



United States
Department of
Agriculture

Forest Service

Pacific Northwest
Research Station

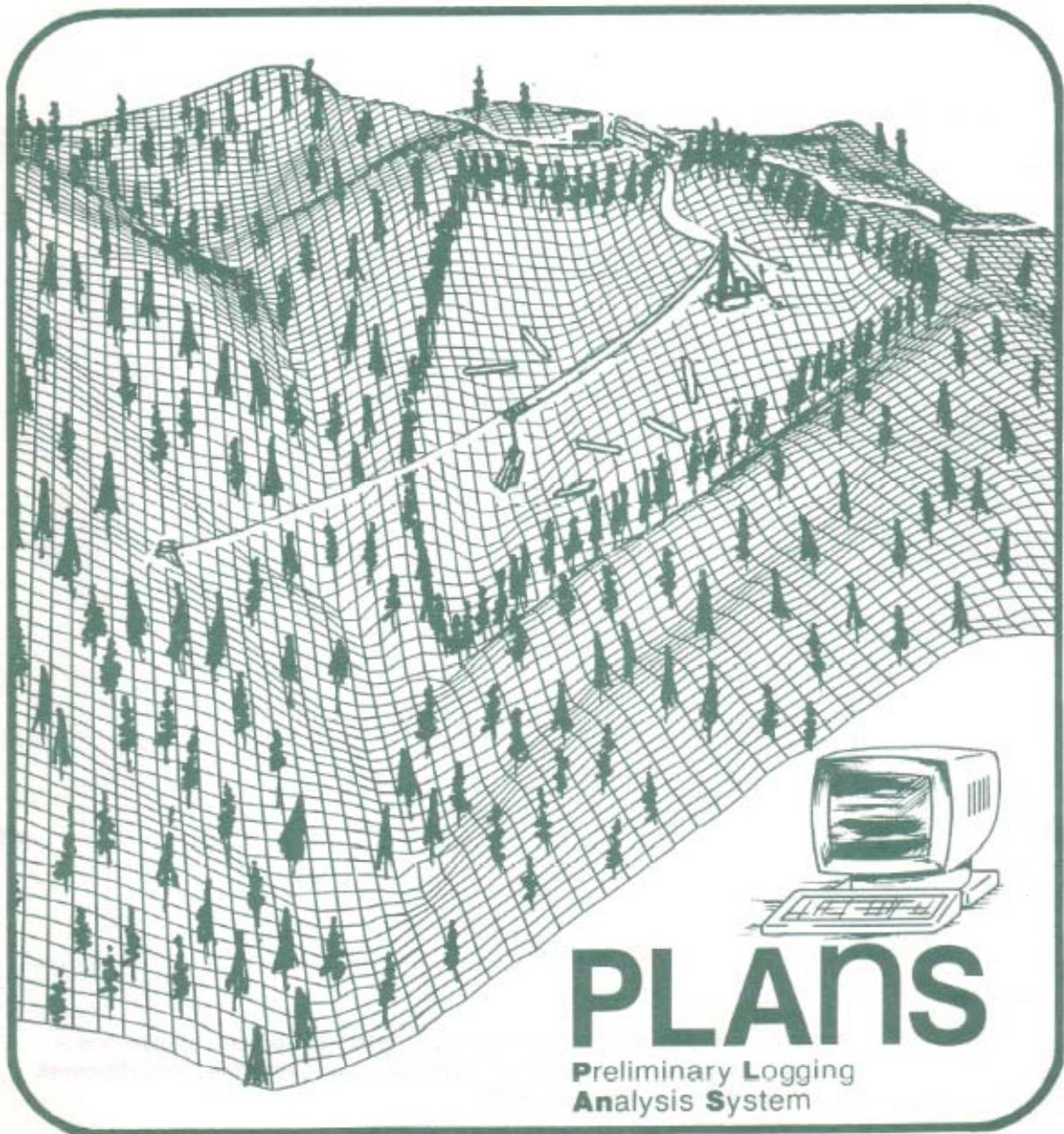
General Technical
Report PNW-GTR-
214

August 1988



VISUAL and SLOPE: Perspective and Quantitative Representation of Digital Terrain Models

Robert J. McGaughey and Roger H. Twito



Authors

ROBERT J. McGAUGHEY and ROGER H. TWITO are research forester and research civil engineer, respectively, Forestry Sciences Laboratory, 4043 Roosevelt Way NE, Seattle, Washington 98105.

Abstract

McGaughey, Robert J.; Twito, Roger H. 1988. VISUAL and SLOPE: perspective and quantitative representation of digital terrain models. Gen. Tech. Rep. PNW-GTR-214. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 26 p.

Two computer programs to help timber-harvest planners evaluate terrain for logging operations are presented. The first program, VISUAL, produces three-dimensional perspectives of a digital terrain model. The second, SLOPE, produces map-scaled overlays delineating areas of equal slope, aspect, or elevation. Both programs help planners familiarize themselves with new terrain and obtain a general feel for the land. Included are descriptions of operating procedures, descriptions of major algorithms, suggested applications, and limitations. Guides for the programs are available from the authors.

Keywords: Logging operations analysis/design, topography, timber harvest planning, computer programs, programing.

Contents

1	Introduction
2	VISUAL
2	Background
2	Procedure
4	Applications
5	Algorithm Description
11	Limitations
14	SLOPE
14	Background
14	Overview
16	Algorithm Descriptions
23	Limitations
24	Conclusion
24	Metric Equivalents
25	Literature Cited

Introduction

Knowledge of the terrain is essential to plan timber harvests. Familiarity with the terrain improves the likelihood that the effort expended in planning will produce a viable timber-harvest plan within a reasonable time. Experienced planners may be able to form an adequate visual image of the terrain from a large-scale topographic map; nevertheless, projections quantifying or displaying terrain in ways other than a topographic map can increase planners' familiarity with the terrain and allow them to more quickly see timber-harvest opportunities or to solidify strategies developed from the topographic map.

This report introduces two programs that create alternative visual displays for terrain. The programs, VISUAL and SLOPE, are part of PLANS (preliminary logging analysis system) reported by Twito and others (1987b). PLANS is an integrated package of computer programs designed to help planners develop and analyze timber-harvest plans. PLANS operates on a Hewlett-Packard 1 (HP) 9020 desktop computer system. Peripherals linked to the 9020 include a dot-matrix printer, a large-format digitizer, and a large-format drum plotter. All the programs in PLANS require topographic map coverage of the planning area. The topographic maps, represented as digital terrain models (DTMs), are a common data source for all PLANS programs. The process of creating a DTM from a topographic map is described by Twito and others (1987a). VISUAL produces three-dimensional perspectives of a DTM such as that shown in figure 1. SLOPE produces map-scaled overlays delineating areas of equal slope, aspect, or elevation within a DTM.

¹ The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

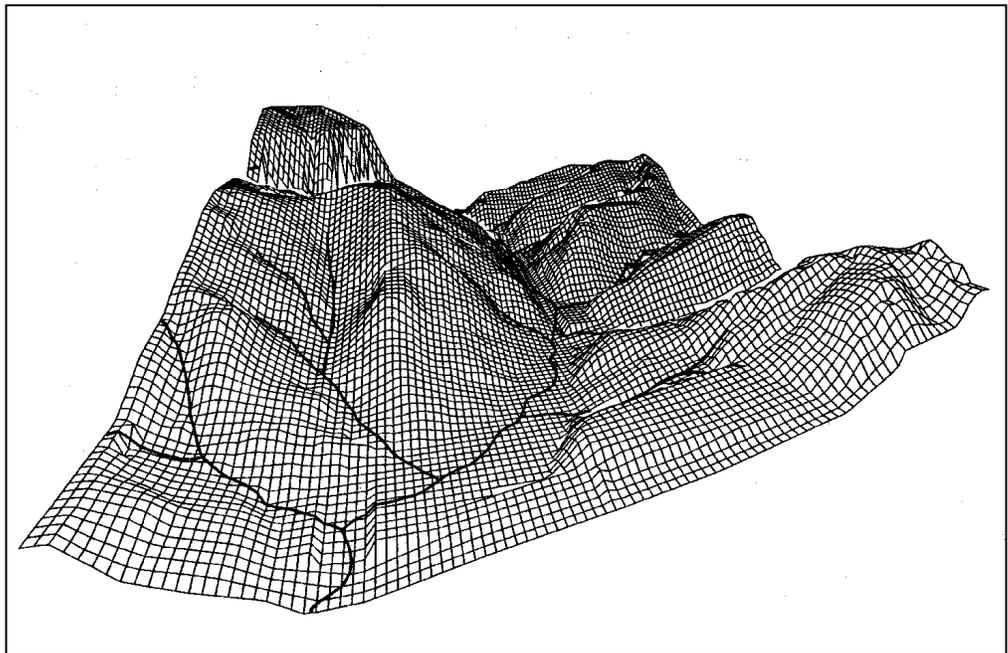


Figure 1 – Perspective of a DTM

VISUAL

VISUAL produces three-dimensional perspectives of a DTM. In addition; harvest-plan features such as unit boundaries and roads can be drawn on the perspective. A major application of VISUAL is helping planners acquire a feeling for the landscape. The three-dimensional perspective may also provide a convenient and useful way to check the appearance of the cutting area in locations where aesthetic values are important. By using perspectives produced by VISUAL, planners can see terrain features not obvious on a topographic map. Perspectives also help planners check the quality of a newly produced DTM. Anomalies in the DTM, whether created when the DTM was built or a result of gross errors in the original topographic map, are obvious on the perspectives.

Background

Early software in forestry that produced three-dimensional views of terrain was developed in the early 1970's on large mainframe computers; that is, CDC 6400 or IBM 370. These applications were designed to meet the needs of visual management specialists responsible for designing the shape of harvest units and scheduling harvest activities to minimize the overall visual impact on forested landscapes. VIEWIT (Travis and others 1975) was designed to compute ground slope and aspect information from a DTM and determine the area that can be seen from specific viewing corridors. PREVIEW (Myklestad and Wagar 1976), developed on a mainframe system, converts mapped harvest proposals into drawings in perspective depicting proposed landscape changes. PREVIEW simulates various types of vegetative cover and depicts stand growth on clearcut units to aid in scheduling harvest activities. Despite the powerful applications presented by these early programs, they were not readily available to timber-harvest planners because of the requirements of the computing system and the expertise required to operate the programs.

Efforts to develop comprehensive topographic-analysis packages by using a DTM on an interactive desktop computer system began with the Digital Terrain Simulator (Lemkow 1977, Young and Lemkow 1976) developed at the University of British Columbia (UBC). One element of this package produces orthographic projections of a DTM and harvest-plan features (roads and harvest boundaries). UBC's pioneering effort in this area was severely hampered by the speed of execution and the limitations of the internal memory in the HP 9830 A computer that it was developed on. Additional efforts with the HP 9830 A are reported by Twito (1978) and Nickerson (1979). Twito's software deals with perspectives of proposed clearcut units, and Nickerson's package of three programs delineates areas on the ground visible from a specified viewpoint and produces perspectives of harvest areas and of DTMs to aid district-level visual management specialists. PERSPECTIVE PLOT (Nickerson 1980), developed on the HP 9845 desktop computer, was designed to provide a full range of viewing options to help visual management specialists analyze proposed landscape changes.

VISUAL, originally developed on an HP 9845 microcomputer, provides a basic way to view harvest units and roads designed with PLANS.

Procedure

Figure 2 shows the process followed during a typical session using VISUAL.

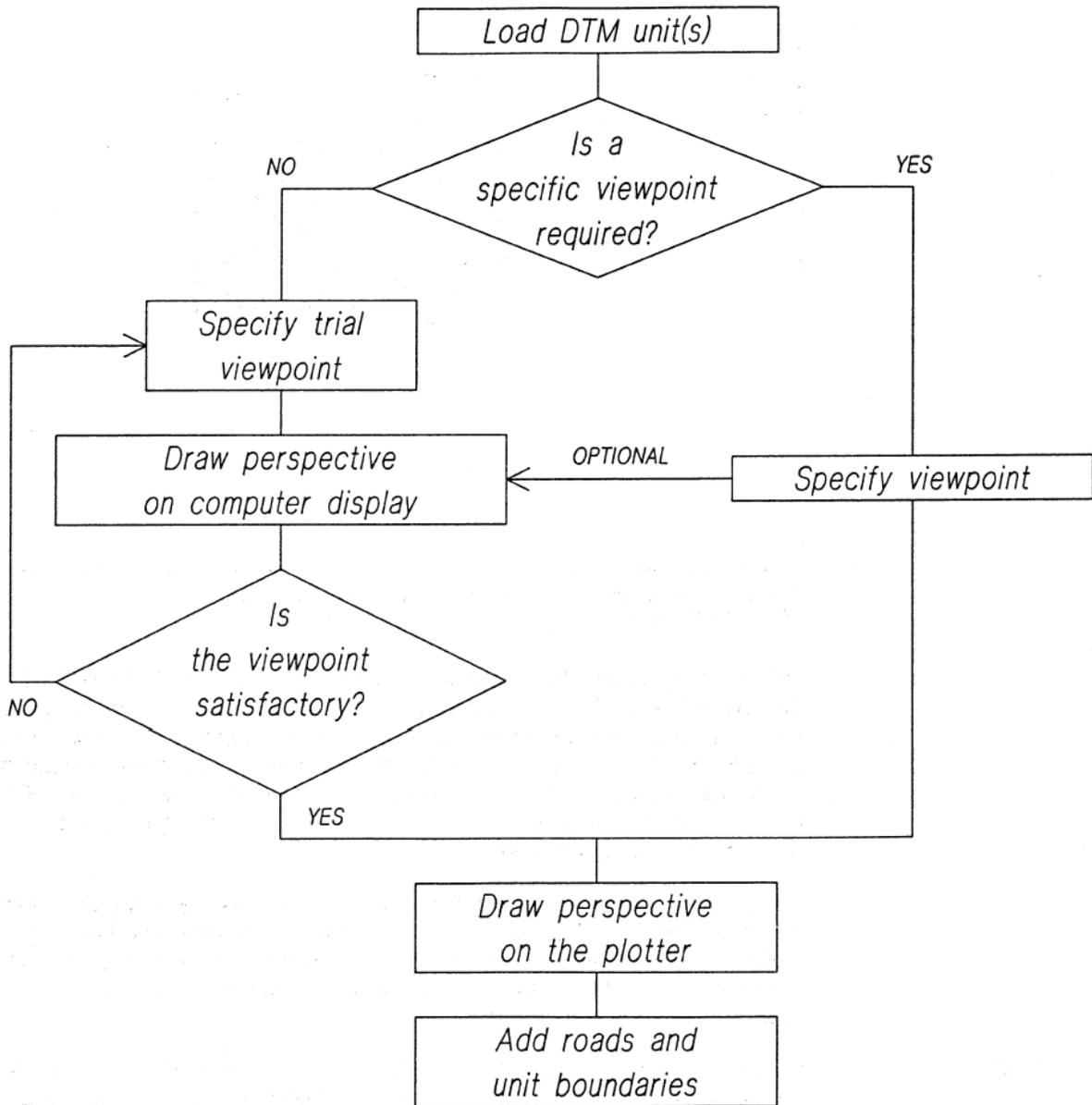


Figure 2—Activities involved in using VISUAL.

The point the terrain is viewed from (viewpoint) can be in an area three times the width and three times the height of the DTM and must be outside the DTM boundary (fig. 3). The viewpoint is selected from the computer display rather than by digitizing a location on a map. The location of the digitizer cursor is shown on the display to help users establish the viewpoint. It is easy to pinpoint a specific viewpoint by aligning the on-screen cursor with the digitizer cursor on the display. When the desired viewpoint cannot be marked with the digitizer cursor, trial and error are required to

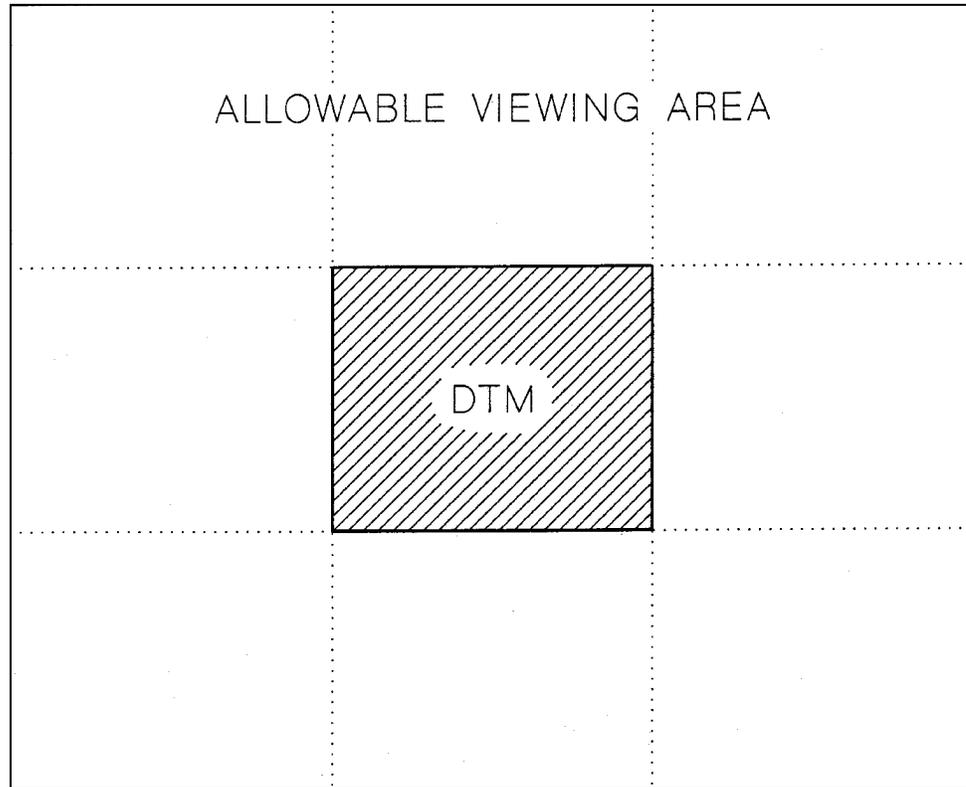


Figure 3—The viewpoint must be outside the DTM unit but within the allowable viewing area.

locate the viewpoint. The distances from trial viewpoint locations to the nearest corners of the DTM are displayed, and when these distances are compared with measurements on the map, the location of the viewpoint can be adjusted until it is reasonably close to the desired map location. After the planimetric location of the viewpoint is established, the user enters the elevation of the viewpoint. Elevations can range from ground level, as if viewing from a trail or highway vista, to high overhead, simulating an aerial view.

Perspectives can be drawn on either the computer display or the drum plotter. Plots drawn on the computer display require less time than those produced on the drum plotter and are especially useful when a viewpoint is needed for a satisfactory view of the harvest area. After viewing a plot on the display, the user can have the plot drawn on the plotter.

Applications

VISUAL can be used as a visual analysis tool because it previews the shape of proposed clearcutting units. It was never intended to provide the full range of visual analysis options offered by other three-dimensional packages such as PERSPECTIVE PLOT (Nickerson 1980); however, when the analytical task is suited to its output (delineating "as seen" harvest-unit boundaries), it is an efficient method. Beyond that, VISUAL can aid in making pre planning decisions by helping the user become familiar with and understand the topographic features of an area. By using perspectives produced by VISUAL, planners can make decisions on equipment allocation based on overall landform and equipment compatibility.

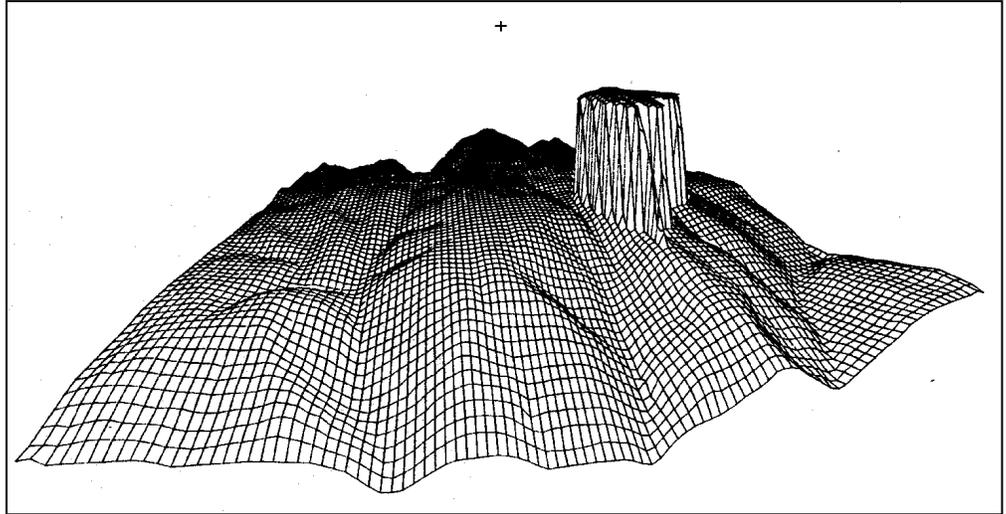


Figure 4—Perspective showing an obvious topographic error resulting from incorrect elevation data.

VISUAL can be used to check the quality of a DTM. Figure 4 shows a perspective of a DTM with a gross elevation error. The error was caused when the individual creating the DTM from the contour map entered an elevation of 3,380 feet instead of the correct elevation of 2,380 feet. This type of error, obvious on the perspective, may be difficult to pinpoint with other PLANS programs. If the extent of such an error is known, a portion of the contour map can be reentered to correct the elevations.

Perspectives produced by VISUAL can also be used to examine a harvest plan. Figure 5 shows a perspective of a portion of a harvest plan developed with PLANS. The plot shows how individual unit designs and road segments fit together to cover the entire planning area. Buffer areas left to protect streams and areas not logged because they are too steep are obvious on the plot. Although planners can generally visualize a harvest plan by examining the topographic map, the perspective may be effective in presentations to others.

Algorithm Descriptions

Perspectives produced by VISUAL are similar to still photographs of the terrain taken from the viewpoint with three exceptions. First, terrain features are shown without any spherical distortion caused by lenses of short focal length. Second, perspective views are always viewed vertically regardless of the viewpoint; photographs, to render true perspective, must be tilted to the same angle as the camera when the photo was taken. Third, perspectives do not contain distortions caused by curvature of the earth or atmospheric refraction. These distortions have little effect unless the viewed objects are great distances away.

Before a perspective can be produced, the position of the viewpoint relative to the DTM must be determined so hidden areas can be removed properly. The perspective-projection algorithm will operate properly regardless of the location of the viewpoint; however, the hidden-line-removal algorithm requires that the DTM be plotted from foreground to background.

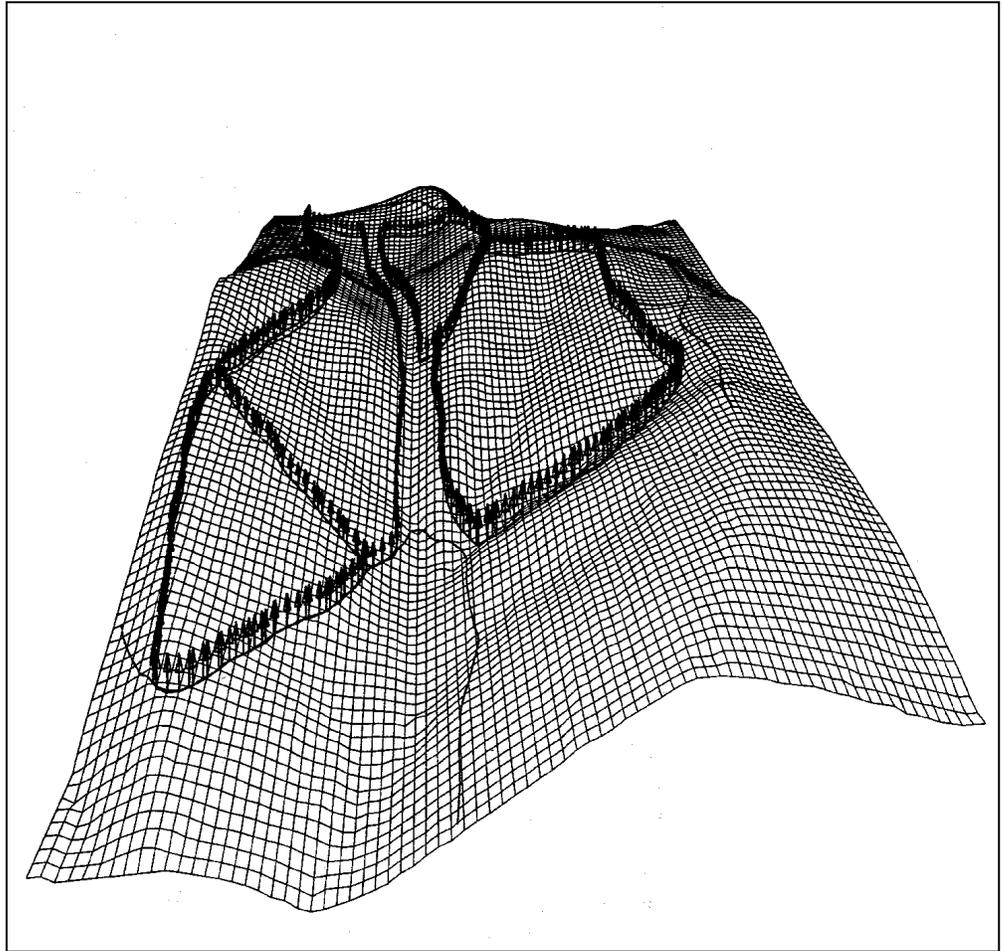


Figure 5—Perspective of a DTM showing a portion of a harvest plan.

Perspective projection—The method used for perspective projection, adapted from Twito (1978), relates solved horizontal and vertical angles from DTM data to a plotted diagram where the viewpoint is a fixed distance from the diagram. Perspective projection, plotting, and hidden-line deletion occur simultaneously. A similar method using matrix algebra is reported by Lemkow (1977) and performs the perspective transformation on the entire DTM, then plots the surface and removes hidden areas in a separate process.

The description of the perspective-projection process uses the following variables:

Variable	Definition
(View_x, View_y)	Coordinates of the viewpoint
View_elev	Elevation of the viewpoint
(Grid_x, Grid_y)	Coordinates of the DTM grid point being projected
Grid_elev	Elevation of the DTM grid point being projected
Eye_dist	Distance from the viewer's eye to the perspective
Ref_az	The azimuth angle of the reference line
Map_scale	Scale of the topographic map used as a planning base

The first step in generating a perspective is to establish a reference line from the viewpoint into the DTM unit boundary. This reference line, perpendicular to the paper or screen the perspective is drawn on, is used as a zero line when calculating angles during the projection process.

The projection of an individual grid point is accomplished with an eight-step process. Steps 1, 2, and 3 determine the abscissa for the DTM grid point from variables shown in figure 6, and steps 4 through 8 determine the ordinate from variables shown in figure 7.

Step 1: Calculate the azimuth angle from the viewpoint to the grid point (Grid_az):

$$\text{Grid_az} = \text{ARCTAN} ((\text{Grid_y} - \text{View_y})/(\text{Grid_x} - \text{View_x})) .$$

Step 2: Calculate the difference in azimuth angles between the reference line and the line from the viewpoint to the grid point (Az_diff):

$$\text{Az_diff} = \text{Ref_az} - \text{Grid_az} .$$

Step 3: Calculate the projected x-value for the plot (Plot_x):

$$\text{Plot_x} = \text{Eye_dist} \times \text{TAN}(\text{Az_diff}) .$$

Step 4: Calculate the horizontal distance from the viewpoint to the grid point (Horiz_dist) :

$$\text{Horiz_dist} = ((\text{Grid_x} - \text{View_x})^2 + (\text{Grid_y} - \text{View_y})^2)^{1/2} \times \text{Map_scale} .$$

Step 5: Calculate the difference in elevation between the grid point and the viewpoint (Elev_diff) :

$$\text{Elev_diff} = \text{Grid_elev} - \text{View_elev} .$$

Step 6: Calculate the vertical angle to the grid point (Vert_angle):

$$\text{Vert_angle} = \text{ARCTAN} (\text{Elev_diff}/\text{Horiz_dist}) .$$

Step 7: Calculate the horizontal distance from the viewer's eye to the projected x value on the perspective (Horiz_proj):

$$\text{Horiz_proj} = (\text{Plot_x}^2 + \text{Eye_dist}^2)^{1/2} .$$

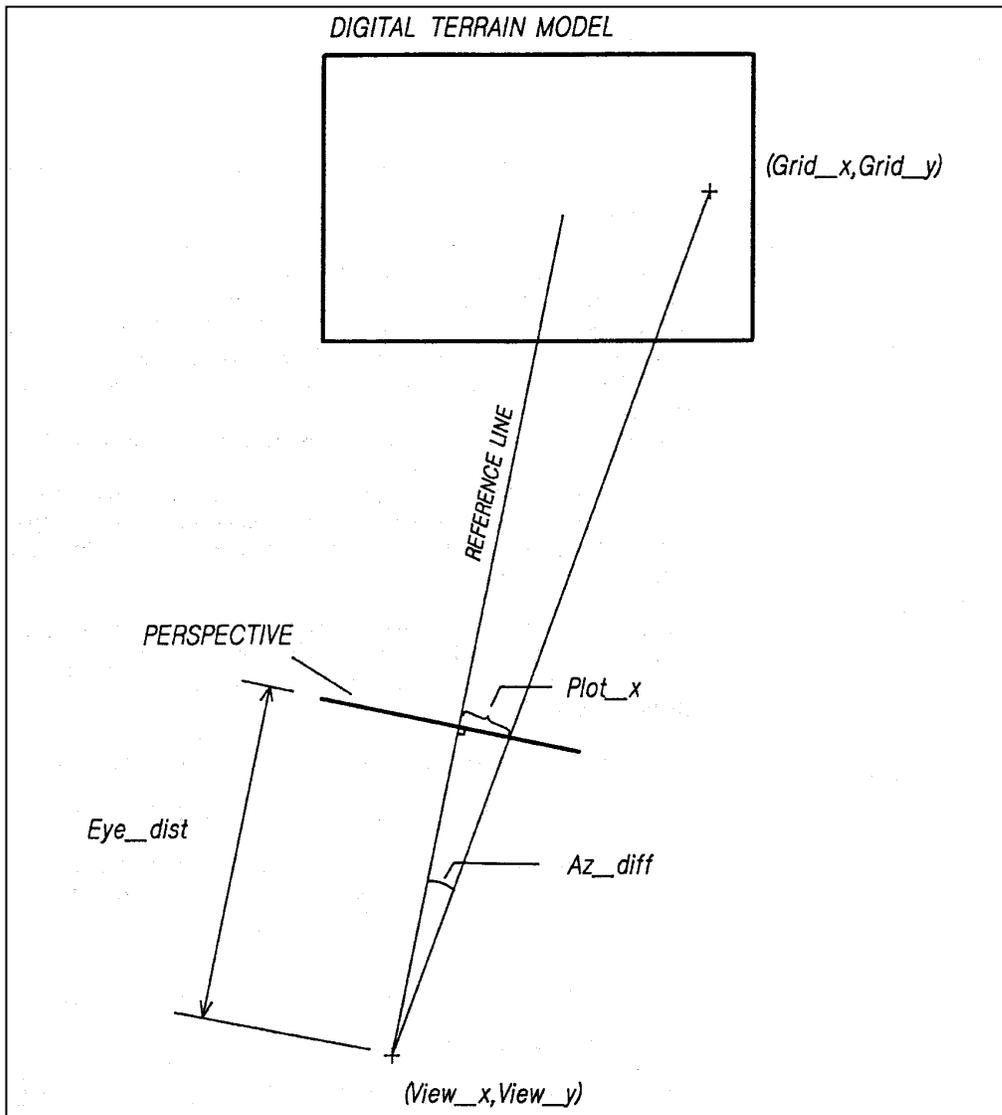


Figure 6—Solving for the abscissa on the perspective corresponding to (Grid_x, Grid_y) in the DTM.

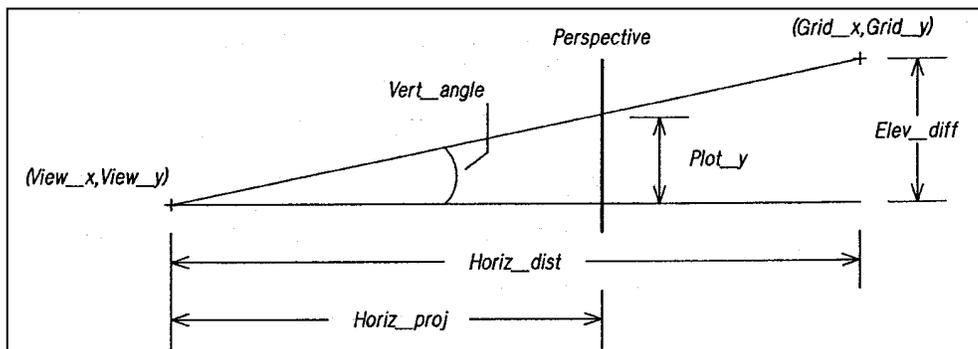


Figure 7—Solving for the ordinate on the perspective corresponding to (Grid_x, Grid_y) in the DTM.

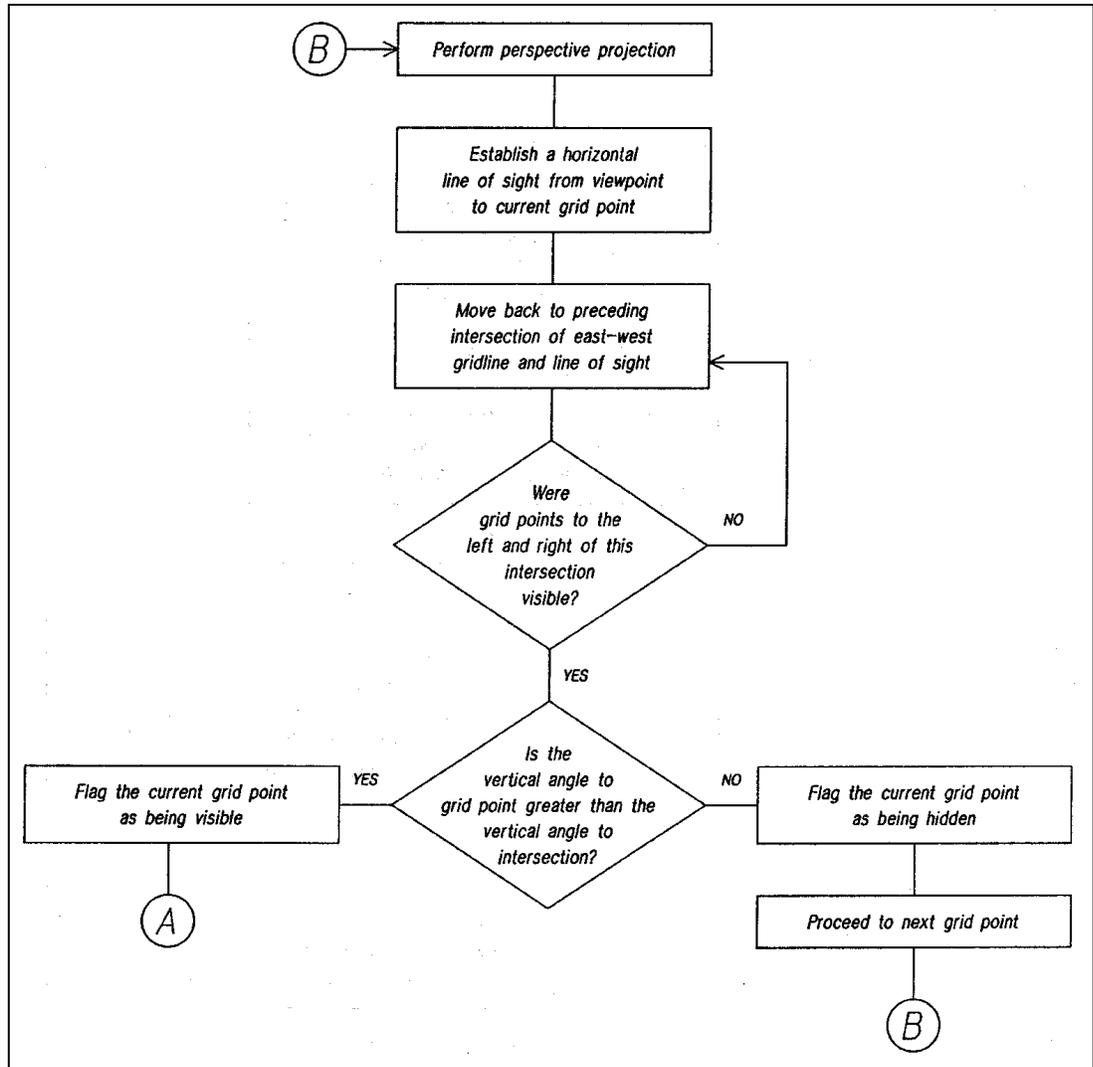


Figure 8—Process used to check the visibility of a DTM grid point.

Step 8: Calculate the projected y-value for the plot (Plot-y):

$$\text{Plot-y} = \text{Horiz_proj} \times \text{TAN}(\text{Vert_angle}) .$$

This eight-step process is repeated for all grid points in the DTM. The decision to plot a particular grid point is based on whether the terrain represented by the grid point would be visible or hidden to someone at the actual viewpoint.

Hidden lines--Deleting hidden lines is necessary to remove areas from the perspective that would not be seen from the actual viewpoint. The logic used to determine whether or not a single grid point is visible or hidden is charted in figure 8. Minor adjustments to this logic ensure that the perspective is drawn from foreground to background regardless of the location of the viewpoint. Vertical angles, used to determine if the line of sight from a particular grid point to the viewpoint is obstructed, are calculated with the method outlined in steps 4, 5, and 6 of the perspective-projection algorithm.

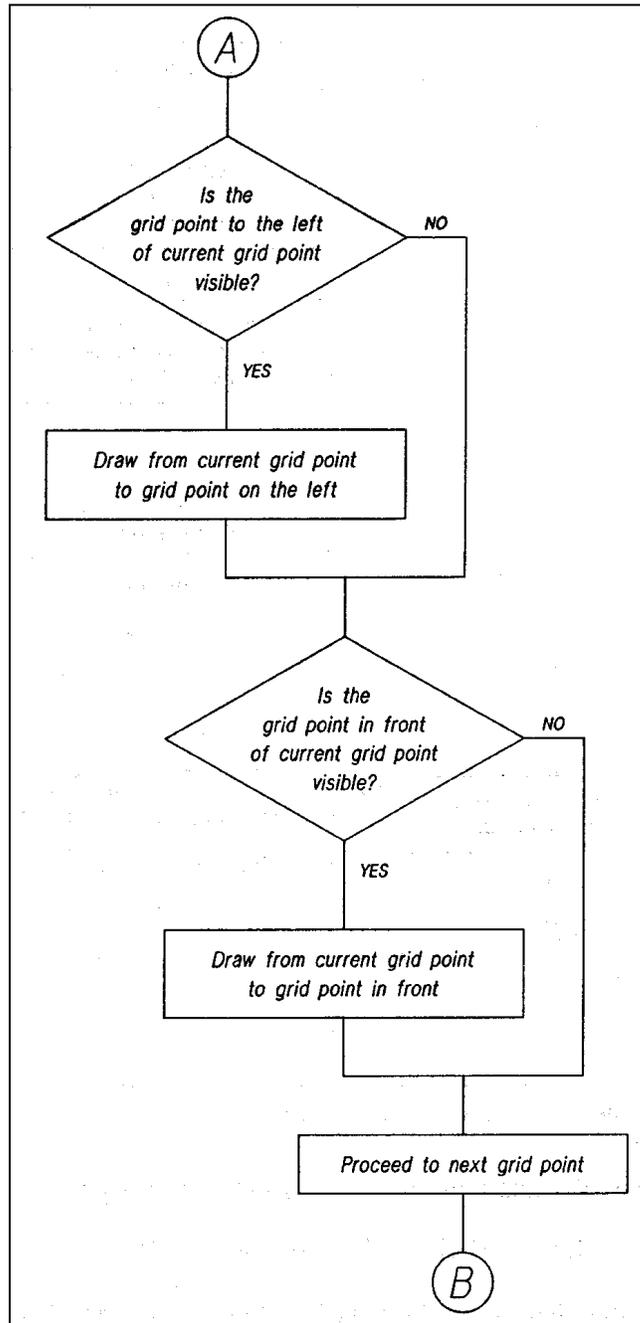


Figure 9—Process used to determine which DTM gridlines should be plotted.

The decision to draw or omit the gridlines associated with a visible grid point depends on the logic diagrammed in figure 9.

Adding features—Linear map features can be added to perspective views produced on the plotter. Features, entered in plan view, are mathematically projected onto the perspective of the terrain. Features can be represented on the perspective as a solid line (for example, a road or trail) or as a solid line with trees drawn intermittently along the line (for example, a timber-harvest boundary). Inputting a feature involves tracing the feature from the topographic map with the digitizer. Coordinates describing the feature are thinned to a spacing equal to about 70 percent of the grid spacing. The thinned points maintain a smooth boundary but require much less storage space than if all coordinates sent from the digitizer were saved. After a feature is traced, all intersections of the feature with horizontal or vertical gridlines are calculated. The coordinates of these intersections are stored and will be used to plot the feature on the perspective. Perspective projection of these coordinates is accomplished with the same process used to project the DTM. As with the perspective, only points visible from the viewpoint are plotted. To determine if a point in the feature is visible or hidden, the visibility of the grid point closest to the point in the feature is checked. Flags were set to indicate the visibility of each grid point when the perspective was drawn. The program checks the appropriate flag; if the grid point is visible, the point in the feature is assumed to be visible.

When plotting a harvest-unit boundary, a tree scaled to the perspective is drawn at each point along the feature.

Limitations

VISUAL has three major limitations: (1) viewpoints are restricted to a specific area, (2) holes can appear in a perspective, and (3) plots can be oriented so they do not fit on the page or screen. These limitations are relatively minor and do not affect the usefulness of VISUAL.

As mentioned earlier, viewpoints are restricted to an area three times the width and three times the height of the DTM and cannot be located inside the DTM boundary. This restriction does not hamper the use of VISUAL as a viewing system; however, it does constrain applications for visual management. Users may find that locating the position of the viewpoint on the CRT requires more effort than digitizing the location of the viewpoint, but this method permits the use of viewpoints not on the map representing the DTM.

Holes in the perspective result from the process used to delete hidden lines. Near transition areas between visible and hidden grid points, the plotting algorithm does not attempt to draw the visible portion of the gridline between a visible and hidden grid point. Thus, portions of the visible grid are not drawn, thereby giving the appearance of holes in the plot.

Figure 10 shows a plot delineating visible and hidden grid points in a DTM as seen from the viewpoint near the lower right corner of the DTM. When the grid points are processed through the perspective-projection algorithm, the region between hidden areas and visible grid points becomes a hole in the perspective. Figure 11 shows the perspective of the DTM with holes corresponding to the hidden areas shown in figure 10. In this figure, as well as most perspectives, the holes are a noticeable quirk but should not affect the visual interpretations of the plot.

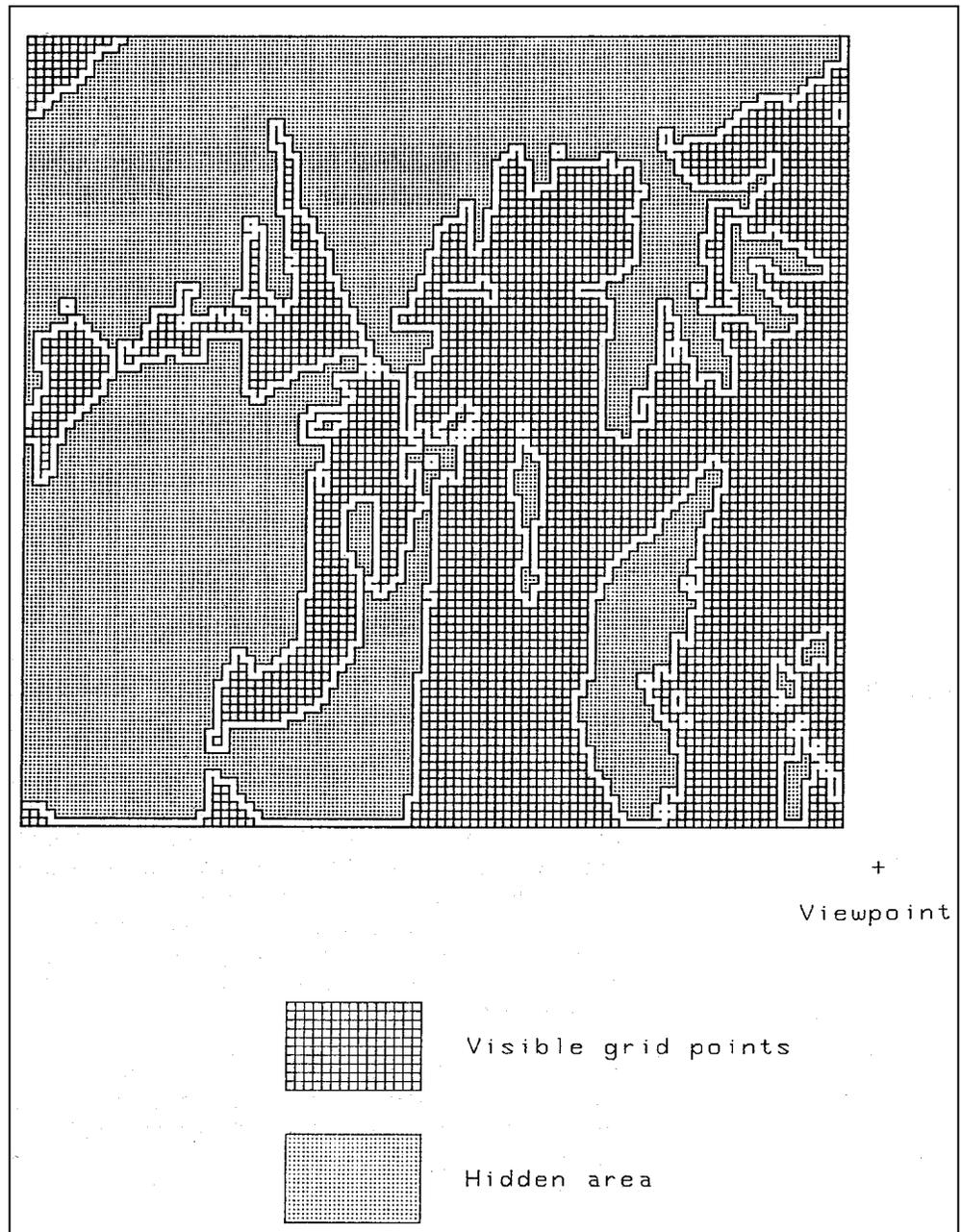


Figure 10— Visible and hidden areas of a DTM as viewed from the lower right corner of the unit.

The final limitation involves a potential scaling problem in drawing a perspective. The plotting routine positions the perspective on the plotting device to provide a specific margin along the sides and bottom of the plot. If the viewpoint is high in elevation and close (horizontally) to the DTM, the height of the perspective can exceed the maximum height allowed on the plotting device. This problem is related to the vertical

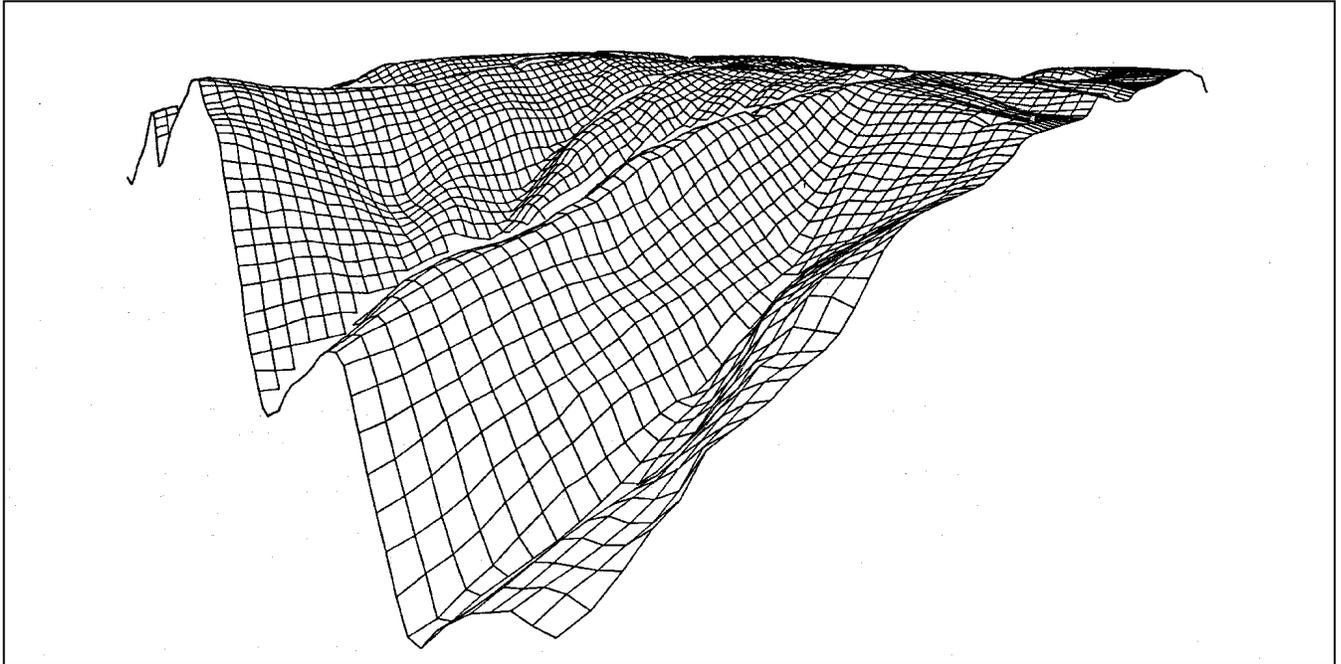


Figure 11—Perspective of the DTM shown in figure 10 showing the holes that appear between hidden and visible areas.

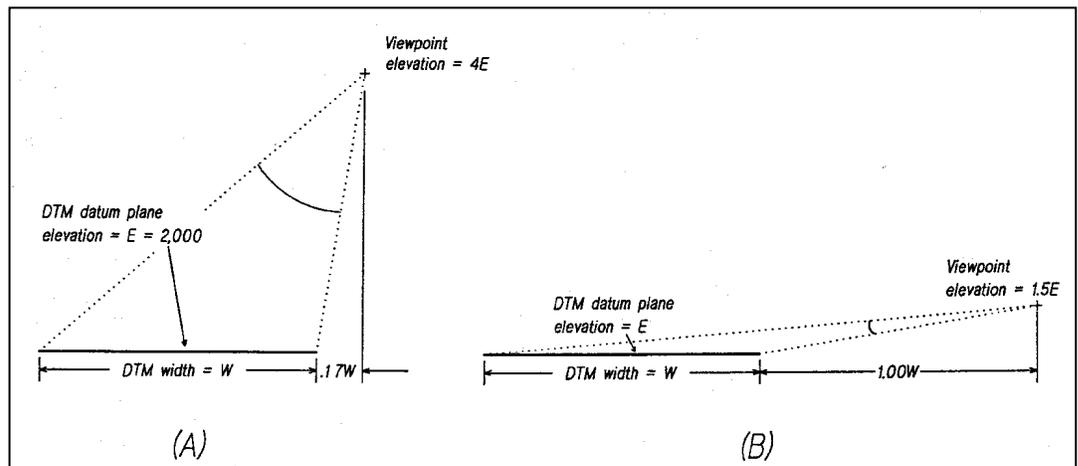


Figure 12—A large vertical angle (A) produces a perspective that may be too large for the plotting device. A small vertical angle (B) produces a perspective that will fit on the plotting device.

viewing angle determined by the position of the viewpoint relative to the DTM. Figure 12 (A) shows the vertical angle associated with a viewpoint close to the DTM ($0.17 \times$ width of the DTM, W) and high in elevation ($4 \times$ elevation of the DTM datum plane, E) and (B) shows a viewpoint farther away from the DTM ($1.00 W$) with an elevation closer to that of the terrain features ($1.5 E$). The large angle in A will cause the perspective to be stretched vertically when plotted. This could result in the plot being too tall for the CRT or paper, but it depends on the elevation and distance from the DTM to the actual viewpoint. In most cases, plots produced with a viewpoint separated from the DTM by a distance equal to or greater than half the DTM width ($0.5 W$) and elevated to a point 1.5 - 2 times the elevation of the highest terrain feature in the DTM will fit easily within the plotting area and result in an acceptable plot of terrain features.

SLOPE

Slope, aspect, and elevation are such basic variables that they affect managerial decisions ranging from when and where trees should be harvested to how a ski slope should be designed. In timber harvesting, severity of the slope limits harvesting options and often dictates the equipment capable of conducting the harvest. Aspect strongly influences the silvicultural options possible for a site. Elevation determines the length of the operating season for a unit and has a strong influence on species composition and the overall productivity of a site.

Slope, aspect, and elevation can be quantified by hand with a topographic map. It may be reasonable to determine slope, aspect, and elevation for small units under consideration for harvest; however, for larger areas, manually identifying and delineating areas of equal slope or aspect is time consuming. SLOPE produces map-scaled overlays delineating areas of equal slope, aspect, or elevation within a DTM. SLOPE can also produce overlays delineating terrain characterized by a specific combination of slope, aspect, and elevation.

Background

Work on GIS at the Harvard Graphics Laboratory included producing maps on line printers that depict slope, aspect, and elevation (Carter 1984). This work required that the slope, aspect, and elevation data be input as rectangular matrices rather than being computed from a DTM. VI EWIT (Travis and others 1975) used a DTM to compute seen areas, slope, and aspect for various land-use planning purposes. VIEWIT produced maps on line printers and tabular summaries of attribute data and was designed to operate on a large mainframe system. Lemkow (1977) describes a method for producing overlays of slope, aspect, and elevation with a small, interactive microcomputer system. His approach, although analytically feasible, required computing power unavailable on microcomputers in the late 1970's. SLOPE implements Lemkow's methods on a state-of-the-art microcomputer.

Overview

SLOPE is an aid to the harvest-planning process extracting data from the DTM and presenting the data in easily understood forms; that is, map-scaled plots and summary tables. Planners can use the overlays and summary tables in several ways. Slope overlays (fig. 13) are useful when general logging-system requirements are determined for a harvesting area. Because categories of harvesting systems (ground-based, highlead, skyline) can be associated with various steepnesses of terrain, planners can obtain estimates of the need for these systems by producing slope overlays broken into appropriate slope categories. This information can be used for unit selection and during the early stages of detailed harvest planning. Additional uses of SLOPE include identifying good reproduction sites and finding areas suitable for winter or year-round logging.

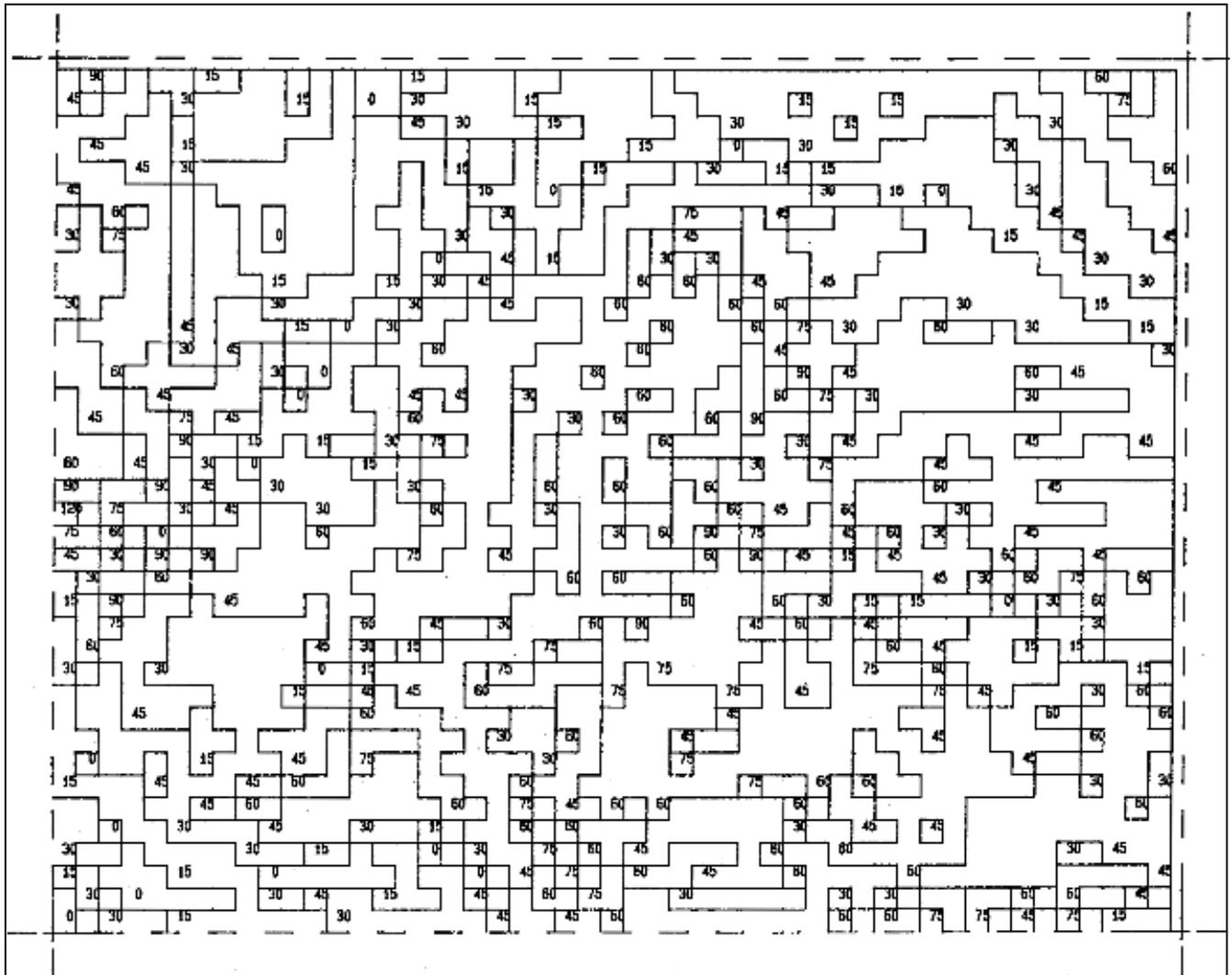


Figure 13—Slope overlay produced by the SLOPE program.

The first step in using SLOPE is to load the desired DTM. Because of the memory requirements of SLOPE, only one DTM unit can be loaded at a time (in other PLANS programs, up to six DTM units can be aggregated). Next, the user specifies the size of a topographic-attribute unit. A topographic-attribute unit can be a single DTM grid cell or it can be a combination of 4 (2 cells by 2 cells), 9 (3 by 3), 16 (4 by 4), or 25 (5 by 5) DTM grid cells. If a topographic-attribute unit consists of a single DTM grid cell, terrain attributes will be calculated and plotted for each DTM grid cell; the result is an overlay with the highest possible resolution. As more DTM grid cells are combined into a single topographic-attribute unit, the resolution of the plot decreases, the plotting time decreases, and the plot becomes easier to interpret. In addition to the size of the topographic-attribute unit, the user must provide a map rotation if north on the original topographic map was not aligned with digitizer north. Digitizer north is parallel to the side of the digitizing tablet with north at the top of the tablet. After specifying the size of the topographic-attribute unit and the map rotation, the user can select the desired overlay.

SLOPE CLASS SUMMARY OF THE EXAMPLE_DTM1 DTM UNIT			
SLOPE CLASS	RANGE OF SLOPES (PERCENT)	ACRES	PERCENT
0	0 - 14.99	11.54	4.98
15	15 - 29.99	26.96	11.65
30	30 - 44.99	47.11	20.36
45	45 - 59.99	73.34	31.69
60	60 - 74.99	51.48	22.25
75	75 - 89.99	12.39	5.35
90	90 - 104.99	2.91	1.26
105	105 - 119.99	.24	.10
120	120 - 134.99	.12	.05
		TOTAL ACREAGE = 231.40 ACRES	

Figure 14—Acreage summary for the slope overlay shown in figure 13.

SLOPE produces slope, aspect, and elevation overlays that delineate areas of equal slope, aspect, or elevation. Slope can be divided into any interval that is a multiple of 5 percent Aspect is represented as one of the eight main aspects (N, NE, E, SE, S, SW, W, NW) plus a flat (F) condition defined as terrain with a slope of less than 3 percent Elevation classes can be any interval that is a multiple of 100 feet Combination plots are specified by inputting the minimum and maximum elevation, minimum and maximum slope (in percent), and the aspect or aspects to be included. When a combination overlay is plotted, only areas with the specified combination of slope, aspect, and elevation will be delineated. In addition to each overlay, a summary (fig. 14) is printed that shows the acreage covered by each category delineated on the overlay.

Algorithm Descriptions

The descriptions of algorithms used to determine average elevation, maximum slope, and the aspect of a cell have been adapted from Lemkow (1977).

The slope, aspect, and elevation for each topographic-attribute unit are computed by using the surface equation for a linear plane:

$$m_1x + m_2y + m_3z = 1 .$$

Only three points are required for this equation. Adding a fourth point (that is, using all four corners of the topographic attribute unit [fig. 15]) necessitates a least-squares statistical fit of the plane. Four linearly independent equations can be developed. These equations can be represented in matrix notation as:

$$Am=b ,$$

where A is the matrix of coefficients:

$$\begin{bmatrix} 0 & 0 & z_{(0,0)} \\ 0 & y_1 & z_{(0,1)} \\ x_1 & y_1 & z_{(1,1)} \\ x_1 & 0 & z_{(1,0)} \end{bmatrix} ;$$

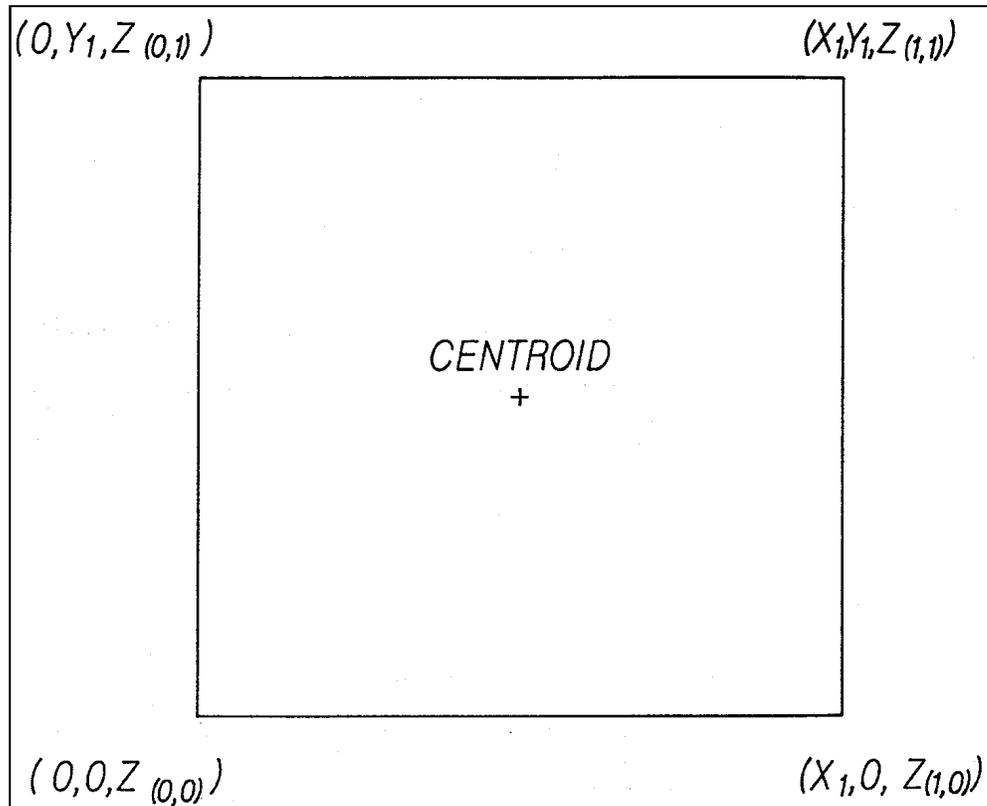


Figure 15—Coordinate system used for calculating topographic attributes.

m is a column vector of parameters:

$$\begin{bmatrix} m_1 \\ m_2 \\ m_3 \end{bmatrix} ; \text{ and}$$

b is a column vector of constants:

$$\begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \end{bmatrix} .$$

The parameter vector, m , is approximated by using a least-squares approach:

$$m = (A^T A)^{-1} A^T b .$$

The solution of the system for the elevation of any point in the plane gives:

$$z = c + ax + by , \tag{1}$$

$$\text{with } c = \frac{1}{m_1} ,$$

$$a = \frac{-(m_1)}{m_3} , \text{ and}$$

$$b = \frac{-(m_2)}{m_3} .$$

Equation (1) is the basis for determining all topographic attributes.

Average elevation—The average elevation is evaluated at the centroid of the topographic-attribute unit. Coordinates of the centroid, from the notation in figure 13, are:

$$x = x_1/2 \text{ and } y = y_1/2$$

Substituting these values in equation (1) yields:

$$z = c + a(x_1/2) + b(y_1/2)$$

which is the average elevation for the topographic-attribute unit.

Maximum surface slope—The plane defined by equation (1) has three intercepts (fig. 16):

$$z \text{ intercept is } c \text{ (} x, y = 0 \text{) ,}$$

$$x \text{ intercept is } -c/a \text{ (} y, z = 0 \text{) , and}$$

$$y \text{ intercept is } -c/b \text{ (} x, z = 0 \text{) ,}$$

The maximum surface slope of z with respect to both x and y is the tangent of angle CPO. Angle CPO is subtended by the plane and the line segment PO with point P lying on segment AB. If the length of segment PO is i , then the tangent of angle CPO will be (c/i) . This tangent will be at a maximum when i is a minimum. This occurs only when segment PO is perpendicular to segment AB.

From equation (1), the line containing segment AB in the x - y plane ($z = 0$) is defined as:

$$ax + by + c = 0 .$$

The directed (perpendicular) distance from segment AB to point 0 (0,0,0) is given by (Fuller, 1973):

$$i = \frac{ax + by + c}{\pm(a^2 + b^2)^{1/2}} \quad (2)$$

The sign of the denominator can be ignored in this case because it affects the direction of the slope, and only slope magnitude is of interest in this case.

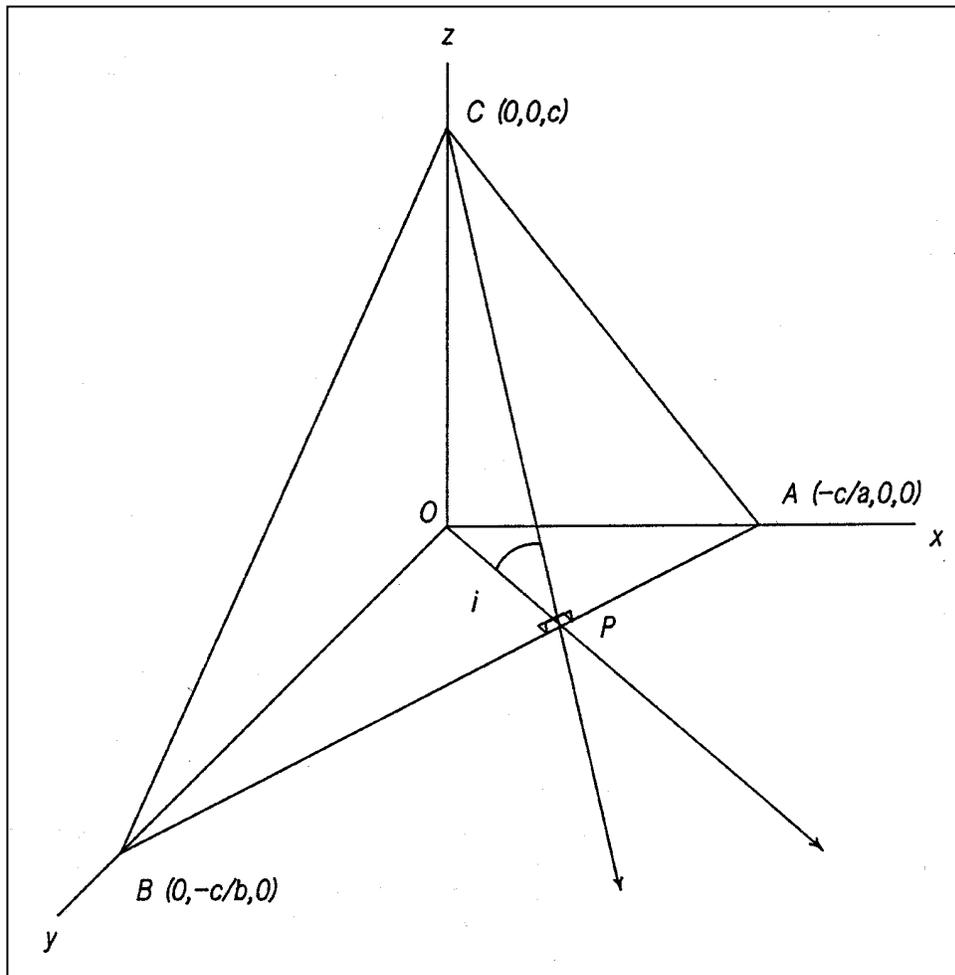


Figure 16—The surface plane representing one grid cell and its three intercepts.

Substituting the point O in equation (2) yields:

$$i = \frac{a(0) + b(0) + c}{(a^2 + b^2)^{1/2}} = \frac{c}{(a^2 + b^2)^{1/2}}$$

Now the tangent of angle CPO can be calculated as:

$$\text{TANGENT angle CPO} = c/i = c/c/(a^2 + b^2)^{1/2} = (a^2 + b^2)^{1/2}$$

From this, the maximum surface slope in percent is:

$$\frac{100 (a^2 + b^2)^{1/2}}{\text{map scale}}$$

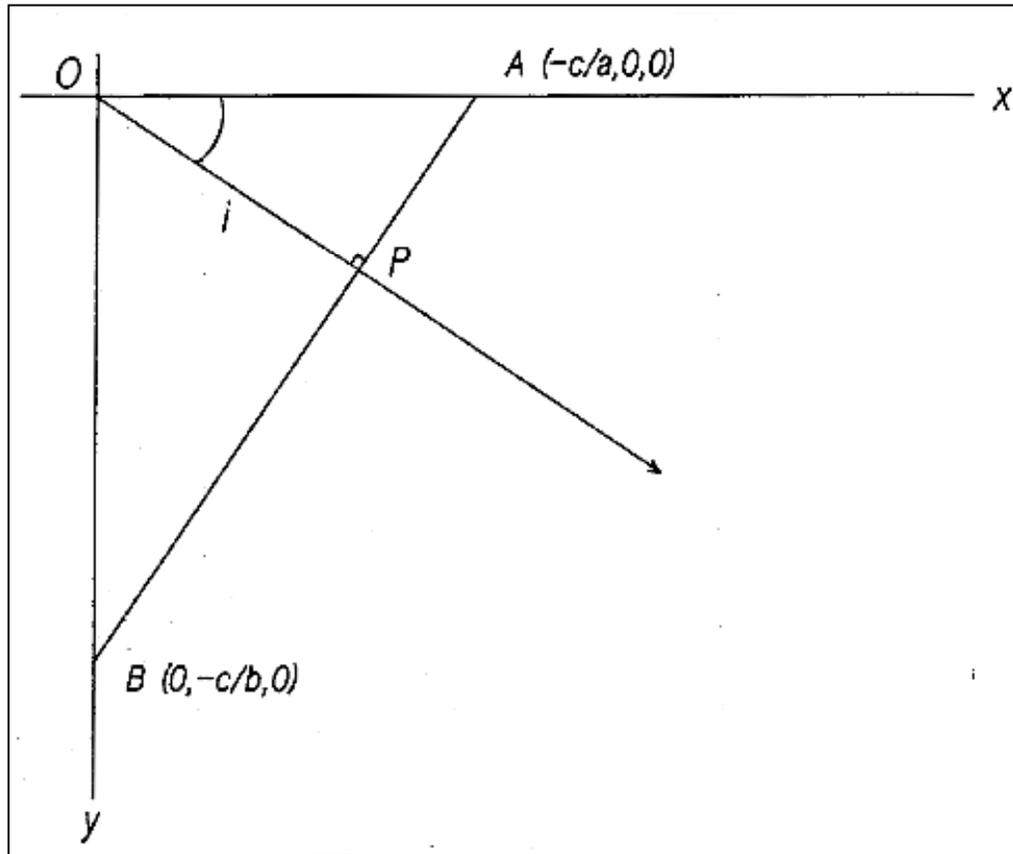


Figure 17— The intersection of the surface plane with the x-y-coordinate plane.

Aspect—The aspect of a topographic-attribute unit is determined by calculating the quadrant ray OP lies in. Figure 17 shows the intersection of the surface plane with the x-y-coordinate plane. In triangle CPA, the sum of angles PAC and POA must equal 90 degrees. Angle BAO, equal to angle PAO, is:

$$\text{angle BAO} = \text{ARCTANGENT: } \frac{-c/b}{-c/a} = \text{ARCTANGENT } (a/b) .$$

Thus angle POA must be:

$$\text{angle POA} = \text{ARCTANGENT } (a/b), 0 < \text{POA} \leq 90 \text{ Degrees} .$$

From equation (1), if $a > 0$, then $dz/dx > 0$; that is, when proceeding east (x increasing) across the surface plane, the elevation will also increase. Consequently, by definition, the aspect will be westerly. Extending this logic to the other three quadrants yields a set of relations that can be used to convert angle AOP to the full 360-degree aspect range (fig. 18).

To convert angle AOP into one of the eight main aspects (N, NE, E, SE, S, SW, W, NW), angle AOP is rotated by 22.5 degrees to shift the boundaries of the aspect classes to even 45-degree multiples (fig. 19). The map orientation used when the contours are digitized must also be accounted for. Assuming the angle of map rotation is positive for counter-clockwise rotation of north, the equation for angle AOP is:

$$\text{angle AOP} = \text{angle AOP} + 22.5 - \text{rotation} + 360 .$$

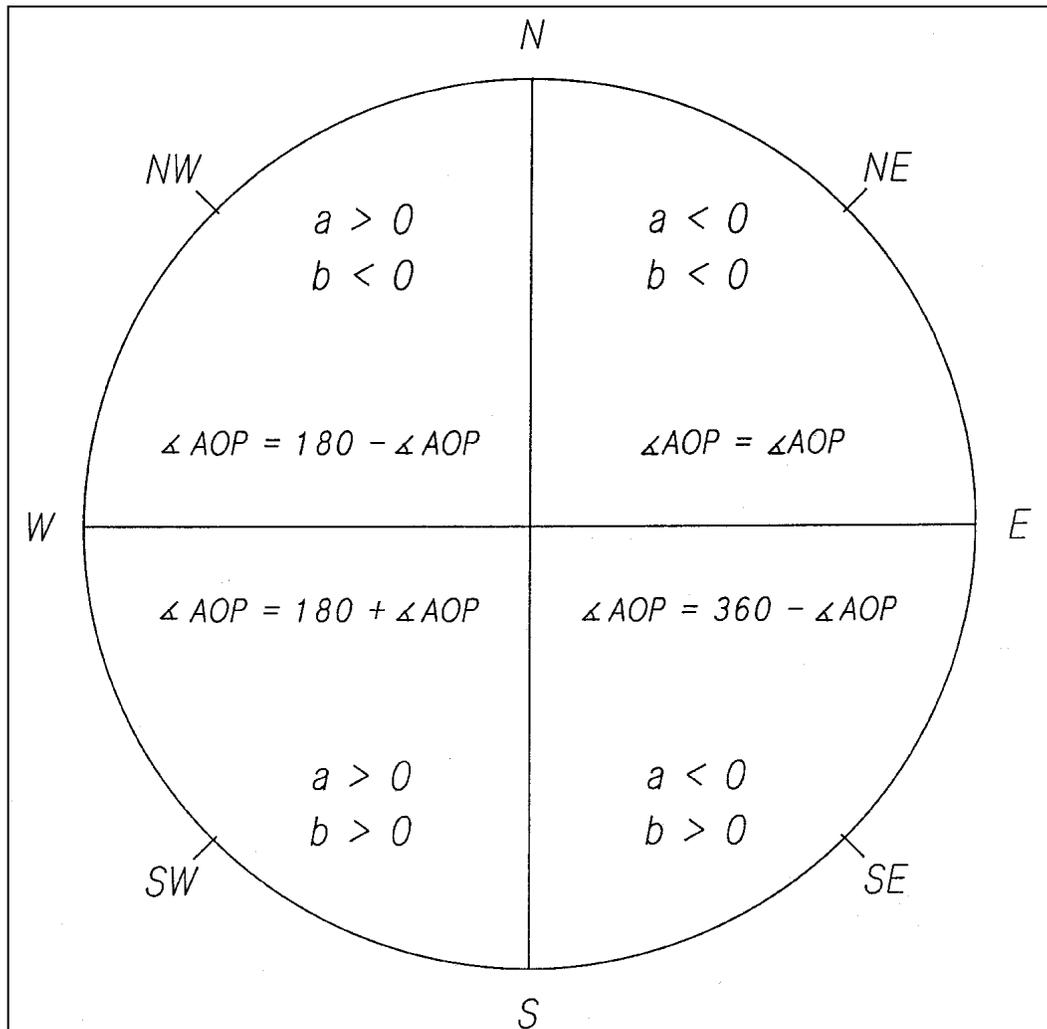


Figure 18—Decision rules for rotating angle AOP into the correct quadrant based on the slope of the surface plane with respect to the x-axis (a) and y-axis (b).

To prevent negative angles, 360 degrees are added. To ensure that angle AOP is not greater than 360:

$$\text{angle AOP} = \text{angle AOP} - \text{INTEGER}(\text{angle AOP}/360) \times 360 .$$

Now angle AOP is an angle between 0 and 360 degrees that defines the aspect of the topographic-attribute unit according to relations defined in figure 19.

Plotting the attribute overlays—Attribute overlays are plotted at the same scale as the original topographic map used to create the DTM. This allows the overlays to be registered to the base map during planning activities. Depending on the size of the DTM and the dimensions of the plotting media, several sheets may be required for the overlay. SLOPE automatically divides the unit into as many sections as needed for plotting on multiple sheets.

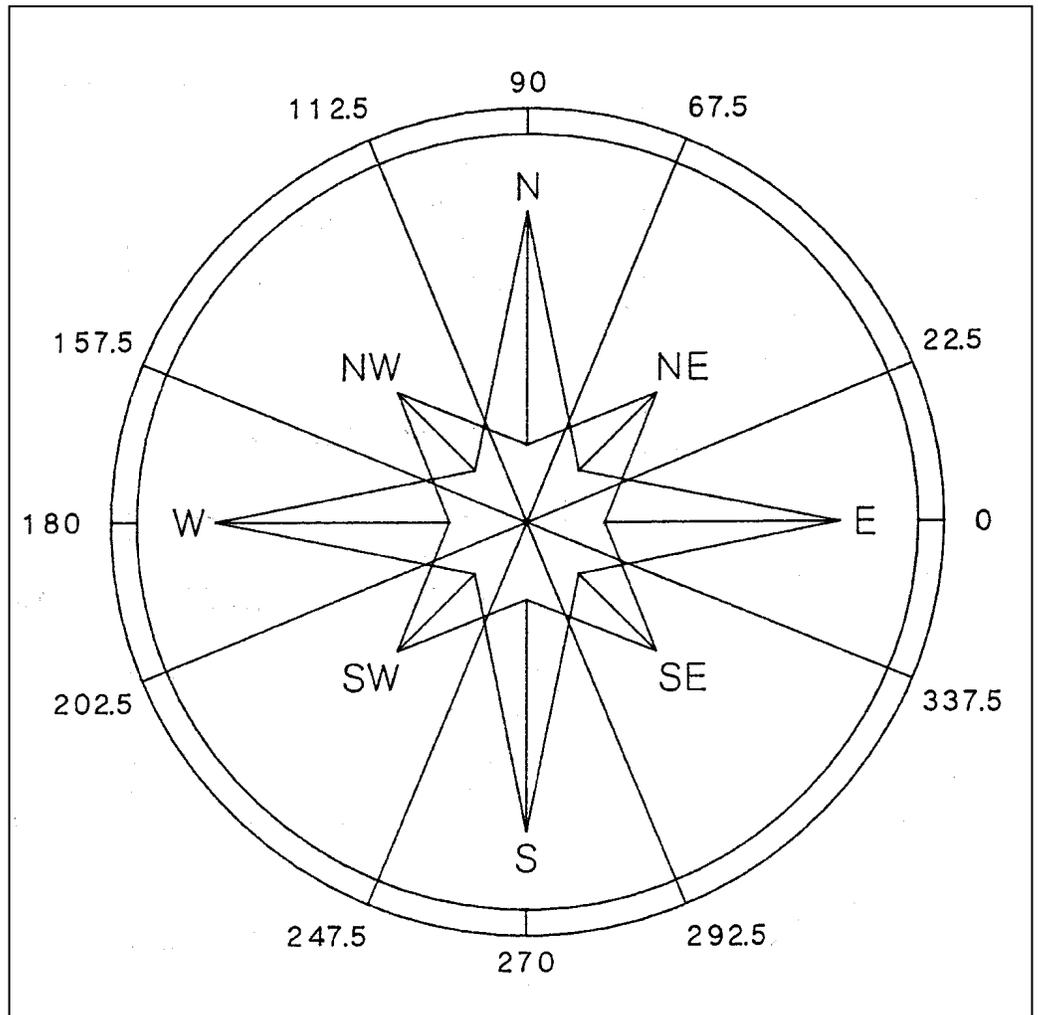


Figure 19—Aspect classes used in SLOPE.

Because attribute area boundaries are based on a rectangular grid, boundary lines between topographic-attribute units will be either horizontal or vertical. When plotting the overlay, SLOPE draws the horizontal and vertical boundary segments on separate passes over the DTM. To draw the horizontal boundary segments, SLOPE begins at the lower left corner of the DTM and compares the attribute in the topographic-attribute unit with the attribute value for the unit above. If the attributes differ, the boundary segment between the two units is drawn. If the attribute values are the same, no boundary segment is drawn. The logic proceeds up to the next topographic-attribute unit and repeats this process. Vertical boundary segments are drawn in a similar fashion with the logic beginning in the lower left corner and proceeding to the right. On a third and final pass over the DTM unit, each attribute area on the overlay is labeled. The number of labels is minimized but every area is labeled at least once.

Limitations

SLOPE has three major limitations: (1) DTM attributes are calculated from a surface plane approximating the ground surface, (2) the amount of detail on an overlay may make the overlay difficult to interpret, and (3) elevations in the DTM must be less than 10,000 feet.

Fitting a surface plane to four points creates a certain amount of error. Because three points uniquely define a plane, the addition of a fourth point necessitates approximation of the surface equation representing the ground. The equation is statistically fit to the four corner points of the unit by using a least-squares process. The approximated surface equation results in slightly erroneous estimates of surface slope and elevation. These errors have an insignificant effect on the usefulness of SLOPE overlays for planning allocations.

If the surface equations for two adjacent grid cells were compared, a discontinuity along the edge common to both would occur. For this reason, the surface-approximation method is used only in SLOPE. Other programs in the PLANS package that extract elevations from the DTM use an approach yielding a continuous surface or profile between DTM cells.

Users of SLOPE may find the overlays difficult to interpret at first. The gridded representation of attribute boundaries is different from the smooth line most people are used to. In addition, distinguishing among attribute areas is often difficult because of the amount of information present on a single overlay. These problems are obvious when overlays are produced with the topographic-attribute unit size equal to the DTM cell size. In such cases, interpreting the overlay without manually color coding each area is difficult. Overlays produced with larger topographic-attribute units are easier to comprehend. We have experimented with textural shading and multicolor overlays to make overlays less confusing. Textural shading means representing each category on an overlay with a different pattern. Shaded overlays are easy to interpret but take a lot of time to plot. Multicolor overlays use a different color to represent each attribute category on the overlay. As with textural shading, clarity of the overlay and plotting time increase for multicolor overlays. The overlays produced by SLOPE provide a suitable compromise between plotting time and ease in understanding. The overlays are easiest to interpret when the topographic-attribute units are at least 0.4 inch square.

The final limitation, restricting elevations to less than 10,000 feet, is a direct result of the data-packing technique used to store topographic attributes. Data on elevation, slope, and aspect are combined and stored as a single, short-precision number to conserve random access memory. Elevations are limited to four digits within this number, so elevations in the DTM must be 9,999 feet or less. This limitation should not present problems for timber-harvest planning activities. But if a DTM contains elevations greater than 10,000 feet, the attribute overlay will be incorrect near these elevations.

Conclusion

If timber-harvest planners have a way to visualize and quantify topographic features, they can develop comprehensive harvest plans. This report described two computer programs designed to help planners -learn more about the ground conditions of a planning area. VISUAL produces three-dimensional perspectives of terrain, and SLOPE produces slope, aspect, and elevation overlays along with tabular acreage summaries for the planning area. Information presented by these programs is most useful during preplanning activities (describing the timber resource, planning field reconnaissance, and selecting harvesting equipment). Perspectives also provide a unique and understandable way to display the final plan.

Metric Equivalents

1 inch = 2.54 centimeters

1 foot = 0.3048 meter

1 acre = 0.4047 hectare

Literature Cited

- Carter, James R. 1984.** Computer mapping progress in the '80s. Washington, DC: Association of American Geographers. 86 p.
- Fuller, Gordon. 1973.** Analytic geometry. 4th ed. Reading, MA: Addison-Wesley Publishing Co. 294 p.
- Lemkow, Daniel Z. 1977.** Development of a digital terrain simulator for short-term forest resource planning. Vancouver, BC: University of British Columbia. 207 p. M.S. thesis.
- Myklestad, E.; Wagar, J.A. 1976.** PREVIEW: computer assistance for visual management of forested landscapes. Res. Pap. NE-355. Morgantown, WV: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 12 p.
- Nickerson, Devon B. 1979.** SIGHTLINE, PERSPECTIVE PLOT, SLOPE—three desktop computer programs for forest landscape design. *Journal of Forestry*. 77 (1): 14-17.
- Nickerson, Devon B. 1980.** PERSPECTIVE PLOT: an interactive analytical technique for visual modelling of land management alternatives. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, Logging Systems Group. 146 p.
- Travis, Michael-R.; Elsner, Gary H.; Iverson, Wayne D.; Johnson, Christine G. 1975.** VIEWIT: computation of seen areas, slope, and aspect for land-use planning. Gen. Tech. Rep. PSW-11. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 70 p.
- Twito, Roger H. 1978.** Plotting landscape perspectives of clearcut units. Gen. Tech. Rep. PNW-71. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 26 p.
- Twito, Roger H.; Mifflin, Ronald W.; McGaughey, Robert J. 1987a.** The MAP program: building the digital terrain model. Gen. Tech. Rep. PNW-GTR-200. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 22 p.
- Twito, Roger H.; Reutebuch, Stephen E.; McGaughey, Robert J.; Mann, Charles N. 1987b.** Preliminary logging analysis system (PLANS): overview. Gen. Tech. Rep. PNW-GTR-199. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 24 p.
- Young, G. Glen; Lemkow, Daniel Z. 1976.** Digital terrain simulators and their application to forest development planning. In: Proceedings of the 1976 Skyline Logging Symposium; 1976 December 8-10; Vancouver, BC. Vancouver, BC: University of British Columbia Press: 81-99.

Appendices to this report containing step-by-step operating instructions for the VISUAL and SLOPE programs are available on request from the Pacific Northwest Research Station. A copy of these appendices can be obtained by photocopying this page, filling in the necessary information, and sending it to:

USDA Forest Service
Pacific Northwest Research Station
Forestry Sciences Lab
Forest Engineering Systems
4043 Roosevelt Way NE
Seattle, WA 98105

These appendices includes examples of using VISUAL and SLOPE to analyze terrain before planning activities as well as showing many of the options and manipulations that can be exercised during this process.

If you wish to receive the PLANS program set, which includes VISUAL and SLOPE stored on diskettes, enclose five 5-1/4-inch double-sided, double-density, flexible mini disks.

Please send supplementary material for the VISUAL and SLOPE programs to:

NAME _____
ADDRESS _____

CITY _____
STATE _____ ZIP CODE _____
PHONE _____

McGaughey, Robert J.; Twito, Roger H. 1988. VISUAL and SLOPE: perspective and quantitative representation of digital terrain models. Gen. Tech. Rep. PNW-GTR-214. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 26 p.

Two computer programs to help timber-harvest planners evaluate terrain for logging operations are presented. The first program, VISUAL, produces three-dimensional perspectives of a digital terrain model. The second, SLOPE, produces map-scaled overlays delineating areas of equal slope, aspect, or elevation. Both programs help planners familiarize themselves with new terrain and obtain a general feel for the land. Included are descriptions of operating procedures, descriptions of major algorithms, suggested applications, and limitations. Guides for the programs are available from the authors.

Keywords: Logging, operations analysis/design, topography, timber harvest planning, computer programs, programing.

The **Forest Service** of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives—as directed by Congress—to provide increasingly greater service to a growing Nation.

The U.S. Department of Agriculture is an Equal Opportunity Employer. Applicants for all Department programs will be given equal consideration without regard to age, race, color, sex, religion, or national origin.

Pacific Northwest Research Station
319 S.W. Pine St.
P.O. Box 3890
Portland, Oregon 97208



U.S. Department of Agriculture
Pacific Northwest Research Station
319 S.W. Pine Street
P.O. Box 3890
Portland, Oregon 97208

BULK RATE
POSTAGE +
FEES PAID
USDA-FS
PERMIT No. G-40

Official Business
Penalty for Private Use, \$300

Do NOT detach Label