**U.S. DEPARTMENT OF THE INTERIOR**

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# SHADED RELIEF, TOPOGRAPHIC SLOPE, AND LAND USE PLANNING IN THE LOS ALTOS HILLS AREA, CALIFORNIA -- AN EXAMPLE OF THE USE OF ELEVATION DATA.

by

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## INTRODUCTION

The steepness of the ground surface can be represented on a map in several ways. The most familiar and widely used is the conventional topographic map, on which points of equal elevation above sea level are joined by contour lines. The most easily visualized, in contrast, is the shaded relief map, with a pictorial representation of the shading of hillsides when the sun is low. The most explicit representation of the steepness of the ground is the slope map, as we discuss below.

Preparation of shaded relief and slope maps for local areas is made possible by modern computers and GIS software and the expanding availability of high-quality digital elevation data from the U.S. Geological Survey and elsewhere. We illustrate the shaded relief and slope maps and their relevance to land-use planning using as an example a small hillside community, Los Altos Hills, in the southern San Francisco Bay Region, California.

This report presents shaded relief and slope maps of the example area (Figures 1 and 2), a histogram of slope (figure 3), and a figure showing the relation between slope and grading to create flat space (Figure 4), together with a descriptive text. The text is divided into three principal sections, (1) an initial discussion of shaded relief, slope, grading, and land use; (2) a central listing of the files composing this digital report, how to obtain them, and how to print the figures; and finally (3) a description of the elevation data and its use in preparing the figures.

The shaded relief and slope maps were prepared at a scale (resolution) of 1:24,000 (1 inch on the map represents 2,000 feet on the ground) using USGS elevation data and version 7.2.1 of ArcInfo, a commercial Geographic Information System (Environmental Systems Research Institute [ESRI], Redlands, California) together with the menu interface ALACARTE (version 3.1: Fitzgibbon and Wentworth, 1991; Fitzgibbon, 1991; Wentworth and Fitzgibbon, 1991) running on a UNIX computer.

## THE USE OF SHADED RELIEF

Shaded relief maps are prepared numerically (see section on Data Preparation and Analysis), but their value is in their representation of the topography in a fashion that mimics a sun-illuminated landscape with the sun fairly low in the sky. The viewer can thus see the hills and valleys, distinguish steeper and gentler slopes, and understand the organization of the topographic features into a coherent landscape (Figure 1). The topographic context of any place can be recognized, so that familiar places can be better understood and compared. For most people, shaded relief is far more effective in displaying the general shape and organization of the landscape than the topographic contours of conventional topographic maps. (For some, the shaded relief may appear inverted; if this occurs, try rotating the map until the relief reverses.)

Shaded relief can also be combined with other map information, including lines, points, and areas of color, thus facilitating visual appreciation of the several kinds of data together. In the shaded relief map presented here, for example, the gray-scale shading is overlaid by lines representing the town boundary, roads, buildings, and streams.

## SLOPE MAPS

In hilly terrain, it is often the slope or inclination that plays the dominant role in land use planning. Slope maps, an example of which is shown in Figure 2, present this useful information by displaying the numerical value of the slope of the land surface. In a slope map, it is not the elevation of an area that is displayed, as in conventional topographic contour maps, but rather the change in elevation of an area. This change in elevation is the inclination of the ground surface to the horizontal. It can be expressed as the percent rise in elevation along a given horizontal distance. A 10 percent slope rises 10 feet over a horizontal distance of 100 feet. (This percentage is actually the trigonometric tangent of the vertical slope angle.)

In the slope map presented here, as in the shaded relief map, the colors representing the six categories of slope are overlain by lines representing cultural and natural features such as town boundary, roads, buildings, and streams. Approximate locations of places can thus be determined by reference to these features and by comparison between the slope and shaded relief maps.

## THE SLOPE MAP AS A PLANNING TOOL

Slope is an important characteristic of the land surface in land-use planning in hilly terrain largely because people generally live, work, and play on flat surfaces. If such surfaces do not exist, they must be created as needed during the development process – the steeper the initial slope, the greater the required alteration of the natural terrain (Figure 4). The flattened surfaces are commonly covered by impermeable paving and rooftops. This causes more rapid runoff of rainwater and erosive effects which, though more complex than the geometric effects of grading, also generally increase sharply with the slope of the terrain (Meyer and Ports, 1976). These slope-sensitive alterations from development generally have important effects of two kinds for land use planning: 1) immediate changes in the <u>appearance</u> of the terrain owing to the changed contours and vegetation, and the introduction of buildings, roads, and other structures, and 2) the associated changes in <u>performance</u> of the terrain in the natural systems, such as runoff, erosion, sedimentation, flooding, slope stability, and wildlife habitat (e.g. Thurow et. al., 1975). As slope increases, it will generally be necessary to either decrease the intensity of development (e.g. flat space and/or impermeable surface per acre) or increase engineering modification of the terrain. In working toward either goal, a map of slope distribution

(Figure 2) provides a useful community-wide planning overview for many potential development issues in hillside settings.

**Flat Space and Grading**

Flat spaces for human activities in hilly terrain are created by erecting buildings and decks and by flattening the ground by grading. The erected structures may require a completely flattened building pad (as for a slab foundation), or little or no grading (as for an elevated pile foundation). But in all residential development, flat graded areas are generally required for outdoor activities including parking, driveways, turnarounds, pools, patios, tennis courts, and other utility and recreation areas.

To create an area flatter than the natural slope, it is generally necessary to modify the surroundings by grading compensating cut and fill banks that are steeper than the natural slope (or more rarely, by erecting retaining walls). The proportion of ground surface that must be dedicated to these banks increases sharply with the initial slope of the site (see Figure 4). The exact amount depends upon how steep the compensating cut and fill banks may be (usually regulated by ordinance), the shape of the planned flat space, and local details of the site's humps and hollows.

Typically, to create a square one-acre flat pad with balanced amounts of cut and fill on a hillside where the natural slope is 20%, a total of two acres of natural terrain must be altered by grading (Figure 4) – the second acre is occupied by the steep compensating cut and fill banks (typically 67% and 50% respectively). Similarly, where the natural slope is 30%, about three acres must be graded to produce one flat acre (see dots, Figure 4A) – the remaining 2 acres are occupied by cut and fill banks that are roughly twice as steep as the original surface. The large areas of cut and fill in these simple examples can generally be reduced significantly for the portions of slopes covered by buildings by careful attention to their foundation design and placement.

The graded cut-and-fill slopes are not only steeper than the natural surface, they are stripped of existing trees and other vegetation; both factors can contribute to the instability and visibility of the graded slopes. Because the impact of grading practices and foundation design is sensitive to slope (Figure 4), many hillside communities restrict these activities as the slope increases. Similarly, the impact of impermeable rooftops and paving is sensitive to the surrounding slope, because slope controls the erosive energy of the added increment of runoff (Meyer and Ports, 1976). To keep the erosional disturbance from increasing disproportionately in steeper portions of a community, it will generally be necessary to either decrease the intensity of (impermeable) development or increase the investment in artificial drainage structures as slope increases. Such planning may be important in communities concerned with maintaining natural drainageways as corridors for wildlife and native vegetation with a minimum of engineering modification.

### Planning with Slope

Problems of regulating the creation of flat space and impermeable surface and their community impacts are generally greater for steeper slopes ( Nilsen and others, 1979, p. 80). Whether such problems might require regulation in any particular community depends upon the community's physical setting and planning goals. For the example of Los Altos Hills, Figure 3 shows that about one third of the community has slopes less than 10%, a category in which experience has shown that grading, erosion, and other development alterations to the natural terrain can generally be handled without difficulty (Mader and others, 1988). According to Figure 3, almost half of the community has slopes from 10% to 30%, a slope category usually targeted for residential development but with progressively increasing concerns and regulatory restrictions toward the upper limit. In the one fifth of the town with slopes greater than 30% (Figure 3), residential development without extensive modification of the surroundings becomes increasingly difficult, and much of the land may be classified for limited uses with conservation easements, or with an open space designation. Because slope is a fundamental physical parameter affecting land use in hillside communities, the community general plan and many controlling ordinances (e.g. for grading, lot size, house size, development intensity, foundation design, impermeable surface area, erosion control, and conservation easements) are often formulated in terms of the slope of the land. The slope map (Figure 2) provides a useful means of viewing the distribution of these potential problem areas, and of visualizing the community-wide implications of various regulations proposed to deal with them.

## SPATIAL RESOLUTION

The data used in making the digital map files in this report are limited to a scale of 1:24,000 (one inch on the map represents 2,000 feet on the ground) and a grid spacing of 10 m (see discussion of the elevation data). Use of these files at a larger scale will not yield greater real detail, although irregularities below the resolution of the data may be evident. The oversize map files in this report are configured to print to scale (1:24,000), whereas the page-size files are configured to print at a scale of about 1:34,800 (one inch on the map represents about 2,840 feet on the ground).

## REPORT CONTENTS

This report contains text, two maps, a histogram, and a graph (Figure 1-4), which are provided as eight digital files in multiple formats. These files are briefly described below by name, content, file format, and file size.

1. Revision List: A list of the different files in this report and a history of any revisions to them.

| | | |
|---|---|---|
| of02-351_1a.txt | ASCII file | 2 Kb |

2. Open-File Pamphlet: The text of the open-file pamphlet (this text), which includes a description of the files within this report and how they were created.

| | | |
|---|---|---|
| of02-351_2a.txt | ASCII file | 27 Kb |
| of02-351_2b.doc | MS Word document | 63 Kb |
| of02-351_2c.pdf | PDF file | 47 Kb |

3. Shaded Relief Map (Figure 1) at PAGE SIZE (1:35,802) of Los Altos Hills with overlaid town limits, roads, buildings, and streams.

| | | |
|---|---|---|
| of02-351_3a.ps | PostScript file | 2.2 MB |
| of02-351_3b.pdf | PDF plotfile | 1.1 MB |

4. Shaded Relief Map (Figure 1) OVERSIZE (1:24,000; image 11.25 x 14 inches) of Los Altos Hills with overlaid town limits, roads, buildings, and streams.

| | | |
|---|---|---|
| of02-351_4a.ps | PostScript file | 2.7 MB |
| of02-351_4b.pdf | PDF plotfile | 1.2MB |

5. Slope Map (Figure 2) at PAGE SIZE (1:35,802) of Los Altos Hills area, in percent slope, with overlaid town limits, roads, buildings, and streams.

| | | |
|---|---|---|
| of02-351_5a.ps | PostScript file | 2.1 MB |
| of02-351_5b.pdf | PDF plotfile | 792 Kb |

6. Slope Map (Figure 2) OVERSIZE (1:24,000; image 11.25 x 14 inches) of Los Altos Hills, in percent slope, with overlaid town limits, roads, buildings, and streams.

| | | |
|---|---|---|
| of02-351_6a.ps | PostScript file | 2.6 MB |
| of02-351_6b.pdf | PDF plotfile | 828 Kb |

7. Histogram (Figure 3; 8.5 x 11 inches) showing the frequency distribution of slope (in percent) in the Los Altos Hills map area, using slope categories equivalent to those shown on the slope map.

| | | |
|---|---|---|
| of02-351_7a.ps | PostScript file | 440 Kb |
| of02-351_7b.pdf | PDF plotfile | 172 Kb |

8. A graph (Figure 4; 8.5 x 11 inches) showing the surface alteration required to create graded flat space as a function of slope.

| | | |
|---|---|---|
| of02-351_8a.ps | PostScript file | 428 Kb |
| of02-351_8b.pdf | PDF plotfile | 176 Kb |

## PRINTING THE FIGURES

The text files (numbers 1 and 2 above) can be opened and printed from a word processing program (ASCII and MS Word files) or from Acrobat reader (PDF file), and the PostScript text file can be sent directly to a printer without opening in an application. The map and histogram files (numbers 3 through 7) can be opened and printed using Acrobat Reader (PDF files), or such drafting programs as Adobe Illustrator (PostScript files), and the Postscript files can be sent directly to a printer or plotter from the command line. The graph (number 8) can be opened and printed from a word processing program (MS Word file) or from Acrobat reader (PDF file), and the PostScript text file can be sent directly to a printer without opening in an application. All files except the oversize maps will fit on 8.5x11-inch paper and can be printed using standard printers. The oversize maps are 11 ¼ x 14 inches and require a plotter with a page size larger than these dimensions. Note that the slope map and the histogram are best plotted and viewed in color.

## OBTAINING THE DIGITAL FILES

The text and image files can be downloaded from the Western Region Geologic Publications Web Server or by anonymous ftp over the Internet.

1. Anonymous ftp over the Internet

The files for this report are stored on the Western Region publication server of the U.S. Geological Survey. The Internet address of this server is:

geopubs.wr.usgs.gov

Connect to this address directly using ftp or through a browser, log in with the user name ‘anonymous’, and enter your e-mail address as the password. This will give you access to all the publications available from the server. The files for this report are stored in the subdirectory:

pub/open-file/of02-351

2. From the Western Region Geologic Publications Web Server

The U.S. Geological Survey supports a set of graphical pages on the World Wide Web from which digital publications such as this one can be obtained. The Web server for digital publications from the Western Region is:

http://geopubs.wr.usgs.gov

This report can be reached by number (of02-351) through either the California or Open-File Reports 2002 options.

## REVISIONS

Changes to any part of this report (parts are the numbered items described above in 'Report Contents' and listed in the revision list of02-351_1a.txt) may be made in the future if needed. This could involve, for example, fixing files that don't work properly, revising figure details, adding new file formats, or adding other components to the report.

The report begins at version 1.0. Any revisions will be specified in the revision list and will result in the recording of a new version number for the report. Small changes will be indicated by decimal increments and larger changes by integer increments in the version number. Revisions will be announced and maintained on the Web page for this report on the Western Region Geologic Publications Web Server. Consult the revision list there to determine if a revision is significant for your purposes.

## DATA PREPARATION AND ANALYSIS

The shaded relief map and the slope map of the Los Altos Hills Area were both created from USGS 10-meter Digital Elevation Models (DEMs), which are regular x,y arrays, or raster grids, of elevation values with a grid spacing of 10 meters. The grids are georeferenced, meaning that the x,y locations of the grid points are correct relative to the earth as represented in a particular map projection (here, Universal Transverse Mercator, or UTM; see Table 1).

Two derivative grids representing shaded relief and slope were prepared from the elevation grid (see below) using ArcInfo and ALACARTE, and these were then used to prepare the maps presented here. This was done by coloring the grids with gray shades or colors (shaded relief or slope map, respectively) according to the values stored in each of the individual grid cells. To complete the maps, streams, roads, buildings, and the town and quadrangle boundaries (all obtained from USGS Digital Line Graph (DLG) data) were overlaid for reference.

Table 1. Map Projection

| | | |
|---|---|---|
| Projection | utm | (Universal Transverse Mercator) |
| units | meters | |
| zone | 10 | |
| Datum | NAD27 | |

## Elevation Data

USGS elevation arrays (called Digital Elevation Models, or DEMs) are prepared by computer interpolation of a regular grid of elevations from digital contours, and are thus a derivative of USGS topographic contour maps. The most detailed DEMs are prepared from the 1:24,000-scale, 7.5-minute quadrangle maps, with a grid spacing typically of 30 m. If the finer details of the shapes of the contours are to be captured, however, 10-m gridding is required and 10-m DEMs, such as those used in this report, are now being prepared for some areas.

The DEMs used for the present work were originally prepared by the USGS from 1:24,000 vector contours at a grid spacing of 10 m as part of a larger regional project. DEMs for that larger area were obtained directly from the production specialists, and the individual 7.5-minute data blocks were assembled as a continuous elevation grid in ArcInfo by S.E. Graham. Elevations were then clipped from that continuous grid for the present study. The elevation (or Z) values in the dataset are expressed in decimeters, compared to horizontal dimensions in meters, which required a 10-fold correction factor in calculating slope.

The interpolation techniques used in preparing these DEMs, like all such techniques, introduce various kinds of artifacts that distort an ideal smooth surface passing through the contour lines (Acevedo, 1991). Most of these artifacts are most prominent in areas of low slope, and hence are inconsequential for present purposes.

The central source for USGS DEMs is the National Elevation Dataset, which is described in U.S. Geological Survey Fact Sheet 148-99, available on line at

http://mac.usgs.gov/mac/isb/pubs/factsheets/fs14899.html

Another general source is the National Spatial Data Infrastructure Web page on USGS DEMs:

http://nsdi.usgs.gov/products/dem.html

These pages have links to other information about USGS DEMs. A more direct site for USGS DEMs of the San Francisco Bay region is the USGS Bay Area Regional Database (BARD) at

http://bard.wr.usgs.gov,

which contains information about both 30- and 10-m DEMs.

## Shaded Relief

The raster shaded relief layer was created in ArcInfo GRID using the hillshade command with the “shade” option.  The azimuth and altitude of the illumination source were set to 90 degrees and 45 degrees, respectively.  This simulates light coming from the east and 45 degrees above the horizon. A Z tolerance of 0.1 was used when creating the shaded relief map to prevent vertical exaggeration of the topographic relief. Hillshade examines the relation between the orientation of a plane through each cell center (determined from the elevation values in the surrounding 3 by 3 cell block) and the direction to the illumination source, and assigns a resulting reflectance value to the cell. The “shade” option ignores interruption of the illumination by intervening topography and does not create shadows.

The cells were colored with gray values proportional to the reflectance values to produce the shaded relief image. The result is that slopes facing toward the illumination source are bright and those facing away are dark, with all gradations in between, so that the landscape looks three dimensional.

## Slope

The raster slope layer was made with the GRID module in ArcInfo using the slope command.  This command fits an inclined plane at each cell center to represent the maximum rate of change of elevation amongst the surrounding 3 by 3 cell block. We have used the percentrise option in order to express the slope in percent rise relative to the horizontal cell spacing (or run). Slope can also be expressed in degrees. A surface involving equal rise and run, such as a rise of 100 feet in a distance of 100 feet, has a slope of 100 percent and of 45 degrees. Because the x and y axes on the grid are in meters and the Z (elevation) values are in decimeters, a correction factor (Z) of 0.1 was used to obtain true slope values.

In order to produce a legible map, slope intervals were selected to effectively divide the range of values (0-10, 10-20, 20-30, 30-40, 40-55, and >55), and different colors were assigned to each of these intervals (using a color remap table).

Although the particular slope intervals used here conveniently subdivide the range of values in the study, they are not directly related to any particular set of planning considerations. Maps can be made from the same digital slope data for any other set of slope intervals simply by reassembling the map graphic using different coloring instructions (remap tables). Thus, where slope categories have been specified for planning or regulatory purposes, equivalent slope maps displaying those categories can be easily made.

## Streams, Roads, Houses, and Town Boundary

The streams, roads, buildings, and town and quadrangle boundaries are all separate vector coverages, or layers, created in ArcInfo. These layers were all created using the Palo Alto, Mountain View, Cupertino, and Mindego Hill Digital Line Graphs (DLGs) downloaded from the BARD website. These DLGs were prepared by the USGS as georeferenced vector datasets from the published 7.5-minute quadrangle maps. The DLGs were converted into ArcInfo coverages (vector layers) using Arc’s dlgarc command. All four quadrangles of corresponding topics were combined and then trimmed (clipped) to a box surrounding Los Altos Hills. Boundary lines showing highly developed areas (see below) were deleted. All individual building and house outlines present in the DLG data are shown on the maps.

The data represented in the different topical layers are limited to the date of the topographic map from which the DLGs were prepared. The town of Los Altos Hills is located at the junction of four 7.5-minute quadrangles, which range in publication date from 1973 to 1981:

| Quadrangle Name | Year | Location in Map |
|---|---|---|
| Palo Alto | 1973 | northwest part |
| Cupertino | 1980 | southeast part |
| Mindego Hill | 1980 | southwest part |
| Mountain View | 1981 | northeast part |

Not all current cultural features are shown on the maps. Any road or building constructed after the years listed above will not be shown on the maps. Also, only selected buildings are shown where dense development is represented on the quadrangle maps by shaded areas. The boundary lines of these shaded regions would interfere with the other data on the shaded relief and slope maps and in any case do not indicate specific buildings.

## ACKNOWLEDGEMENTS

We thank John C. Tinsley and George G. Mader for helpful comments and suggestions, and S.E. Graham for access to the assembled 10-m elevation grid.

## REFERENCES CITED

Acevedo, William, 1991, First assessment of U.S. Geological Survey 30-minute DEMs, A great improvement over existing 1-degree data, *in* American Society for Photogrammetry and Remote Sensing, American Congress on Surveying and Mapping, Annual Convention, Baltimore, March 25-29, Technical Papers, v. 2 (Cartography and GIS/LIS), p. 1-12.

Fitzgibbon, T.T., 1991, ALACARTE installation and system manual (version 1.0): U.S. Geological Survey, Open-File Report 91-587B.

Fitzgibbon, T.T., and Wentworth, C.M., 1991, ALACARTE user interface – AML code and demonstration maps (version 1.0): U.S. Geological Survey, Open-File Report 91-587A.

Mader, G., and others, 1988, Geology and Planning: the Portola Valley Experience: William Spangle and Associates, Portola Valley, California.

Meyer, L.D., and Ports, M.A., 1976, Prediction and control of urban erosion and sedimentation, *in* National Symposium On Urban Hydrology, Hydraulics, and Sediment Control, Univ. of Kentucky, p. 323-331.

Nilsen, T.H., Wright, R.H., and others, 1979, Relative slope stability and land-use planning in the San Francisco Bay region, California: U.S. Geological Survey Professional Paper 944.

Wentworth, C.M., and Fitzgibbon, T.T., 1991, ALACARTE user manual (version 1.0): U.S. Geological Survey, Open-File Report 91-587B.

Thurow, C., Toner, W, and Erly, D., 1975, Performance controls for sensitive lands: Chicago, American Society Plan. Officials, 156 p.