



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

© Copyright by Douglas L Wittren (1994)

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.

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
Bozeman, Montana
May, 1994

7378
W787

APPROVAL

of a thesis submitted by

Douglas L. Wittren

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.

4/29/94
Date

John P. Wick
Chairperson, Graduate Committee

Approved for the Major Department

4/29/94
Date

[Signature]
Head, Major Department

Approved for the College of Graduate Studies

5/12/94
Date

[Signature]
Graduate Dean

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library.

If I have indicated my intention to copyright this thesis by including a copywrite notice page, copying is allowable only for scholarly purposes, consistent with "fair use" as prescribed in the U.S. Copyright Law. Requests for permission for extended quotation from or reproduction of this thesis in whole or in parts may be granted only by the copyright holder.

Signature

Douglas L. Witten

Date

5/6/94

ACKNOWLEDGMENTS

The author would like to thank the following people for their support and assistance in fulfillment of this effort. To my major advisor, Dr. John P. Wilson, I wish to express my deepest appreciation for his dedication, support, and constructive assistance throughout the duration of my graduate education at Montana State. I would also like to thank the members of my graduate committee for their assistance: Professor Robert Taylor and Dr. Cliff Montagne. Also, a sincere thank you to Dr. Katherine Hansen and the Yellowstone Center for Mountain Environments for all their support. And finally, I would like to acknowledge the assistance of others directly involved with the completion of this thesis: Christine Ryan and Bob Snyder, MSU - Geographic Information and Analysis Center; Kristin Gerhardt, USDA Soil Conservation Service; Michael Ankeny and Robert Schaap, Lone Mountain Ranch; Bill Murdock, Big Sky Owners Association; and Daphne Minton, Earth Sciences (Geography) undergraduate.

TABLE OF CONTENTS

	Page
1. INTRODUCTION	1
Development and Testing of Viewshed Analysis Techniques	4
Description of Big Sky Resort Area	8
2. METHODS AND DATA SOURCES	12
The ARC/INFO GIS Software	12
Types and Sources of Data	13
Data Input and Preprocessing	14
Development of Viewshed Analysis Techniques	16
Verification of Computer-Generated Viewsheds	18
3. RESULTS	20
GIS Data Layers	20
A GIS Based Viewshed Analysis Technique	23
Evaluation of the Accuracy GIS-based Viewshed Analysis Technique	45
4. DISCUSSION	56
REFERENCES CITED	65

LIST OF TABLES

Table	Page
1. ARC/INFO Version 6.1 Module Descriptions	13
2. Optional feature attributes for VISIBILITY command	17
3. AML Introduction and Initialization	25
4. Portion of AML used to select observation point(s)	26
5. Portion of AML used to add a vertical offset	29
6. Portion of AML used to define scan angle limits	30
7. Portion of AML used to define vertical scan angle limits	31
8. Portion of AML used to define a search radius	32
9. Portion of AML used to compute viewshed	35
10. Portion of AML used to examine viewshed analysis results	36
11. Subroutines used to select display types and drawing parameters	38
12. Subroutine used to draw map elements	38
13. Subroutine used to draw map title	39
14. Subroutine used to draw key legend, north arrow and scale bar	41
15. Visibility from selected roadside vantage points	46
16. Visibility matrices for four viewpoints	48

LIST OF FIGURES

Figure	Page
1. Map of the Big Sky Resort Area	10
2. GIS map of four viewpoints and roadside vantage points at 1/10 mile intervals	19
3. GIS map of land cover in Meadow Village	21
4. GIS map of land ownership in Meadow Village	22
5. Viewshed Determination Components	24
6. Schematic showing effect of viewpoint attributes in defining search area ..	34
7. GIS viewshed map from Viewpoint 2	43
8. 3-D viewshed map from Viewpoint 1	44
9. GIS viewshed map computed with new technique from Viewpoint 1	49
10. GIS viewshed map computed with new technique from Viewpoint 2	50
11. GIS viewshed map computed with new technique from Viewpoint 3	51
12. GIS viewshed map computed with new technique from Viewpoint 4	52
13. Photograph taken in January, 1993 from Viewpoint 3 looking toward the southwest	53
14. Photograph taken in January, 1993 from Viewpoint 4 looking westward ..	53
15. Photograph taken in January, 1993 from Viewpoint 1 looking eastward ..	54
16. GIS viewshed map computed with new technique using the OBSERVERS option	61

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 choropleths 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 km² (100 mi²) 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.

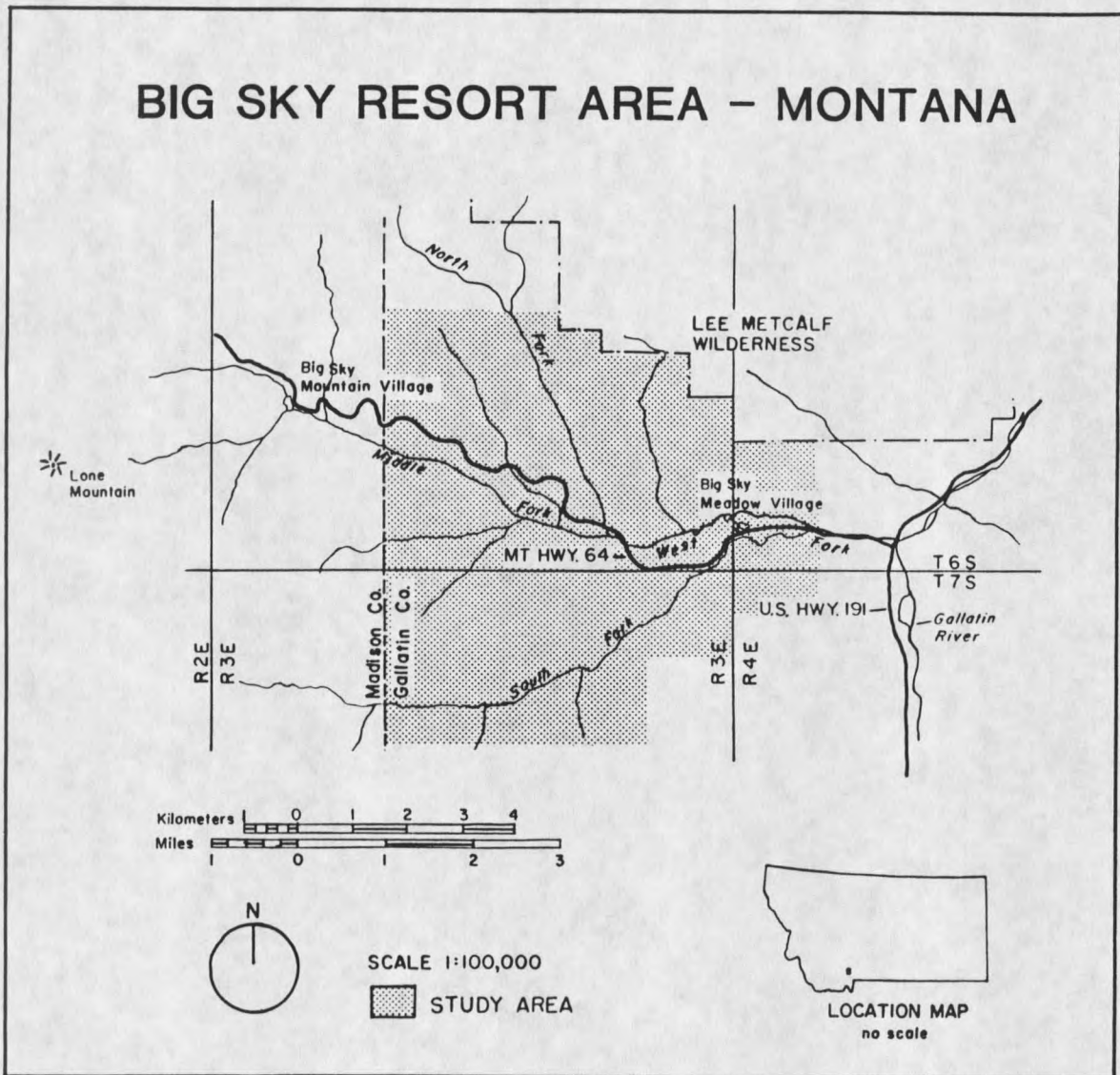


Figure 1. Map of the Big Sky Resort Area. The extent of the study area, defined as the landscape visible from the Meadow Village (dotted pattern), was determined by locating visual boundary features on the landscape such as ridgelines, hilltops and drainage divides from topographic maps of the region.

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

<u>Module Name</u>	<u>Description</u>
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.

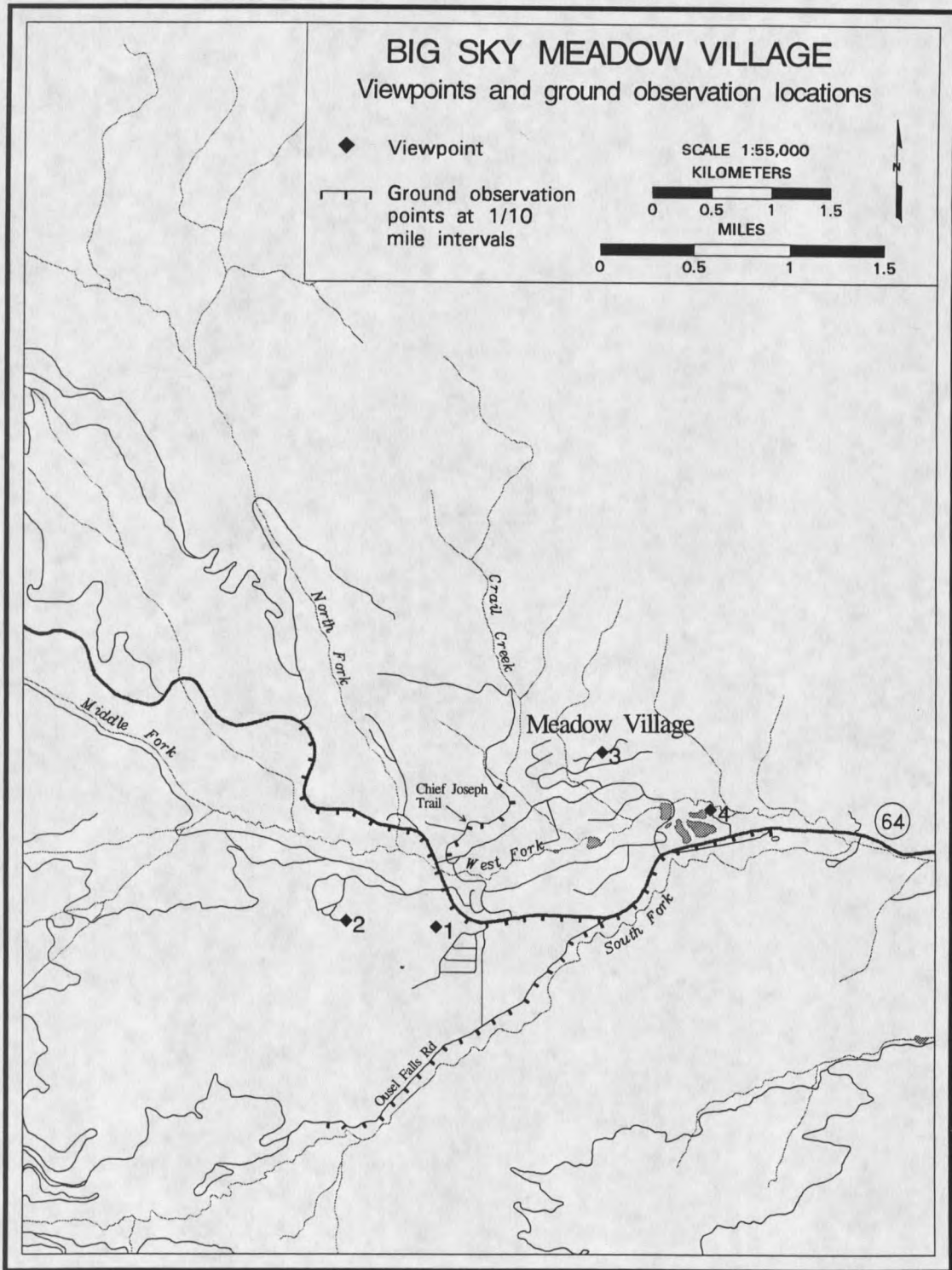


Figure 2. GIS map of four viewpoints and roadside vantage points at 1/10 mile intervals.

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 1991 and 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

scale, much of the property owned by Boyne USA Inc. or Lone Peak Inc. is actually broken into smaller residential lots containing private homes and condominiums.

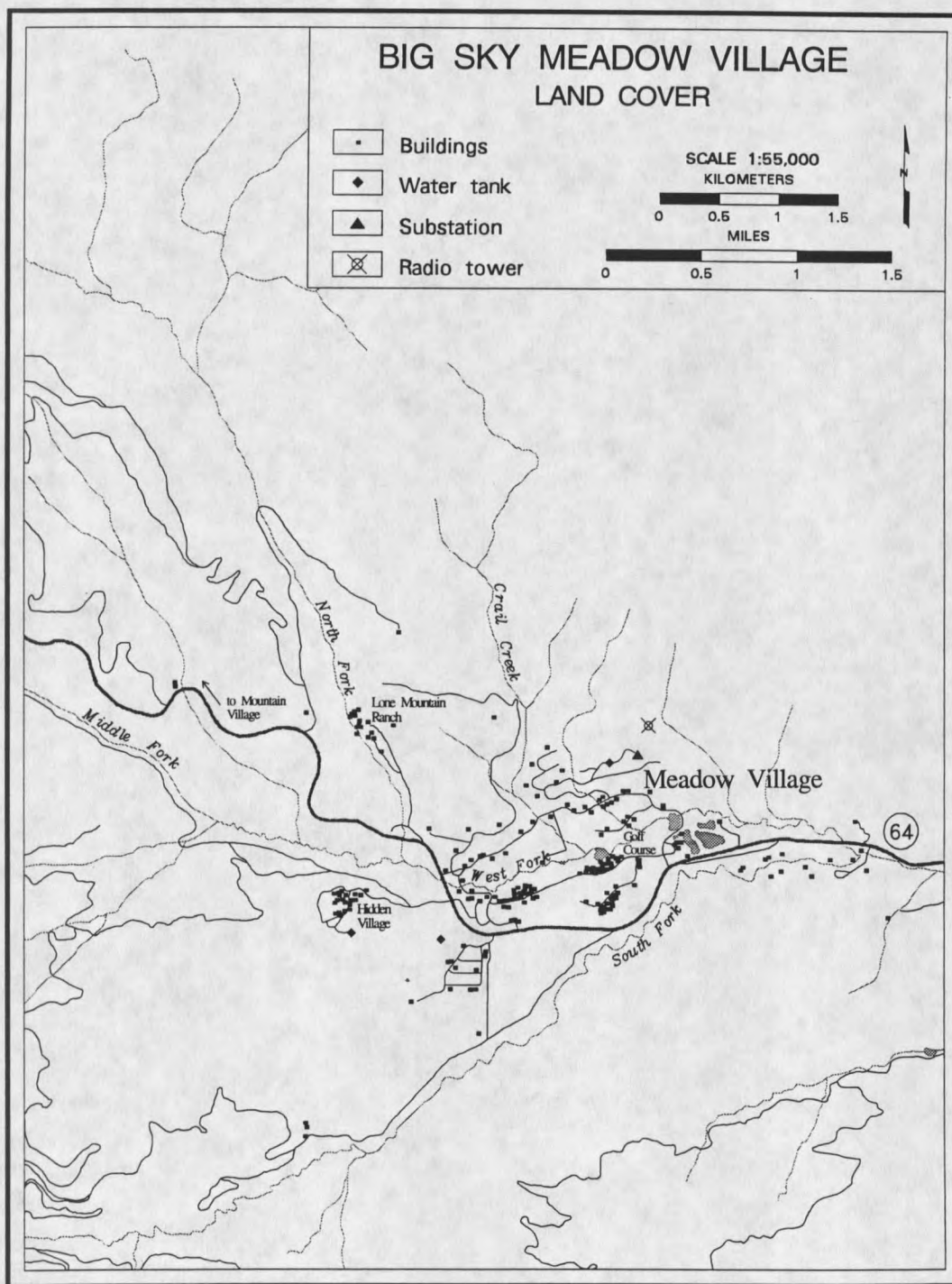


Figure 3. GIS map of land cover in Meadow Village.

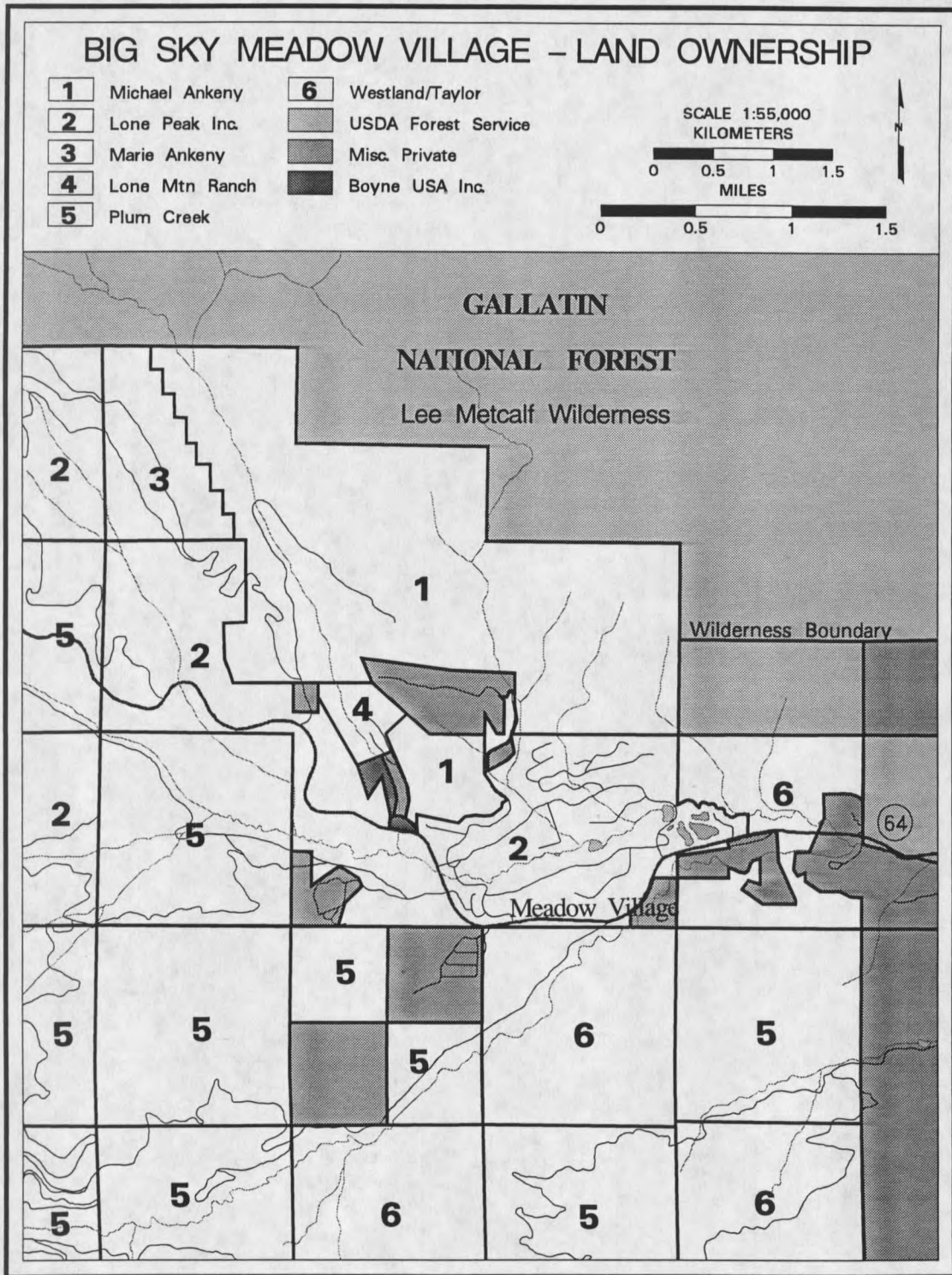


Figure 4. GIS map of land ownership in Meadow Village.

A GIS Based Viewshed Analysis Technique

The second objective involved the development of a GIS-based viewshed analysis technique. In order to accomplish this task and be able to test the method repeatedly, it was necessary to write an AML that would essentially automate the process while enhancing the computer interface. For the purposes of description, the AML can be divided into a series of functional, ordered steps which when executed take the user through the procedure of selecting an observation point, adding optional enhancement parameters to it, computing the viewshed, and finally producing a display of the results either to the screen or on paper, or both (Figure 5).

Several conventions are used to help with the interpretation of the AML code in the tables that follow. Special macro language commands are designated with italics. Commands that begin with the & symbol are AML directives which control the flow of the program, set program variables, and along with the bracketed AML functions determine much of the user interface. Commented text is signified by a line beginning with a /* symbol. Bold and capitalized commands within the body of the AML are ARC/INFO commands which are interpreted by the software without the need for any special characters.

The AML begins with a "header", or introduction, which consists of a description of what the AML does along with any special instructions or data requirements specific to the execution of the program (Table 3). There is also an error handling routine designed to issue a warning, if and when circumstances require this result. Depending on the severity of the error, the routine will either ignore or abort the current process returning the user to the ARC environment.

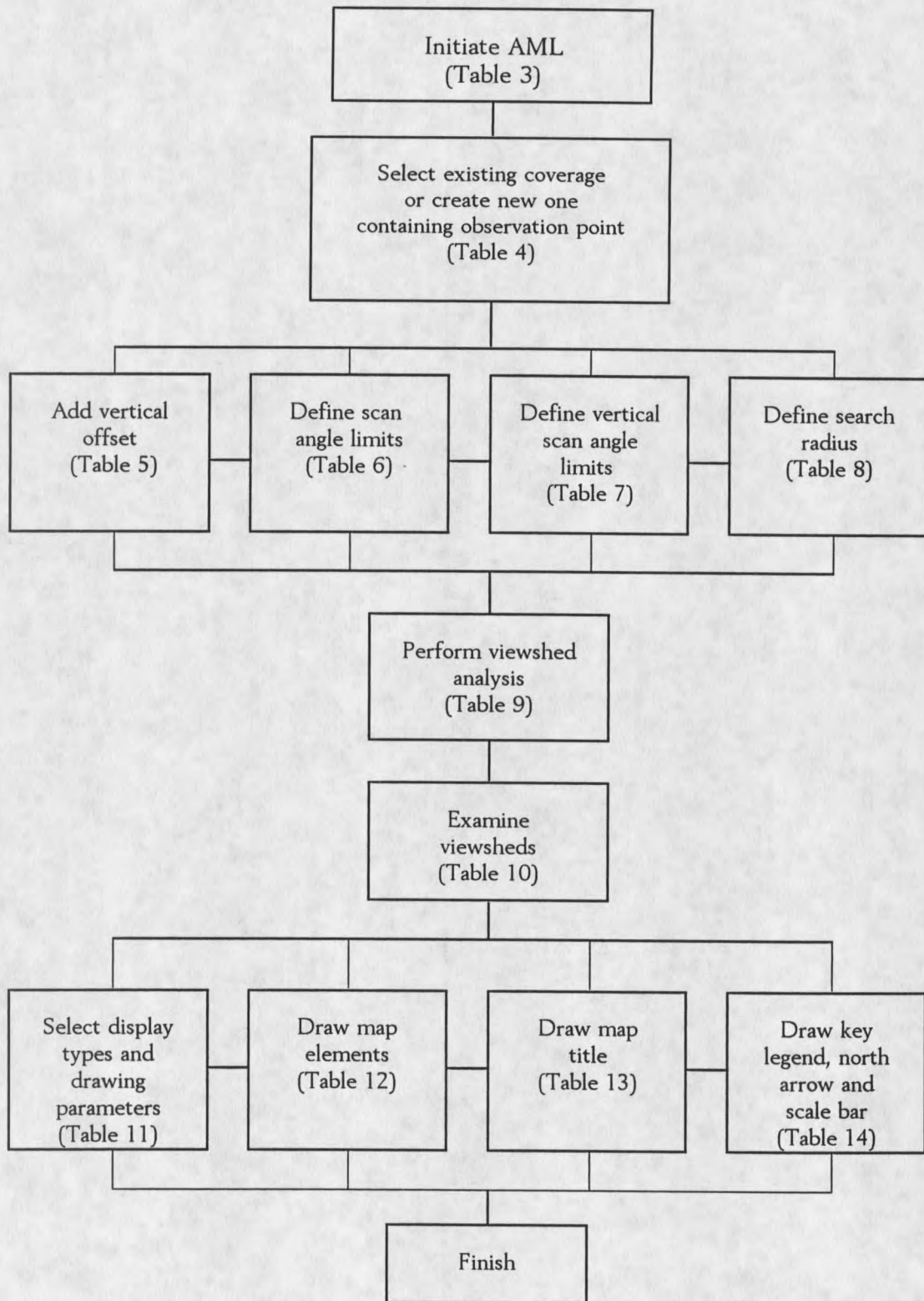


Figure 5. Viewshed Determination Components.

Table 3. AML Introduction and Initialization

```

/*      Program: VIEWSHED.AML - ARC/INFO VERSION 6.1
/*      Purpose: To allow user to perform viewshed analysis and view results.
/*      Author: DOUG WITTREN, 6/93
/*

```

```

/*      Inputs: Digital elevation model (DEM) converted to an ARC/INFO lattice file. Also
/*              any other thematic coverage of interest to be used as backcoverage reference
/*              in the selection of a viewpoint from which to compute the viewshed.
/*

```

```

/*      Comment: This AML will be used to perform interactive viewshed analysis by persons
/*              interested in scenic resource analysis.
/*              The operator will answer a set of queries and prompts pertaining to the
/*              viewshed they wish to determine. When the AML has finished executing
/*              the operator will be able to view the results on the screen and will be
/*              given the choice to have the output plotted as a paper map.
/*

```

```

&severity &error &routine error      /*call routine ERROR in case of an AML execution
/*                                  error
/*
/******
/*                                  ROUTINE ERROR
/* Cleans up an error, returns to the ARC prompt.
&routine error
&severity &error &ignore
&return;&return &error Error in Viewshed.Aml: Aborting..
/******

```

Following the initialization procedure, the main body of the AML begins with the code reproduced in Table 4. This portion of the AML allows the user to select or create a coverage containing the observation point that will be used for the viewshed analysis. The user is presented with a brief message and a series of questions to determine if the user wants to select an existing observation point or choose a new one. The AML will create a new coverage if the user chooses a new observation point, and skip this part of the AML if he/she chooses an existing viewpoint coverage (i.e. observation point). This part of the AML

requires that a lattice coverage be chosen and stored as a variable to be used not only in the actual computation of visibility, but also to calculate the elevation of the newly created observation point. Both the selection of an already existing viewpoint coverage, and the lattice coverage, are made from popup screen menus controlled by the GETCOVER and GETGRID functions found approximately half-way through Table 4.

Next, if the viewpoint coverage is being created for the first time, the operator may want to display one or two background coverages to aid in the selection of the viewpoint. These background coverages, which may portray terrain in the form of contours, or a stream or road network, are selected from a menu and displayed on the graphics window in different colors. The operator is then asked whether or not the exact coordinates of the desired viewpoint are known, in which case they are entered at the keyboard and used by the AML to establish the viewpoint location. In the more likely case where coordinates are not known, the operator will be instructed to select and create the viewpoint location using the mouse with the crosshairs on the graphics window. Having selected the coordinate location of the viewpoint, this portion of the AML ends with a series of ARC/INFO commands that build the topology and interpolate the elevation of the viewpoint from the lattice of elevation points chosen earlier (Table 4).

Table 4. Portion of AML used to select observation point(s).

*/** The following are messages to be displayed on screen for the user's benefit.
&type This routine is designed to determine visibility by calculating the number of times an area is seen from an observation point defined by the user.
&type This first section will allow you to select a viewpoint from a reference coverage such as a contour or road map.
&type To produce accurate results, both map units and surface elevations must be measured in meters.
&type IN ORDER FOR THIS AML TO RUN YOU MUST HAVE A LATTICE FILE AND AT LEAST ONE REFERENCE COVERAGE AVAILABLE TO AID IN THE SELECTION OF A VIEWPOINT.

```

&&s continue = [QUERY 'Do you wish to continue? [Y or N]'] /* sets variable "continue"
&&if %continue% = .false. &&then &&do /* % = symbol to denote a program variable
    &&type Leaving AML...
    &&return

```

```

&&end

```

```

&&s answer = [QUERY 'Do you have a viewpoint coverage in your workspace? [Y or N]']

```

```

&&if %answer% = .true. &&then &&do

```

```

    &&type Select a viewpoint coverage from the popup menu.

```

```

    &&terminal 9999

```

```

    DISPLAY 9999

```

```

    &&s .viewpt = [GETCOVER # -ALL 'Select a viewpoint coverage']

```

```

    &&type The procedure also requires that you select a lattice file for the analysis of
    visibility. Please select one now from the popup menu.

```

```

    &&s latticefile [GETGRID *LAT 'Select a lattice (GRID)']

```

```

&&end

```

```

&&if %answer% = .false. &&then &&do

```

```

    &&s .viewpt [RESPONSE 'Specify a name for your viewpoint coverage']

```

```

    &&type \Starting up ARC PLOT . . . . .

```

```

    ARC PLOT

```

```

    &&terminal 9999

```

```

    DISPLAY 9999

```

```

    /* Setting up graphics environment

```

```

    &&type Select a lattice file from the popup menu.

```

```

    &&s latticefile = [GETGRID *LAT 'Select a lattice (GRID):']

```

```

    &&type Select a coverage from the popup menu to be ~
    used as reference for the location of a viewpoint.

```

```

    &&s backcov = [GETCOVER # -ALL 'Select a coverage:']

```

```

    MAPEXTENT %backcov%

```

```

    LINECOLOR red

```

```

    ARCS %backcov%

```

```

    /* Draws background coverage on screen

```

```

    &&s secondcov = [QUERY 'Do you need to display another coverage [Y or N]']

```

```

    &&if %secondcov% = .true. &&then &&do

```

```

        &&type Select another coverage from the popup menu.

```

```

        &&s backcov2 = [GETCOVER # -ALL 'Select a coverage:']

```

```

        LINECOLOR blue

```

```

        ARCS %backcov2%

```

```

        /* Draws second background coverage

```

```

    &&end

```

```

    &&type Do you know the exact xy coordinates for the viewpoint?

```

```

    &&s answer [QUERY 'Specify Y or N']

```

```

    &&if %answer% = .true. &&then &&do

```

```

        &&s x [RESPONSE 'Please enter the x coordinate']

```

```

        &&s y [RESPONSE 'Please enter the y coordinate']

```

```

        CREATE %.viewpt% POINT %x% %y% /* Creates point coverage
&end
        &else &do
            &type Use the mouse to locate and select a viewpoint.
            CREATE %.viewpt% POINT * /* Creates point coverage
        &end
    QUIT
&end
BUILD %.viewpt% POINT /* Builds coverage topology
LATTICESPOT %latticefile% %.viewpt% /* Interpolates viewpoint elevation

TABLES
ADDITEM %.viewpt%.pat anno 10 10 I
SELECT %.VIEWPT%.PAT /* Adding annotation to viewpoint
MOVE 'Viewpoint' TO ANNO
Q STOP
&severity &error &routine error

```

The next four sections of the AML are designed to allow the user to employ some of ARC/INFO's capabilities for customizing the viewpoint created in the previous section (Tables 5 through 8). This is accomplished by adding attribute items to the viewpoint which control such things as the vertical offset from ground elevation, horizontal and vertical viewing angle limits, and search distances from the viewpoint (for a description of these attributes refer to Chapter 2).

This part of the AML is written in modular form. It contains a series of routines, or sub-programs, which are designed and written to perform specific tasks when they are called from the main part of the AML. The section begins by informing the operator about the optional attributes, asking whether or not to continue adding them, or to skip that process and compute the viewshed using the viewpoint with none of the enhancements added. In the case where the user declines to add attributes, the AML will skip ahead to the VISIBILITY routine reproduced in Table 9. If the operator chooses to add attributes, the AML prompts the user for a response to each one of the optional attributes in turn (Tables

5 through 8). In this manner, the operator has the opportunity to select and add as many of the attributes as he or she wishes. As soon as a "yes" response is given, the AML calls a subroutine to handle the addition of the item to the attribute table. The operator is responsible for giving the item a value. Hence, the first attribute item to be added is for a vertical offset from the surface (OFFSETA). If the operator would like to compute the viewshed as seen by an average adult standing at the chosen viewpoint, when asked to specify a value for an offset, typing a value of 2 meters would be an appropriate response. The AML calculates the number 2 as the value for the attribute item OFFSETA.

Table 5. Portion of AML to add a vertical offset.

```
/* The user has now made a simple viewpoint coverage which becomes the <incover> for
/* the visibility analysis. The next step gives the user the option of customizing the
/* viewpoint coverage by adding items to the feature attribute table.
```

```
&type You will now be asked whether you would like to add items to the viewpoint ~
feature attribute table which contributes to the functionality of the viewshed analysis. ~
Items such as an observation point vertical offset, horizontal and vertical angle limits
&type and search distance limits will enable you to tailor the analysis to better suit ~
your needs. If you should elect to skip this section, the viewshed analysis will continue ~
with the default settings for the viewpoint.
```

```
&&s add = [QUERY 'Do you wish to add items? [Y or N]']
&if %add% = .false. &then &do
    &call visibility                /* call to routine VISIBILITY
    &return
```

```
&end
```

```
&else &do
```

```
    &type Would you like to add a vertical offset to your viewpoint?
```

```
    &&s answer = [QUERY 'Specify Y or N']
```

```
    &if %answer% = .true. &then &do
```

```
        &call add-offset            /* call to routine ADD-OFFSET
```

```
    &end
```

```
/******!*****
```

```
&routine add-offset          /* Adds item OFFSETA to viewpoint feature attribute table
```

```
&&s temp = [RESPONSE 'Specify a value (in meters)']
```

```
&&s off = [UNQUOTE %temp%]    /* change from character to numeric variable
```

```
&&s offseta = offseta
```

```
&&s ext = .pat                /* concatenates viewpt and .pat to fat1
```

```

&&s fat1 = %.viewpt%%ext%          /* where fat = feature attribute table
  ADDITEM %fat1% %fat1% %offseta% 4 4 F 2
  TABLES
  SELECT %fat1%
  CALCULATE %offseta% = %off%      /* puts user value for offset in viewpt.pat
  Q STOP
&&return
/*****

```

Table 6 shows the portion of the AML which issues a call to a routine titled SCAN-ANGLE, which limits the horizontal scanning angle of the search through the addition of two attribute items to the viewpoint coverage's attribute table. When these items are present the search is limited to a window less than a full 360° search path around the viewpoint. Setting ANGLE1 and ANGLE2 to 90° and 270° respectively would restrict the search to a 180° search centered on 180° (due south). This example is discussed when the user tries to implement this portion of the AML (Table 6).

Table 6. Portion of AML used to define scan angle limits.

```

&&type The next items are used to limit the horizontal scan angle when determining ~
visibility. The sweep proceeds in a clockwise direction from AZIMUTH1 to AZIMUTH2.
&&type Values can vary from 0 to 360 degrees, with zero oriented to the north. ~
For example, if you were standing at a point looking directly north and you wanted ~
to limit the scan angle to 180 degrees (i.e. from west to east), the value for ~
ANGLE1 = 270, while ANGLE2 = 90.
&&type If you do not add these items a full sweep of 360 degrees will be implemented.

```

```

&&type Would you like to add horizontal scan angles to your viewpoint?

```

```

&&s answer = [QUERY 'Specify Y or N']

```

```

&&if %answer% = .true. &&then &&do

```

```

  &&call scan-angle

```

```

  /* call to routine SCAN-ANGLE

```

```

&&end

```

```

/*****

```

```

&&routine scan-angle          /* To specify horizontal scan angle limits

```

```

&&s temp2 = [RESPONSE 'Specify the first angle (ANGLE1)']

```

```

&&s angle1 = [UNQUOTE %temp2%] /* change variable from character to numeric

```

```

&&s azimuth1 = azimuth1

```

```

&&s temp3 = [RESPONSE 'Specify the second angle (ANGLE2)']

```

```

&&s angle2 = [UNQUOTE %temp3%] /* change variable from character to numeric

```

```

&&s azimuth2 = azimuth2
&&s ext = .pat /* concatenates viewpt and .pat to fat1
&&s fat1 = %.viewpt%%ext% /* where fat = feature attribute table
  ADDITEM %fat1% %fat1% %azimuth1% 3 3 I
  ADDITEM %fat1% %fat1% %azimuth2% 3 3 I
  TABLES
  SELECT %fat1%
  CALCULATE %azimuth1% = %angle1%
  CALCULATE %azimuth2% = %angle2%
  Q STOP
&&return
/*****

```

The next optional attribute items will set vertical angle limits to the scan and are added by the routine VERTICAL-ANGLE reproduced in Table 7. The value of VERT1 sets the upper limit of the scan while VERT2 sets the lower limit. Both items are expressed in degrees between 90 (straight overhead) and -90 (directly under foot). The horizontal plane (0 degrees) is defined by the z-value of the observation point plus the value of OFFSETA, should it exist (ESRI, 1991). Setting VERT1 and VERT2 to 0° and -90° respectively would limit the vertical search angle to a 90° search from the horizontal plane (0°) to directly under foot (90°) and would not search anything above the viewpoint elevation. This example would be most appropriate if the user knew that the viewpoint was at a local high point and it was not necessary to search the landscape any higher than the viewpoint location. Conversely, the exact opposite may be true when computing a viewshed from a local low point.

Table 7. Portion of AML used to define vertical scan angle limits.

&&type The next items are options that specify vertical angle limits to the scan. The value ~ of VERT1 sets the upper limit of the scan, VERT2 sets the lower limit. The VERT1 and ~ VERT2 angles are expressed in degrees between 90 and -90 degrees.

&&type Positive angles are above the horizontal plane, negative angles are below. ~ The default values are 90 for VERT1 and -90 for VERT2.

&&type Would you like to add vertical angle limits to your viewpoint?

&&s answer = [QUERY 'Specify Y or N']

```

&if %answer% = .true. &then &do
    &call vertical-angle          /* call routine VERTICAL-ANGLE
&end
/*****
&routine vertical-angle          /* To specify vertical scan angle limits
&s temp5 = [RESPONSE 'Specify the upper limit (VERT1) in degrees between zero ~
and 90']
&s vertical1 = [UNQUOTE %temp5%]
&s vert1 = vert1
&s temp6 = [RESPONSE 'Specify the lower limit (VERT2) in degrees between zero ~
and -90']
&s vertical2 = [UNQUOTE %temp6%] /* change character to numeric variable
&s vert2 = vert2
&s ext = .pat                    /* concatenates viewpt and .pat to fat1
&s fat1 = %.viewpt%%ext%         /* where fat = feature attribute table.
    ADDITEM %fat1% %fat1% %vert1% 3 3 I
    ADDITEM %fat1% %fat1% %vert2% 3 3 I
    TABLES
    SELECT %fat1%
    CALCULATE %vert1% = %vertical1%
    CALCULATE %vert2% = %vertical2%
    Q STOP
&return

```

Table 8 shows a routine called SEARCH-RADIUS which is designed to limit the search distance from the observer during the visibility analysis. Lattice mesh points closer than the value in RADIUS1 are not visible but can still block the visibility of mesh points further away. Lattice mesh points beyond the RADIUS2 search distance are excluded from the analysis. The default search distances are from zero to infinity (ESRI, 1991).

Table 8. Viewpoint customization routine: Defining search radius.

&type The next items, RADIUS1 and RADIUS2 are used to limit the search distance ~ from the observation point and are particularly useful in specifying distance zones or ~ bands such as FOREGROUND, MIDDLEGROUND or BACKGROUND zones. Lattice points beyond the RADIUS2 search distance are excluded from the analysis
&type Lattice mesh points closer than the RADIUS1 search distance are not visible in ~ the viewshed coverage but can still block the visibility of lattice points between RADIUS1 and RADIUS2. The default RADIUS1 distance is zero. The default RADIUS2 distance is infinity (diagonal distance of the lattice).

```

&type Would you like to add a search radius to your viewpoint?
&s answer = [QUERY 'Specify Y or N']
&if %answer% = .true. &then &do
    &call search-radius          /*call to routine SEARCH-RADIUS
&end
/*****
&routine search-radius          /* To limit the search distance from the viewpoint.
&type If you do not know an exact distance for a radius, the USDA Forest Service's ~
Visual Management System defines distance zones as follows:
&type FOREGROUND = 0 - 800m (1/2 mile)
&type MIDDLEGROUND = 0 - 4800 or 8050m (3 to 5 miles)
&type BACKGROUND = MIDDLEGROUND to infinity

&s temp4 = [RESPONSE 'Specify a value for RADIUS1 (in whole meters)']
&s rad1 = [UNQUOTE %temp4%]      /* changes character to numeric variable
&s radius1 = radius1
&s temp5 = [RESPONSE 'Specify a value for RADIUS2 (in whole meters)']
&s rad2 = [UNQUOTE %temp5%]      /* changes character to numeric variable
&s radius2 = radius2
&s ext = .pat                    /* concatenates viewpt and .pat to fat1
&s fat1 = %.viewpt%%ext%         /* where fat = feature attribute table
    ADDITEM %fat1% %fat1% %radius1% 4 4 i
    ADDITEM %fat1% %fat1% %radius2% 4 4 i
    TABLES
    SELECT %fat1%
    CALCULATE %radius1% = %rad1%
    CALCULATE %radius2% = %rad2%
    Q STOP

&return
/*****
&end                               /* End of Section 2 - adding attributes to viewpoint

```

Together with the attributes for controlling the horizontal scan angle (AZIMUTH1, AZIMUTH2; see Table 6 for further details), the optional radius attributes offer considerable flexibility when attempting to target specific zones for visibility analysis. Figure 6 shows how the azimuth and radius items define the boundaries of a search area when specified as viewpoint attributes.

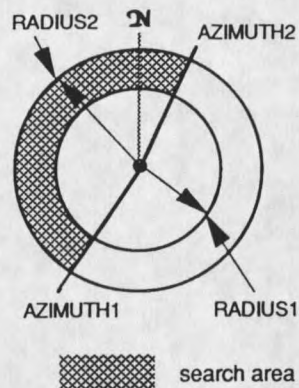


Figure 6. Schematic showing effect of viewpoint attributes in defining search area (from ESRI, 1991).

At this point, the operator has successfully completed the execution of several routines which have the cumulative result of producing a coverage containing a single viewpoint for the determination of a viewshed. The choice to add attributes to the viewpoint was presented as an option that would enhance and further define the viewing parameters as interpreted by the ARC/INFO VISIBILITY command. Each attribute was presented individually (by routine) so that he/she could select as many as desired. While each attribute provides a useful dimension to the visibility analysis, it is not necessary to add each one for the analysis to be effective. For instance, the user might add a vertical offset to a viewpoint by specifying a value which could be anything from the height of a person standing or the height of a forest fire watch tower, however, it may not be as important to specify horizontal and vertical scanning angles. Similarly, the addition of a search radius is an effective way to evaluate the impact of distance from the viewer in the analysis of visibility and visual magnitude. The user may be more interested in evaluating visible terrain that is closer to the viewer than terrain that is further away. One of the strengths of the ARC/INFO VISIBILITY command is the ability to customize the analysis to better suit the requirements

of the user.

With a viewpoint coverage intact, it is time to perform the viewshed analysis by invoking the VISIBILITY command. The third part of the AML reproduced in Table 9 contains the code necessary to perform this analysis using the lattice coverage selected earlier along with a previously selected or created viewpoint coverage. The user must choose whether to continue and then enter a name for the output coverage. The algorithm takes the selected viewpoint and radiates a sphere of straight line rays to each one of the lattice mesh points checking to see whether any intermediate mesh points come between them. The locations of the resultant contact points are coded as visible while the others are not. For further analysis or display purposes a simple query on the resultant viewshed coverage's attribute table will reveal the extent of visible terrain. Visibility determination can be a computer intensive process, depending on the size of the study area and the spatial resolution of the lattice. The Digital DECStation 5000 workstation located in the GIAC took, on average, 3 to 7 minutes to complete a viewshed computation on a lattice the size of one 7.5 minute USGS quadrangle with 30m mesh intervals.

Table 9. Portion of AML used to compute viewshed.

```
&routine visibility      /* Computes visible area from an observation point on a lattice file.
&type You are now ready to perform the visibility analysis. The ARC/INFO VISIBILITY ~
command performs visibility analysis on a lattice by determining which regions on the ~
lattice mesh are visible from the observation point. The result is a polygon coverage ~
where each polygon identifies areas with common visibility characteristics (i.e., visible or ~
not-visible).
```

```
&s continue = .true.
&s continue = [QUERY 'Do you wish to continue? [Y or N]']
&if %continue% = .false. &then &do
    &return
&end
    &else &do
        &s .vshed = [RESPONSE 'Please enter a viewshed coverage name']
```

```

VISIBILITY %latticefile% %.viewpt% POINT %.vshed%
&end
&return

```

When the visibility routine is finished, the user is guided to the next section of the AML which displays the results of the analysis on the screen or as a paper map. This fourth part of the AML includes a routine called MAPVIEW which is executed from the ARCPLOT module (Table 10). The main AML submits a call to the MAPVIEW routine when the user chooses to view the results of the visibility analysis. This part of the AML is actually a compilation of several subroutines which generate map elements in a specific order and are discussed on the pages which follow.

Table 10. Portion of AML used to examine viewshed analysis results.

&type You have now successfully created a viewshed coverage and at this point you ~ are faced with the option of either displaying the results on the screen, and, if you like, ~ plotting a map when the AML has finished. The AML will display the results of your ~ *&type* viewshed analysis on the screen; then when you have finished viewing, if you ~ decide to plot a map, the technicians in the Center will assist you.

```

&s answer = [QUERY 'Would you like to view the results of your analysis? [Y or N]']
&if %answer% = .false. &then &do

```

```

    &type Leaving AML... returning control to ARC...

```

```

    &return

```

```

&end

```

```

    &else &call mapview

```

```

/*****

```

```

&routine mapview

```

```

&s .comp = [GETCHOICE GRA.FILE SCREEN -PROMPT 'Choose Your Output']

```

```

&return

```

```

/*****

```

```

/* Starting ARCPLOT

```

```

/*****

```

```

&type \Starting up ARCPLOT . . . . .

```

```

ARCPLLOT

```

```

&if %comp% = GRA.FILE &then &call graphics

```

```

    &else &call screen

```

```

&call setup

```

```

&call drawmap

```

&call title
&call key
&call north
&call scale
&return

As part of the MAPVIEW routine from the previous table, the user is able to direct the output to the screen or to a graphics file for plotting by selecting his/her choice from a window that appears on the screen. Table 11 shows the subroutines necessary to create each output type (GRAPHICS or SCREEN) along with a subroutine called SETUP which determines the drawing parameters. The GRAPHICS routine is called when the user selects GRA.FILE to be the output type from the selection window. This routine uses the DISPLAY 1040 command to create an output file called viewshed.gra which can then be sent to a plotter for hard copy output. When the user selects SCREEN as the output type from the selection window, a call is made to the SCREEN routine which uses the DISPLAY 9999 3 command to open a large canvas window for graphics drawing. The size of the canvas window can be specified by the number following DISPLAY 9999, in this case, a 3 would open a canvas window nearly the full size of the screen. It should be noted that if the graphics file option is selected as output, there is not a simultaneous display to the screen, and vice versa, although the graphics file may be drawn to the screen later. The purpose of the SETUP routine, appropriate for either output type, is to define the initial drawing parameters. Parameters defining the size and positioning of the map on the graphics page, along with the scale and spatial extent of the map are determined by the commands in SETUP.

Table 11. Subroutines used to select display types and drawing parameters.

```

&routine graphics
  display 1040
  viewshed.gra
&return
/*****
&routine screen
  display 9999 3
&return
/*****
&routine setup
  pagesize 16 20
  mapextent %.vshed%
  mapunits meters
  mapposition cen cen
  maplimits 0.5 0.5 15.5 19.5
  mapscale 31250
&return

```

The DRAWMAP routine (Table 12) is a collection of commands that draw the geographic features to the graphics file or screen display. The routine loads the appropriate set of drawing symbols (line, shade and marker) and then, using ARC/INFO's selection logic, selects features and draws them according to the specified symbol. Comments have been placed throughout the code in Table 12 to help explain what each command is doing.

Table 12. Subroutine used to draw map elements.

```

&routine drawmap
  lineset color.lin
  shadeset colornames.shd
  markerset plotter.mrk
  linesymbol 14
  arcs mdowncontour /* draws contour coverage with gray line
  reselect ponds1 poly ponds1-id gt 0
  polygonshades ponds1 47 /* shades pond polygons with blue shade
  linesymbol 5
  arcs stream
  polys ponds1
  lineset plotter

```

```

reselect trans line class le 3
arclines trans class road.lut          /* draws roads coded by class
shadeset plotter
reselect %.vshed% poly visible-code = 1 /* selects visible polygons from viewshed coverage
polygonshades %.vshed% 70             /* shades visible polygons with red hatch pattern
linesymbol 2
polys %.vshed%                          /* draws red lines around perimeter of visible polygons
markersymbol 71
markerscale 1.25
points %.viewpt%                         /* draws viewpoint with green star symbol
annotext stream                          /* places stream names as annotation
annotext trans                           /* places highway names as annotation
textset font
textsymbol 2
textsize 0.15
textoffset -0.07 0
labeltext %.viewpt% anno ur            /* places label text 'Viewpoint'
textoffset 0 0
linesymbol 1
box 0 0 16 20                          /* boxes of different line widths
linesymbol 9                            /* are drawn around the borders of the map
box 0.05 0.05 15.95 19.95
linesymbol 5
box 0.5 0.5 15.5 19.5
&return

```

The next routine, called TITLES, places a title in large text along the top of the map (Table 13). The first few lines determine the text font, size, and title position on the graphics page. The wording of the title was predetermined and drawn with the TEXT command for this study.

Table 13. Subroutine used to draw map title.

```

&routin titles
textset font
textsymbol 1
textsize 0.5
move 8 19.25
text 'BIG SKY MEADOW VILLAGE - VIEWSHED MAP' lc
&return

```

The final three cartographic elements consisted of a key legend, north arrow, and scale bar. These elements were drawn with the three subroutines reproduced in Table 14. The key legend describes the symbology used to portray the different map features. The routine KEY lists the code necessary to draw the key legend. The key is drawn in a patch that has been placed in the upper-right corner of the map. With a few commands to set the positioning, size and style of the legend, ARC/INFO will produce a legend using a predetermined text file with a .key extension. This text file contains the legend text along with a number corresponding to the appropriate symbol for each element or feature shown on the map. The number in the text file is the link to the symbol number in the ARC/INFO symbol set. ARC/INFO will create a columnar key using shade, line, or marker symbols drawn to the left of a line of descriptive text. Other descriptive text listing the author's name and the origin of the map is read from another predetermined text file and drawn with the textfile command.

The routine NORTH selects a marker symbol from the makerset called municipal and draws a north arrow at a specific size and position in the same patch area as the key legend described previously. Similarly, the routine SCALE draws a predetermined scale bar stored as a graphics file at a specific position within the patch area. This scale bar shows the relative distance relationship of map units to ground units in kilometers and miles. Map scales vary as a function of the areal extent shown in the graphics window or physical page. If the page size is kept constant while the area shown in the map increases in size, the map scale will become smaller when stated as a relative fraction and vice versa.

Table 14. Subroutine used to draw key legend, north arrow and scale bar.

```

&routine key
shadeset colornames
shadesymbol 27
patch 8 15 14.2 18.75 outline
textsymbol 14
textsize 0.3
textquality kern
textspacing 2
move 11.1 18.4
text Legend lc
textsym 2
textsize 0.2
textspacing 1
keyarea 8.75 17.9 14 18.3
keybox 0.4 0.3
keyseparation 0.15 0.2
shadeset plotter
keyshade viewshed.key
keymarker vpt3.key nobox
textsymbol 1
textsize 0.12
move 8.5 15.7
textfile giac.txt
&return
/*****
&routine north
markerset municipal
markersym 128
markersize 0.7
marker 13.9 17.5
&return
/*****
&routine scale
plot scale-3125.gra 11 15.2
&return

```

Figures 7 and 8 show 2 and 3-D examples of the maps created with the viewshed analysis and mapping routines reproduced in Tables 3 through 14. The size of the graphics page was adjusted to fit the map on an 8.5 by 11 inch sheet of paper in this example. Figure 7 was plotted in black and white from an ARC/INFO graphics file on a Postscript laser

printer. The shaded pattern on the map represents the spatial extent of visible terrain (viewshed) from the viewpoint denoted by the star symbol (near the center of map). In this particular instance the selected viewpoint is a water tower (Viewpoint 2) on the west side of Meadow Village. The viewpoint coverage was created prior to the execution of the AML and was given a vertical offset of 7 meters to simulate the height of a water tower. No other viewpoint attributes were assigned. The transportation and hydrology coverages have been draped over the viewshed to provide some locational references. Figure 8 is a three-dimensional perspective view of the viewshed from another water tower (Viewpoint 1) shown by the symbol in the center of the view. The stream coverage is draped over the terrain model to provide some additional landscape definition.

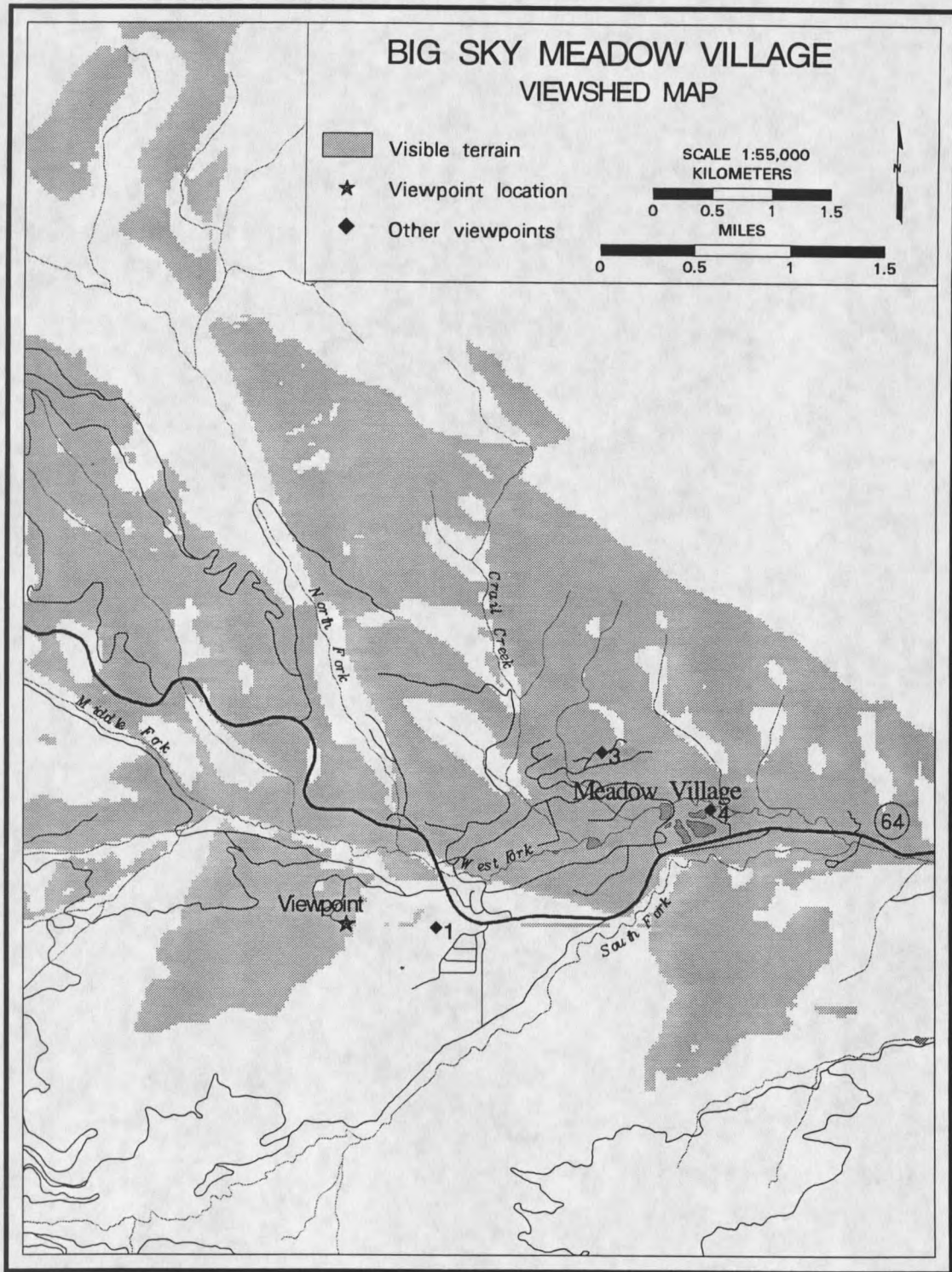


Figure 7. GIS viewshed map from Viewpoint 2.

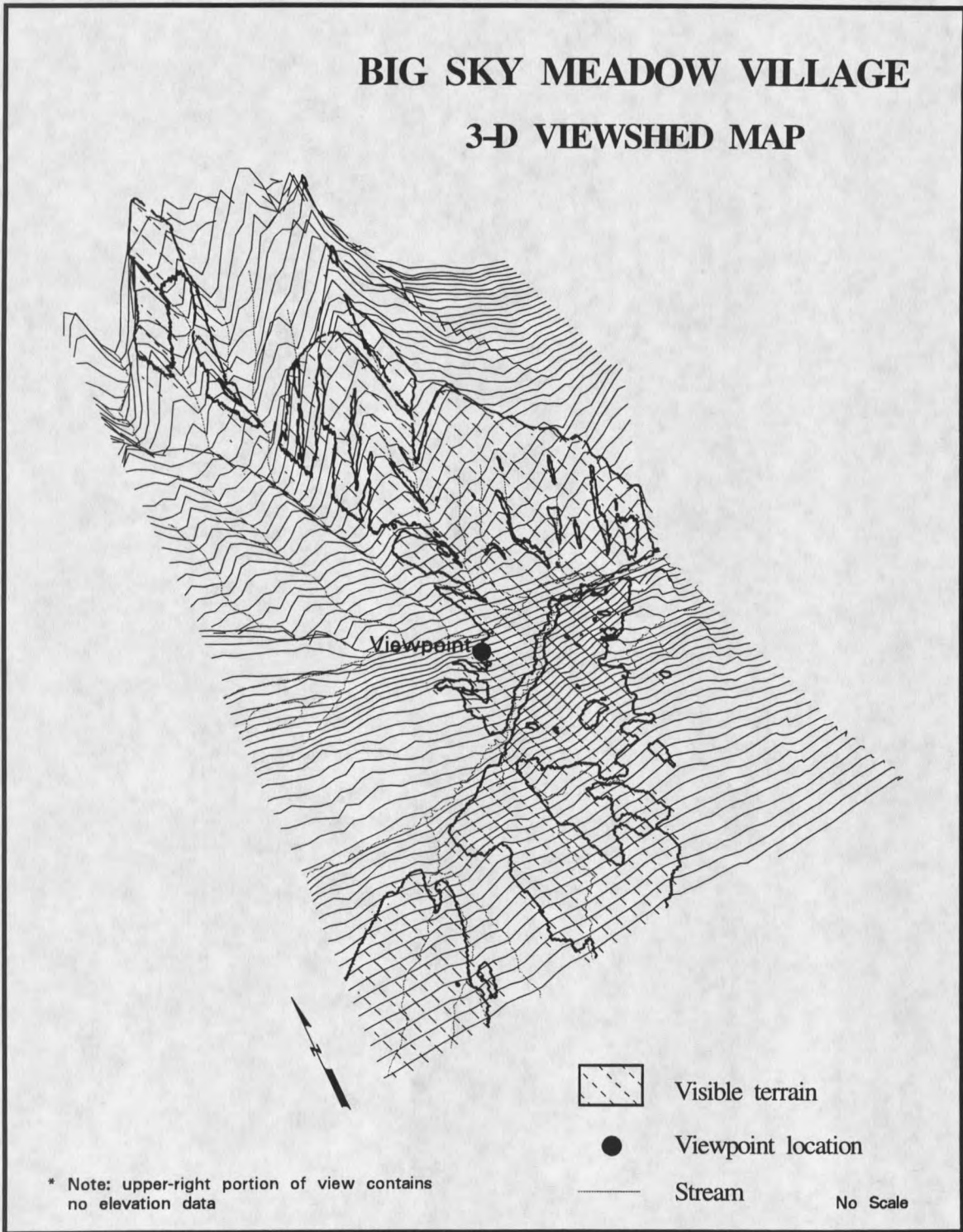


Figure 8. 3-D viewshed map from Viewpoint 1.

Evaluation of the Accuracy GIS-based Viewshed Analysis Technique

This final section examines the accuracy of the GIS-based viewshed analysis technique. Four viewpoints were selected for this portion of the study based on their visual significance and/or their spatial distribution within the Meadow Village area (Figure 2). Three of the viewpoints represent above-ground water storage towers that are located on hillsides (#1 - 3) and, except for some screening by trees near Tower #3, are relatively exposed. The fourth viewpoint (#4) was selected for its exposure at the east end of the village giving it a relatively clear, panoramic view of the valley. Computer-generated viewsheds were prepared and compared with field observations and a series of black and white photographs to demonstrate the efficiency of the GIS-based technique. These results are presented with a series of tables, maps and photographs on the next few pages. Tables 15 and 16 summarize the overall results and serve to highlight some of the problems that are encountered with this type of verification exercise.

Examination of Table 15 reveals two general trends when comparing the roadside observations with the computer generated viewsheds. First, the 87 percent cumulative success rate for the number of times the computed viewsheds matched the field observations (shown in part C) suggests a good fit between the analysis technique and the DEM. Second, the results exhibit a tendency for computed viewsheds to see the viewpoints more often than they are actually observed (comparison of parts A and B) which could be explained, in part, by the resolution (30m) and origination of the digital elevation data. Because the data was originally scanned from USGS 7.5 minute quadrangles with 40 foot contour intervals it is reasonable to believe that some local relief was omitted in the DEM. Those areas of local relief that are not represented in the DEM but do obscure ground observations cause the computer-generated viewsheds to over-represent the extent of visible terrain. In addition,

the low number of successful roadside observations from Chief Joseph Trail to Viewpoint 3 in relation to the computed number can be attributed to features on the surface (houses, trees, etc.) which obscure the ground observation, but which are not represented in the DEM.

Table 15. Visibility from selected roadside vantage points.

A. Number of times viewpoints were observed from roadside vantage points

		Observed visibility of			
		No. of trials	1	2	3
View computed from	State Route 64	35	18	16	19
	Ousel Falls Road	21	13	0	17
	Chief Joseph Trail	7	4	6	2

B. Number of times viewpoints were visible in computer-generated viewsheds

		Computed visibility of			
		No. of trials	1	2	3
View computed from	State Route 64	35	19	20	23
	Ousel Falls Road	21	19	0	19
	Chief Joseph Trail	7	4	7	7

C. Number of times computed viewsheds matched field observations

		Computed visibility of			Percent correct	
		No. of trials	1	2		3
View computed from	State Route 64	35	32	31	31	90
	Ousel Falls Road	21	15	21	17	84
	Chief Joseph Trail	7	7	6	7	71
	Percent correct		92	98	85	87

Figures 9 through 12 show the viewsheds computed for the four viewpoints using a 2 meter vertical offset (to replicate the viewshed captured by the person taking the photographs) and horizontal scans that encompassed the full 360° search path. Figure 9 is a small scale reproduction of a map used to tabulate the number of times the roadside vantage points were within the viewshed computed from Viewpoint 1. The actual map used in the analysis was drawn at a much larger scale to capture more of the detail necessary to tabulate the results (Table 15, part B). The map also shows the position of the other three viewpoints for the purposes of determining their relative visibility. Similar maps for Viewpoints 2 and 3 are shown in Figures 10 and 11 respectively. Figure 12 is a larger scale map showing the viewshed computed from Viewpoint 4 clearly showing the positions of the other viewpoints within the visible terrain. The first part of Table 16 summarizes whether or not the different viewpoints were visible relative to one another.

The four viewpoints were then visited in the field and the visibility of the other three viewpoints was determined (Part B, Table 16). Several black and white photographs also were taken with a 35 mm camera to confirm several of the personal observations. Figures 13 through 15 show three of the photographs and illustrate some of the problems encountered.

Table 16. Visibility matrices for four viewpoints.

A. Visibility Computed with GIS-based Viewshed Technique

Computed Visibility of

		1	2	3	4
View Computed From	1	---	NO	YES	YES
	2	NO	---	YES	YES
	3	YES	YES	---	YES
	4	YES	YES	YES	---

B. Visibility as Documented from Field Reconnaissance and Photographs

Observed Visibility of

		1	2	3	4
View Observed From	1	---	NO	YES	YES
	2	not shown	---	not shown	not shown
	3	YES	YES	---	YES
	4	YES	YES	YES	---

Figure 12 shows one of the photographs taken from Viewpoint 3. The open area on the center-right side of this photograph contains a dark spot near the right-hand boundary. This dark spot is the water tower that constitutes Viewpoint 2. The presence of this dark spot confirms the GIS-based viewshed determination in that the dark spot represents the water tower which constituted Viewpoint 2. Figures 13 and 14 corroborate the GIS-based technique in that Viewpoint 2 is visible in the photograph taken from Viewpoint 4 in Figure 13, and Viewpoint 4 is visible (though not readily apparent in the reproduction of the photograph) in the photograph taken from Viewpoint 1.

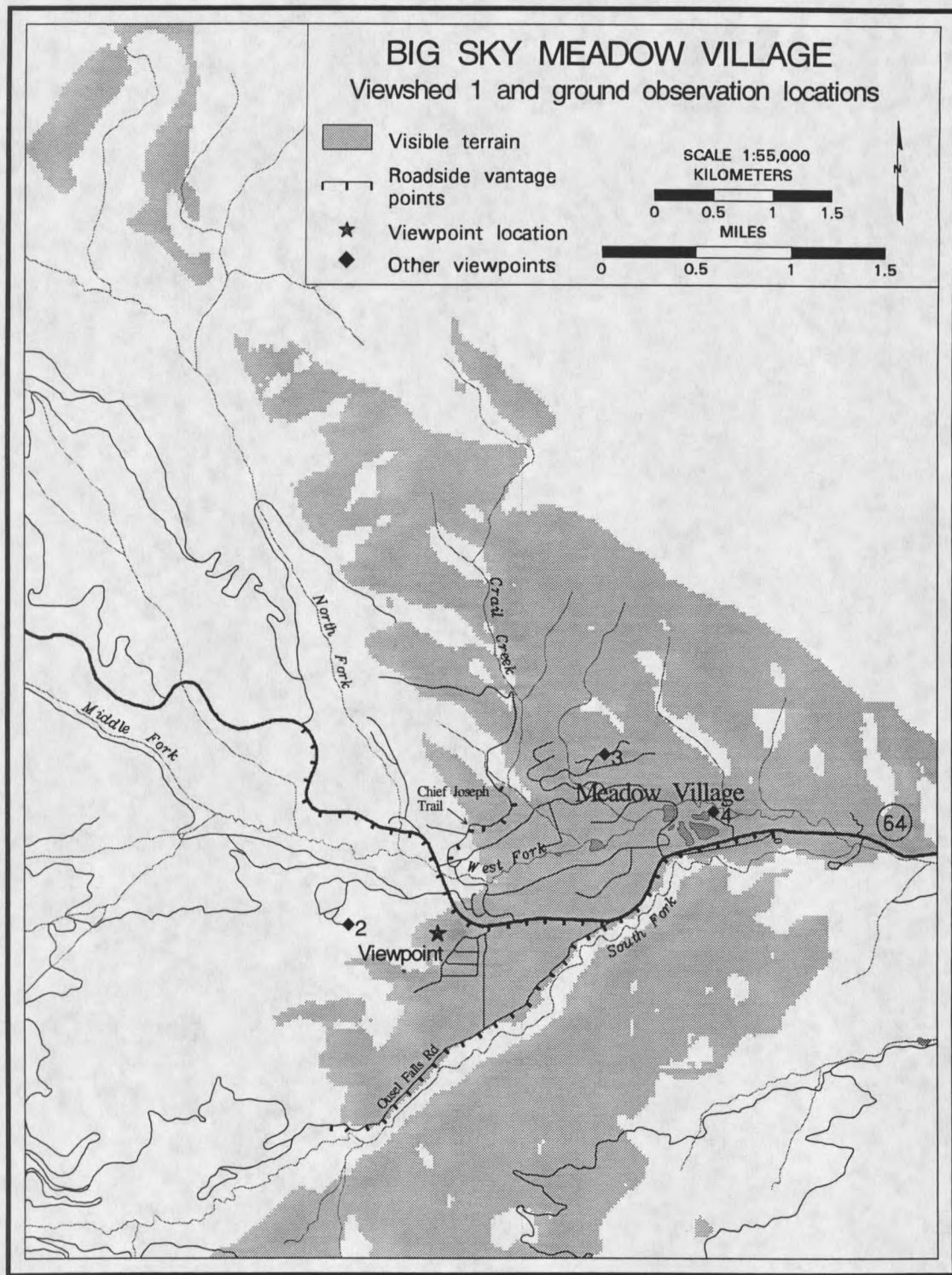


Figure 9. GIS Viewshed map computed with new technique from Viewpoint 1.

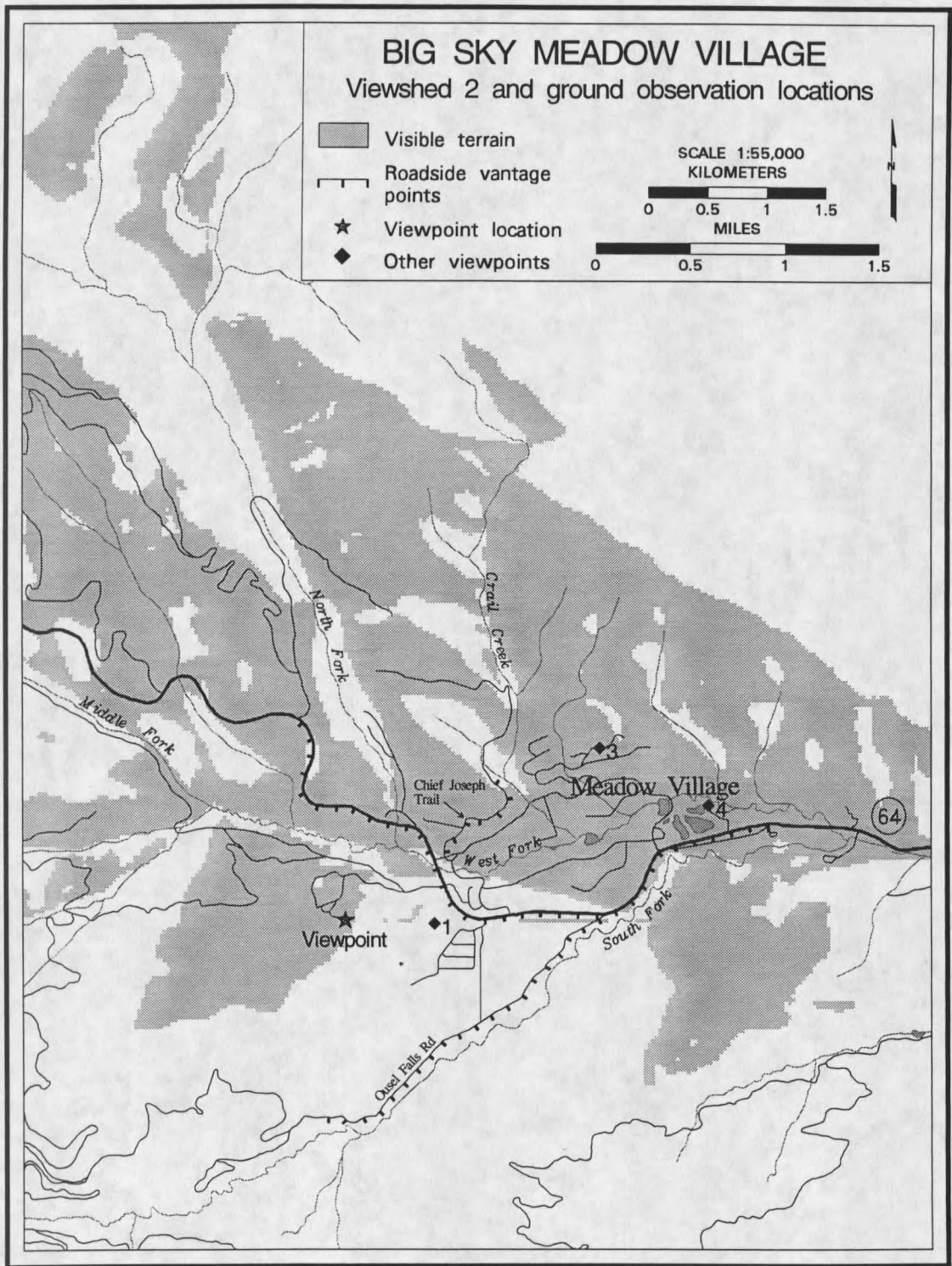


Figure 10. GIS Viewshed map computed with new technique from Viewpoint 2.

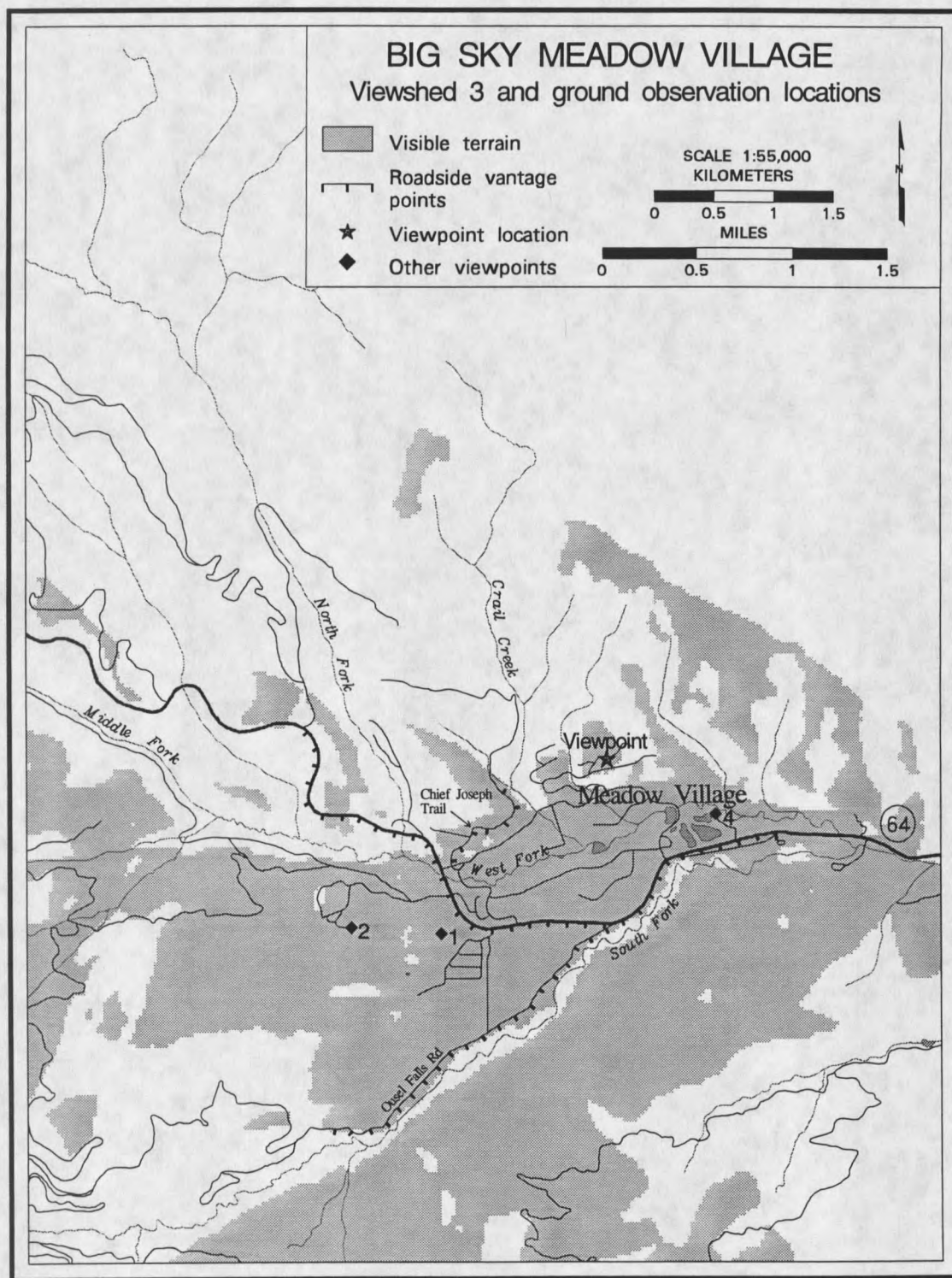


Figure 11. GIS viewshed map computed with new technique from Viewpoint 3.

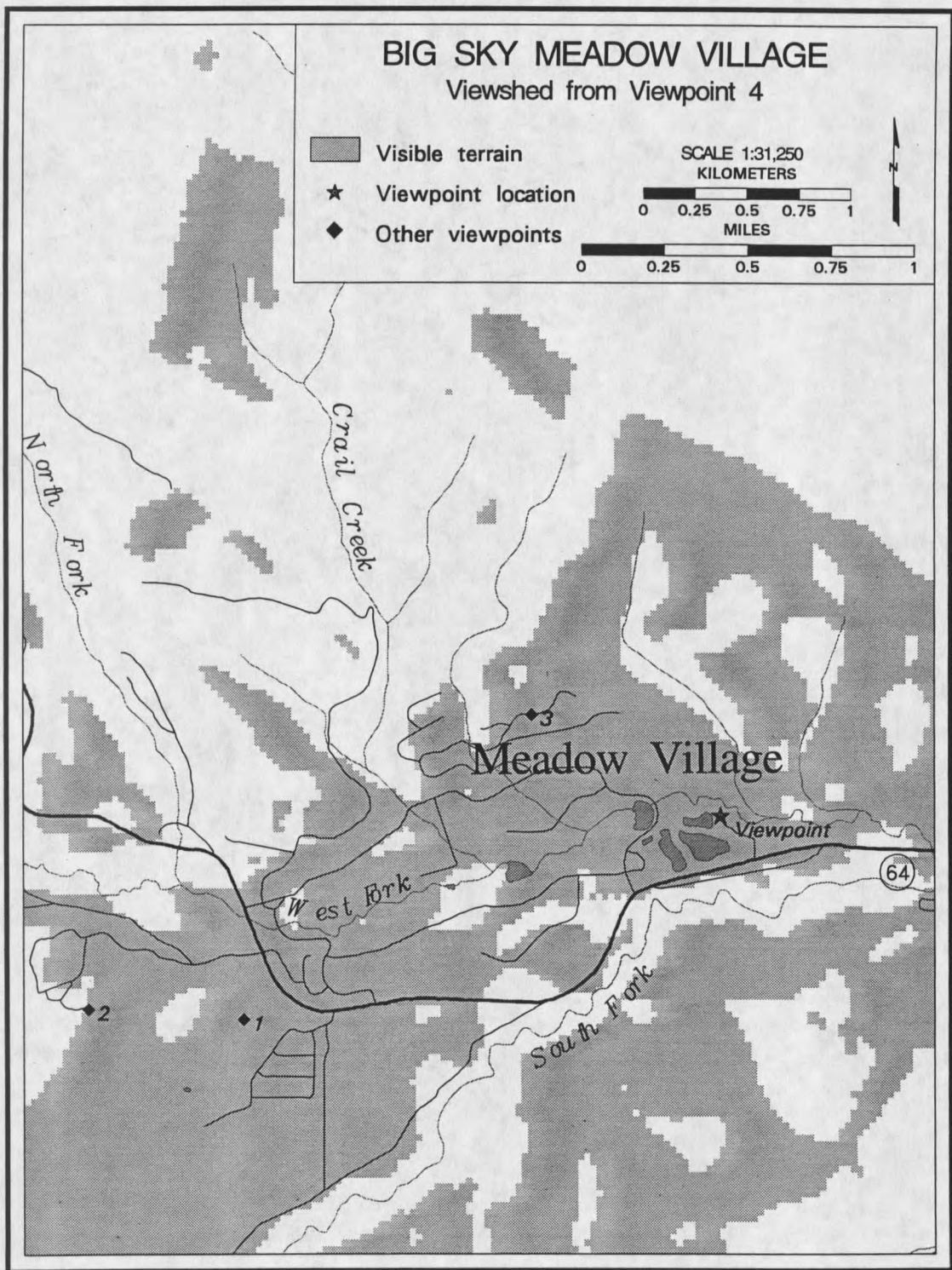


Figure 12. GIS Viewshed map computed with new technique from Viewpoint 4.

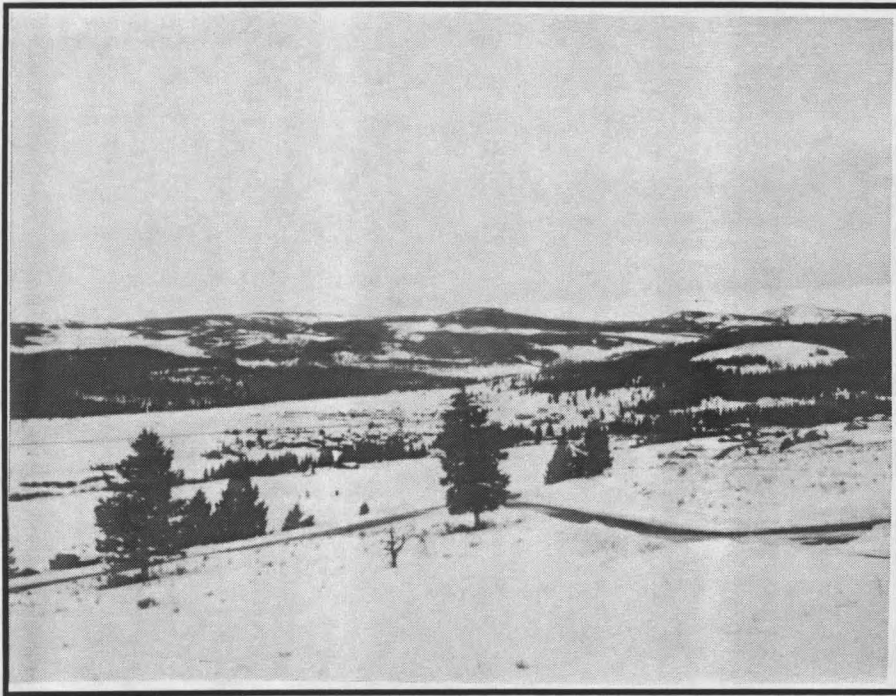


Figure 13. Photograph taken in January 1993 from Viewpoint 3 looking toward the southwest.

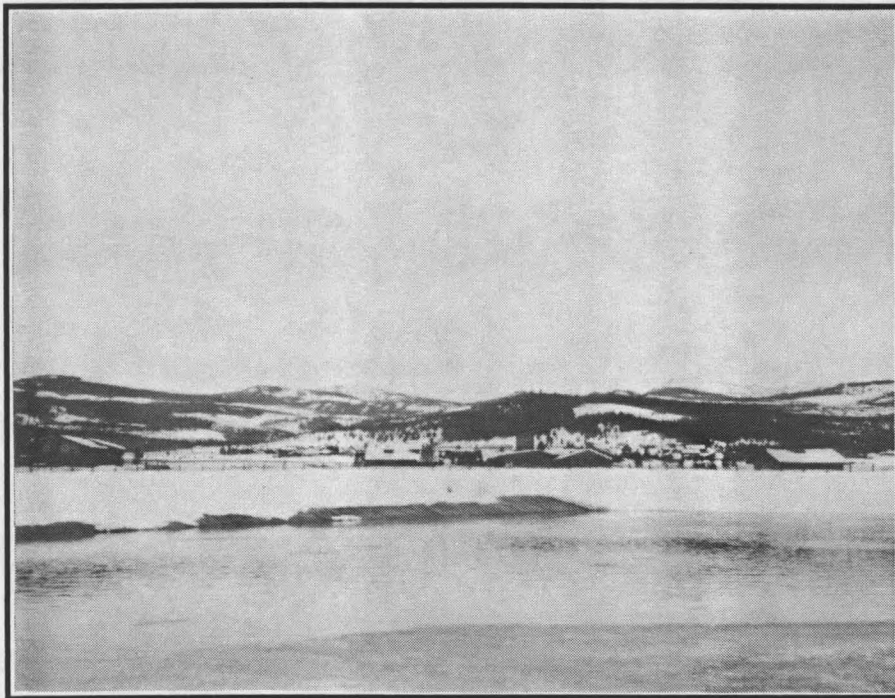


Figure 14. Photograph taken in January 1993 from Viewpoint 4 looking westward.



Figure 15. Photograph taken in January 1993 from Viewpoint 1 looking eastward.

Figure 13 shows one of the photographs taken from Viewpoint 3. The open area on the center-right side of this photograph contains a dark spot near the right-hand boundary. This dark spot is the water tower that constitutes Viewpoint 2. The presence of this dark spot confirms the GIS-based viewshed determination in that the dark spot represents the water tower which constituted Viewpoint 2. Figures 14 and 15 corroborate the GIS-based technique in that Viewpoint 2 is visible in the photograph taken from Viewpoint 4 in Figure 14, and Viewpoint 4 is visible (though not readily apparent in the reproduction of the photograph) in the photograph taken from Viewpoint 1.

The overall results reproduced in Table 16 indicate that 9 of the 12 viewpoint pairs which the GIS-based technique classified as visible were actually visible in the field. The three that were classified as "not shown" were classified as such because of the difficulty in accessing the property to take photographs from Viewpoint 2. In summary, the results from

Tables 15 and 16 (taken together) confirm that the combination of ARC/INFO visibility assessment tools and 30m USGS DEMs can correctly identify visible terrain 80 - 85 percent of the time in mountainous landscapes such as the Big Sky Resort Area.

CHAPTER 4

DISCUSSION

This thesis was designed in part with a desire to explore and apply geographic information systems technology to evaluate complex spatial data relationships. The advent and evolution of GIS technology in the past decade has revolutionized the way in which we are able to capture, store, analyze and display spatial data. Algorithms for surface analysis have become a substantial part of many GIS software packages and the determination of visible terrain is a common function. Simplifying the manner in which we capture and store digital spatial data in a series of themes or layers provides a very flexible platform for analysis and meaningful graphic display. These developments have vastly improved and enhanced the manner in which researchers and those involved with land management decisions approach assessments of landscape aesthetics and environmental quality.

The Arc Macro Language (AML) program presented in Chapter 3 is but one example of these new possibilities. This AML was designed and constructed to satisfy the five criteria outlined in Chapter 1. The first and most important criterion is concerned with accuracy; in particular, whether or not and if so, how often the GIS-based viewshed analysis technique and database correctly identifies visible features in landscapes. The other criteria are secondary in the sense that their presence (or absence): (1) depend on the actual design and implementation of the AML in Chapter 3, and (2) they cannot correct viewshed determination errors due to faulty techniques and/or poor data. The discussion which

follows reviews the accuracy issues, examines how well the final AML matches up with the criteria, and explores the wider significance of these features for visibility assessments.

There are two possible kinds of problems with the data. The first set of problems occur because the DEM must sample the landscape. A 30 meter DEM was constructed from the 40 foot contour lines drawn in a series of 1:24,000-scale topographic maps for this study. The contours and DEM points may miss significant terrain features such as peaks, ridges and depressions and/or these features may have been dropped when the contour lines are converted to DEM points. Intuitively, we would expect the likelihood of the first of these problems to vary with different types of terrain. The comparison of field observations and computed viewsheds in Table 15 indicate that the 1:24,000 scale data were adequate since 87 percent of the viewpoints were correctly identified as visible or non-visible from the roadside vantage points. Similarly, all three of the viewsheds computed for the viewpoints listed in Table 16 matched those that were documented from field reconnaissance and photographs. Similar problems may arise if the data structure is revised and/or the data are interpolated in some way. Lee (1991a), for example, tackled this problem with his comparison of four different methods for building triangular irregular network models from grid elevation models. He compared the skeleton, filter, hierarchy and heuristic methods and determined that the heuristic methods performed better (i.e., the resulting TINs from this method were most similar to the DEM from which they were derived). In addition, all four methods performed better the greater the number of TIN facets included. None of these problems were experienced in the current study because the viewsheds were computed directly from gridded elevation models.

The study results reported in Chapter 3 point to another source of error in that human and natural features may interrupt the views that can be seen from key viewpoints.

Land cover features like trees and buildings play a role in obscuring views from selected viewpoints as was the case for Viewpoint 3 which was screened by a stand of trees and was not readily visible in the photographs or during the roadside observations. There were also occasions when buildings and/or trees obscured the view to one of the viewpoints when performing the roadside observations. While recent enhancements in the ARC/INFO VISIBILITY routine provide a means to incorporate the effects of intervening features (such as a stand of trees) on the computed viewshed, the complexity of this option would increase the size of the AML by 15 to 20 percent and would make the user interface that much more complicated. In addition, proper and accurate execution of this option would require current land cover data with appropriate attributes (i.e., heights of buildings, trees, etc.) which are not widely available and can be costly to acquire.

The viewshed determination techniques themselves may also contribute to inaccurate results. For example, it is important to include a vertical offset so that we can compute a viewshed that can be viewed by a person standing at that position and/or a person standing on a particular type of structure (i.e., fire watch tower) at that position. The importance of these options was illustrated in Chapter 3 and is discussed further by Lee (1991b). Overall, the AML reported in Chapter 3 suffered from none of these kinds of problems and the discussion will now shift to an assessment of how well the technique matched up with the other four criteria summarized in Chapter 1.

The remainder of the testing of the viewshed analysis technique was accomplished by trial and error when the AML was developed. The AML was designed to meet the three criteria that many commentators have deemed necessary to adequately perform GIS-based viewshed analysis. Briefly, these criteria were aimed at achieving three objectives: (i) allowing a user to define a viewpoint location and direction of view, (ii) offering the means

for evaluating the relative "visibleness" of each parcel of terrain based on distance, slope and aspect relative to the viewer, and (iii) providing the capability of counting and recording the number of times a parcel is seen from each viewpoint (when required). The AML code was organized and written in such a way that this functionality was incorporated sequentially and tested for functionality and robustness as part of the AML development process.

The flexibility built into the AML does allow the user to select a precise location from which to perform the viewshed analysis. Furthermore, the options available to add attributes to the viewpoint, such as a vertical offset, horizontal and vertical scanning angle limits and search radius, offer an additional level of flexibility suited to a broad spectrum of user requirements. In particular, the ability to add viewpoint attributes for the specification of horizontal scanning angle limits and search radii satisfies, in part, the first and second criteria noted above. The scanning angle limits define a direction of view, while the search radius addresses the effect that distance contributes to the analysis. For instance, the creation of viewing distance zones can be achieved by running the AML multiple times using different search radii thereby producing a series of viewshed coverages, each from the same viewpoint. With the spatial relationships stored in a GIS, and some additional map composition assistance, it is possible to show the effect of distance by shading the viewsheds based on distance from the observation point.

A variation of this approach can be used to determine which regions of the lattice can be seen from multiple observation points. The VISIBILITY command (described in Chapter 2) includes options that will either record the number of times each region can be seen from the observation points (FREQUENCY), or the reverse, which regions of the lattice can be seen from each individual observation point (OBSERVERS). The OBSERVERS option creates a key file listing every observation point that is visible from each output polygon. In

addition, an attribute called `VISIBLE-CODE` is added to the viewshed coverage's polygon attribute table. This item stores binary-encoded information about which observation points can see each polygon. Two AML's provided with the software (`VISDECODE`, `VISENCODE`) are used to decode this information and assist in making queries based on the `VISIBLE-CODE` value (ESRI, 1991). These commands were used with a series of vantage points located on State Route 64 to construct the map reproduced in Figure 16. This map divides the study area into map units based on the number of times these units were visible from eight vantage points approximately 500 meters apart. The map shows the terrain visible from one or more viewpoints in a light grey shade, while the darker grey areas are visible from all eight viewpoints as reported by the `VISENCODE` AML mentioned above. The viewshed coverage from which this map is derived was compiled as follows. First, a viewpoint coverage was created by selecting observation points at 500 meter intervals along the roadway (it should be noted that there is a software limitation of 16 points in one viewpoint coverage). Second, the visibility command was executed specifying the `OBSERVERS` option. Third, the `VISENCODE` AML was executed to return the `VISIBLE-CODE` of the viewshed polygons visible from all eight viewpoints. Fourth, using the query and display tools in `ARCPLLOT`, a selection set which included all polygons visible from at least one viewpoint was drawn in light grey. The polygons visible from all eight viewpoints were selected according to the `VISIBLE-CODE` determined in the third step and drawn in a darker shade of grey. Finally, the roads, streams and viewpoint locations were drawn to provide locational references.

The `OBSERVERS` information can be used to perform an analysis of visual quality. For example, assigning a value to the visible polygons in your viewshed based on the number of times they are seen from each observation point would be an objective way to rank the

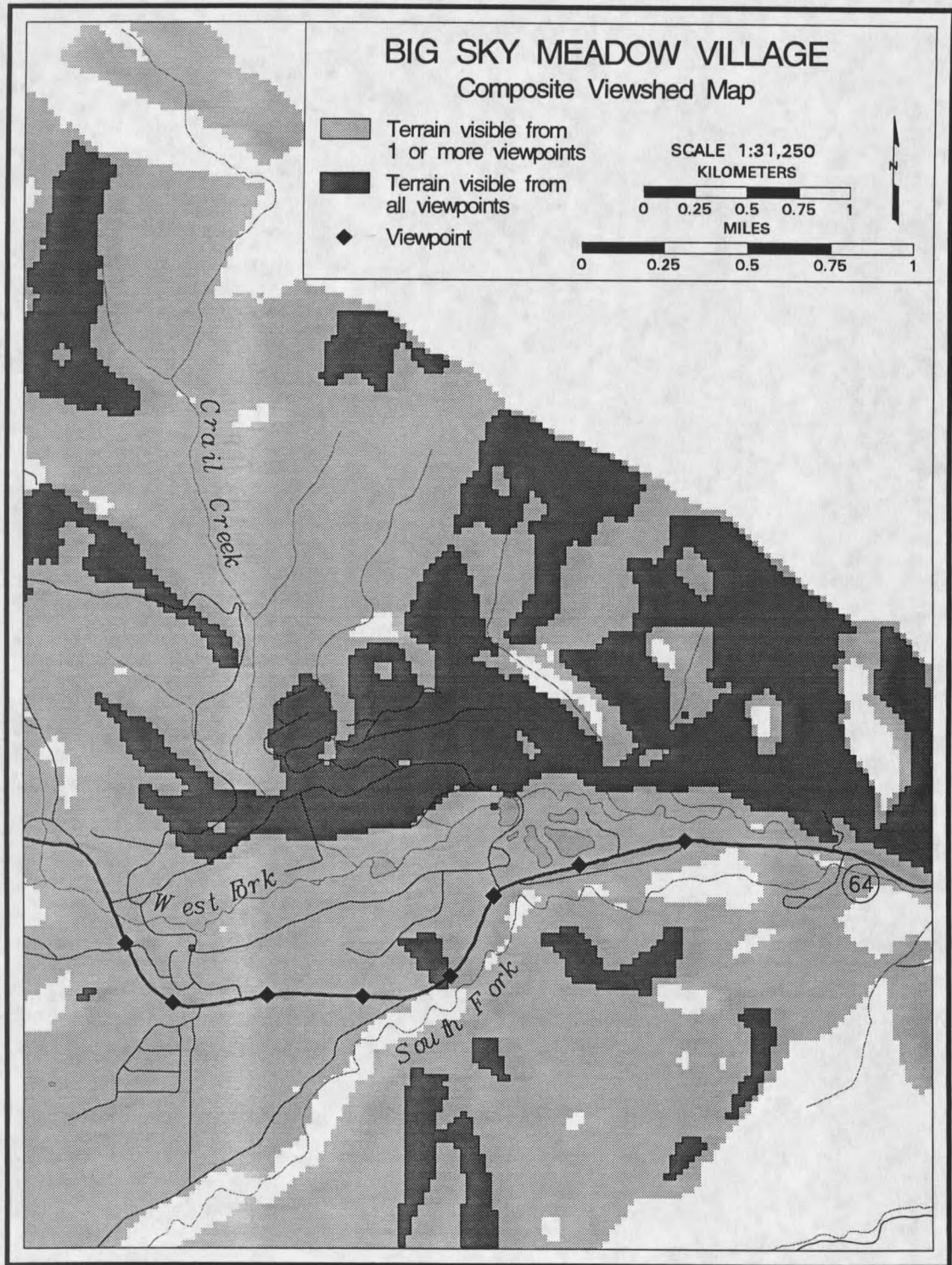


Figure 16. GIS viewshed map computed with new technique using the OBSERVERS option.

scenic quality of a region or landscape feature of interest. For instance, the darker grey polygons in Figure 15, which are seen by each of the 8 viewpoints, might be ranked higher in terms of visual sensitivity or significance than the other polygons because they are more visible from numerous locations throughout the Meadow Village. Also, you could select a number of observation points representing features of various visual quality such as transmission line towers, a landfill, parks, smokestacks, etc. and weight them accordingly. After running VISIBILITY with the OBSERVERS option, use the key file to select those polygons that can see each visual feature and tally a score for each viewshed polygon reflecting the visual quality and weight of each observation point. After all observation points have been considered, those polygons with the best scores will have the best visual quality.

The final criterion discussed in Chapter 1 involved the quantification of the character as well as the extent of the viewshed. This requires information about land cover - which based on earlier comments may affect the actual viewshed as well as determine what can be seen. This approach was attempted here, however it is difficult and expensive to undertake. Essentially, there are two options: (1) build the coverage from field reconnaissance by gathering information on the location of buildings, land cover types, etc. and key attributes describing them (height of buildings, type and size of trees, etc.), or (2) acquire remotely sensed imagery (orthophotograph, LANDSAT, SPOT) and use this information to build your land cover data base.

Because of the relatively high cost of digital imagery, the best option for acquiring land cover data was USGS paper orthophotography. The photographs could have been scanned as raster images and converted to an ARC/INFO vector format for interpretation and classification of land cover types. While this technology offers some clear advantages in terms of time and effort required to automate spatial data, there is still considerable effort

required to make the data intelligent by adding attributes and classifying land cover types. Aside from this, the most current orthophotographs of the study area were taken in 1976, just a few years after initial construction of the resort began. Given the rapid pace of development and logging activity in and around the resort during the past 18 years, it was decided to forego the implementation of the land cover layer because of concerns about the accuracy of the resultant data products.

Overall, this study has shown how a tool-box GIS like ARC/INFO can be utilized and customized to make a simple but powerful viewshed analysis technique. The Arc Macro Language programs described in Chapter 3, for example, sought to implement the viewshed analysis tools in such a way that people unfamiliar with ARC/INFO could utilize them. This goal was at least partially accomplished by writing the user prompts as a series of easy-to-follow questions. The portions of the AML reproduced in Tables 4 through 8, for example, ask the user to select or create a viewpoint coverage and add attributes to the viewpoint in order to customize the viewing parameters to suit their individual needs. The increasing availability of digital data from the USGS and other federal and state agencies will make the implementation of these programs easier in the future as well. This study also contributes to the field of cartography by offering a method to produce maps that were essentially impossible to make prior to the advent of computerized methods.

This increasing software functionality and data availability is timely because an increasing number of environmental impact studies include an assessment of the visual impacts of various land use and development proposals. Because visual quality can be a difficult resource to quantify and map, the automated determination of viewsheds and the resultant map products produced by the GIS are an effective means of evaluating the scenic resource. This study also contributes to the field of cartography by offering a method to

produce maps that were essentially impossible to make prior to the advent of GIS and computerized cartography. The results from visibility analyses may be used to help determine locations where the visual exposure of a project is minimized, for example, the development of a large condominium complex in a resort area, a site to harvest timber, and a corridor to build an electrical transmission line which is the least visible from a roadway, town, or other key viewing location. Other applications seek to maximize visibility for the placement of forest fire watch towers, communication and/or navigation facilities. This is but a sampling of the many diverse applications that can benefit from the utilization of GIS technology and automated viewshed determination techniques.

REFERENCES CITED

DeFloriani, L., Falcidieno, B., and C. Pienovi. 1986. A visibility-based model for terrain features. In: Proceedings of the Second International Symposium on Spatial Data Handling held in Seattle, Washington, 1986. pp. 235-250.

Doward, S. 1991. Character and quality: Successful resort edge. Ski Area Management, 2: 54.

ESRI, 1991. ARC/INFO User's Guide: Surface modeling with TIN. Redlands, CA: Environmental Systems Research Institute, Inc.

ESRI, 1992. Understanding GIS: The ARC/INFO Method. Redlands, CA: Environmental Systems Research Institute, Inc.

Felleman, J. and C. Griffin. 1990. The role of error in GIS-based viewshed determination: A problem analysis. Unpublished Final Project Report, USDA Forest Service, North Central Experiment Station, Agreement No. 23-88-27.

Gallatin County Planning Department, 1992. Draft land use plan. Gallatin Canyon/Big Sky Planning and Zoning District. Bozeman, Montana.

Goodchild, M.F. and S. Gopal (eds). 1989. The Accuracy of Spatial Databases. London: Taylor and Francis.

Goodchild, M.F. and J. Lee. 1989. Coverage problems and visibility regions on topographic surfaces. Annals of Operations Research, 18: 175-86.

Huang, S., Shepherd, W.E., and B.C. Johnson. 1991. Using GIS in power line route selection: Applications for landscape quality assessment. In: Proceedings of the Eleventh Annual ESRI User Conference held in Palm Springs, California, June, 1991. pp. 651-660.

Lee, J. 1991a. Comparison of existing methods for building triangular irregular network models of terrain from grid digital elevation models. International Journal of Geographical Information Systems, 5(3): 267-285.

Lee, J. 1991b. Analyses of visibility sites on topographic surfaces. International Journal of Geographical Information Systems, 5(4): 413-429.

Lee, J., P.K. Snyder, and P.F. Fisher. 1992. Modeling the effect of data errors on feature extraction from digital elevation models. Photogrammetric Engineering and Remote Sensing, 58(10): 1461-1467.

Lemkow, D.Z. 1977. Development of a digital terrain simulator for short-term forest resource planning. Unpublished M.S. Thesis, Department of Forestry, University of British Columbia. 207p.

McGaughey, R.J. and R.H. Twito. 1988. VISUAL and SLOPE: Perspective and quantitative representation of digital terrain models. Portland, OR: USDA-Forest Service, Pacific Northwest Research Station, Technical Report PNW-GTR-214.

Moore, I.D., Grayson, R.B., and A.R. Ladson. 1991. Digital terrain modeling: A review of hydrological, geomorphological, and biological applications. Hydrologic Processes, 5: 3-30.

Myklestad, E. and J.A. Wagar. 1976. PREVIEW: Computer assistance for visual management of forested landscapes. Morgantown, WV: USDA-Forest Service, Northeastern Forest Experiment Station, Research Paper NE-355.

Nickerson, D.B. 1980. PERSPECTIVE PLOT: An interactive analytical technique for visual modeling of land management alternatives. Portland, OR: USDA-Forest Service, Pacific Northwest Region, Logging Systems Group.

Smardon, R.C., Palmer, J.F., and J.P. Felleman. 1986. Foundations for Visual Project Analysis. New York, NY: John Wiley and Sons.

Theobald, D.M., and M.F. Goodchild, 1990. Artifacts of TIN-based surface flow modeling. In GIS/LIS '90 Proceedings. Anaheim: American Congress on Surveying and Mapping. pp. 955-967.

Travis, M.R., Elsner, G.H., Iverson, W.D., and C.G. Johnson. 1975. VIEWIT: Computation of seen areas, slope and aspect for land-use planning. Washington, D.C.: USDA-Forest Service, Technical Report PSW-11.

Twito, R.H. 1978. Plotting landscape perspectives of clearcut units. Portland, OR: USDA-Forest Service, Pacific Northwest Forest and Range Experiment Station, Technical Report GTR-PNW-71.

Twito, R.H., Mifflin, R.W., and R.J. McGaughey. 1987. The MAP program: Building the digital elevation model. Portland, OR: USDA-Forest Service, Pacific Northwest Forest and Range Experiment Station, Technical Report PNW-GTR-200.

USDA Forest Service, 1977. The visual management system. National Forest Landscape Management, Volume 2. Agriculture Handbook Number 462. Washington, D.C.: U.S. Government Printing Office.

Young, G.G. and D.Z. Lemkow. 1976. Digital terrain simulators and their application to forest development planning. In Proceedings of the 1976 Skyline Logging Symposium held in Vancouver, British Columbia, December 8-10, 1976. Vancouver, B.C.: University of British Columbia Press. pp. 81-99.



05 01
04 02
04 02
13
08