A viewshed information system for mountain resort areas

by Douglas L Wittren

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Earth Sciences
Montana State University

Abstract:
Scenic landscapes are an essential part of the mountain resort experience, although continued growth and development threaten to irreversibly alter the visual qualities of mountain environments. The advent of workstation-and personal computer-based geographic information systems (GIS) software coupled with the emergence of low cost digital elevation models (DEMs) have encouraged the automation of visibility (viewshed) mapping as an important component of landscape assessment in planning and resource management applications. This research project aimed to develop and test a methodology for determining viewsheds. Criteria considered relevant and necessary to the creation of a methodology include the ability to: select user defined viewpoint locations and directions of view, evaluate each visible parcel of terrain based on its distance and aspect from the viewer, and count and record the number of times a parcel is seen from each viewpoint. The ARC/INFO GIS software, a grid-based DEM and several other sources of spatial information converted to digital format were used. The interpretive Arc Macro Language (AML) programming capability of ARC/INFO was used to automate the viewshed determination and display process and provide a simpler user interface. Results include a series of digital thematic data layers portraying terrain, land cover and land use for the Meadow Village area at Big Sky of Montana resort in Southwest Montana. The AML program not only automates the process for repeated analyses, but also provides less experienced users the opportunity to evaluate impacts of various development proposals to the scenic resource. The final viewsheds illustrate how terrain analysis applications using GIS offer scientists, land managers and planners a powerful, pro-active means of evaluating land use alternatives.

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

Scenic landscapes are an essential part of the mountain resort experience, although continued growth and development threaten to irreversibly alter the visual qualities of mountain environments. The advent of workstation-and personal computer-based geographic information systems (GIS) software coupled with the emergence of low cost digital elevation models (DEMs) have encouraged the automation of visibility (viewshed) mapping as an important component of landscape assessment in planning and resource management applications. This research project aimed to develop and test a methodology for determining viewsheds. Criteria considered relevant and necessary to the creation of a methodology include the ability to: select user defined viewpoint locations and directions of view, evaluate each visible parcel of terrain based on its distance and aspect from the viewer, and count and record the number of times a parcel is seen from each viewpoint. The ARC/INFO GIS software, a grid-based DEM and several other sources of spatial information converted to digital format were used. The interpretive Arc Macro Language (AML) programming capability of ARC/INFO was used to automate the viewshed determination and display process and provide a simpler user interface. Results include a series of digital thematic data layers portraying terrain, land cover and land use for the Meadow Village area at Big Sky of Montana resort in Southwest Montana. The AML program not only automates the process for repeated analyses, but also provides less experienced users the opportunity to evaluate impacts of various development proposals to the scenic resource. The final viewsheds illustrate how terrain analysis applications using GIS offer scientists, land managers and planners a powerful, pro-active means of evaluating land use alternatives.

CHAPTER 1

INTRODUCTION

Scenic landscapes are an essential part of the experiences of both visitors and residents of mountain recreation and resort areas. Attractive natural surroundings are the primary reason people visit, live, and recreate in mountain resort areas. However, continued growth and development threaten to irreversibly alter the visual qualities of these mountain environments. Visibility mapping has emerged as an important component in scenic landscape assessments, contributing to the delineation of management zones, quantification of impacted viewer publics, and selection of visual control or simulation positions. Traditional methods involving field observation, map interpretation and scale models are inflexible, resource intensive and suffer from accuracy limitations. The advent of workstation- and personal computer (PC)-based geographic information systems (GIS) software coupled with the emergence of low cost digital elevation models (DEMs) has encouraged the automation of this critical activity during the past decade (Felleman and Griffin, 1990).

A viewshed is defined as: 1) the surface areas visible from an observer's viewpoint, and conversely, 2) surface areas from which a critical object or viewpoint is seen (Smardon et al., 1986). Viewshed preservation and management are important to resort owners and planners interested in sustainable development since this concept implies continued growth and development without the degradation of scenic resources in mountain environments.

Visitors come to ski resorts with a certain set of expectations about the character of these places. These expectations are most often bound up with the images of the natural landscapes, the forests and water, peaks and views, cool air and quality of life, found in mountain resorts (Doward, 1991). The quantity and quality of the visual landscape thus becomes a primary factor in meeting their expectations.

Virtually all GISs with surface analysis capabilities offer tools for conducting visibility assessments. Some determine the "image space" or what a terrain scene would look like (in 2 1/2-D isometric or 3-D perspective) from a viewer position. Others determine the "object space" or the geographic location of the viewshed (DeFloriani et al., 1986). In both cases, the critical algorithm is a point source radiating a sphere of straight line rays which pass through space until intersecting a facet of the earth's surface or an object (e.g., vegetation, buildings, etc.) attached to it. The locations of the resultant contact points projected on to a planimetric base map constitute a viewshed map.

The methodology used to compute viewsheds in this study will be evaluated based on a set of desirable criteria considered necessary and sufficient to adequately perform visual landscape assessments. The literature on viewshed analysis outlines three criteria that an automated analysis tool should be capable of performing (Huang et al., 1991; Nickerson, VisualQuality promotional literature; Smardon et al., 1986; Travis et al., 1975). First, the technique should allow the user to define a viewpoint location(s) and direction of view. In addition, it should be possible to compute the "reverse viewshed" from an object or landscape feature which represents the area from which a person can see the feature in question. Secondly, the technique should provide a means for selecting and evaluating the visual magnitude, a parameter for measuring the relative apparent size or relative "visibleness" of each parcel of terrain based on its distance and aspect from the viewer. Viewing distance has traditionally been described in terms of "foreground, middleground, and background" zones and is important as land closer to the viewer is more visible than land farther away (USDA Forest Service, 1977). Furthermore, land that is steeply tilted and oriented toward the viewer is more visible than flat land turned obliquely to the line of sight (Nickerson, VisualQuality). The third requirement is that the technique should be capable of counting and recording the number of times a parcel is seen from each viewpoint. The user could then select a weighting factor to be used in determining view duration and the view expectations that result from the amount of time a parcel is seen (Huang et al., 1991).

There is at least two other criteria that are not covered in the literature. The first of these additional criteria has to do with the accuracy of the computed viewsheds. It is important to recognize that the development of a technique which meets the first three criteria discussed above will count for nought unless it also accurately (correctly) identifies the viewshed. The technique may fail because the technique itself is faulty or because the data are inappropriate. The most commonly available digital elevation models (DEMs) are produced by the United States Geological Survey (USGS) and consist of regularly spaced grids of sample elevations. These data sets have been criticized for their inability to adequately represent spatial variability in certain types of landscapes (Lee, 1991b) and as a result, they may not be suitable for delineating viewsheds. Their impact on computed viewsheds needs to be evaluated further. The final criterion reflects the recent growth and development of GIS software and digital databases, because modern GIS tools should make it possible to quantify not only the extent, but also the character of the viewshed. Digital land cover maps of land ownership, roads, streams, structures, and vegetation can be created in many GISs and draped over the terrain model in order to classify the character of the viewshed in terms of natural as opposed to human-altered landscapes. These last two requirements were added to the three criteria noted in the previous paragraph and used to guide the development and testing of a viewshed determination methodology in this study.

The methodology used the ARC/INFO GIS software running on Digital workstations in the Geographic Information and Analysis Center (GIAC) at Montana State University. Three tasks were completed: 1) a series of digital databases depicting terrain and land cover were prepared for the Big Sky Resort Area; 2) these data were used to develop a GIS-based viewshed determination technique that quantified the extent and character of the viewshed as it relates to natural verses human-altered landscapes; and 3) a combination of photography and fieldwork were used to evaluate the accuracy of the final computer-generated viewsheds prepared for the Big Sky Resort Area. The overall goal was to determine whether or not the ARC/INFO viewshed determination tools and 1:24,000 scale USGS 30m DEMs could be combined and used to adequately delineate viewsheds in mountainous environments.

Development and Testing of Viewshed Analysis Techniques

There are three principal ways of representing land surfaces as digital elevation models (DEMs): a regular square grid, contours, and triangulated irregular networks (TINs) (Moore et al., 1991). Regardless of the approach used to model topography, DEMs are a part of a system that uses numeric data to represent the elevation of the ground surface. The concept of a DEM may be more readily visualized as a model that is equivalent to a topographic map; both the DEM and the topographic map are models that represent the surface elevation of the earth. A topographic map translates the surface to a form that is readily understood and visualized by people, and a DEM translates the surface into numeric data readily processed by a computer (Twito et al., 1987).

The merits of the three conventional ways of representing terrain have been reviewed with several different applications in mind (e.g., Goodchild and Lee, 1989; Theobald and Goodchild, 1990; Lee, 1991a; Moore et al., 1991). Favorable reviews of raster-based terrain models for visibility and other kinds of analyses are based primarily on the relative abundance of data sources and the large number of previously tested terrain simulation models that use this data structure. Raster-based DEMs consist of a regularly spaced grid of sample elevations and as noted earlier, they have been criticized for their inability to adequately represent spatial variability in certain types of landscapes (Lee, 1991b). Because digitized contours are often converted to a gridded elevation matrix, the contour approach to terrain modeling is similar to the raster for most applications (Twito et al., 1987).

TIN-based models are favored in areas with highly variable terrain, and are becoming increasingly popular because of their efficiency in storing data and the ease in which this simple data structure accommodates irregularly spaced elevation data (DeFloriani et al., 1986; Goodchild and Lee, 1989; Lee, 1991b). A TIN approximates a terrain surface by a set of triangular facets. Each triangle is defined by three edges and each edge is bounded by two vertices. Vertices in TINs describe nodal terrain features such as peaks, pits or passes, while edges depict linear terrain features such as break, ridge and channel lines. Most TIN-building methods are essentially a series of procedures for selecting a set of points from a grid DEM to best approximate the terrain surface (Lee, 1991a). The strengths and weaknesses of these methods relative to specific applications are of particular concern to users. Lee (1991b), for example, has argued that the four vertices in each grid cell do not necessarily define a plane thereby subjecting the analysis to oversimplification, and advocated using TINs as the preferred model for surface representation in visibility analyses. Lee (1991a) reviewed four methods for extracting TINs from USGS DEMs and found the drop heuristic method performed better than the skeleton, filter, and hierarchy methods.

Most viewshed maps, from turn of the century military versions to contemporary examples, are binary chloropleths of visible and invisible zones (Felleman and Griffin, 1990). Several software programs were developed that produced three-dimensional views of terrain for forestry applications on large mainframe computers during the early 1970s. These programs were designed to meet the needs of visual management specialists responsible for designing the size and shape of harvest units and scheduled harvest activities in order to minimize the overall visual impact on forested landscapes. VIEWIT (Travis et al., 1975) computes ground slope and aspect information from a DEM and determines the area that can be seen from specific viewing corridors. PREVIEW (Myklestad and Wagar, 1976) converts mapped harvest proposals into perspective drawings depicting proposed landscape changes. However, these early programs were not readily available to timber-harvest planners because of the need for a mainframe computer and the expertise required to operate the programs (McGaughey and Twito, 1988).

Literature pertaining to viewshed determination and mapping prior to the development of computerized methods was essentially non-existent, leading to the conclusion that it was a procedure that was done infrequently and without standardization and/or documentation. In fact, the brevity of the list of references accompanying this document suggests that while, in theory, viewshed mapping was possible without the assistance of computers, it was rarely practiced. The light list of references also suggests that this type of study is one of only a few to apply GIS viewshed determination and mapping techniques for use as a resource planning and management tool other than within the U.S.D.A. Forest Service.

Efforts to develop comprehensive topographic analysis packages using DEMs on interactive desktop computer systems began with the Digital Terrain Simulator (Lemkow, 1977; Young and Lemkow, 1976) developed at the University of British Columbia. Subsequent efforts include Twito's (1978) software dealing with perspectives of proposed clearcut units, and Nickerson's (1980) PERSPECTIVE PLOT package which provides a full range of viewing options to help visual management specialists analyze proposed landscape changes. Nickerson has since formed his own company, Visual Simulations Inc., and developed two software packages designed to operate on personal computer systems, NEWPERSPECTIVES and VISUALQUALITY, the former used mainly in forestry and the latter tailored toward the field of land use planning (Nickerson, personal communication and promotional brochure, 1991). Another recent forestry package (VISUAL; McGaughey and Twito, 1988) produces three-dimensional perspectives from a DEM and is designed to help planners acquire a "feeling" for the landscape. The three-dimensional perspective option within VISUAL also provides a convenient and useful way to check the appearance of cutting areas in locations where scenic resources are important (McGaughey and Twito, 1988).

The viewshed systems described thus far are notable in that they all represent stand-alone, single-purpose software products. Their continued development and refinement is due, at least in part, to improvements in computer hardware (high performance workstations, PCs, peripherals, etc.) and operating systems (networking, user interfaces, etc.). The improvements to viewshed systems have occurred more or less separately from the tremendous growth in geographic information systems (GIS) technology that has occurred during the past decade. These GIS systems have benefitted from the same computer hardware advances and the best GIS software offer a "toolbox" approach to automated geoprocessing (e.g., ARC/INFO, Intergraph MGE). These systems provide generic tools for spatial analysis and display that the user adapts to their own needs. Private and public sector organizations can use these systems to perform a large number and variety of geoprocessing tasks, including viewshed determination. These systems also offer increased flexibility in terms of data sources and data formats, thereby reducing the cost of data input and transfer.

The advent of the personal computer, distributed computing, and high performance workstations have prompted renewed interest in error propagation and analysis as well (e.g., Goodchild and Gopal, 1989; Felleman and Griffin, 1990; Lee et al., 1992). Much of this work to date has taken the form of sensitivity analyses to explore the effects of data structure (grid, contour, and TIN-based DEMs) and scale on computed terrain attributes (e.g., Lee, 1991a). This work has important implications for viewshed analysis because small errors in the elevations recorded for specific points in the landscape can produce large errors in visibility (Goodchild and Lee, 1989).

Description of Big Sky Resort Area

The viewshed determination techniques were developed and tested within the Big Sky Resort Area. Big Sky is located in southwestern Montana approximately 80.5 km (50 mi.) southwest of Bozeman via U.S. Highway 191 which passes through the Gallatin River Canyon (Figure 1) and is the only year-round road access at this time. The resort and recreational development complex is located in the West Fork drainage, a broad Gallatin River tributary basin rising from an elevation of 1826 m (5992 ft) to 3403 m (11,166 ft) at the summit of Lone Mountain. The basin occupies about 160 km^2 (100 mi^2) and is bordered on the north by the Lee Metcalf Wilderness (formerly the Spanish Peaks Primitive Area), on the east by the Gallatin Mountain Range, and on the west and south by the Madison Mountain Range.

Big Sky comprises two distinct but interdependent development clusters: Meadow Village (the focus of this study), located in the lower part of the West Fork Basin, contains most of the residential development and is the site of much of the summer recreational activity; and Mountain Village, located 14.5 km off U.S. Highway 191 at the base of Lone Mountain, where much of the winter recreation (alpine skiing) takes place. Meadow Village contains the majority of the single family homes and permanent residents, whereas Mountain Village is comprised primarily of condominiums and overnight lodging facilities which play host to the transient tourist population. The division of the 1990 Big Sky population between Meadow Village (534 Gallatin County residents) and Mountain Village (285 Madison County residents) reflects this pattern of development. As the resort expanded both in physical size and popularity during the 1980s, so too did the population. Meadow Village, for example, has experienced an 87 percent increase (285 to 534) during the past decade.

The residents and visitors are attracted by the spectacular scenery and recreational facilities. Glaciation in past times has given the terrain its strongly alpine scenic character. The construction of modern recreational facilities commenced in the summer of 1971. The West Fork Basin itself was sparsely populated prior to this time and commercial opportunities were limited to livestock, dude ranching and timber harvesting. Some recreational land use occurred with fishing, hunting, hiking, horseback riding and camping as the main activities.

The construction and operation of modern cross-country and alpine skiing facilities since 1971 has forever changed the character of this once remote and isolated area. The pristine character has given way to the more "urban" atmosphere of a large resort complex with numerous facilities and roads in varying stages of development. Access has continued to improve both by air and land as new roads have been constructed or existing ones have been improved. The net result of the development activity is a dramatic change in the character and uses of the recreation resources of the West Fork region.

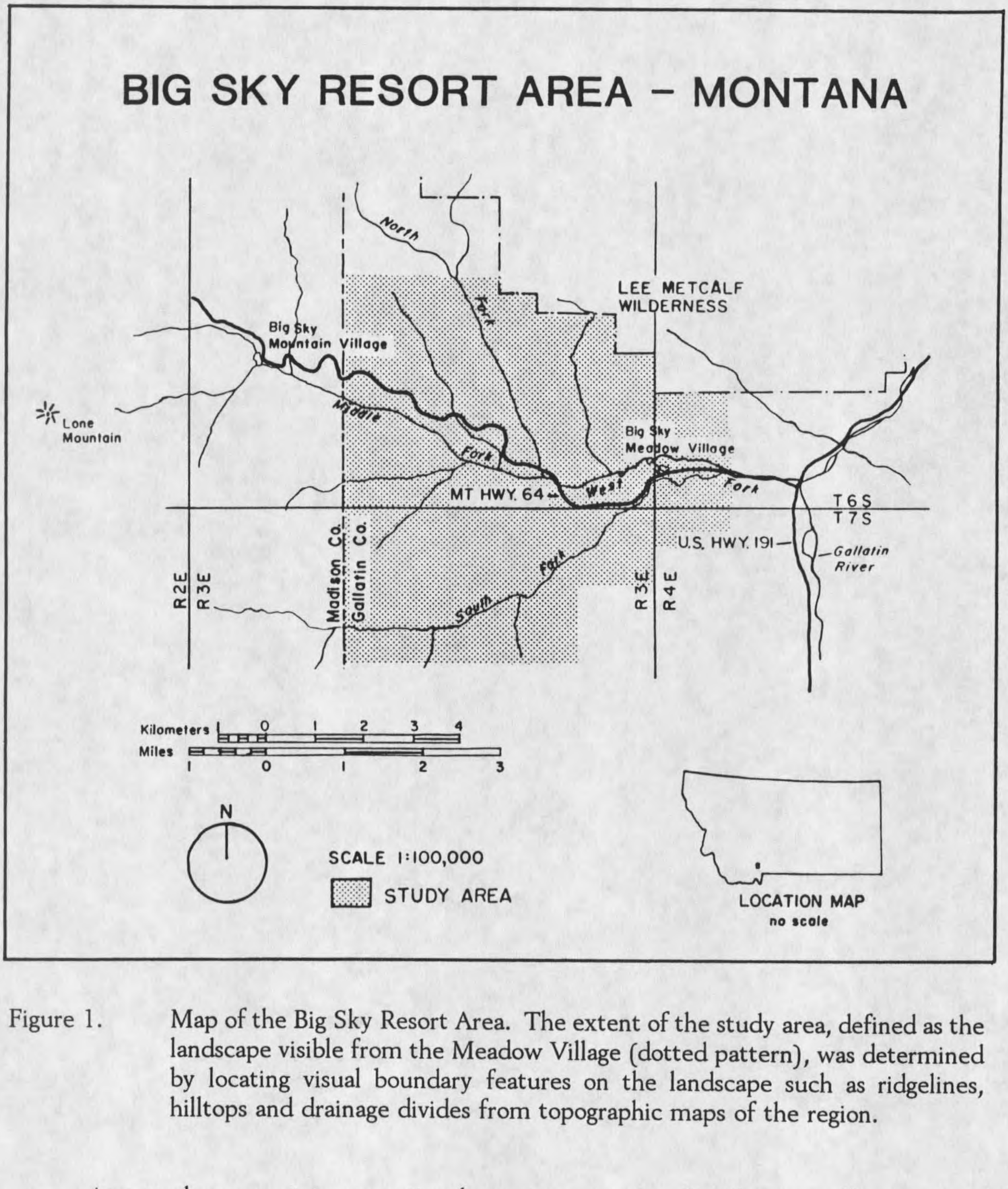

Figure 1. Map of the Big Sky Resort Area. The extent of the study area, defined as the landscape visible from the Meadow Village (dotted pattern), was determined by locating visual boundary features on the landscape such as ridgelines, hilltops and drainage divides from topographic maps of the region.

As a modern mountain recreational resort community, Big Sky now offers a variety of year-round recreation opportunities. The primary vehicles of change in terms of landscape alterations and recreational activities are the alpine skiing facilities on the mountain and a golf course and residences located in the Meadow Village. Alpine skiing facilities, and most of the commercial activity associated with them, take place in the Mountain Village area which has seen rapid expansion and development in recent years. The Lone Mountain Ranch serves the area as the nordic skiing center and is located just west of the Meadow Village on the way to the Mountain Village (Figure 1).

Summer activities are numerous with something to satisfy most outdoor recreationalists. The centerpiece of Meadow Village is an 18-hole, Arnold Palmer designed public golf course. Other activities include tennis, hiking, rock climbing, horseback riding, and mountain biking. The area is also adjacent to the Gallatin River, one of Montana's "blue ribbon" trout streams, and an excellent whitewater river for rafters and kayakers. Opportunities for viewing and photographing the area's wildlife are excellent, as are hunting for big game and upland game birds in the Gallatin Canyon area.

While growth and development are an inevitable component of Big Sky's future, concerns over the management and wise use of resources become an important factor in determining the human impact, and ultimately the success of such development. As a means of providing growth management and development guidelines, the Gallatin Canyon/Big Sky Planning and Zoning District was formed to generate a land use plan and zoning document. A draft of the land use plan released in Spring 1992 by the Planning and Zoning Committee has identified the beauty of the natural environment, significant views, and open space as highly valued resources worthy of protection under the Zoning Ordinance (Gallatin County Planning Department, 1992). Concern regarding the preservation of attractive natural scenery meant that Big Sky provided an ideal site for the development and testing of a methodology to determine not only the areal extent, but also the character of viewsheds.

CHAPTER 2

METHODS AND DATA SOURCES

The ARC/INFO GIS Software

ARC/INFO is produced by Environmental Systems Research Institute, Inc. (ESRI, Inc.) in Redlands, CA, and is one of many commercial GIS software packages on the market today. It is essentially comprised of two interrelated software programs linking spatial data with information about a particular feature on a map. In ARC/INFO, ARC handles where the features are, while the INFO component handles the feature descriptions (i.e., attributes) and how each feature is related to others (ESRI, Inc., 1992). The structure and organization of the software is analogous to a toolkit full of a very large number of application specific tools designed to solve and present the results of complex spatial analyses and modeling techniques. ARC/INFO runs on a network of Digital Equipment Corporation (DEC) Unix (Ultrix) workstations in the GIAC at Montana State University.

As with most software packages, ARC/INFO continues to evolve as users demand greater functionality and computers become faster and more efficient at processing data. It is important to note that the majority of the data collection, processing and analysis for this study was completed when the GIAC supported ARC/INFO Version 5.0. Toward the latter stages of the study, and through its completion, ARC/INFO Version 6.1 was used to perform analysis and produce output. The upgrade to Version 6.1 was significant in that the added functionality offered by a suite of new commands was combined with a reorganization of the surface modeling and display capabilities and their inclusion in the ARC and ARCPLOT modules (Table 1). The descriptions of the analysis and display techniques which follow apply to the most recent release of the software (i.e., Version 6.1).

Table 1. ARC/INFO Version 6.1 Module Descriptions

Module Name	Description
ARC	Main level commands, coverage management, broad-based applications, data conversion, topology generation, surface analysis and modeling
ARCEDIT	Building and editing coverages and tables
ARCPLOT	Map display and query, surface analysis, modeling and display, image integration
AML	Interpreted programming language, applications development, user interface
GRID	Cell based modeling and analysis functions
INFO	Relational database manager, linked to spatial features

Types and Sources of Data

Computerized terrain analysis applications including the determination of visible terrain rely at the most basic level on the digital representation of the surface from which computations are made. As explained earlier, the digital elevation model (DEM) translates the surface into numeric data readily processed by the computer. At present, the United States Geological Survey (USGS) is working on the production of 7.5 minute (30 meter) grid DEMs for the entire United States, at a cost, if available, of roughly $40 each. Unfortunately these products were not available for the area involved in this study and other alternatives were explored. An agreement was struck with the USDA-Soil Conservation

Service (SCS) to provide the DEMs in a timely and cost effective manner. Basically, mylar contour separates acquired from the USGS were scanned with a digital raster scanning device and converted to a USGS formatted grid DEM which could then be accepted by ARC/INFO. Concerns over the compatibility of the data from the SCS were addressed early on through the testing of a sample data set. The testing of the DEMs followed the steps necessary to convert a USGS DEM to an ARC/INFO lattice file and the successful completion of this process verified that the data were compatible.

In addition to the DEMs, the capture of other land use and land cover features was required to adequately perform the visibility analysis and cartographic display. The remainder of the data acquired for this study were obtained from USGS 7.5 minute topographic maps and orthophotographs. Thematic data layers showing the locations of streams, roads, structures, property boundaries and vegetation patterns were extracted from these sources to create individual ARC/INFO coverages.

Data Input and Preprocessing

The SCS delivered two partial DEMs in the 7.5 minute USGS digital format corresponding to the study area which spanned the Gallatin Peak and Ousel Falls quadrangles in Southwest Montana. The DEMs were copied to the GIAC workstation computers and converted to an ARC/INFO lattice surface data structure. A lattice is the surface interpretation of a grid, represented by equally spaced sample points referenced to a common origin and a constant sampling distance in the x and y directions. Each mesh point contains the z value of that location representing a value on the surface only at the center of the grid cell; it does not imply an area of constant value (ESRI, Inc. 1991). Since the study area spanned two adjacent quadrangles in the north-south direction, it was necessary to physically join the two together to form one continuous lattice. This step was accomplished using the ARC/INFO LATTICEMERGE command. The new lattice was then clipped to the bounding rectangle enclosing the study area (roughly one quadrangle in size) using the ARC/INFO LATTICECLIP command. At this point the lattice was ready for surface analysis.

The additional data layers appearing on the paper maps were digitized into the GIS and organized by theme (i.e., streams, roads, ownership). Almost without exception, digitized coverages require some manual editing to correct lines that either do not connect (undershoots) or lines that extend beyond a desired intersection (overshoots). ARC/INFO is capable of correcting some digitizing errors automatically and, when necessary, offers many tools within the ARCEDIT module to accomplish this task manually. In ARC/INFO, the automated means of error correction (CLEAN) also establishes the topological relationships between features. Topology is the way in which geographical elements are linked together to explicitly define relationships between spatial data. These relationships are saved as lists, so that a line is defined by its endpoints or a polygon is defined by lines comprising its border. The existence of a topologically sound spatial database is essential in performing nearly all types of GIS analyses from spatial adjacency functions to network analysis. In every instance it is critical to know the spatial arrangement of the geographic features and how their positions relate to one another.

A data layer representing land cover was captured from two 7.5 minute orthophotographs using a digital scanning device which extracts the data as a binary raster image. The raster image was imported into ARC/INFO and converted to a vector coverage of polygons that were classified in one of two ways depending on whether the cover was primarily vegetation (trees or open grassland) or bare rock and/or otherwise devoid of vegetation.

Development of Viewshed Analysis Techniques

Following the entry and processing of the data, the actual task of viewshed analysis and the formulation of a methodology to determine viewsheds using ARC/INFO began. Visibility analysis is one of the more powerful surface analysis capabilities available with ARC/INFO. The VISIBILITY command identifies visual exposure and performs viewshed analysis on a lattice surface. Observation points are defined by point or line features from a line coverage and may represent the location of observation towers, vantage points, or points along a road or power line (ESRI, Inc., 1991). With VISIBILITY it is possible to determine how many times each region of the lattice can be seen by the observation points (FREQUENCY), or the reverse, which regions of the lattice can be seen by each individual observation point (OBSERVERS). The results from both tasks are stored in the output coverage's feature attribute table and they may be accessed with ARC/INFO's selection logic to perform visual quality analyses.

It is possible to limit the region of the lattice inspected by specifying any of the optional feature attribute items listed in Table 2. With the ability to specify optional viewing parameters, VISIBILITY offers the user significant flexibility to enhance the viewshed determination process. The options available with VISIBILITY include items to specify a vertical offset from the surface elevation for both the observation point as well as the target point on the lattice; the latter being used to simulate the screening effects of vegetation and other intervening obstacles occurring on the landscape. It is also possible to specify values which define the field of view in both a horizontal and vertical direction, and furthermore, limit the near and far search distances (Table 2).

Table 2. Optional feature attributes for VISIBILITY command.

Option	Function
SPOT	Specifies surface elevations for observation points or vertices
OFFSETA	Vertical distance to be added to the z-value of observation point
OFFSETB	Vertical distance to be added to z-value of each lattice mesh point
AZIMUTH1	Horizontal scan angle limit 1; sweep proceeds clockwise to angle limit defined by AZIMUTH2
AZIMUTH2	Horizontal scan angle limit 2
VERT1	Upper limit of vertical scan, essentially the angle overhead
VERT2	Lower limit of vertical scan, essentially the angle underfoot
RADIUS1	Limit to near search distance, used to define a scan area from a specified ground distance away from viewpoint location
RADIUS2	Outer limit to the search distance from the viewpoint

ARC/INFO is a command driven software package with a steep learning curve. Considerable experience is required for a user to become a proficient ARC/INFO operator. The computation of viewsheds, as well as any subsequent analysis regarding the characteristics of the viewshed or the production of map products would be very difficult for novice ARC/INFO users. Bearing this in mind, the study also focused on the generation of a "user friendly" interface for those less experienced with ARC/INFO with an interest in utilizing the powerful terrain analysis tools, such as the determination of visible terrain.

ARC/INFO also provides interpreted programming capabilities with the Arc Macro Language (AML). AMLs enable the automation of frequently performed actions, provision of start-up utilities for new users or operations that require specific command settings, and the development of menu-driven user interfaces designed to meet the needs of end users. An AML consists of a structured series of ARC/INFO commands, special directives and functions written in ASCII format using any standard text editor.

A large AML was prepared to implement the viewshed determination techniques that were developed and tested in this study. The methodology (described in Chapter 3) was designed to utilize the optional enhancements of the VISIBILITY command which are considered necessary and sufficient to adequately perform viewshed analyses (i.e., user defined viewpoint location and direction of view, distance weighting, etc.). The creation of the AML was intended to assist in the process of viewshed determination by bringing together this technology and prospective users interested in managing the scenic resource.

Verification of Computer-Generated Viewsheds

The viewshed maps were compared with field observations and photographs to verify that the computer-generated viewsheds were correct. Four observation points for the viewshed analysis were selected from the point coverage created to represent the structures appearing on the 7.5 minute quadrangles. Each of the four observation points represented a significant and identifiable feature on the landscape, such as a water storage tank, radio tower or electrical substation. Success occurred when visible features on the map were also found in the corresponding photographs. The presence or absence of these features was also noted at 1/10 mile increments along State Route 64, Ousel Falls Road, and Chief Joseph Trail (Figure 2) and this information was used along with photographs taken from the four observation points to help corroborate the results of the viewshed analysis. Using the overlay capabilities of the GIS, the viewshed maps were combined with the road coverage containing the roadside vantage points at 1/10 mile intervals to determine which stations were visible from each viewpoint. Success occurred when the vantage point was within the computed viewshed and the viewpoint was visible from the vantage point and vice versa.

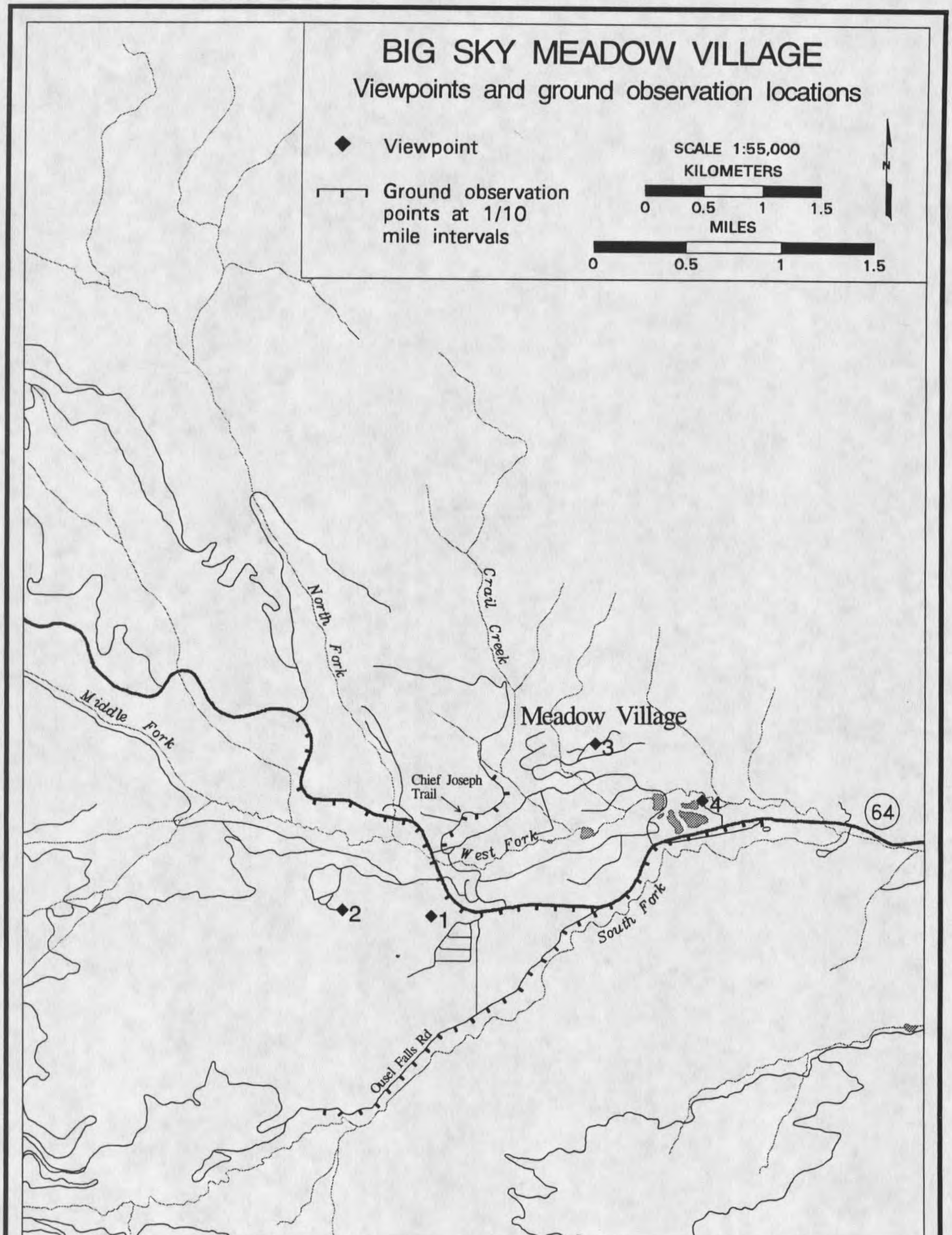

Figure 2. GIS map of four viewpoints and roadside vantage points at 1/10 mile intervals.

CHAPTER 3

RESULTS

GIS Data Layers

Fulfillment of the study's first objective required the creation of a digital database that depicts terrain and land cover in a mountain recreation area. This objective was accomplished with the acquisition of the DEMs of the Big Sky Meadow Village area from the USDA-SCS and their conversion to an ARC/INFO lattice (grid) coverage. This lattice coverage became the primary data layer for the analysis and determination of visible terrain. In addition, a series of thematic digital data layers were compiled from information presented on the 7.5 minute USGS quadrangles of the same region. Figures 3 and 4 show maps of land use/land cover and land ownership produced with ARC/INFO. Figure 3 depicts land cover features, both natural and man-made, such as streams and water bodies, transportation, and buildings and other structures on the land surface, all of which were identified from USGS 7.5 minute quadrangles and were digitized as individual, thematic ARC/INFO coverages. The coverages consist of the spatial features along with a set of feature attributes describing them stored in a related tabular database. Figure 4 shows land ownership in the Meadow Village area. This information was taken from a large scale map prepared for the Big Sky Owners Association in 1991and transferred to a 7.5 minute quadrangle for entry into the GIS. Land ownership in the Meadow Village area is characterized by large parcels held by a relatively small number of owners or corporations. Although not shown on the map at this