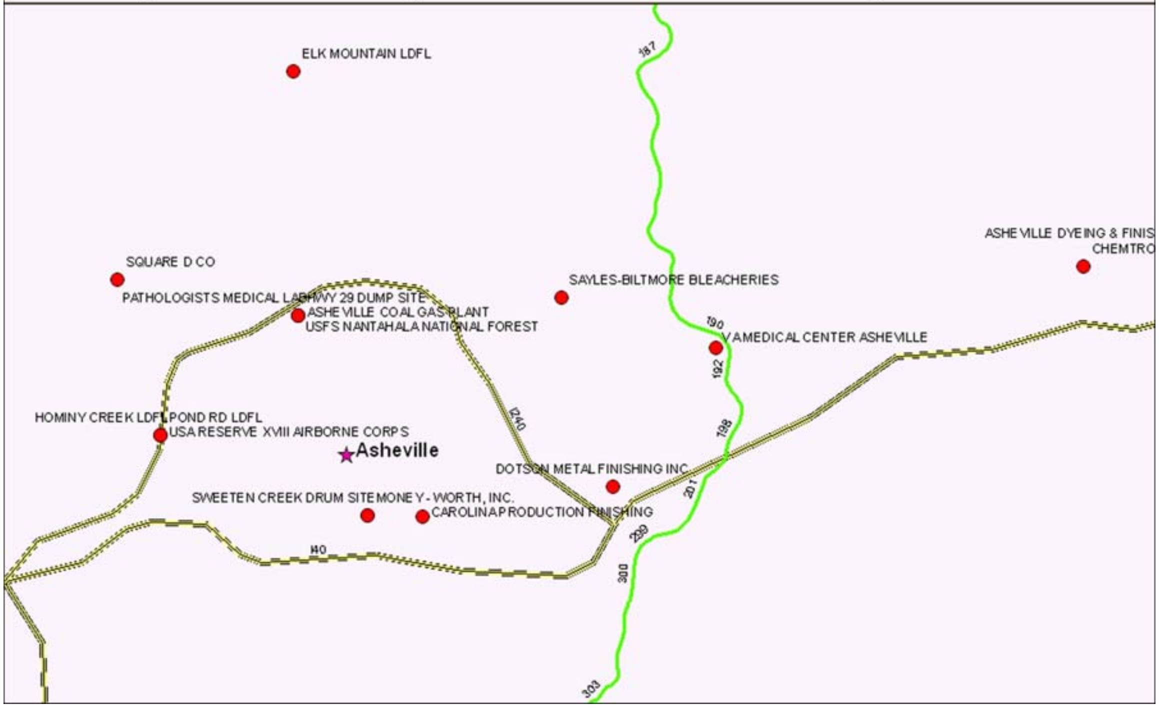


Data Analysis: Buffering

Buffering is used to establish boundaries around areas based upon distance. In the example provided in Figure 7-16, a buffer has been established around pollutant sites based upon the premise that initial development will tend to shy away from polluted sites. This premise is supported by the traditional relegation of heavy industry into industrial zones, as well as the negative publicity that results from developers building in areas that may be unsafe for human inhabitation. Figure 7-15 shows the location of a number of hazardous waste and pollutant sites of various types, and unioned into one layer. The original layers included Superfund sites, as well as sites identified as sources for carbon monoxide, nitrous oxide, sulfur dioxide, and particulate matter.

Figure 7-15. Buffer Operation: Introduction.
(SAMAB 2003). This graphic shows the points to be buffered. Indicated in red and annotated to show the name of the site, the points below have been identified as originating pollutant material (Environmental Protection Agency 2006).

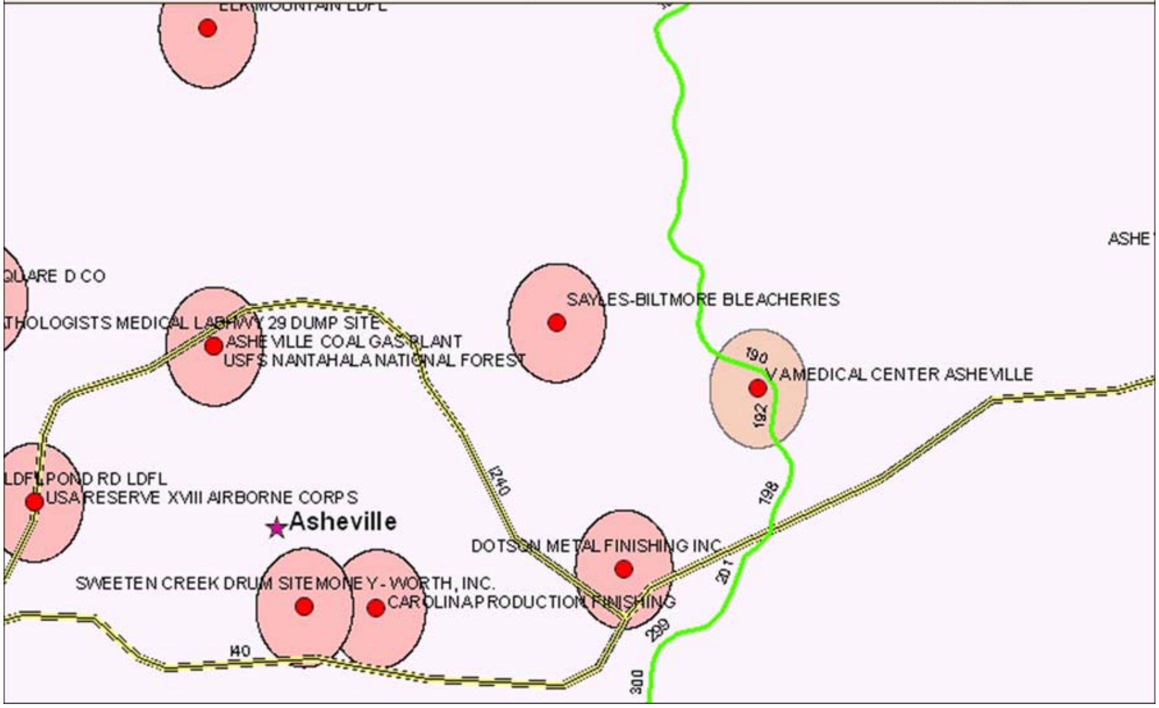
Visual analysis reveals sites as being concentrated around urban areas and major roads.



The VA Medical Center shown in the graphic is not a Superfund Site, but has been identified by the Environmental Protection Agency as a source for Carbon Monoxide (SAMAB 2003). Established in 1980, the Superfund program was tasked with identifying and cleaning up hazardous waste sites throughout the United States (Environmental Protection Agency 2006). To date, over five hundred Superfund sites have been cleaned up.

Figure 7-16 illustrates buffers of 2500 feet around each pollutant site. Most sites fall within areas already eliminated from having the potential for pressure from urban development, because most of the sites fall within urban areas. The primary sites of interest are those located in rural areas, and these will be included in the final composite.

Figure 7-16. Buffer Operation: Complete.
(SAMAB 2003). A buffer of 2500 feet has been created around each of the pollutant sites. The amount of buffer is for illustrative purposes, as appropriate buffer distances could vary according to the types and amounts of pollutants that originate from each site. For the purposes of this study, the buffer has been created on the basis that development would tend to shy away from pollutant sites. As pressure increases to build in communities where developable land is scarce, the standards may change.



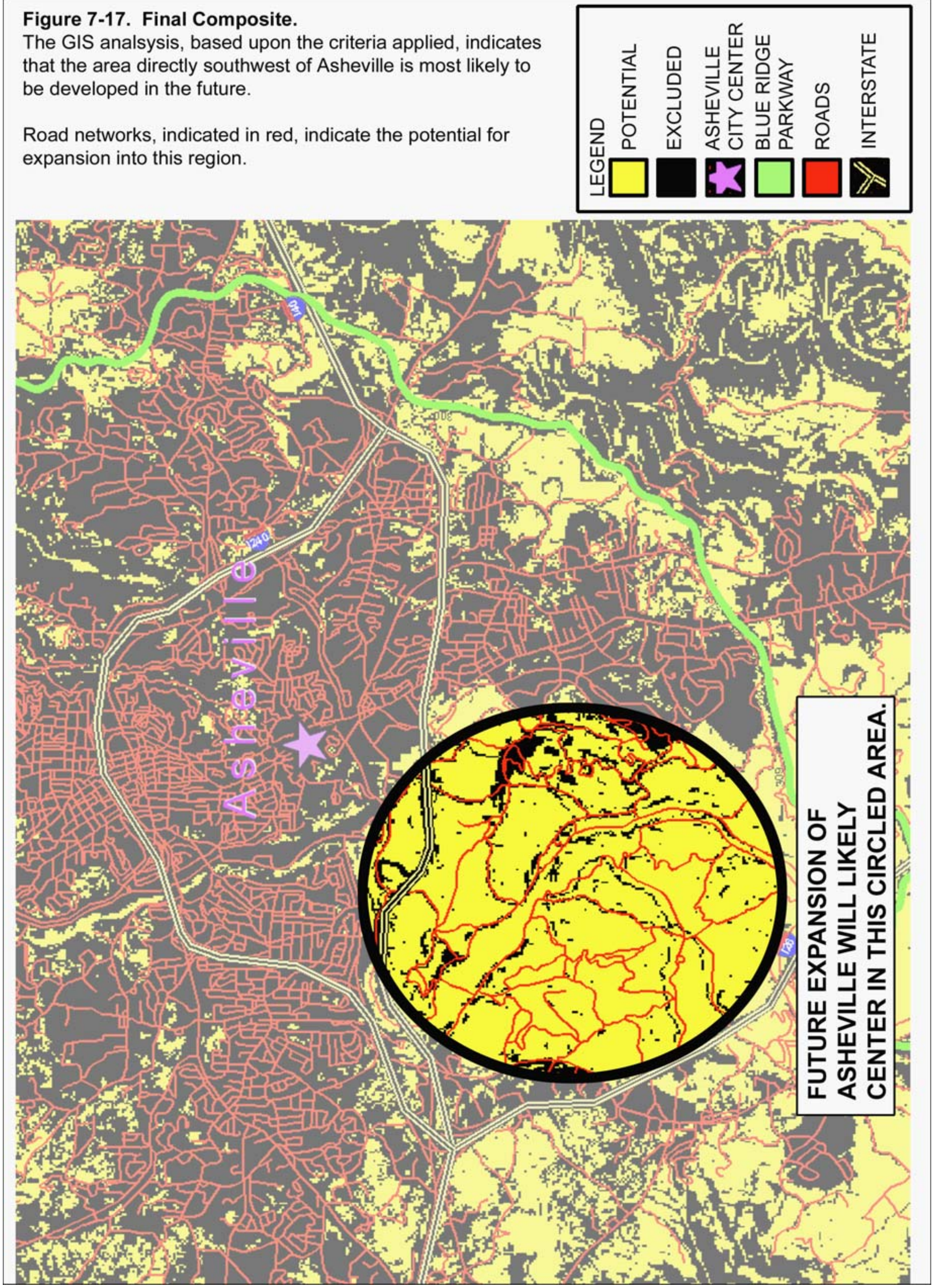
Creating the Final Composite

The steps leading up to this section have been oriented towards preparation of the data, as well as excluding areas that are susceptible to urban development pressure. This exclusion of areas may be considered ‘subtractive analysis,’ whereby areas are ruled out due to factors that would discriminate against development. For example, areas around waste sites or areas that have hilly terrain were excluded using GIS analysis. The final composite, or solution to this study, will use existing road networks to predict, in those areas still under consideration, where urban development might occur. This analysis may be considered ‘additive analysis.’

In Figure 7-17, all of the work that has come before has been unioned. Areas that have been excluded from consideration include slope, urban, wetlands, pollutant sites, and water bodies. The processing of wetlands and water body layers was not illustrated, as the processes were duplications of operations already demonstrated. In addition, the road network has been introduced, and it is in the areas where land that was not excluded in earlier steps and presence of roads overlap that the most likely locations for urban development may be found based upon the variables considered in this study. This chapter laid out in succinct terms the steps for making decisions based upon environmental criteria, and the techniques used offer a direct link to Ian McHarg and traditional landscape architecture.

Figure 7-17. Final Composite.
The GIS analsysis, based upon the criteria applied, indicates that the area directly southwest of Asheville is most likely to be developed in the future.

Road networks, indicated in red, indicate the potential for expansion into this region.



FUTURE EXPANSION OF ASHEVILLE WILL LIKELY CENTER IN THIS CIRCLED AREA.

CHAPTER 8

CONCLUSION

This thesis set out to present GIS as a critical tool to decision making for landscape architects by introducing a vocabulary of terms and concepts presented in a format specifically targeted at landscape architects. It is very important to close this thesis by emphasizing that there are varying degrees to which landscape architects should adopt GIS. Many landscape architects may never learn to encode information or manipulate GIS software. However, most landscape architects will benefit from being able to access the information held in GIS databases. Also, they will be able to communicate with GIS experts in local planning departments.

Chapters Six and Seven of this thesis show two examples of these layers of GIS knowledge quite clearly. The landscape architect working as a planner in the case study in Chapter Six only needs a rudimentary comprehension of the technology in order to be able to apply it to solving basic mapping and zoning questions. The planning example in Chapter Seven is a demonstration of using basic skills to apply GIS to a traditional inventory and analysis problem which ultimately leads to a landscape design solution. It is essential that we understand that our question today is not whether or not to use GIS, but to determine to what degree. No matter what the degree of GIS knowledge, knowing the vocabulary of GIS promotes basic communication between landscape architecture and related disciplines.

APPENDIX A

A GLOSSARY OF GIS TERMS FOR LANDSCAPE ARCHITECTS

Absorption. The process where electromagnetic energy, as it passes through the Earth's atmosphere, interacts with gas molecules and energy and is converted into the internal energy of the molecule. The energy is usually considered to be 'lost', particularly in remote sensing applications. (Association of Geographic Information GIS Dictionary, http://www.geo.ed.ac.uk/agidexe/term?51)

Active Sensor. Solar image sensors that both emit and receive radiation. Radar and Sonar are examples of active sensors. (*ERDAS Field Guide, Fifth Edition* 1999, 589)

Address Matching. A procedure where objects in a non-geocoded database are geocoded using an address field such as a postcode or UPRN. (*Association of Geographic Information GIS Dictionary,* http://www.geo.ed.ac.uk/agidexe/term?150)

Aerial Photograph. A photograph, usually taken from an airplane, as a means of remotely recording ground level events. Not to be confused with satellite remote sensing which produces digital images, aerial photography provides black and white, color and infrared photographs on film. Aerial photography differs from satellite imagery in that the results are almost instantaneous and require only developing, as opposed to images which must undergo a great deal of processing before electromagnetic signals resemble real world features. (*Association of Geographic Information GIS Dictionary,* http://www.geo.ed.ac.uk/agidexe/term?448)

Aggregation. The collecting together of a set of similar, usually adjacent polygons to form a single, larger entity. Any associated attribute data is also grouped together. (*ESRI Online Dictionary,* http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=aggregation)

Algorithm. A finite ordered set of well defined rules for the solution of a problem. (*Association of Geographic Information GIS Dictionary,* http://www.geo.ed.ac.uk/agidexe/term?162)

Annotation. Descriptive text used to label coverage and map features. Annotation is not topologically linked with other features. Used for display purposes; it is not used in analysis. *(Understanding GIS* 1990, xxv*)*

Appending. Adding input features from multiple input data sources of the same data type into an existing feature class. See also merging. (*ESRI Online Dictionary,* http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=appending)

Arc. A continuous string of x,y coordinate pairs (vertices) beginning at one location and ending at another location, having length but no area. Represents line features, the borders of area features, or both. *(Understanding GIS* 1990, xxv*)*

Aspect. The orientation, or the direction that a surface faces, with respect to the directions of the compass: north, south, east, west. (*ERDAS Field Guide, Fifth Edition* 1999, 591)

Attenuation. The combined effect that absorption and scattering have on light or other incident radiation that passes through the Earth's atmosphere, i.e. to make it appear blurred and less bright. Attenuation is particularly important in remote sensing, as it influences the clarity of the imagery. The amount of attenuation will depend upon the amount of particulate matter within the atmosphere, the angle of the sun in the sky, the position of the sensor, and the atmospheric path length of the incident energy. (*Association of Geographic Information GIS Dictionary,* http://www.geo.ed.ac.uk/agidexe/term?50)

Attribute. The tabular information associated with a raster or vector layer. (*ERDAS Field Guide, Fifth Edition* 1999, 591)

Attribute Table. DBMS tables directly associated to spatial data. Contains both spatial data characteristics and attributes. *(Understanding GIS* 1990, xxvi*)*

Autocad. Leading CAD design software, developed by software developer Autodesk.

Backscatter. The reflecting of electromagnetic energy by the particles in the Earth's atmosphere back towards the source of energy. (*Association of Geographic Information GIS Dictionary,* http://www.geo.ed.ac.uk/agidexe/term?80)

Band. A set of data file values for a specific portion of the electromagnetic spectrum of reflected light or emitted heat (red, green, blue, near-infrared, infrared, thermal, etc.), or some other user-defined information created by combining or enhancing the original bands, or creating new bands from other sources. Sometimes called channel. (*ERDAS Field Guide, Fifth Edition* 1999, 591)

Base Map. A map portraying background reference information onto which other information is placed. Base maps usually show the location and extent of natural surface features and permanent human-made features. (*ERDAS Field Guide, Fifth Edition* 1999, 591)

Batch Processing. A term that describes a form of processing that takes a set of commands or jobs, executes them and returns the results, all without direct human intervention. The instructions, or commands, are normally held within a batch file, and submitted to a batch queue to be executed at a later, predetermined time. This contrasts with an interactive system where the user interacts with the computer directly, in real time. (*Krzanowski, R. M., Palylyk, C. L. and Crown, P. H. (1995) Lexicon of Terms for Users of Geographic Information Systems. GIS World Inc.)*

Bilinear Interpolation. A resampling method that uses the data file values of four pixels in a 2x2 window to calculate an output file value by computing a weighted average of the input data file values with a bilinear function. (*ERDAS Field Guide, Fifth Edition* 1999, 592)

Buffer Generation. A form of proximity analysis where zones of a given distance are generated around coverage features. The resulting buffer zones form polygons – areas that are inside or outside of the specified buffer distance from each feature. *(Understanding GIS* 1990, xxvi*)*

Buffer Zone. A specific area around a feature that is isolated for or from further analysis. For example, buffer zones are often generated around streams in site assessment studies so that further analyses exclude these areas that are often unsuitable for development. (*ERDAS Field Guide, Fifth Edition* 1999, 593)

CAD (Computer Aided Design). An automated system for the design, drafting and display of graphically oriented information. *(Understanding GIS* 1990, xxvi*)*

Cadastral Map. A map showing the boundaries of the subdivisions of land for purposes of describing and recording ownership or taxation. (*ERDAS Field Guide, Fifth Edition* 1999, 593)

Cartography. The art and science of making maps. (*ERDAS Field Guide, Fifth Edition* 1999, 593)

Cartesian Coordinate System. A two-dimensional, planar coordinate system in which x measures horizontal distance and y measures vertical distance. Each point on the plane is defined by an x,y coordinate. Relative measures of distance, area, and direction are constant throughout the Cartesian coordinate plane. (*Association of Geographic Information GIS Dictionary,* http://www.geo.ed.ac.uk/agidexe/term?501)

CCD. See Charge Coupled Device.

Census Block. The smallest geographic entity for which the U.S. Bureau of the Census tabulates decennial census data. Visible and/or invisible features shown on a map prepared by the U.S. Census Bureau bound its geographic area. Many blocks correspond to city blocks bounded by streets, but blocks in rural areas may include many square miles and have some boundaries that are not streets. The Census Bureau established blocks covering the entire nation for the first time in 1990. Previous censuses back to 1940 had blocks established only for part of the nation. (*ESRI Online Dictionary,* http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=census%20block)

Census Tract. A small, relatively permanent statistical subdivision of a county. Tract boundaries normally follow visible features, but may follow governmental unit boundaries or other invisible features. Designed to be relatively homogeneous units with respect to population characteristics, economic status, and living conditions at the time of establishment, census tracts average about 4,000 inhabitants. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=census%20tract)

Centroid. The geometric center of a feature. Of a line, it is the midpoint; of a polygon, the center of area; of a three-dimensional figure, the center of volume. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=centroid)

Change Detection. Process using different time sets of classified imagery to detect changes over time, normally used in environmental sciences. (Mathews, Bridges, Caseldine, Luckman, and Owen 2003, p. 200).

Charged Couple Device (CCD). Initially designed as memory device, soon after the invention other applications were suggested. Since the CCD chip was sensitive to light it could be used as an image sensor. The first who recognized the potential of the CCD for high quality scientific images were astronomers. The CCD had a significantly higher sensitivity than the devices of that time: photographic film and vidicon tubes. With sensitivity 100 times greater than film, the CCD displaced other sensors within a few years. *(Portland State University Physics Department 2003, http://www.physics.pdx.edu/~d4eb/ccd/)*

Class. A set of pixels in a GIS file that represents areas that share some condition. Classes are usually formed through classification of a continuous raster layer. (*ERDAS Field Guide, Fifth Edition* 1999, 594)

Classification. The process of assigning the pixels of a continuous raster image to discrete categories. (*ERDAS Field Guide, Fifth Edition* 1999, 594)

Clip. The process of extracting data from a coverage that reside entirely within the boundary of features in another coverage (called the clip coverage) – much like a cookie cutter. *(Understanding GIS* 1990, xxvi*)* Author's note: Clipping and subsetting (see subsetting) are used interchangeably in many cases; 'clipping' is the term most commonly associated with vector GIS, while 'subsetting' is the term most commonly associated with raster GIS.

Command-Line Processing. Commands on a computer screen are typed in sequentially, and then executed by hitting the 'Enter' key on the keyboard. Command line interfaces are still used, but represent the transition from early punch card computing processes to today's graphical user interfaces. (*Stephenson 1999, 13)*

Comprehensive Plan. A comprehensive plan is a written document that identifies the goals, objectives, principles, guidelines, policies, standards, and strategies for the growth and development of the community. (*Pace University School of Law 1998)*

Contour Interval. The difference in elevation between two contour lines. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=contour%20interval)

Contour Map. A map in which a series of lines connects points of equal elevation. (*ERDAS Field Guide, Fifth Edition* 1999, 596)

Controlled Vocabulary. A consistent collection of terms chosen for specific purposes with explicitly stated, logical constraints on their intended meanings and relationships. (*USGS* http://geo-nsdi.er.usgs.gov/talk/thesaurus/definition.html)

Control Point. A point with known coordinates in the ground coordinate system, expressed in the units of the specified map projection. (*ERDAS Field Guide, Fifth Edition* 1999, 596)

Coordinate. An x,y location in a Cartesian coordinate system or x,y,z in a three-dimensional coordinate system. Coordinates are used to represent locations on the Earth's surface relative to other locations. *(Understanding GIS* 1990, xxvi*)*

Coordinate System. A method of expressing location. In two-dimensional coordinate systems, locations are expressed by a column and row, also called *x* and *y*. (*ERDAS Field Guide, Fifth Edition* 1999, 597)

Corona. Corona was the nation's first photo reconnaissance satellite system, operating from August 1960 until May 1972. The program was declassified in February 1995. *(National Reconnaissance Office 2005)*

Corridor Analysis. Buffer analysis usually applied to environmental and land-use data in order to find the best locations for building roads, pipelines, and other linear transportation features. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=corridor%20analysis)

Coverage. A digital analog of a single map sheet forming the basic unit of data storage in Arc/Info. 2. A set of thematically associated data considered to be a unit. A coverage usually represents a single theme or layer, such as soils, streams, roads, and land use. *(Understanding GIS* 1990, xxvii*)*

Cubic Convolution. A method of resampling that uses the data file values of sixteen pixels in a 4x4 window to calculate an output data file value with a cubic function. (*ERDAS Field Guide, Fifth Edition* 1999, 597)

Dangermond, Jack. Founder of ESRI (Environmental Systems Research Institute), a leading provider of GIS software.

Data. Data is information. GIS data is information contained in a database tied to geographic location.

Database. A logical collection of files managed as a unit. (*Understanding GIS* 1990, xxvii) Author's note: A GIS may be considered a database with spatial attributes.

Decision Rule. An equation or algorithm that is used to classify image data after signatures have been created. (*ERDAS Field Guide, Fifth Edition* 1999, 598)

Demographics. The statistical characteristics (such as age, birth rate, and income) of a human population. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=demographics)

***Design with Nature*.** Written by landscape architect Ian McHarg, this landmark publication introduced overlay techniques that were the forerunners to GIS. The book is much more than the blueprint for what would eventually become GIS, as McHarg's inclusion of social and environmental values in design established him as arguably the most famous landscape architect since Frederick Law Olmsted. (*Center for Spatially Integrated Social Science*, http://www.csiss.org/classics/content/23)

Digital Elevation Model (DEM). A raster grid of regularly spaced elevation values that have been primarily derived from USGS topographic map series. 7.5-Minute DEMs correspond to the USGS 1:24,000-scale and 1:25,000-scale topographic quadrangle maps. *(Collins 2004, http://cwt33.ecology.uga.edu/gis/dem_catalog.html)*

Digital Orthophoto. An aerial photograph or satellite scene that has been transformed by the orthogonal projection, yielding a map that is free of most significant geometric distortions. (*ERDAS Field Guide, Fifth Edition* 1999, 599)

Digital Orthophoto Quadrangle (DOQ). A computer-generated image of an aerial photograph. *(USGS 1999)*

Digital Raster Graphic (DRG). A digital raster graphic (DRG) is a scanned image of a U.S. Geological Survey (USGS) standard series topographic map, including all map collar information. Consider the terms 'DRG', 'digital topographic map', and 'digital raster graphics' to describe the same product: a scanned USGS topographic map. *(Collins 2004, http://cwt33.ecology.uga.edu/gis/drg_catalog.html)*

Digitizing. Any process that converts nondigital data into numeric data, usually to be stored on a computer. (*ERDAS Field Guide, Fifth Edition* 1999, 599)

Dissolve. The process of removing boundaries between adjacent polygons having the same values for a specified attribute. (*Understanding GIS* 1990, xxviii)

Displacement. The shift in the location of an object in a photo that does not change the perspective characteristics of the photo, and is the fiducial distance between an object's image and it's true plan position which is caused by change in elevation. *(Hemphill 2005)*.

Distortion. On a map or image, the misrepresentation of shape, area, distance, or direction of or between geographic features when compared to their true measurements on the curved surface of the earth. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=demographics)

DLG (Digital Line Graph). A product of the USGS, these files include digital information from the USGS map base categories, such as transportation, hydrography, contours, and public land survey boundaries. (*Understanding GIS* 1990, xxviii)

Draping. A perspective or panoramic rendering of a two-dimensional image superimposed onto a three-dimensional surface. For example, an aerial photograph might be draped over a digital elevation model to create a realistic terrain visualization. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=draping)

Drum Scanner. Used to reproduce analog images as very high resolution digital files, drum scanners have a cylinder that spins while a focused light source on a track shines through or on it and onto the image sensors. Drum scanners produce large, very-high quality images with fine dynamic range and resolutions to 12000 dpi. (Johnson 2003, 86).

DTM (Digital Terrain Model). A discrete expression of topography in a data array, consisting of a group of Planimetric coordinates (X,Y) and the elevations of the ground points and breaklines. (*ERDAS Field Guide, Fifth Edition* 1999, 599)

Edge Detection. A digital image processing technique for isolating optical edges in a digital image by examining it for abrupt changes in pixel value. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=edge%20detection)

Edge Matching. A vector editing procedure for adjusting the locations of connecting arcs and polygons that cross coverage boundaries. (*Understanding GIS* 1990, xxviii)

Electromagnetic Radiation. Energy that moves through space at the speed of light as different wavelengths of time-varying electric and magnetic fields. Types of electromagnetic radiation include gamma, x, ultraviolet, visible, infrared, microwave, and radio. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=electromagnetic%20radiation)

Electromagnetic Spectrum. The range of electromagnetic radiation extending from cosmic waves to radio waves, characterized by frequency or wavelength. (*ERDAS Field Guide, Fifth Edition* 1999, 602)

Environmental Systems Research Institute (ESRI). Based in Redlands, California, ESRI produces vector GIS software such as ArcInfo and ArcView. (*ERDAS Field Guide, Fifth Edition* 1999, 602)

Ephemeris. A list of the predicted positions of a satellite for each day of the year, or for other regular intervals. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=ephemeris)

Extent. The area of the Earth's surface to be mapped. (*ERDAS Field Guide, Fifth Edition* 1999, 603)

False Color. A color scheme in which features have expected colors. For example, vegetation is green, water is blue, etc. These are not necessarily the true colors of these features. (*ERDAS Field Guide, Fifth Edition* 1999, 604)

File Coordinates. The location of a pixel within the file in x,y coordinates. The upper left file coordinate is usually 0,0. (*ERDAS Field Guide, Fifth Edition* 1999, 605)

Filter. The removal of spatial or spectral features for data enhancement. (*ERDAS Field Guide, Fifth Edition* 1999, 605)

FIPS Code. Federal information processing standards codes (FIPS codes) are a standardized set of numeric or alphabetic codes issued by the National Institute of Standards and Technology (NIST) to ensure uniform identification of geographic entities through all federal government agencies. The entities covered include: states and statistically equivalent entities, counties and statistically equivalent entities, named populated and related location entities (such as, places and county subdivisions), and American Indian and Alaska Native areas (http://www.census.gov/geo/www/fips/fips.html). *(U.S. Census Bureau 2006)*

Fuzzy Tolerance. In ArcInfo, the distance within which coordinates of nearby features are adjusted to coincide with each other when topology is being constructed. Nodes and vertices within the fuzzy tolerance are merged into a single coordinate location, connecting previously separate features. Fuzzy tolerance is a very small distance, usually from 1/1,000,000 to 1/10,000 times the width of the coverage extent, and is generally used to correct inexact intersections. The fuzzy tolerance defines the resolution of a coverage resulting from the Clean operation or a topological overlay operation, such as Union, Intersect, or Clip. In geodatabase feature classes, this concept is replaced by cluster tolerance. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=fuzzy%20tolerance)

Generalization. 1. In vector GIS, reducing the number of points in a line without losing the line's essential shape. 2. In raster GIS, enlarging and resampling cells in a raster format. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=generalization)

Geocode. The process of identifying an x,y coordinate location from another geographic location description such as an address. For example, an address for a student can be matched against TIGER street networks to locate the student's home. (*Understanding GIS* 1990, xxix)

Geographic Coordinates. A measurement of a location on the Earth's surface expressed in degrees of latitude and longitude. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=geographic%20coordinates)

Geographic Information System (GIS). A system that stores, enhances, combines, and analyzes layers of geographic data to produce interpretable information. (*ERDAS Field Guide, Fifth Edition* 1999, 606)

Geometric Correction. The correction of errors of skew, rotation, and perspective in raw, remotely sensed data. (*ERDAS Field Guide, Fifth Edition* 1999, 606)

Georeferencing. The process of assigning map coordinates to image data and resampling the pixels of the image to conform to a map projection. (*ERDAS Field Guide, Fifth Edition* 1999, 606)

GeoTiff. Tiff files that are georeferenced for use in a GIS system. (*ERDAS Field Guide, Fifth Edition* 1999, 606)

Global Positioning System (GPS). System of orbiting satellites used to pinpoint precise locations on the Earth's surface. (*ERDAS Field Guide, Fifth Edition* 1999, 607)

Gradient. The ratio between the vertical distance (rise) and horizontal distance (run), often expressed as a percentage. A 10-percent gradient rises ten feet for every one hundred feet of horizontal distance. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=gradient)

Grain Tolerance. A parameter controlling the number of vertices and the distance between them on lines that represent curves. The smaller the grain tolerance, the closer the vertices can be. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=grain%20tolerance)

Graphical User Interface (GUI). A program interface that takes advantage of the computer's graphics capabilities to make the program easier to use. Well-designed graphical user interfaces can free the user from learning complex command languages. (*Webopedia, http://www.webopedia.com/TERM/G/Graphical_User_Interface_GUI.htm*l)

Gray Scale. A color scheme with a gradation of gray tones ranging from black to white. (*ERDAS Field Guide, Fifth Edition* 1999, 607)

Great Circle. An arc of a circle for which the center is the center of the Earth. A great circle is the shortest possible surface route between two points on the Earth. (*ERDAS Field Guide, Fifth Edition* 1999, 607)

Grid Lines. Intersecting lines that indicate regular intervals of distance based on a coordinate system. Sometimes called a graticule. (*ERDAS Field Guide, Fifth Edition* 1999, 607)

Ground Control. A system of points with established positions, elevations, or both, used as fixed references in relating map features, aerial photographs, or remotely sensed images. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=ground%20control)

Ground Control Point (GCP). Specific pixel in image data for which the output map coordinates are known. GCP's are used for computing a transformation matrix, for use in rectifying an image. (*ERDAS Field Guide, Fifth Edition* 1999, 607)

Ground Truthing. The acquisition of knowledge about the study area from field work, analysis of aerial photography, personal experience, etc. Ground truth data are considered to be the most accurate (true) data available about the area of study. (*ERDAS Field Guide, Fifth Edition* 1999, 607)

Groundwater Recharge Areas. Water seeping into an aquifer is known as recharge. This takes place intermittently during and immediately following periods of rain and snow-melt. Recharge occurs where permeable soil or rock allows water to readily seep into the ground. These areas are known as recharge areas. Permeable soil or rock formations where recharge occurs may occupy only a very small area or extend over many square miles. Valley aquifers may also receive recharge from hillside runoff or streams that flow down from hillsides in addition to the rain and snow that falls directly onto the land surface overlying the aquifer. (*ERDAS Field Guide, Fifth Edition* 1999, 607)

GUI. See Graphical User Interface.

Hardcopy Output. Any output of digital computer (softcopy) data to paper. (*ERDAS Field Guide, Fifth Edition* 1999, 608)

Header File. A file usually found before the actual image data on tapes or CD-ROMs that contains information about the data, such as number of bands, upper left coordinates, map projection, etc. (*ERDAS Field Guide, Fifth Edition* 1999, 608)

Heads-up Digitizing. Digitization directly from a computer screen. (*GIS Data Sources* 2001, 30).

High-pass Filter. In digital image processing, a spatial filter that blocks low-frequency (long wave) radiation, resulting in a sharpened image. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=high%2Dpass%20filter)

Hillshading. The hypothetical illumination of a surface according to a specified azimuth and altitude for the sun. Hillshading creates a three-dimensional effect that provides a sense of visual relief for cartography, and a relative measure of incident light for analysis. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=hillshading)

Histogram. A graph of data distribution, or a chart of the number of pixels that have each possible data file value. For a single band of data, the horizontal axis of a histogram graph is the range of all possible data file values. The vertical axis is a measure of pixels that have each data value. (*ERDAS Field Guide, Fifth Edition* 1999, 608)

Hyperspectral Sensors. Image sensors that record multiple bands of data, such as the AVIRIS with 224 bands. (*ERDAS Field Guide, Fifth Edition* 1999, 609)

IHS (Intensity, Hue, Saturation). An alternate color space from RGB (red, green, blue). This system is advantageous in that it presents colors more nearly as perceived by the human eye. (*ERDAS Field Guide, Fifth Edition* 1999, 609)

Image. A picture or representation of an object or scene on paper, or a computer display screen. Remotely sensed images are digital representations of Earth. (*ERDAS Field Guide, Fifth Edition* 1999, 609)

Image Processing. The manipulation of digital image data, including (but not limited to) enhancement, classification, and rectification operations. (*ERDAS Field Guide, Fifth Edition* 1999, 609)

Interpolation. The estimation of surface values at unsampled points based on known surface values of surrounding points. Interpolation can be used to estimate elevation, rainfall, temperature, chemical dispersion, or other spatially-based phenomena. Interpolation is commonly a raster operation, but it can also be done in a vector environment using a TIN surface model. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=interpolation)

IR. Infrared portion of the electromagnetic spectrum. See electromagnetic spectrum. (*ERDAS Field Guide, Fifth Edition* 1999, 610)

ISODATA (Iterative Self-Organizing Data Analysis Technique) Classification. A method of clustering used in land cover classification that uses spectral distance as in the sequential method, but iteratively classifies the pixels, redefines the criteria for each class, and classifies again, so that the spectral distance patterns in the data gradually emerge. (*ERDAS Field Guide, Fifth Edition* 1999, 611)

Iterative. A repetitive or recurring procedure. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=iterative)

Jet Propulsion Laboratory. The lead U.S. center for robotic exploration of the solar system, the Jet Propulsion Laboratory is managed by NASA. (*ERDAS Field Guide, Fifth Edition* 1999, 612)

Jordan, Lawrie. Landscape architect who with partner Bruce Rado co-founded ERDAS, a leading remote sensing software developer.

Land Cover. A map of the visible ground features of a scene, such as vegetation, bare land, pasture, urban, etc. (*ERDAS Field Guide, Fifth Edition* 1999, 612)

Landsat. A series of Earth-orbiting satellites that gather MSS or TM imagery. (*ERDAS Field Guide, Fifth Edition* 1999, 612)

Land Use. The classification of land according to what activities take place on it or how humans occupy it; for example, agricultural, industrial, residential, urban, rural, or commercial. (*ERDAS Field Guide, Fifth Edition* 1999, 612)

Lat/Lon. Latitude/Longitude, a map coordinate system. (*ERDAS Field Guide, Fifth Edition* 1999, 612)

Layer. A spatial dataset containing a common feature type. Layers are also referred to as coverages or themes. (*GIS Lounge 2006*, http://gislounge.com/glossary/bldeflayer.shtml)

Lens Distortion. Small effects due to the flaws in the optical components (i.e. lens) of camera systems leading to distortions (which are typically more serious at the edges of photos). Car windows/windshields, carnival mirrors are probably the best know examples of this type of effect. These effects are radial from the principal point (making objects appear either closer to, or farther from the principal point than they actually are); and may be corrected using calibration curves. *(Hemphill 2005)*

Lossless Compression. Data compression that has the ability to store data without changing any of the values; however, it is only able to compress the data at a low ratio (typically 2:1 or 3:1). In GIS, this type of compression is often used to compress raster data when the pixel values of the raster will be used for analysis or deriving other data products. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=lossless%20compression)

Lossy. A term describing a data compression algorithm which actually reduces the amount of information in the data, rather than just the number of bits used to represent that information. (Free On-Line Dictionary of Computing 1999)

Lossy Compression. Data compression that provides high compression ratios (for example 10:1 to 100:1); however, lossy compression does not retain all the information in the data. In GIS, lossy compression is used to compress raster datasets that will be used as background images, but this compression is not suitable for raster analysis. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=lossy%20compression)

Low-pass Filter. A spatial filter that blocks high-frequency (shortwave) radiation, resulting in a smoother image. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=low%2Dpass%20filter)

Macro. A computer program, usually a text file, containing a sequence of commands that are executed as a single command. Macros are used to perform commonly used sequences of commands or complex operations. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=macro)

Map. A graphic representation of spatial relationships on the Earth or other planets. (*ERDAS Field Guide, Fifth Edition* 1999, 614)

Map Coordinates. A system expressing locations of the Earth's surface using a particular map projection, such as UTM, State Plane, or Polyconic. (*ERDAS Field Guide, Fifth Edition* 1999, 614)

Map Extent. The rectangular limits (xmin, ymin, xmax, ymax) that include all the features displayed on the graphics screen or on a plotted map. (*Understanding GIS* 1990, xxxi)

Map Projection. A method of representing the three-dimensional spherical surface of a planet on a two-dimensional map surface. All map projection involve the transfer of latitude and longitude onto an easily flattened surface. (*ERDAS Field Guide, Fifth Edition* 1999, 614)

Map Scale. A statement of a measure on the map and the equivalent measure on the Earth, often represented as a representative fraction of the distance, such as 1:24,000. This means that one unit of distance on the map represents 24,000 of the same units of distance on the Earth. (*Understanding GIS* 1990, xxxi)

Metadata. Information that describes the content, quality, condition, origin, and other characteristics of data or other pieces of information. Metadata for spatial data may document its subject matter; how, when, where, and by whom the data was collected; availability and distribution information; its projection, scale, resolution, and accuracy; and its reliability with regard to some standard. Metadata consists of properties and documentation. Properties are derived from the data source (for example, the coordinate system and projection of the data), while documentation is entered by a person (for example, keywords used to describe the data).

(*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=metadata)

Merging. Combining input features from multiple input data sources of the same data type into a single, new, output feature class. See also appending. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=merging)

Model. A set of rules and procedures for conducting spatial analysis to derive new information that can be analyzed to aid in problem solving and planning. Analytical tools in a GIS are used for describing the spatial distribution of a natural or social phenomenon. Models can include a combination of logical expressions, analytical procedures, and criteria, which are applied for the purpose of simulating a process, predicating an outcome, or characterizing a phenomenon. (*Understanding GIS* 1990, xxxii)

Modeling. The process of creating new layers from combining or operating upon existing layers. Modeling allows the creation of new classes from existing classes. (*ERDAS Field Guide, Fifth Edition* 1999, 616)

Mosaicing. The process of piecing together images side by side, to create a larger image. (*ERDAS Field Guide, Fifth Edition* 1999, 616)

MrSID (Multiresolution Seamless Image Database). A wavelet transform-based compression algorithm. (*ERDAS Field Guide, Fifth Edition* 1999, 616)

Multispectral Classification. The process of sorting pixels into a finite number of individual classes, or categories of data, based on data file values in multiple bands. See also classification. (*ERDAS Field Guide, Fifth Edition* 1999, 616)

Multispectral Imagery. Satellite imagery with data recorded in two or more bands. (*ERDAS Field Guide, Fifth Edition* 1999, 616)

Multitemporal. Data from two or more different dates. (*ERDAS Field Guide, Fifth Edition* 1999, 616)

Nadir. In aerial photography, the point on the ground vertically beneath the perspective center of the camera lens. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=nadir)

Nearest Neighbor. Resampling method in which the output data file value is equal to the input pixel that has coordinates closest to the retransformed coordinates of the output pixel. (*ERDAS Field Guide, Fifth Edition* 1999, 617)

Neighborhood Analysis. Any image processing technique that takes surrounding pixels into consideration, such as convolution filtering and scanning. (*Becker* 1996, 28)

Needs Assessment. Systematic evaluation at how departments in local government function and the spatial data needed to do their work. (*ERDAS Field Guide, Fifth Edition* 1999, 617)

Neural Network. A computer architecture modeled after the human brain, and designed to solve problems that human brains solve well, such as recognizing patterns and making predictions from past performance. Neural networks are composed of interconnected computer processors that calculate a number of weighted inputs to generate an output. For example, an output might be the approval or rejection of a credit application. This output would be based on several inputs, including the applicant's income, current debt, and credit history. Some of these inputs would count more than others; cumulatively, they would be compared to a threshold value that separates approvals from rejections. Neural networks "learn" to generate better outputs by adjusting the weights and thresholds applied to their inputs. (*ESRI Online Dictionary,* http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=neural%20network)

Node. The ending points of a line. (*ERDAS Field Guide, Fifth Edition* 1999, 617)

Noise. In remote sensing, any disturbance in a frequency band. (*ESRI Online Dictionary,* http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=noise)

Nominal. Data divided into classes where no class comes before another in sequence or importance; for example, a group of polygons colored to represent different soil types. See also ordinal. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=nominal)

Null Value. The absence of a recorded value for a geographic feature. A null value differs from a value of zero in that zero may represent the measure of an attribute, while a null value indicates that no measurement has been taken. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=null%20value)

Ordinal. Data classified by comparative value; for example, a group of polygons colored lighter to darker to represent less to more densely populated areas. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=ordinal)

Orientation Angle. The angle between a perpendicular to the center scan line and the North direction of the satellite scene. (*ERDAS Field Guide, Fifth Edition* 1999, 619)

Orthorectification. A form of rectification that corrects for terrain displacement. (*ERDAS Field Guide, Fifth Edition* 1999, 619)

Overlay. A function that creates a composite file containing either the minimum or the maximum class values of the input files. Overlay sometimes refers generically to a combination of layers. (*ERDAS Field Guide, Fifth Edition* 1999, 619)

Outline Map. A map showing the limits of a specific set of mapping entities such as counties. Outline maps usually contain a very small number of details over the desired boundaries with their descriptive codes. (*ERDAS Field Guide, Fifth Edition* 1999, 619)

Panchromatic Imagery. Single-band or monochrome satellite imagery. (*ERDAS Field Guide, Fifth Edition* 1999, 620)

Parcel. A tract or plot of land. The term is usually used in the context of land use or legal ownership. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=parcel)

Passive Sensors. Solar imaging sensors that can only receive radiation waves and cannot transmit radiation. (*ERDAS Field Guide, Fifth Edition* 1999, 620)

Photogrammetry. The art, science, and technology of obtaining reliable information about physical objects and the environment through the processes of recording, measuring, and interpreting photographic images and patterns of electromagnetic radiant energy and other phenomena. (ASPRS 1980)

Pixel. Abbreviated from ‘picture element’. The smallest part of a picture (image). (*ERDAS Field Guide, Fifth Edition* 1999, 621)

Planimetric Map. A map that correctly represents horizontal distances between objects. (*ERDAS Field Guide, Fifth Edition* 1999, 621)

Point. A vector GIS element consisting of a single (x,y) coordinate pair. (*ERDAS Field Guide, Fifth Edition* 1999, 621)

Polygon. A vector GIS area feature defined by the series of arcs defining its boundary. (*Understanding GIS* 1990, xxxiii)

Projection. A mathematical model that transforms the locations of features on the Earth’s surface to locations on a two-dimensional surface. Some projections preserve the integrity of shape; others preserve accuracy of area, distance, or direction. (*Understanding GIS* 1990, xxxiii)

Proximity Analysis. A technique used to determine which pixels of a thematic layer are located at specified distances from pixels in a class or classes. (*ERDAS Field Guide, Fifth Edition* 1999, 622)

Pseudo Color. A method of displaying an image (usually a thematic layer) that allows the classes to have distinct colors. (*ERDAS Field Guide, Fifth Edition* 1999, 623)

Quadrangle. Any of the hardcopy maps distributed by the USGS. (*ERDAS Field Guide, Fifth Edition* 1999, 623)

Radar Data. Remotely sensed data that are produced when a radar transmitter emits a beam of micro or millimeter waves. The waves reflect from the surfaces they strike, and the backscattered radiation is detected by the radar system's receiving antenna, which is tuned to the frequency of the transmitted waves. See also active sensor, passive sensor. Radar is an active sensor. (*ERDAS Field Guide, Fifth Edition* 1999, 623)

Radiometric Correction. The correction of variations in data that are not caused by the object or scene being scanned, such as scanner malfunction and atmospheric interference. (*ERDAS Field Guide, Fifth Edition* 1999, 623)

Radiometric Resolution. The dynamic range, or number of possible data file values, in each band. (*ERDAS Field Guide, Fifth Edition* 1999, 623)

Rado, Bruce. Landscape architect who with partner Lawrie Jordan co-founded of ERDAS, a leading remote sensing software developer.

Raster Data. Data that are organized in a grid of columns and rows. Raster data usually represent a planar graph or geographical area. (*ERDAS Field Guide, Fifth Edition* 1999, 624)

Rasterization. The conversion of vector points, lines, and polygons into raster cell data. (*ESRI Online Dictionary,* http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=rasterization)

Recoding. The assignment of new values to one or more classes. (*ERDAS Field Guide, Fifth Edition* 1999, 624)

Rectification. The process of making image data conform to a map projection system. (*ERDAS Field Guide, Fifth Edition* 1999, 624)

Reference System. The map coordinate system to which an image is registered. (*ERDAS Field Guide, Fifth Edition* 1999, 625)

Registration. The process of making image data conform to another image. (*ERDAS Field Guide, Fifth Edition* 1999, 625)

Relate. An operation establishing a connection between corresponding records in two tables using an item common to both. (*Understanding GIS* 1990, xxxiii)

Relational Database Management System (RDBMS). A database management system with the ability to access data organized in tabular files that may be related together by a common field. (*Understanding GIS* 1990, xxxiii)

Relational Join. The operation of relating and physically merging two attribute tables using their common item. (*Understanding GIS* 1990, xxxiii)

Relief Map. A map that appears to be three-dimensional. (*ERDAS Field Guide, Fifth Edition* 1999, 625)

Remote Sensing. The measurement or acquisition of data about an object or scene by a satellite or other instrument above or far from the object. Aerial photography, satellite imagery, and radar are all forms of remote sensing. (*ERDAS Field Guide, Fifth Edition* 1999, 625)

Resampling. The process of extrapolating data file values for the pixels in a new grid when data have been rectified or registered to another image. (*ERDAS Field Guide, Fifth Edition* 1999, 625)

Resolution. A level of precision in data. For specific types of resolution, see radiometric resolution, spatial resolution, spectral resolution, and temporal resolution. (*ERDAS Field Guide, Fifth Edition* 1999, 626)

RGB (Red, Blue, Green). The primary additive colors that are used on most display hardware to display imagery. (*ERDAS Field Guide, Fifth Edition* 1999, 626)

RMS (Root, Mean, Square) Error. 1. The distance between the input (source) location of a GCP (Ground Control Point) and the retransformed location for the same GCP. RMS error is calculated with a distance equation. 2. Used to measure how well a specific calculated solution fits the original data. For each observation of a phenomena, a variation can be computed between the actual observation and a calculated value. Each variation is then squared. The sum of these squared values is divided by the number of observations and then the square root is taken. (*ERDAS Field Guide, Fifth Edition* 1999, 626)

Rubber Sheeting. A procedure for adjusting the coordinates of all the data points in a dataset to allow a more accurate match between known locations and a few data points within the dataset. Rubber sheeting preserves the interconnectivity, or topology, between points and objects through stretching, shrinking, or reorienting their interconnecting lines. (*ESRI Online Dictionary,* http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=rubber%20sheeting)

Scale. The ratio of distance on a map as related to the true distance on the ground. (*ERDAS Field Guide, Fifth Edition* 1999, 627)

Scene. Image captured by a satellite. (*ERDAS Field Guide, Fifth Edition* 1999, 627)

Screen Digitizing. The process of drawing vector graphics on the display screen with a mouse. A displayed image can be used as a reference. (*ERDAS Field Guide, Fifth Edition* 1999, 627)

Search Radius. The distance around each pixel within which the software searches. (*ERDAS Field Guide, Fifth Edition* 1999, 628)

Selective Availability. Introduces a positional inaccuracy of up to 100 meters to commercial GPS receivers. (*ERDAS Field Guide, Fifth Edition* 1999, 628)

Sensor. A device that gathers energy, converts it to a digital value, and presents it in a form suitable for obtaining information about the environment. (*ERDAS Field Guide, Fifth Edition* 1999, 628)

Shapefile. An ESRI vector format that contains spatial data. Shape files have the .shp extension. (*ERDAS Field Guide, Fifth Edition* 1999, 628)

Short Wave Infrared Region. The near-infrared and middle-infrared regions of the electromagnetic spectrum. (*ERDAS Field Guide, Fifth Edition* 1999, 628)

Signature. A set of statistics that defines a training sample or cluster. The signature is used in a classification process. Each signature corresponds to a GIS class that is created from the signatures with a classification decision rule. See decision rule and spectral signature. (*ERDAS Field Guide, Fifth Edition* 1999, 629)

Slope. The change in elevation over a certain distance. Slope can be reported as a percentage or in degrees. (*ERDAS Field Guide, Fifth Edition* 1999, 629)

Snapping. The vector GIS process of moving a feature to coincide exactly with coordinates of another feature. (*Understanding GIS* 1990, xxxiv).

Spatial Analysis. 1. The study of the locations and shapes of geographic features and the relationships between them. Spatial analysis is useful when evaluating suitability, when making predictions, and for gaining a better understanding of how geographic features and phenomena are located and distributed. 2. The process of modeling spatial data and examining and interpreting the results. Spatial analysis is useful for evaluating suitability and capability, for estimating and predicting, and for interpreting and understanding. There are four traditional types of spatial analysis: topological overlay and contiguity analysis, surface analysis, linear analysis, and raster analysis. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=spatial%20analysis)

Spatial Data. Information about the location, shape, and relationships among geographic features. (*Understanding GIS* 1990, xxxiv).

Spatial Enhancement. The process of modifying the values of pixels in an image relative to the pixels that surround them. (*ERDAS Field Guide, Fifth Edition* 1999, 630)

Spatial Frequency. The difference between the highest and lowest values of a contiguous set of pixels. (*ERDAS Field Guide, Fifth Edition* 1999, 630)

Spatial Modeling. A methodology or a set of analytical procedures that simulate real-world conditions within a GIS using the spatial relationships of geographic features. For example, a spatial model could simulate conditions that lead to the contamination of an aquifer or the spread of a forest fire. There are three categories of spatial modeling functions that can be applied to geographic features within a GIS: geometric modeling (generating buffers, calculating areas and perimeters, and calculating distances between features); coincidence modeling (topological overlay); and adjacency modeling (pathfinding, redistricting, and allocation). (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=spatial%20modeling)

Spatial Resolution. A measure of the smallest object that can be resolved by the sensor, or the area on the ground represented by each pixel. (*ERDAS Field Guide, Fifth Edition* 1999, 630)

Spectral Enhancement. The process of modifying the pixels of an image based on the original values of each pixel, independent of the values of surrounding pixels. (*ERDAS Field Guide, Fifth Edition* 1999, 630)

Spectral Resolution. The specific wavelength intervals in the electromagnetic spectrum that a sensor can record. (*ERDAS Field Guide, Fifth Edition* 1999, 630)

Spectral Signature. The pattern of electromagnetic radiation that identifies a chemical or compound. Materials can be distinguished from one another by examining which portions of the spectrum they reflect and absorb. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=spectral%20signature)

Spline. The process of smoothing or generalizing all currently selected lines using a specified grain tolerance during vector editing. (*ERDAS Field Guide, Fifth Edition* 1999, 630)

Split. The process of making two lines from one by adding a node. (*ERDAS Field Guide, Fifth Edition* 1999, 630)

Standard Deviation. 1. The square root of the variance of a set of values which is used as a measurement of the spread of the values. 2. A neighborhood analysis technique that outputs the standard deviation of the data file values of a user-specified window. (*ERDAS Field Guide, Fifth Edition* 1999, 631)

Standard Parallel (or Standard Meridian). The line of latitude where the surface of a globe conceptually intersects with the surface of the projection cylinder or cone. (*ERDAS Field Guide, Fifth Edition* 1999, 631)

Stereo Pair. Two photographs having sufficient perspective overlap to record parallax of detail to make possible stereoscopic examination of an object or an area common to both photographs. A three-dimensional perspective is provided. *(Blinn, Queen, Maki 2005)*

Striping (or Banding). A data error that occurs if a detector on a scanning system goes out of adjustment. (*ERDAS Field Guide, Fifth Edition* 1999, 631)

Subsetting. The process of breaking out a portion of a large image file into one or more smaller files. (*ERDAS Field Guide, Fifth Edition* 1999, 631)

Suitability/Capability Analysis (SCA). A system designed to analyze many data layers to produce a plan map. Discussed in Ian McHarg's book *Design with Nature*. *(Star and Estes 1990)*

Sun-Synchronous. A term used to describe Earth-orbiting satellites that rotate around the Earth at the same rate as the Earth rotates on its axis. (*ERDAS Field Guide, Fifth Edition* 1999, 632)

Supervised Training. Any method of generating signatures for classification, in which the analyst is directly involved in the pattern recognition process. Usually, supervised training requires the analyst to select training samples from the data that represent patterns to be classified. (*ERDAS Field Guide, Fifth Edition* 1999, 632)

Symbology. The set of conventions, rules, or encoding systems that define how geographic features are represented with symbols on a map. A characteristic of a map feature may influence the size, color, and shape of the symbol used. (*ESRI Online Dictionary,* http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=symbology)

Tables. A tabular DBMS used by ArcInfo to store and manipulate map feature attributes. (*Understanding GIS* 1990, xxxiv).

Tabular Data. Descriptive information, usually alphanumeric, that is stored in rows and columns in a database and can be linked to map features. See also tables. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=tabular%20data)

Temporal Resolution. The frequency with which a sensor obtains imagery of a particular area. (*ERDAS Field Guide, Fifth Edition* 1999, 632)

Terrain Analysis. The processing and graphic simulation of elevation data. (*ERDAS Field Guide, Fifth Edition* 1999, 632)

Terrain Data. Elevation data expressed as a series of x, y, and z values that are either regularly or irregularly spaced. (*ERDAS Field Guide, Fifth Edition* 1999, 633)

Thematic Data. Raster data that are qualitative and categorical. Thematic layers often contain classes of related information, such as land cover, soil type, slope, etc. (*ERDAS Field Guide, Fifth Edition* 1999, 633)

Theme. See ‘Layer’.

Threshold. A limit, or cutoff point, usually a maximum allowable amount of error in an analysis. In classification, thresholding is the process of identifying a maximum distance between a pixel and the mean of the signature to which it was classified. (*ERDAS Field Guide, Fifth Edition* 1999, 633)

Tick Marks. Small lines along the edge of the image area or neatline that indicate regular intervals of distance. (*ERDAS Field Guide, Fifth Edition* 1999, 633)

Tie Point. A point; its ground coordinates are not known, but can be recognized visually in the overlap or sidelap area between to images. (*ERDAS Field Guide, Fifth Edition* 1999, 633)

Tiff Data. Tagged Image File Format data is a raster data format developed by Aldus, Corporation in 1986 for the easy transportation of data. See GeoTiff. (*ERDAS Field Guide, Fifth Edition* 1999, 633)

TIGER (Topologically Integrated Geographic Encoding and Referencing System). Files in vector line network products produced by the US Census Bureau. (*ERDAS Field Guide, Fifth Edition* 1999, 633)

Tilt Displacement. A tilted photograph presents a slightly oblique view rather than a true vertical record. All photos have some tilt. The perfect gyro stabilization unit, like the perfect lens, has yet to be built. Tilt is caused by the rotation of the platform away from the vertical. This type of displacement typically occurs along the axis of the wings or the flight line. Tilt displacement radiates from the isocenter of the photo and causes objects to be displaced radially towards the isocenter on the upper side of the tilted photo and radially outward on the lower side. If the amount and direction of tilt are known then the photo may be rectified. (Hemphill 2005)

Tolerance. In vector editing, the minimum or maximum variation allowed when processing or editing a geographic feature's coordinates. For example, during editing, if a second point is placed within the snapping tolerance distance of an existing point, the second point will be snapped to the existing point. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=tolerance)

Topographic. A term indicating elevation. (*ERDAS Field Guide, Fifth Edition* 1999, 634)

Topographic Data. A type of raster data in which pixel values represent elevation. (*ERDAS Field Guide, Fifth Edition* 1999, 634)

Topographic Map. A map depicting terrain relief. (*ERDAS Field Guide, Fifth Edition* 1999, 634)

Topology. A term that defines the spatial relationships between features in a vector layer. (*ERDAS Field Guide, Fifth Edition* 1999, 634)

Training. The process of defining the criteria by which patterns in image data are recognized for the purpose of classification. (*ERDAS Field Guide, Fifth Edition* 1999, 634)

Training Sample. A set of pixels selected to represent a potential class. (*ERDAS Field Guide, Fifth Edition* 1999, 634)

Transformation Matrix. A set of coefficients that is computed from GCPs, and used in polynomial equations to convert coordinates from one system to another. (*ERDAS Field Guide, Fifth Edition* 1999, 634)

Triangulation. Establishes the geometry of the camera or sensor relative to objects on the Earth's surface. (*ERDAS Field Guide, Fifth Edition* 1999, 635)

True Color. A method of displaying an image that retains the relationships between data file values and represents multiple bands with separate color guns. (*ERDAS Field Guide, Fifth Edition* 1999, 635)

Union. The area or set that is a combination of two or more input areas or sets without repetition. (*ERDAS Field Guide, Fifth Edition* 1999, 635)

United States Geological Survey (USGS). A scientific agency of the U.S. government, part of the Department of the Interior. The USGS is a fact-finding research agency that monitors, analyzes, and provides scientific understanding about natural resource issues and conditions, the environment, and natural hazards. The USGS is the primary civilian mapping agency in the United States. It produces digital and paper map products; aerial photography; and remotely sensed data on land cover, hydrology, geology, biology, and geography. (*ESRI Online Dictionary,* http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=usgs)

Universal Transverse Mercator (UTM). An international plane (rectangular) coordinate system developed by the US Army that extends around the world from 84 Degrees North to 80 Degrees South. The world is divided into 60 zones each covering six degrees longitude. Each zone extends three degrees eastward and three degrees westward from its central meridian. Zones are numbered consecutively west to east from the 180 Degree Meridian. (*ERDAS Field Guide, Fifth Edition* 1999, 635)

Unsplit. The process of joining two lines by removing a node. (*ERDAS Field Guide, Fifth Edition* 1999, 635)

Unsupervised Training. A computer-automated method of pattern recognition in which some parameters are specified by the user and are used to uncover statistical patterns that are inherent in the data. (*ERDAS Field Guide, Fifth Edition* 1999, 635)

Variable. A numerical value that is changeable, usually represented with a letter. (*ERDAS Field Guide, Fifth Edition* 1999, 636)

Variance. The measure of central tendency. (*ERDAS Field Guide, Fifth Edition* 1999, 636)

Vector. 1. A line element. (*ERDAS Field Guide, Fifth Edition* 1999, 636) 2. A coordinate-based data structure commonly used to represent map features. Attributes are associated with the feature (as opposed to a raster data structure). (*Understanding GIS* 1990, xxxiii).

Vector Data. Data that represent physical forms (elements) such as points, lines, and polygons. (*ERDAS Field Guide, Fifth Edition* 1999, 636)

Vertex. A point that defines an element, such as a point where a line changes direction. (*ERDAS Field Guide, Fifth Edition* 1999, 636)

Vertical Control. The vertical distribution of GCPs in aerial triangulation (z = elevation). (*ERDAS Field Guide, Fifth Edition* 1999, 636)

Viewshed Analysis. The calculation of all areas that can be seen from a particular viewing point or path. (*ERDAS Field Guide, Fifth Edition* 1999, 636)

Watershed. The geographic area drained by a river or river system. (Glennon 2002, 244).

Weed Tolerance. In vector editing, the minimum distance allowed between any two vertices along a line, set before digitizing. When new lines are added, vertices that fall within that distance of the last vertex are ignored. Nodes are always retained. (*ESRI Online Dictionary*, http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.search&searchTerm=weed%20tolerance)

Weight. The number of values in a set; particularly, in clustering algorithms, the weight of a cluster is the number of pixels that been averaged into it. (*ERDAS Field Guide, Fifth Edition* 1999, 637)

Weighting Factor. A parameter that increases the importance of an input variable. For example, in GIS indexing, one input layer can be assigned a weighting factor that multiplies the class values in that layer by that factor, causing that layer to have more importance in the output file. (*ERDAS Field Guide, Fifth Edition* 1999, 637)

X,Y Cartesian Coordinate System. See Cartesian Coordinate System.

APPENDIX B

GIS USERS IN LOCAL GOVERNMENT

Government Departments/Functions:
Engineering
Planners
Sewer Maintenance
Police
Fire
Disaster Coordination
Community Development
Facilities Management
Highway Department
Tax Assessor
Youth and Recreation Services
Zoning Board
Sanitation
Building and Plumbing Inspection
Traffic Safety
Senior Services
Conservation
Utility Services
Site Planning
Sign Permitting
Schools

Public/Corporate Users:
Hospitals
Developers
Scientists (ecologists, archaeologists, economists)
Home Owners
Retailers (stores, restaurants, services)

APPENDIX C

GIS INVENTORY IN LOCAL GOVERNMENT

District Boundaries
Parcel Maps
Storm Sewers
Lighting
Easements
Streets
Streams & Ditches
Soils
Slope
Wetlands
Woodlands
Archaeological Sites
Hazardous Materials Sites
Critical Environmental Zones
Drainage Basins
Tributary Areas
Storm Drain Flow Analysis
Scheduled Repair Work
Emergency Repair Work
Dispatch (Fire, Police)
Route Selection (Fire, Police)
Building Types
Building Codes
Zoning
Crime Statistics
Demographics
Fires
Subdivisions
Flood Plains
Land Use
Assessed Value
Grievances
Comparable Property
Vacant Land
Impervious Surfaces

Open Space/Parks
Golf Courses
Building Permits
Census Data
Office/Commercial/Retail Sites
Industrial Sites
Recreation Facilities
Mosquito Control
Snow Fences
Snow Removal
Leaf Removal
Brush Collection
Refuse/Trace Collection
Traffic Signals
Sidewalks
Bike/Pedestrian Ways
Housing Density
Population Density
Contours
Airports
Disturbed Areas
Railroads
Utilities
Political Boundaries
County Boundaries
Ground Control
Historic Landmarks
Voting Districts
School Districts

REFERENCES

Alexandria, City of. *City of Alexandria GIS – Parcel Viewer*. Retrieved November 12, 2005, from the City of Alexandria website, http://rockford.ci.alexandria.va.us/website/ParcelViewer/viewer.htm.

Allen, Chris. 1997. *Using Boolean Search Techniques.* Retrieved January 21, 2006, from the Clark University website, http://www.ncgia.ucsb.edu/cctp/units/unit41/41.html.

Asheville Planning Department. 2005. *Hillside and Ridgetop Regulations: A Recommendation for Asheville.* Retrieved March 1, 2006, from the Asheville Planning Department website, http://www.landofsky.org/downloads/Hillside%20&%20Ridgetop%20Regs%20report%20-%20A'ville.doc

ASPRS (American Society of Photogrammetry and Remote Sensing). 1980. *Manual of Photogrammetry, Fourth Edition.* Retrieved November 8, 2005, ASPRS website, http://www.123photogrammetry.com/photogrammetry.html.

Athens-Clarke County. 2003. *Aerial photograph of downtown Athens, Georgia.* Athens Clarke County Planning Department. Athens, Georgia.

Autodesk. 2005. *Autodesk Map 3D.* Retrieved December 2, 2005, Autodesk website, http://usa.autodesk.com/adsk/servlet/index?siteID=123112&id=5168954

Beatley, Timothy, David J. Bower, and Anna K. Schwab. 2002. *An Introduction to Coastal Zone Management*. Washington, D.C.: Island Press.

Becker, Paul, Hugh Calkins, Carmelle J. Cote, Christina Finneran, Graham Hayes, and Thomas Murdoch. 1996. *GIS Development Guide*. Albany, New York: Local Government Technology Services State Archives and Records Administration.

Bernhardsen, Tor. 2002. *Geographic Information Systems: An Introduction*. New York: John Wiley & Sons.

Bernstein, Alan B. 2003. *The Princeton Review Guide to Your Career, Fifth Edition*. New York, New York: Princeton Review Publishing, L. L. C.

Bickmore DP, and MA Shaw. 1963. *Atlas of Great Britain and Northern Ireland*. Oxford: Clarendon Press.

Blinn Charles R., Lloyd P. Queen, and Les W. Maki. *Geographic Information Systems: A Glossary.* Retrieved November 8, 2005, from the University of Minnesota website, http://www.extension.umn.edu/distribution/naturalresources/components/DD6097sz.htm.

Buncombe County Planning and Development. 1999. *Comprehensive Land Use Plan.* Retrieved February 27, 2006, from the Buncombe County Planning and Development website, http://www.buncombecounty.org/governing/depts/Planning/landUseAgreement.htm.

Buncombe County Planning and Development. 2003. *Code of Ordinances.* Retrieved February 27, 2006, from the Buncombe County Planning and Development website, http://www.municode.com/services/gateway.asp?sid=33&pid=12776.

Censusscope.org. *Population Growth of Asheville, North Carolina.* Retrieved February 27, 2006, from the Census Scope website, *http://www.censusscope.org/us/m480/print_chart_popl.html*

Chrisman, Nicholas R. "Academic Origins of GIS." In Foresman, Timothy W. (Ed.). 1998. *The History of Geographic Information Systems: Perspectives from the Pioneers.* Upper Saddle River: Prentice Hall PTR.

Cook, Thomas. Map: Cook's Plan of Jerusalem. Retrieved September 6, 2005, from the University of California, Berkeley web site, http://library.berkeley.edu/EART/maps/jerusalem.gif.

Coppock, J. T., and D.W. Rhind. 1991. "The History of GIS." In Maguire, David J., Michael F. Goodchild, and David Rhind (Eds.). 1991. *Geographical Information Systems: Principles and Applications.* London: Longman Group UK Ltd.

Corona Project. *Photograph: Corona satellite photograph of the Pentagon.* Retrieved October 17, 2005, from the Corona Project Website, http://www.geog.ucsb.edu/~kclarke/Corona/Corona.html

Coticchia, Mark E. 1993. *CAD/CAM/CAE Systems*. Monticello, New York: Marcel Dekker, Inc.

__________. 1086. *Domesday Book, A Survey of the Counties of England,* Translated by Veronica Sankaram. Sussex: Phillimore & Co. Ltd. 1983.

Davis, Bruce E. 2001. *GIS: A Visual Approach.* Albany, New York: OnWord Press.

Decker, Drew. 2001. *GIS Data Sources*. New York, New York: John Wiley & Sons.

Downey, Gary Lee. 1998. *The Machine in Me: An Anthropologist Sits Among Computer Engineers*. New York, New York: Routledge.

Emmitt, M., and J. Pollock. 1997. *Language and Learning, 2nd Edition.* South Melbourne: Oxford University Press.

Environmental Protection Agency. 2006. *Superfund.* Retrieved March 1, 2006, from the Environmental Protection Agency website, http://www.epa.gov/superfund/ .

Erskine, R.W.H., and Ann Williams (Eds.). 1987. *The Story of the Domesday Book.* West Sussex: Phillimore & Co. Ltd.

ESRI. *Photograph: Harvard Graduate School of Design in the 1960's.* Retrieved September 6, 2005, from the ESRI website, http://www.esri.com/company/about/timeline/flash/index.html.

Faust, Nicholas. "Raster Based GIS." In Foresman, Timothy W. (Ed.). 1998. *The History of Geographic Information Systems: Perspectives from the Pioneers.* Upper Saddle River: Prentice Hall PTR.

Fisk, Dale. 2003. "Programming with Punch Cards." Retrieved January 26, 2005, from the Columbia University website, http://www.columbia.edu/acis/history/fisk.pdf.

Foresman, Timothy W. (Ed.). 1998. *The History of Geographic Information Systems: Perspectives from the Pioneers.* Upper Saddle River: Prentice Hall PTR.

Forsyth County Planning Department. *Zoning Map.* Retrieved November 28, 2005, from the Forsyth County Planning Department website, http://www.forsythco.com/DeptPage.asp?DeptID=115&PageID=670.

Forest, David. "Canada Today." In Foresman, Timothy W. (Ed.). 1998. *The History of Geographic Information Systems: Perspectives from the Pioneers.* Upper Saddle River: Prentice Hall PTR.

Freeman, Michael. 2003. *The Complete Guide to Digital Photography*. New York, New York: Lark Books.

Garbrecht, Jurgen, and Lawrence W. Martz. 2000. "Digital Elevation Model Issues in Water Resources Modeling." In Maidment, David, and Dean Djokic (Eds.). 2000. *Hydrologic and Hydraulic Modeling Support with Geographic Information Systems*. Redlands, California: ESRI Press.

Georgia GIS Data Clearinghouse. *Projections and Datums*. Retrieved December 3, 2005, from the Georgia GIS Data Clearinghouse web site, http://www.gis.state.ga.us/Clearinghouse/FAQ/proj/proj.html#Coordinate_system.

Gilfoyle, Ian, and Peter Thorpe. 2004. *Geographic Information Management in Local Government*. Boca Raton, Florida: CRC Press LLC.

Glennon, Robert. 2002. *Water Follies: Groundwater Pumping and the Fate of America's Fresh Waters*. Washington, D.C.: Island Press.

GeoSpatial Solutions. *ESRI Corporate Profile*. Retrieved August 25, 2005, from the GeoSpatial Solutions web site, http://www.geospatial-online.com/geospatialsolutions/article/articleDetail.jsp?id=81508.

Goodchild, Michael F., Louis T. Steyaert, and Bradley O. Parks. 1993. *Environmental Modeling with GIS*. New York, New York: Oxford University Press, Inc.

Green, David R. (Ed.). 2001. *GIS: A Sourcebook for Schools*. London: Taylor & Francis.

Green, R. W. 2002. *Confronting Catastrophe*. Redlands, California: ESRI Press.

Hemphill, Jeff. *Basics of Aerial Photography*. Retrieved November 7, 2005, from the University of Santa Barbara California web site, http://www.geog.ucsb.edu/~jeff/115a/lectures/camera_systems.html

Hewitt, M.J., III, H.F. Stone, and E.T. Slonecker. 1992. "Overview of the Use and Formulation of Geographic Information Systems (GIS) Standards Within the U.S. Environmental Protection Agency." In Johnson, A.I., Pettersson, C.B., and J.L. Fulton (Eds.). 1992. *Geographic Information Systems (GIS) and Mapping – Practices and Standards.* Philadelphia: American Society for Testing and Materials.

Hopkins, Lewis. 1977. "Methods for Generating Land Suitability Maps." *Journal of the American Institute of Planners.* 43(4): 386-400.

Hutchinson, Scott, and Larry Daniel. 2004. *Inside ArcView GIS 8.3*. Clifton Park, New York: Delmar Learning.

Illinois Department of Natural Resources. 1997. *Land Cover in the Kishwaukee River Basin*. Retrieved January 24, 2006, from the Illinois Department of Natural Resources website, http://dnr.state.il.us/orep/c2000/assessments/kishwaukee/images/land_cover1.jpg.

Johnson, Harald. 2003. *Mastering Digital Printing*. Boston: Thomson Course Technology.

Johns, Merida L. 2002. *Information Management for Health Professions*. Albany, New York: Delmar.

Johnson, Bart, and Kristina Hill. 2002. *Ecology and Design*. Washington, D.C.: Island Press.

Kaiser, Edward J., and F. Stuart Chapin. 1995. *Urban Land Use Planning*. Chicago: Chicago University Press.

Kennedy, Heather. 2004. *Data in Three Dimensions: A Guide to ArcGIS 3D Analyst*. Clifton Park, New York: Delmar Learning.

Kennedy, Michael. 2002. *The Global Positioning System and GIS.* New York: Taylor & Francis Inc.

Lock, Gary R. 2003. *Using Computers in Archaeology*. London: Routeledge (UK)

Lucent Technologies. *Researchers Inventions Span the Decades.* Retrieved November 2, 2005, from the Bell Labs/Lucent Technologies website, *http://www.bell-labs.com/project/feature/archives/ccd/.*

Lyle, Raymond S. 1992. *What is Groundwater?* Retrieved November 7, 2005, from the University of Minnesota Extension Service website, http://www.extension.umn.edu/distribution/naturalresources/DD5867.html#Recharge.

Madison County Council of Governments. *Driving Distances from Anderson, Indiana.* Retrieved January 25, 2006, from the Madison County Council of Governments website, http://www.mccog.net/gis_Anderson_500mile_popup.htm.

Malczewski, Jacek. 1999. *GIS and Multicriteria Decision Analysis*. New York, New York: John Wiley & Sons, Inc.

Masursky, Harold. 1978. *Apollo Over the Moon: A View from Orbit*. Government Printing Office, NASA SP-362.

McCarthy, Catherine, Moni J. Fox, and Gary Zaepfel. 2002. *Getting the Word Out Drives Planners Mad.* Retrieved January 25, 2006, from the ESRI website, http://gis.esri.com/library/userconf/proc02/pap0711/p0711.htm.

McHarg, Ian L. 1969. *Design with Nature.* New York: John Wiley & Sons.

McHarg, Ian L. "Preface." In Foresman, Timothy W. (Ed.). 1998. *The History of Geographic Information Systems: Perspectives from the Pioneers.* Upper Saddle River: Prentice Hall PTR.

McTaggart, Bill. 2000. *European Computer Driving License*. London: Springer-Veriag London Ltd.

Maguire, David J., and Michael F. Goodchild, David Rhind (Eds.) 1991. *Geographical Information Systems: Principles and Applications.* London: Longman Group UK Ltd.

Mathews, John A., E. Michael Bridges, Christopher J. Caseldine, Adrian J. Luckman, and Geraint Owen. 2003. *The Encyclopaedic Dictionary of Environmental Change*. New York, New York: Oxford University Press Inc.

Miller, Lynn E. 1999. “Environmental Conscience Before Ian McHarg.” *Ecology,* November 1999: 58-62.

Millington, Andrew C., Stephen J. Walsh, and Patrick E. Osborne. 2001. *GIS and Remote Sensing Applications in Biogeography and Ecology*. Norwell, Massachusetts: Kluwer Academic Publishers.

Monmonier, Mark S. 2001. *Bushmanders and Bullwinkles: How Politicians Manipulate Electronic Maps and Census Data to Win Elections*. Chicago: Chicago University Press.

Mumford, Lewis. 1969. Preface. *Design with Nature.* New York: John Wiley & Sons.

National Reconnaissance Office. 2005. *Corona Facts.* Retrieved November 8, 2005, from the National Reconnaissance Office website, http://www.nro.gov/corona/facts.html/.

New Jersey Geological Survey. 1996. Retrieved January 23, 2006, from the New Jersey Geological Survey website, http://njgeology.org/enviroed/aqfrchrg.htm.

NOAA (National Oceanic & Atmospheric Administration) Coastal Services Center. 2005. *Land Cover Analysis General FAQs*. Retrieved November 15, 2005, from the NOAA website, http://www.csc.noaa.gov/crs/lca/faq_gen.html#GORR/.

NOAA (National Oceanic & Atmospheric Administration). 2001. *NOAA Remote Sensing Expertise Aids World Trade Center Recovery Efforts*. Retrieved November 12, 2005, from the NOAA website, http://www.noaanews.noaa.gov/stories/s781.htm/.

O’Looney, John. 2000. *Beyond Maps: GIS and Decision Making in Local Government*. Redlands, California: ESRI Press.

Pace University School of Law. 1998. *Universal Glossary of Land Use Terms and Phrases.* Retrieved November 29, 2005, from the Pace University School of Law website, *http://www.nymir.org/zoning/Glossary.html#C.*

Peng, Zhong-Ren, and Tsou Ming-Hsiang. 2003. *Internet GIS: Distributed Geographic Information Services for the Internet and Wireless Networks*. Hoboken: John Wiley & Sons, Inc.

Pickles, John (Ed.). 1995. *Ground Truth: The Social Implications of Geographic Information Systems*. New York, New York: The Guilford Press.

Purba, Sanjiv. 2000. *Data Management Handbook*. Boca Raton, Florida: CRC Press LLC.

Randolph, John. 2004. *Environmental Land Use Planning and Management*. Washington, D.C.: Island Press.

Ritter, Niles, and Mike Ruth. 2000. *GeoTIFF Format Specification*. Retrieved November 2, 2005, from the GeoTIFF Format Specification website, *http://remotesensing.org/geotiff/spec/geotiffhome.html.*

Ryden, David K. (Ed.). 2002. *The U.S. Supreme Court and the Electoral Process.* Washington, D.C.: Georgetown University Press.

Sawyer, Peter (Ed.). 1985. *Domesday Book: A Reassessment*. London: Edward Arnold Ltd.

Sayre, Roger, Ellen Roca, Bruce Young, and Gina Sedaghatkish. 2000. *Nature in Focus: Rapid Ecological Assessment*. Washington, D.C.: Island Press.

Shamsi, Uzair M. *GIS Tools for Water, Wastewater, and Stormwater Systems*. Danvars, Massachusetts: American Society of Civil Engineers.

Sivanandam, Chitra. *The Lunar Surface: Visualizing Changes. A comparison of images from the Clementine Mission to images from the Lunar Orbiter Program.* Retrieved November 8, 2005, from http://www.cis.rit.edu/research/thesis/bs/1998/sivanandam/thesis.html.

South Florida Water Management District. 1999. *Wetlands Analysis Map, Osceola County, Florida*. Retrieved January 24, 2006, from the South Florida Water Management District website, http://www.sfwmd.gov/org/pld/proj/wetcons/devpress/os-wdpl.jpg.

Southport Cottage Point (n. d.). http://www.southportcottagepoint.com/homesites.html. Downloaded September 6, 2005.

Space Imaging Corporation. *World Trade Center Aftermath Image.* Retrieved January 24, 2006, from the Space Imaging Corporation website, http://www.spaceimaging.com/gallery/top1001/wtc.htm.

Stacy, Robert. *Salt Lake City*. Retrieved November 2, 2005, from the 3DNature web site, http://3dnworld.com/users/56/images/Saltlake.jpg

Star, Jeffrey, and John Estes. 1990. *Geographic Information Systems*. New Jersey: Prentice Hall.

Stephenson, Neal. 1999. *In the Beginning…was the Command Line*. New York: HarperCollins Publishers.

Steinitz, Carl, Paul Parker, and Lawrie Jordan. 1976. “Hand-Drawn Overlays: Their History and Prospective Uses.” *Landscape Architecture*, 66 (5): 444-455.

Steede-Terry, Karen. 2000. *Integrating GIS and the Global Positioning System*. Redlands, California: ESRI Press.

Stokes, Samuel N. 1997. *Saving America's Countryside: A Guide to Rural Conservation*. Baltimore: The Johns Hopkins University Press.

Suwanee, City of. *Groundwater Recharge Area Protection Ordinance of Suwanee, Georgia*. Retrieved November 2, 2005, from the City of Suwanee website, *http://www.suwanee.com/pdfs/groundwaterrechargeord.pdf#search='groundwater%20recharge%20area'*

Tomlinson, Roger. 1998. "The Canada Geographic Information System." In Foresman, Timothy W. (Ed.). 1998. *The History of Geographic Information Systems: Perspectives from the Pioneers.* Upper Saddle River: Prentice Hall PTR.

Tomlinson, Roger. 2003. *Thinking About GIS: Geographic Information System Planning for Managers*. Redlands, California: ESRI Press.

UNESCO. 1999. *Topology and Spatial Relationships*. Retrieved November 21, 2005, from the UNESCO Web site, *http://ioc.unesco.org/oceanteacher/resourcekit/Module2/GIS/Module/Module_g/module_g1.html*

USGS. 2005. *Aerial Photographs and Satellite Images.* Retrieved November 2, 2005, from the United States Geological Survey Web site, http://erg.usgs.gov/isb/pubs/booklets/aerial/aerial.html.

USGS. 2006. *Digital Topographic Map*. Retrieved January 23, 2006, from the Carolina Map Distributors website, http://www.carolinamapdistributors.com/images/digital/drg/drghillside.jpg

USGS. 2004. *Organizing USGS Information with Consistent Vocabulary*. Retrieved August 26, 2005, from the United States Geological Survey Web site, http://geo-nsdi.er.usgs.gov/talk/thesaurus/definition.html.

U.S. Bureau of the Census. 2000. *Demographic Data.* Retrieved January 24, 2006, from the Decision Support Services website, http://www.dsslink.com/images/coopdemo.jpg l.

Wagner, Roger C. 2000. *Boolean Logic.* Retrieved January 24, 2006, from the University of Delaware website, http://www.udel.edu/Biology/Wags/b667/lect4/lect4_4.gif.

Warren County Environmental Commission. 1999. *Aquifer and Watershed Boundaries.* Retrieved January 16, 2006, from the Warren County Environmental Commission website, http://www.warrennet.org/warrencounty/enviro/maps.html.

Webodia. 2005. *Graphical User Interfaces*. Retrieved November 21, 2005, from the Webopedia Web site, http://www.webopedia.com/TERM/G/Graphical_User_Interface_GUI.html

Worboys, Michael F., and Matt Duckham. 2004. *GIS: A Computing Perspective*. Boca Raton, Florida: CRC Press, LLC.