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MAPPING SMOOTH SURFACES
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Mark Philip Kumler

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Master of Arts degree in Geography

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MAPPING SMOOTH SURFACES
WITH
CONTINUOUS TONE MAPS

by

Mark Philip Kumler

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

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1988

5178083

ABSTRACT

MAPPING SMOOTH SURFACES WITH CONTINUOUS TONE MAPS

by

Mark Philip Kumler

Smooth surfaces such as elevation and temperature are often represented with isarithm maps or block diagrams. These illustrations are difficult for many map readers to interpret. This study presents a technique for representing smooth surfaces with visually continuous tone maps produced on a high resolution color graphics computer system. The technique relies on a very dense, regular grid of surface values, similar to those used to produce conventional isarithm maps and block diagrams. The continuous tone maps represent changes in the surface value with gradual, continuous changes in tone or hue. The effectiveness of the continuous tone technique was examined by testing sixty-four map readers. Each test subject answered several questions about two real surfaces represented in a variety of ways. Traditional isarithm maps, block diagrams, and continuous tone maps were compared. The subjects performed significantly better on the maps employing the continuous tone technique.

To my mother and father,
for encouraging me to pursue
a graduate degree.

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TABLE OF CONTENTS

LIST OF TABLES

Table

LIST OF FIGURES

Figure

CHAPTER I

INTRODUCTION

Maps are representations of reality. Most maps are designed to represent some phenomenon that occurs on the earth in a simple, easy-to-understand manner. The success of a map hinges upon how well the information is represented. A good map will convey the desired information clearly and accurately. Many cartographers seek ways to improve upon existing map techniques; this paper presents a method for representing smooth statistical surfaces with continuous tone maps.

The Smooth Statistical Surface

Many geographic phenomena can be thought of as statistical surfaces. Any data that varies quantitatively over space can be perceived as a surface; the data values can be thought of as heights above a given base value (Robinson, 1961).

Statistical surfaces are often divided into two basic types -- smooth and stepped. Surfaces such as elevation and temperature, with values that vary continuously from place to place on the surface of the earth, are considered smooth. Other surfaces, with uniform values over certain areas and abrupt changes at sharp boundary lines, are considered stepped (Jenks, 1963).

Illustrating smooth statistical surfaces has been a challenge to cartographers for many years. A number of techniques have been proposed, with varying degrees of success. Before evaluating the success of any technique, one must consider what characteristics the ideal representation should have. Groop and Smith (1982) identified four qualities of the ideal representation of a smooth surface: the data should be accurately represented, not for the purpose of specific data extraction by the map reader but to provide a faithful depiction of the true surface; map planimetry should be maintained in order to minimize possible reader disorientation; the general configuration of the surface should be obvious to the map reader; and, finally, the surface representation should have smooth visual changes from point to point. Many types of maps meet two or three of these criteria; very few meet all four.

Existing Mapping Techniques

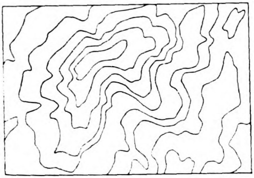
Many of the techniques for illustrating continuous surfaces have been developed to represent terrain or elevation on the surface of the earth. Hill shading is one of the oldest of these techniques and is perhaps still one of the best for depicting terrain. Unfortunately, it takes a great deal of time and training to produce high quality shadings. A number of cartographers, including Yoeli (1967), Brassel (1974), and Hügli (1979) have developed automated techniques for the production of hill shadings; these automated approaches have reduced production time and improved the accuracy of the shadings, although most do not match the high quality of manually produced work.

The application of hill shading to the depiction of smooth surfaces remains limited since it is based on the concept of slope instead of height. A surface is shaded proportionally to the angle of slope relative to the light source, rather than elevation. Variations on the simple slope shading technique exist, but none incorporate the actual elevation, or height, of the smooth surface.

Most maps of smooth surfaces seen today employ the isarithmic technique. This technique, originally developed to represent bathymetry, is based on the idea of horizontal planes intersecting the surface to be mapped (Robinson *et al.* , 1978). The lines of intersection are drawn in two dimensions and are labeled with the associated surface values. Isarithm maps depicting land elevation have come to be known as contour maps; the lines of equal elevation are known as isohypse (Huschke, 1959), or contours.

A number of studies have shown that isarithm maps are difficult for many map readers to interpret (Phillips, DeLucia, *and* Skelton, 1975; Phillips, 1979; Griffin *and* Locke, 1979). Even before such studies were conducted, cartographers proposed modifications to the simple isarithm map in attempts to make the surface more readable. Keil (1860) suggested that the widths of the isolines increase with increasing elevation. Tanaka (1932) introduced the use of 'inclined contours'; these are simply the tracings of the intersections of inclined planes (instead of horizontal planes) with the surface being represented. Phillips (1979) proposed the addition of a 'wedding cake' effect by displacing and re-drawing all 'south-facing' contour lines; although this tiered effect helped interpretation of the surface form, it did not prove popular. Imhof (1982) suggested that the color, or tone, of the contours should vary with the level of illumination from an imaginary light source. Although many of these suggestions have made the surface configuration more readable, few have gained popularity. In many cases, the disadvantages, either in production or interpretation, have outweighed the advantages. Examples of some of these techniques are presented in Figure 1.

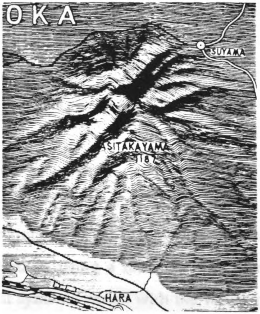
Another approach to improving the simple isarithm technique is to combine it with one or more of the other techniques. Imhof (1982) has proposed a number of combinations of two or more techniques, including contours with hill shading and contours with hypsometric tints. Robinson (1961) has suggested the combination of traces of inclined planes and oblique hill shading. One of the most common modifications to the simple isarithm map is the addition of gray tones or colored tints to the areas between the



Simple isoline
(Imhof, 1982)

Wedding cakes
(Phillips, 1979)

Varying widths
(Keil, 1860)



Inclined contours
(Tanaka, 1932)

Figure 1. Examples of Isarithmic Techniques.

isolines. Studies have shown that the addition of these tones or colors may help map readers interpret the overall surface form at the expense of giving the smooth surface a stepped appearance (Phillips, DeLucia, *and* Skelton, 1975).

A rather different approach to the representation of smooth statistical surfaces is the perspective block diagram. This three-dimensional illustration has been popularized with the advent of computers; the illustrations that once took many hours to create by hand can now be plotted in seconds on many microcomputers. In addition to significantly reducing the time necessary to produce the illustrations, computers allow the cartographer to select from any number of viewing azimuths, elevations, and distances. The best azimuth from which to view a block diagram is usually determined by the surface configuration; Rowles (1978) carried out an extensive study on the effect of different view elevations and distances. She concluded that neither had a significant effect on the interpretation of the surface. Although block diagrams can have smooth visual changes and fairly obvious surface forms, their use is hindered by the loss of planimetry and the frequent presence of hidden areas.

In the past few years, research efforts have shifted back to the idea of using gradual changes in tone to represent changes in value (cf. hill shading). The difficulty with this idea lies in the production of gradual changes in tone. Groop and Smith (1982) introduced a method using a lattice of graduated point symbols. The diameters of the point symbols varied with the values on the surface, resulting in a continuous-appearing transition from areas with high values to areas with low values. They encountered difficulties in the actual production process; in order to obtain a visually smooth progression, the maps had to be plotted at many times the final size and reduced photographically. The lengthy plotting times and high computing costs proved impractical.

More recent efforts by Groop (1982) and Lavin (1984) have resulted in a technique know as dot-density shading. By varying the density of dots within a lattice of cells, instead of varying the size of regularly spaced point symbols, a visually more continuous image is possible. Johnson (1984) implemented the algorithm for production on dot-matrix printers and carried out a test of the effectiveness of the representation. He concluded that the dot-density technique was as effective as the isarithmic technique, but its application was hindered by negative map reader impressions. Some examples of these more recent techniques are presented in Figure 2.

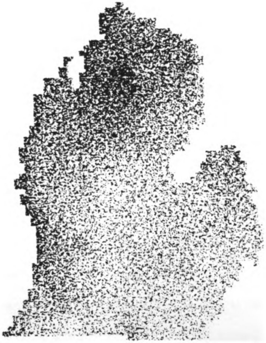
Statement of Purpose

The sheer number of techniques proposed for the representation of smooth surfaces suggests that an ideal solution has yet to be found. In fact, it is probable that no single technique will ever be best suited for all representations.

A number of recent studies have shown that continuous-appearing changes in tone may be an effective means of representing smooth surfaces. These studies have involved techniques that simulate continuous tones with solid dots at varying sizes or varying densities. The technique presented here produces continuous tone maps on a high-resolution color graphics monitor. Such CRT-based systems are able to simulate continuous tones by simultaneously displaying a very large number of colors or shades. This technique incorporates state-of-the-art technology and represents yet another application of computers to cartography.

(a) Groop and Smith, 1982

(b) Groop, 1984



(c) Johnson, 1984

Figure 2. Examples of Graduated Point Symbol, Dot-Density Techniques.

The purpose of this research was to develop a new technique for representing smooth statistical surfaces and to evaluate the usefulness of the technique by testing a number of map readers.

CHAPTER II

THE CONTINUOUS TONE TECHNIQUE

Continuous tone maps are readily created on a computer monitor. Monitors that can display multiple shades or multiple colors can be used to produce maps that are more continuous visually than simple black-and-white continuous tone maps. The method proposed here has been implemented on an Advanced Electronic Design (AED) high resolution color graphics system. The monitor on this system is capable of simultaneously displaying 256 colors from a palette of over 16.7 million colors.

Creation of the Base Matrix

The first step in producing any continuous tone map is to compile a set of control points for which the actual values are known. The x- and y-coordinates for these points are typically digitized from base maps; surface values are added to create a number of xyz triplets. If the area to be mapped is non-rectangular, an outline may also be digitized. The surfaces for this study were digitized on a Tektronix 4956 digitizing tablet (interfaced to an IBM PC); the z-values were added to the coordinate files with Microsoft Word, a commercially available word processor.

If the control points are irregularly spaced, a regular grid of data values is created. This regular grid is interpolated from the irregularly spaced control points and consists of numeric values for every intersection of an imaginary square (or rectangular) grid. Such gridding techniques are frequently used to produce isarithm maps and perspective block diagrams; the same grids can be used to generate the base matrix for continuous tone maps.

A number of software packages are available to perform these interpolations; SURFER, by Golden Software, was used for the maps in this study. SURFER offers a variety of interpolation algorithms; a sophisticated Kriging technique was selected to insure close approximations of the original surfaces. The grid generated by SURFER was rectangular -- all rows contained the same number of columns.

The base matrix, a dense version of the regular grid, was generated so that every pixel on the screen had a specific value. The AED monitor has 1024 pixels in each of 766 displayable rows. Ideally, a sophisticated algorithm would be used to directly interpolate a matrix of this size; in practice, this is seldom feasible. A computer program, GRDTOPXL (Appendix A), was written to 'densify' the grids produced by SURFER. This program linearly interpolated additional rows and columns between the original grid, resulting in a dense matrix of values that were assigned to individual pixels on the monitor. GRDTOPXL also scaled the values into a range of integers from 0 to 250. These numbers corresponded to values in a color table that determined the appearance of the continuous tone image.

Displaying the Surface on a Computer Monitor

Once the base matrix was prepared, the continuous tone image was displayed on the computer monitor. PXLTOAED (Appendix B) was written to display such digital bases on an AED system. The program uses the matrix as a template to assign an integer between 0 and 250 to every pixel on the screen. Once the rectangular image is on the screen in digital form, colors can be assigned to the different values. This coding of colors to numbers is known as a color table and can be changed easily and quickly on the AED system. A default color scheme was followed for the initial display.

PXLTOAED lets the user determine what colors are used in the image. Colors are defined in the AED system by specifying intensities, from 0 to 255, for the red, green, and blue phosphors that make up each pixel. The colors in the image were changed by simply redefining the colors in the color table. Colors were defined for the lowest and highest values in the image (0 and 250) and for selected intermediate values; PXLTOAED interpolated the color specifications for all other values in the color table. For example, a user could specify that all pixels with value 0 appear black (0,0,0) and all pixels with value 250 appear white (256,256,256); all values between 0 and 250 would be calculated automatically and would appear as varying shades of gray. Similarly, one could specify that pixels with value 0 appear red (256,0,0), pixels with value 125 appear blue (0,0,256), and pixels with value 250 appear green (0,256,0); all values between the three specified values would be assigned colors with linearly interpolated red, green, and blue intensities.

An outline file was created when the control points were digitized. This outline was plotted on the screen and the area outside the outline changed to a designated background color.

Reproduction of Continuous Tone Imagery

Reproduction of continuous tone imagery is a challenge. Conventional computer output devices, such as dot-matrix, ink-jet, and laser printers, are not able to produce the many shades of a color or shades of gray required for continuous tone maps. However, several photographic processes are possible.

The simplest technique is to photograph the computer monitor with a standard 35-mm camera, using a telephoto lens to compensate for the curvature of the screen. The exposure time must be long enough to permit multiple refreshes of the image, necessitating the use of a tripod. The room must be completely dark; the only light entering the camera should be coming from the image on the computer monitor. The use of slow films with high resolution results in high quality reproductions. Many images on the AED monitor were successfully photographed with 100 ASA color print film and one-half second exposure times. The photographic prints were as visually continuous as the original images on the screen; photographing the monitor appears to be the best technique for acquiring a small number of very high quality reproductions.

Photographic prints of continuous tone images consisting of gray tones can be photocopied. White dot screens could be placed between the print and the glass of the copier to improve the quality of the reproduction. Most photocopiers reproduce the original image by fusing tiny dots of black toner onto white paper. Reproduced in this manner, the copies are technically no longer continuous tone; certain photocopiers, however, can simulate continuous tones of gray with a modest degree of success. Ordinary photocopiers produce reasonable copies of gray tone imagery at minimal cost.

Color copiers are a feasible approach to reproducing colored continuous tone imagery. Color photocopiers are marginally successful, while color laser copiers are significantly more successful. Color laser copiers scan the original image four times, once for each of the subtractive primaries (yellow, cyan, and magenta) and once for black. The component images are transferred, by laser, to ordinary paper, where subtractive color toners are fused. Color laser copiers produce fairly high quality reproductions very quickly. A Canon Color Laser Copier has been used to reproduce several continuous tone maps (Figure 3).

The only feasible technique for reproducing large numbers of continuous tone maps is conventional offset lithography. Full color continuous tone images can be separated into their component colors and printed in the

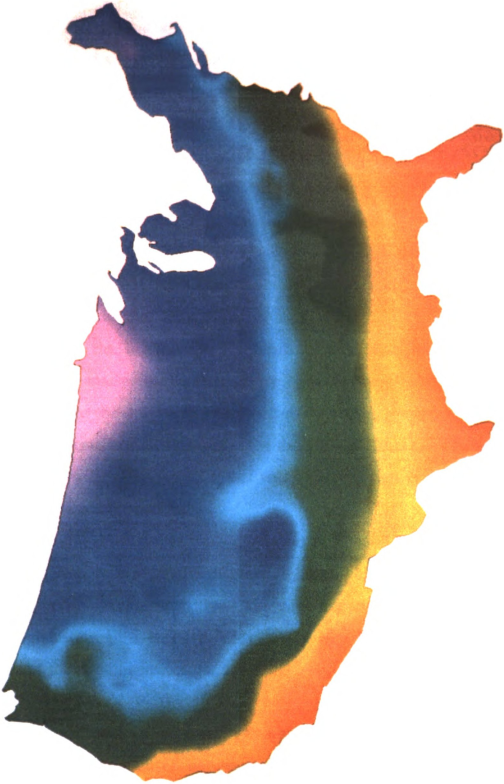


Figure 3. Color Laser Copy of Continuous Tone Map.

traditional process-color inks. This approach was used to reproduce all the imagery for this study; six black-and-white maps and six color maps were printed as part of a course in map design at Michigan State University.

Color separations and composite negatives were produced in the Center for Cartographic Research and Spatial Analysis. The full color images were separated into their component colors digitally; PXLTOAED was modified to PXLTORGB (Appendix C) to create three digital files for the red, green, and blue components. This step was simplified by the fact that all colors on the AED monitor are produced by combining various intensities of red, green, and blue light. RGBTOAED (Appendix D) was then written to display the three component images independently.

To obtain the highest quality reproductions possible, the composite negatives were made directly from the component images. The AED monitor was moved into the darkroom and positioned in front of the copy camera. A platform was constructed to support the monitor on the camera track in place of the copyboard. The camera lights were disconnected and the copy room was made as dark as possible.

The component images were displayed on the AED sequentially. Each image was displayed in shades of green light, to which 3M high-contrast BL4 lithographic film is most sensitive. The three negatives were held in register with registration pins taped directly to the film board; crosshairs in the corners of the component images provided a secondary method of registering the three negatives.

Exposure times and aperture settings were determined experimentally; most images were exposed between three and four minutes with the lens aperture wide open. These lengthy times were considered reasonable given that the AED monitor was providing all of the incident light energy.

Experimentation with halftone screens proved redundant; the component images are already composed of very small dots of light in varying intensities.

This method for producing continuous tone maps on a color monitor is feasible. The images can be reproduced in a variety of ways; many continuous tone maps have been successfully reproduced with conventional printing techniques. The following chapter presents an evaluation of this continuous tone symbology and its effectiveness at successfully depicting the smooth statistical surface.

CHAPTER III

THE EXPERIMENT

Continuous tone maps can be used to represent smooth statistical surfaces, but how effective they are at accurately portraying such surfaces has not been conclusively determined. Earlier studies by Smith (1980) and Johnson (1984) have dealt exclusively with black-and-white imagery; both concluded that the continuous tone technique was no less effective than other more conventional representations. One of the objectives of this study was to determine whether continuous tone maps initially produced on a color monitor effectively depict the smooth surface being represented. An experiment was devised to compare continuous tone maps to other more conventional representations.

Goals of the Experiment

The primary goal of this experiment was to determine whether continuous tone maps are more or less effective than other conventional representations. For this study, effectiveness was defined as whether map readers could locate surface extrema, accurately interpret the slope between a pair of points, and accurately estimate the relative and exact values at specific points. Continuous tone maps were compared to two more conventional representations -- isarithm maps and perspective block diagrams.

A secondary goal of this experiment was to determine whether the continuous tone shading technique could be successfully used in conjunction with the isarithmic technique. The two techniques can be presented together -- isarithms can be added to a continuous tone map, or, conversely, continuous tone shading can be added to an isarithm map. The effectiveness of combining the two techniques was examined.

A final goal of this experiment was to compare different color schemes on continuous tone maps. Certain color schemes may be more effective at representing smooth surfaces than others. A variety of color schemes, including one achromatic scheme, were tested.

Hypotheses

To determine the effectiveness of continuous tone maps, the following four hypotheses were proposed:

H1 Map readers can locate the surface extrema on continuous tone maps more accurately than on isarithm maps or block diagrams.

H2 Map readers can interpret the slope between a pair of points on continuous tone maps more accurately than on isarithm maps or block diagrams.

H3 Map readers can estimate the relative values of two points on continuous tone maps more accurately than on isarithm maps or block diagrams.

H4 Map readers can estimate the exact values at points on continuous tone maps more accurately than on isarithm maps or block diagrams.

To determine whether the continuous tone and isarithm techniques can be used together effectively, two hypotheses were proposed:

H5 Map readers perform better on maps using the continuous tone and isarithm techniques than on maps using only the isarithm technique.

H6 Map readers perform better on maps using the continuous tone and isarithm techniques than on maps using only the continuous tone technique.

To determine which color scheme was most effective, two additional hypotheses were proposed:

H7 Map readers perform better on continuous tone maps with chromatic schemes than on continuous tone maps with achromatic schemes.

H8 Map readers perform better on continuous tone maps with spectral color schemes than on continuous tone maps with three-color schemes.

All of these research hypotheses have associated null hypotheses that were to be accepted or rejected on the basis of differences in subjects' responses. A rejection level of 0.05 was used for all significance tests; in other words, the probability of incorrectly rejecting a null hypothesis (accepting a research hypothesis) was 0.05.

Test Illustrations

A number of map readers were tested to determine whether continuous tone maps are more or less effective than other conventional representations. To compare directly the different representations, the subjects answered the same questions about the same surfaces represented in different ways.

Since continuous tone maps can be used to portray a variety of smooth statistical surfaces, two different surfaces were included in the test. Although both represented the same type of information, land elevation, one surface was fairly regular, with moderate changes in value, while the other surface was less regular, with fairly sharp changes in value. Real surfaces were used instead of hypothetical surfaces. Elevation in Northern Ireland was used as an example of a fairly regular continuous surface (hereafter referred to as surface I). Elevation in Ethiopia was used as an example of a less regular continuous surface (hereafter referred to as surface II). To reduce the likelihood of a subject identifying the mapped surfaces by their shapes and possibly biasing the results, rectangular sub-areas of each region were used.

To compare different representations of the same surface, eight different maps of surface I and four different maps of surface II were prepared. Fewer versions of surface II were used to keep the project manageable. The eight representations of surface I included two conventional isarithm maps (with and without bands of uniform gray tones between black isolines), one perspective block diagram, and five continuous tone maps. Four of the continuous tone maps differed only in their color schemes -- one achromatic scheme progressed from white to black through shades of gray; one three-color scheme progressed from yellow to cyan through green; another three-color scheme progressed from cyan to magenta through blue; and a spectral scheme progressed from red through orange, yellow, green, cyan, and blue, to magenta. All four of these continuous tone representations had white isolines superimposed; a fifth continuous tone map, employing the spectral scheme, had none. The four representations of surface II included a traditional isarithm map with bands of uniform gray tones, a perspective block diagram, and two continuous tone maps employing the spectral color scheme, one with white isolines superimposed, and one without.

The eight maps of surface I and the four maps of surface II are summarized in Table 1. A code letter has been assigned to each map so that the individual maps may be easily referenced. Copies of the printed maps are presented in Figures 4, 5, and 6.

Using production techniques devised earlier, all twelve images were prepared in the Center for Cartographic Research and Spatial Analysis at Michigan State University. Control points for the two surfaces were digitized

Table 1. Descriptions of Twelve Test Illustrations

Code	Surface	Description
A	I	Simple isarithm map with black lines and labels on white background
B	I	Isarithm map with bands of uniform grey tones between black isolines
C	I	Perspective block diagram -- fishnet of black lines on white background
D	I	Achromatic continuous tone map -- white to black through shades of grey -- with white isolines superimposed
E	I	Three-color continuous tone map -- yellow to blue through shades of green -- with white isolines superimposed
F	I	Three-color continuous tone map -- cyan to magenta through shades of blue -- with white isolines superimposed
G	I	Spectral continuous tone map -- red to magenta through orange, yellow, green, cyan, and blue -- with white isolines superimposed
H	I	Spectral continuous tone map -- red to magenta through orange, yellow, green, cyan, and blue -- no isolines superimposed
W	II	Isarithm map with bands of uniform grey tones between black isolines
X	II	Perspective block diagram -- fishnet of black lines on white background
Y	II	Spectral continuous tone map -- red to magenta through orange, yellow, green, cyan, and blue -- with white isolines superimposed
Z	II	Spectral continuous tone map -- red to magenta through orange, yellow, green, cyan, and blue -- no isolines superimposed

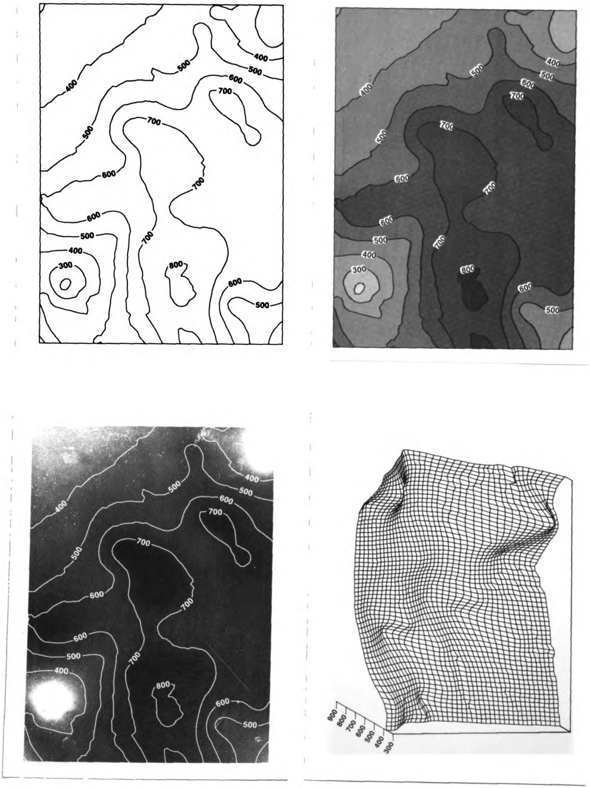


Figure 4. Test Illustrations A, B, C, and D.

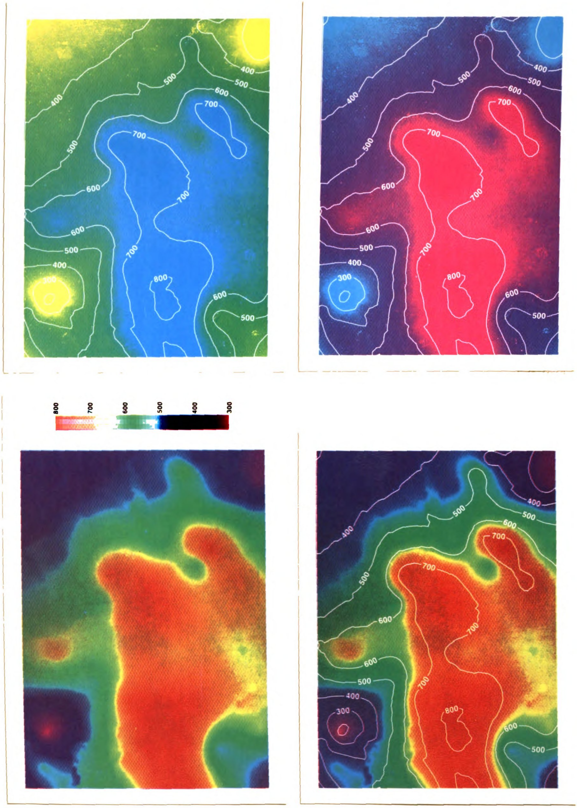


Figure 5. Test Illustrations E, F, G, and H.

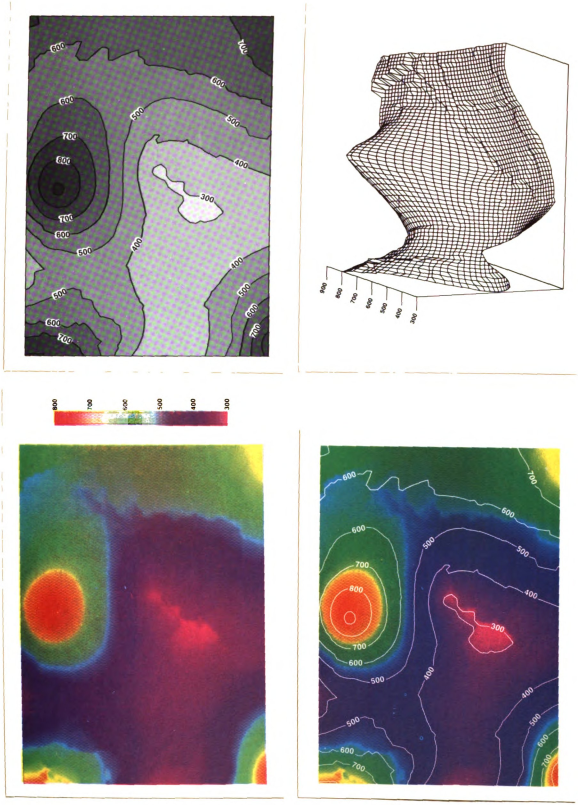


Figure 6. Test Illustrations W, X, Y, and Z.

on a Tektronix 4956 digitizing tablet in the Geography Computing Laboratory. Regular rectangular grids were generated for each surface with SURFER; a Kriging interpolation algorithm was selected to insure close approximations of the original surfaces. SURFER was also used to produce the simple isarithm maps and perspective block diagrams. These were plotted on glossy paper with a Hewlett-Packard 7475A pen plotter.

The same rectangular grids that were used to produce the isarithm maps and block diagrams were used to create the base matrices for the continuous tone images. The images were separated into their component color images and exposed onto negative-acting film on the copy camera. Before developing the negatives, white isolines and labels were added to four of the continuous tone maps by exposing the negatives of the corresponding simple isarithm maps. Bands of uniform gray tones were added to the simple isarithm maps with tint screens at ten percent intervals.

After the test illustrations were printed and cut to size, three point symbols and labels were placed on each map with colored pens (metallic silver for the achromatic map). These labeled points were to be referred to in the test questions. The three points were randomly selected for each surface; the points were placed in the same positions on all the different representations of each surface.

Test Questions

To measure the effectiveness of the different representations, five questions were asked about each map. The first two questions asked the subjects to locate the highest and lowest points on the map; these questions were intended to determine whether map readers could locate the relative extrema on the map of the surface. The third question asked the subjects whether one point was higher, lower, or 'about the same' elevation as another point; this was intended to measure how well the map readers could determine relative values. The fourth question involved the slope between two points; the subjects were asked whether a straight line between two points was generally uphill, downhill, or level. The final question asked the subjects to estimate the elevation at a specific point. A copy of the test questions, as they appeared in the test booklets, is provided in Figure 7. The letters corresponding to the point labels varied with the positions of the maps in the test booklet.

Test Booklets

Four different versions of the test were prepared. To keep the test to a reasonable length, each version contained seven maps and seven sets of questions. Different combinations of maps appeared in different versions. Each of the twelve test illustrations appeared in at least two versions of the test booklet. The different versions were color coded with red, yellow, green, and blue covers. The covers were imprinted with a brief description of the experiment, a statement about the subjects' participation in the experiment, and a brief set of instructions. Inside the booklets, the maps appeared on the left hand pages, and the questions for each map appeared on the right hand pages.

Testing subjects about the same points on the same surfaces has advantages and disadvantages. The primary advantage is the ability to compare directly the subjects' responses on two or more different representations. The main disadvantage results from the possibility of 'learning'; test subjects might improve over the course of the test or recognize a map as similar to one seen earlier. Either of these types of learning could bias the results.

1. Draw an **H** at the highest point on the map.

2. Draw an **L** at the lowest point on the map.

3. Point **A** is ______ point **B**.

    a) higher than
    b) lower than
    c) about the same elevation as

4. A straight line from point **B** to point **C** is generally:

    a) uphill
    b) downhill
    c) level

5. Estimate the elevation at point **A**.

    ____

Figure 7. The Test Questions.

To reduce the likelihood of a subject recognizing a representation of one surface as being similar to another representation of the same surface, the maps were alternated, rotated, and titled with fictitious names. Because each test booklet contained multiple maps of the two different surfaces, it was often (but not always) possible to alternate representations of one surface with representations of the other surface. Some of the maps could be rotated without appearing illogical -- the isarithm maps were designed so that the isoline labels could be read easily from two different orientations. All maps in a booklet were titled with different, fictitious names. The three points on each map were labeled with different letters of the alphabet.

The first map in all versions of the test booklet was map A, a simple isarithm map of the fairly regular surface. The remaining maps appeared in different orders and combinations in the four versions of the test. Table 2 indicates which maps appeared in the different versions and the order in which they appeared. The order of the fictitious titles and the letters used to label the points remained constant.

Table 2. Order of Test Illustrations in Test Booklets

			test version			
position	fictitious name	lettered points	red	yellow	green	blue
1	Goodhope	ABC	A	A	A	A
2	Hanover	DEF	W	Y	C	W
3	Ingram	IJK	E	B	Z	E
4	Johnstown	MNO	C	F	D	X
5	Keene	PQR	H	X	H	F
6	Lancaster	STU	Y	D	Y	Z
7	Vernon	XYZ	D	G	B	G

Sample pages from some of the test booklets are reproduced in Appendix E. Copies of the actual test booklets can be found in a packet bound into the back cover of this thesis.

Test Administration

Students in four sections of a course in American Thought & Language were tested. This interdisciplinary course, required of all undergraduates at Michigan State University, was selected for its probable fair representation of the undergraduate student body. The number of subjects in each class ranged from thirteen to twenty. The students were allotted fifteen minutes to complete the exercise.

In two of the classes, the test was administered at the beginning of the class period; the few students who arrived late did not take the exam. In the other two classes the test was administered at the end of the class period; all students present in these classes took the exam. After a brief introduction and explanation of the experiment (Appendix F), the test booklets were distributed. The different versions of the test had been collated together beforehand to insure a random distribution of the different versions.

Two minutes into the test, the students were told that they should be 'finishing up' the first map and starting to answer the questions on the second map. At the ten minute mark five supplementary questions were written on the chalkboard; these questions concerned the subjects' class level, map reading experience, and opinions of the maps in the test booklets. The students were asked to write their answers to the five supplementary questions on the back of their test booklets, after finishing the test. A transcript of all oral instructions and a copy of the supplementary questions appear in Appendix F. Collection of the completed test booklets began at the thirteen minute mark; no subject needed more than fifteen minutes to complete the exercise. Sixty-four subjects took the test, yielding a minimum of thirty-one responses to every map.

CHAPTER IV

RESULTS

Responses to the first two questions, in which the subjects were asked to identify the highest and lowest points, were deemed correct if the subjects placed the appropriate symbol within one-quarter inch of the actual position. The correct answers to the third and fourth questions, about slope and relative elevation, were determined by the actual elevations of the two points involved. Answers to the final question, in which the subjects were asked to estimate the elevation at a specific point, were considered correct if within twenty-five units of the actual value. A score was calculated for each map and for each test by dividing the total number of correct answers by the total number of questions.

Preliminary Analysis of Class Sections

Before aggregating the results from the four different classes, the scores were analyzed to determine if the four groups were samples from the same population. Since the different versions of the test booklet contained different combinations of maps, the scores for each version were analyzed independently.

A Kruskal-Wallis H test was used to determine whether the four classes were samples from the same population. This test analyzes the variance between samples by comparing the ranks of the observed values. It can be applied to three or more samples and is non-parametric, that is, it does not rely on possibly unrealistic assumptions about the distributions of the scores. All scores on each version of the test were ranked; the rankings for each sample were summed and an H statistic was calculated. The value of H can be used to estimate the probability of the observed differences occurring by chance. The average scores, H statistics, and significances are presented in Table 3.

The significance of the H value for the red version of the test was low (0.074) but above the chosen rejection level of 0.05. The low value was probably the result of a few 'above average' students receiving the red version in section I and a few 'below average' students receiving the red version in section IV. The high significance values for the other three versions of the test support this assumption. Since the differences between the four classes could be attributed to chance variation in the process of random sampling, the scores from the four different sections were aggregated.

Effects of Order and Combination of Maps in the Test

The orders and combinations of the maps in the different versions of the test were varied to determine whether either would bias the results. It was possible that a subject might recognize one surface as similar to another seen earlier in the booklet. It was also possible that a subject might 'catch on' to the map exercise and improve over the course of the test. Either of these types of 'learning' could bias the results.

To determine whether such bias occurred, the scores on the individual maps were tested for dependence on the position of the map in the test booklet. If the score on a given map depended on the position of that map in the booklet, it would be assumed that 'learning' took place. All scores on a given map in a given position were treated as a single sample. All scores on the same map in a different position were treated as a separate sample. A Kruskal-Wallis H test was then applied to these different samples to determine whether they were taken from populations with similar

Table 3. Kruskal-Wallis H Tests for Differences between Sections

H_0: Samples are from populations with identical distributions
($\alpha = 0.05$)

test version	class section I	II	III	IV	H	significance	decision
red (n=17)	86.5 (n=5)	72.3 (n=4)	63.2 (n=4)	53.7 (n=4)	6.94	0.074	accept H_0
yellow (n=16)	74.8 (n=5)	67.5 (n=4)	79.5 (n=4)	59.9 (n=3)	1.04	0.791	accept H_0
green (n=15)	72.4 (n=5)	77.0 (n=4)	77.0 (n=3)	67.4 (n=3)	1.07	0.785	accept H_0
blue (n=16)	67.8 (n=5)	71.0 (n=4)	60.7 (n=4)	79.9 (n=3)	1.84	0.606	accept H_0

distributions. All twelve maps were tested in this manner; the H statistics and significances are presented in Table 4. There were no significant differences between the distributions of the scores on any of the twelve maps; the positions of the maps in the test booklets did not bias the results.

Although the positions of the maps in the test booklets did not influence the scores, it was still possible that the combination of other maps in the booklets influenced the subjects' responses. To determine whether this type of 'learning' occurred, two pairs of maps were analyzed. These two pairs were selected because they appeared in different versions of the test in opposite orders. Map B appeared before map D in the yellow version of the test, but after map D in the green version. Similarly, map H appeared before map D in the red version, but after map D in the green version. Since all of the maps were of the same surface and the five questions concerned the same points, it was possible to directly compare subjects' scores from one map to the other.

The changes in score, from map B to map D, and from map D to map H, were calculated for each subject. A subject who answered three questions correctly on map B, and five questions correctly on map D, had a change in score of positive two. Similarly, a subject who answered four questions correctly on map B, and one question correctly on map D, had a change in score of negative three. These changes in score, from B to D and D to H, were calculated for all subjects who viewed either pair of maps and were separated according to the actual order in which the maps appeared.

The changes in score were then subjected to Mann-Whitney U tests to determine whether the differences varied significantly with the order in which the maps appeared. This statistical test relies upon the overall rankings of the values out of the total set of data and is not restricted by

Table 4. Kruskal-Wallis H Tests for Dependence on Version (Position)

H_0: Samples are from populations with identical distributions
($\alpha = 0.05$)

map code	in versions	H statistic	significance	decision
A	r, y, g, b	0.908	0.823	accept H_0
B	y, g	0.548	0.459	accept H_0
C	r, g	0.031	0.860	accept H_0
D	r, y, g	0.845	0.655	accept H_0
E	r, b	1.808	0.179	accept H_0
F	y, b	1.204	0.272	accept H_0
G	y, b	0.000	0.982	accept H_0
H	r, g	0.635	0.425	accept H_0
W	r, b	0.112	0.738	accept H_0
X	y, b	0.275	0.600	accept H_0
Y	r, y, g	2.309	0.315	accept H_0
Z	g, b	0.017	0.897	accept H_0

assumptions of normality. The U statistics and significances are presented in Table 5.

As Table 5 indicates, there were no significant differences between the two samples; any differences between the two distributions are attributable to chance in the sampling process. The combination of different maps in the test booklets did not bias the results.

Having concluded that the four samples of test subjects were not significantly different and that the positions and combinations of the maps in the test booklets did not significantly affect the results, the scores on the individual maps from the different versions and the different classes could be combined. The average scores for each of the twelve test maps, and the averages for the three basic map types, are presented in Table 6.

Comparing Performances on Maps and Map Types

The primary objective of this experiment was to determine whether continuous tone maps are more effective than isarithm maps or block diagrams. Effectiveness in this study was measured by how well map readers performed on certain questions about the surfaces being represented.

To compare one representation to another, a test was devised that compared each subject's performance on one map with the same subject's performance on a different map. Since the subjects answered the same questions about the same points, their answers could be directly compared. A subject who correctly answered four questions on map X, but only three questions on map Y, performed better on map X. In this example, for this subject, map X has represented the surface more effectively than map Y. Similar comparisons could be made about the subjects' performances on

Table 5. Mann-Whitney U Tests for Dependence on Order

H_0: Samples are taken from a common population
($\alpha = 0.05$)

map pair	order	n	median change in score	U	significance	decision
BD	B then D	16	+0.5	83.0	0.452	accept H_0
	D then B	15	0.0			
DH	D then H	15	+1.0	177.0	0.457	accept H_0
	H then D	17	0.0			

Table 6. Average Scores for Individual Maps and Map Types

map codes	surfaces	short description	sample size	average score
A	I	simple isarithm	64	67.2
B	I	isarithm w/ grey bands	31	69.7
C	I	block diagram	32	47.5
D	I	B+W CT with isolines	48	72.1
E	I	YGB CT with isolines	33	64.2
F	I	CVM CT with isolines	32	75.6
G	I	spectral CT with isolines	32	81.9
H	I	spectral CT	32	84.4
W	II	isarithm w/ grey bands	33	71.5
X	II	block diagram	32	49.4
Y	II	spectral CT with isolines	48	73.3
Z	II	spectral CT	31	83.9
CX	I,II	all block diagrams	64	48.4
ABW	I,II	all isarithm maps	128	68.9
DEFGHYZ	I,II	all continuous tone maps	256	75.9

individual questions. A subject who answered a question about the slope between two points correctly on map X and incorrectly on map Y performed better on map X. For this subject, and this surface, map X represented the slope between the two points more effectively than map Y.

To compare one map to another, all responses by all subjects who saw both maps were considered. The responses by subjects who saw only one of the two maps were not considered, since these could not be paired to the same subjects' responses on the other map.

For example, if map A were compared to map C, the paired responses of thirty-two subjects would be considered; although sixty-four subjects answered questions about map A, only thirty-two of these also answered questions about map C. The differences in performance for all subjects who saw both maps of a pair were tabulated. A number of these subjects performed equally well on the two representations, while others performed better on one representation than the other. The responses by the subjects who performed better on one of the two maps were examined to determine whether one representation was more effective than the other. Of the thirty-two subjects who answered the same questions about maps A and C, seven performed equally well on the two representations while twenty-five performed better on one of the two. Of these twenty-five, twenty performed better on map A, while five performed better on map C. If the two representations were equally effective, one would expect the number performing better on map A to be approximately equal to the number performing better on map C; that is, one would expect the distribution of the scores between the two classes to be even. The observed numbers can be compared to the expected numbers, and the differences can be tested for significance.

The differences between the expected and the observed distributions were subjected to chi square tests with one degree of freedom. The formula for the χ^2 statistic is:

$$\chi^2 = \Sigma \frac{(O-E)^2}{E}$$

where O and E are the observed and expected frequencies for each category. For all of the comparisons in this study the subjects were divided into only two classes, and the expected frequencies were simply one-half the total of the observed frequencies. Once the χ^2 statistic has been calculated, the probability of such a distribution occurring by chance can be estimated. A probability of less than 0.05 indicates that such a distribution could be expected to occur by chance fewer than five times in one hundred. In the example above, in which the performances on maps A and C were compared, the calculated value of χ^2 is 9.00. The probability of this distribution occurring by chance is less than 0.05 (in fact, less than 0.01), and the null hypothesis can be rejected. For the twenty-five subjects who did not perform equally well on the two maps, map A was significantly more effective than map C.

Many of the research hypotheses involved comparisons of different map types. When making such comparisons, all varieties of a given map type were considered. For example, when comparing the continuous tone technique to the traditional isarithm technique, the five varieties of continuous tone maps were compared to the two traditional isarithm maps. All possible pairings of maps of the same surface were considered. In many cases, this resulted in more pairings than test subjects, since most versions of the test booklet contained multiple varieties of each map type. When all varieties of continuous tone maps were compared to both isarithm maps, 288 pairings were possible. When comparing continuous tone maps to block diagrams, 113 pairings were possible.

Testing the Research Hypotheses

The first four hypotheses involved specific map reading tasks. To test these hypotheses, the subjects' paired responses to the individual questions were examined. The differences in performance on each of the five questions were examined independently. The distributions of these performance differences were compared to the expected even distributions. The results of all tests on the differences between the three basic map types, by question, are presented in Table 7.

The first two questions on each map asked the subjects to locate the highest and lowest points. The responses to these questions were used to determine how well the subjects could locate the surface extrema on the different maps. On question one there were thirty-two pairings of isarithm maps and continuous tone maps in which the subjects performed differently. In five of these pairings, the subjects performed better on the isarithm map; in the remaining twenty-seven, the subjects performed better on the continuous tone map. The difference between these frequencies is significant at the 0.05 rejection level; the null hypothesis for this comparison can be rejected.

When comparing the continuous tone maps to the block diagrams, there were fifty-five pairings in which the subjects performed differently on question one. In fifty-four of these pairings the subjects performed better on the continuous tone maps; in one pairing the subject performed better on the block diagram. The difference between these frequencies is also significant; the null hypothesis for this comparison was rejected.

Table 7. Chi Square Tests of Differences between Isarithms, Block Diagrams, and Continuous Tone Maps

H_0: Performance differences are evenly distributed
($\alpha = 0.05$)

question	number of pairings in which subject performed better on isarithm	number of pairings in which subject performed better on continuous tone	χ^2	probability	decision
1	5	27	15.125	~0.003	reject H_0
2	20	38	5.586	~0.04	reject H_0
3	26	51	12.481	~0.003	reject H_0
4	13	26	4.330	~0.03	reject H_0
5	22	66	22.000	~0.001	reject H_0
overall	55	115	21.176	~0.001	reject H_0

question	number of pairings in which subject performed better on block diagram	number of pairings in which subject performed better on continuous tone	χ^2	probability	decision
1	1	54	51.073	~0.000	reject H_0
2	8	30	12.736	~0.001	reject H_0
3	14	17	0.290	~0.88	accept H_0
4	0	37	37.000	~0.000	reject H_0
5	4	54	43.103	~0.000	reject H_0
overall	6	88	71.532	~0.000	reject H_0

The responses to the second question, about the lowest point on the surface, were similar. Of the subjects who performed better on one representation than the other, a significant number performed better on the continuous tone maps than on the isarithm maps or block diagrams. The probabilities of these differences occurring by chance were below the rejection level of 0.05; the null hypotheses were rejected.

The rejection of all null hypotheses on the first two questions indicates that for the surfaces represented in this study, and the subjects who performed better on one representation than another, the continuous tone maps were more effective than isarithm maps or block diagrams at representing the surface extrema. The first research hypothesis, H1, was accepted.

The second research hypothesis concerned the slope between two points on a surface. The responses to question three were used to compare the effectiveness of the different techniques at depicting slope. When comparing continuous tone maps to isarithm maps, the distribution of performance differences was significantly different than the expected even distribution. The null hypothesis could be rejected in favor of the continuous tone representation. When comparing the continuous tones to the block diagrams, however, the null hypothesis could not be rejected. The continuous tone maps were not significantly more effective than block diagrams at representing the slope between the two points tested on these surfaces. The second research hypothesis, H2, was not accepted.

The third and fourth research hypotheses concerned the relative and absolute values of points on the surface. Questions four and five were designed to measure the effectiveness of the different maps at representing this information. When comparing the continuous tone maps to the isarithm maps, the distribution of different performances was significantly different from the expected distribution on both questions. The differences observed in comparing the continuous tone maps to the block diagrams were also significant. All null hypotheses on questions four and five were rejected; research hypotheses H3 and H4 were accepted.

In addition to comparing the continuous tone technique to other more conventional techniques, this study examined the effectiveness of combining the isarithmic and continuous tone techniques. Hypotheses H5 and H6 were proposed to determine whether the maps employing both techniques were more or less effective than either alone. To test the first of these two hypotheses, the performances on the simple isarithm maps were compared to the performances on all of the continuous tone maps that had isolines superimposed. This test did not include the isarithm maps with gray tones between the bands, or the continuous tone maps without isolines. The subjects' scores on the different representations were paired, and the distribution of the performance differences was compared to a hypothetical even distribution. The results of this comparison, and several others described below, are summarized in Table 8. The number of pairings in which the subjects scored better on the map employing both techniques was significantly greater than the number of pairings in which the subjects performed better on the simple isarithmic technique. The null hypothesis was rejected at the 0.05 confidence level; research hypothesis H5 was accepted.

To test H6, the scores on the continuous tone maps without isolines were compared to the scores on the continuous tone maps with isolines that employed the same color scheme. Restricting the comparison to only those pairs of maps that employed the same color scheme significantly reduced the number of responses that could be paired. Fifteen subjects answered the same questions on maps Y and Z. Both of these maps represented the same surface

Table 8. Chi Square Tests of Differences between Selected Map Types

H_0: Performance differences are evenly distributed
($\alpha = 0.05$)

map types compared	map codes	# of pairings	# of higher scores	χ^2	probability	decision
simple isarithms	A W		39			
to		162		4.455	~0.04	reject H_0
CTs with isolines	DEFGY		60			
spectral CT w/iso's	Y		4			
to		15		0.818	~0.4	accept H_0
spectral CT	Z		7			
achromatic CTs	D		9			
to		49		3.000	~0.09	accept H_0
color CTs	EFG		18			
3-color CTs	EF		8			
to		48		4.481	~0.04	reject H_0
spectral CTs	G		19			
YGB CT	E		1			
to		16		4.500	~0.04	accept H_0*
CVM CT	F		7			

* expected frequencies of 4 are below recommended threshhold

with the same spectral color scheme; map Y had white isolines superimposed. Of the eleven subjects that performed better on one of the two maps, seven performed better on map Y and four performed better on map Z. The χ^2 statistic for these frequencies indicated that the distribution was not significantly different from a hypothetical even distribution; the null hypothesis was accepted. Research hypothesis H6 was rejected.

The final two research hypotheses concerned the different color schemes on the continuous tone maps. The first of these, H7, was proposed to test whether color schemes were more effective than achromatic schemes. Eighteen subjects performed better on the maps with a color scheme while nine performed better on the maps with an achromatic scheme. The distribution of the performance differences was tested against the hypothetical even distribution. The difference was not significant at the 0.05 level. The null hypothesis was accepted; H7 was rejected.

The last research hypothesis compared the two continuous tone maps employing three-color schemes to the continuous tone maps employing a spectral scheme. Of the twenty-seven subjects that performed differently on the two maps, nineteen performed better on the map employing the spectral scheme while eight performed better on either of the maps employing a three-color scheme. This distribution is significantly different from the expected even distribution; the null hypothesis was rejected. The final research hypothesis, H8, was accepted.

Additional Results

Only differences in performance pertaining directly to the research hypotheses have been reported in the preceding section. A number of other differences were observed and tested for statistical significance. They are examined here.

When comparing the three basic map types -- conventional isarithms, block diagrams, and continuous tone maps -- the subjects' performances were compared on a question-by-question basis. This was necessary to test the first four research hypotheses but is perhaps not as interesting as the subjects' overall performances on the different map types. The average scores, for all subjects, on the three basic map types were reported in Table 6: 48.4% on the block diagrams, 68.9% on the isarithm maps, and 75.9% on the continuous tone maps. The subjects' total scores on the individual maps can be paired and the differences in overall performance can be examined. The continuous tone technique was compared to the isarithmic and block diagram techniques in this manner. The results are presented in Table 7. When comparing the differences in overall performance on continuous tone maps and isarithm maps, there were 170 pairings in which the subjects performed better on one of the two representations. In 115 of these, the subjects performed better on the continuous tone map, while in 55 pairings the subject performed better on the isarithm map. This distribution is significantly different from the expected even distribution. The subjects in this study performed significantly better on the continuous tone maps than on the isarithm maps.

When comparing the overall performances on continuous tone maps and block diagrams, there were ninety-four pairings in which the subjects performed better on one map than the other. In eighty-eight of these cases, the subject performed better on the continuous tone representation, whereas in six cases the subject performed better on the block diagram. This distribution is also significantly different from the expected even distribution; the subjects in this study performed significantly better on the continuous tone maps than on the block diagrams.

One of the objectives of this study was to compare the different color schemes used on the continuous tone maps. The differences between the color and achromatic schemes were examined in H7; the differences between the three-color and spectral schemes were examined in H8. Although none of the research hypotheses addressed the differences between the two three-color schemes, the differences appeared to be significant. The two maps differed only in their color schemes; map E progressed from yellow to blue through green (identified as YGB), while map F progressed from cyan to magenta through a blueish-violet (identified as CVM). The subjects' responses to the two representations were paired and the distribution of performance differences was compared to the expected even distribution. Of the sixteen subjects that answered the same questions on both maps, eight performed equally well overall, while seven performed better on the YGB color scheme and one performed better on the CVM color scheme. The values of χ^2 and its associated significance are presented in Table 8, but the decision to accept or reject the null hypothesis must be tempered with a statement about the small sample size. Given that only eight subjects performed differently on the two types of maps, the expected frequencies for the two categories were four and four. These values are below the minimum threshhold of five; the results of the chi square test must be discarded. The null hypothesis can not be rejected.

The formal research hypotheses focused on the results of the questions asked about each map. The subjects also answered a supplementary set of questions about their class level, major, map reading experience, and map preferences. There were no patterns or unusual responses to the questions on class level and major. None of the subjects planned to major in geography.

Seven of the sixty-four subjects did indicate some level of cartographic training or experience; this ranged from "a little in a high school earth science class" to "3 years in the Army learning to read maps."

To determine whether the subjects with cartographic training significantly influenced the results, the test subjects were divided into two groups, based on experience, and their performances were compared. The average score for subjects with experience was 76.1%; the average score for the inexperienced subjects was 70.3%. The actual scores were subjected to a Mann-Whitney U test to determine if the difference between the two groups was significant. The calculated U statistic of 163.50 has a significance of 0.493; the performances of the experienced subjects was not significantly different from the performances of the inexperienced subjects.

Two of the supplementary questions asked the subjects to identify their 'favorite' and 'least favorite' maps. Thirty-seven of the fifty-two subjects (71%) who identified a least favorite map selected the block diagram; six subjects (12%) selected the simple isarithm map as their least favorite. Thirty-seven of the fifty-one subjects (73%) who identified a favorite map selected one of the two continuous tone maps with a spectral color scheme. The majority of the subjects preferred a spectral continuous tone representation.

Summary of Results

The subjects in this experiment were asked to answer several questions about two different surfaces represented in a variety of ways. The questions were designed to measure how well the subjects could perform several basic map interpretation tasks on different representations of the same surface. To compare directly the subjects' performances on the different maps, each subject's responses on one map were paired with the same subject's responses on a different map. To determine whether one map was more effective than another, the scores of the subjects who performed differently were examined. Eight research hypotheses were tested by comparing the distribution of the scores of the subjects who performed differently with a hypothetical even distribution.

In testing the first four hypotheses, all continuous tone maps were compared to all conventional isarithm maps and all block diagrams. The subjects' responses to individual questions were examined, since each question was directed at a different map reading task.

Hypotheses H1, H3, and H4 were accepted. For the subjects who performed better on one technique than another, the continuous tone technique proved significantly more effective than the isarithm or block diagram techniques at representing surface extrema, the relative values of two points, and the exact value at a given point. Hypothesis H2, as proposed, could not be accepted. The continuous tone technique was more effective than the isarithm technique at representing the slope between a pair of points, but was not more effective than the block diagram technique. If H2 had been separated into two hypotheses, one comparing continuous tones to isarithms and one comparing continuous tones to block diagrams, the hypothesis comparing the continuous tone technique to the isarithm technique could have been accepted.

Hypotheses H5 and H6 concerned the effectiveness of combining the isarithm and continuous tone techniques. H5 was accepted; for the subjects who performed differently on the two representations, the combination technique was more effective than the simple isarithm technique. H6 was rejected; the combination technique was not more effective than the continuous tone technique by itself.

The final two research hypotheses, H7 and H8, concerned the different color schemes employed on the continuous tone maps. H8 was accepted; spectral color schemes were more effective than three-color schemes. H7 had to be rejected, color schemes were not significantly more effective than the achromatic scheme.

The subjects' overall scores on the three basic map types were also examined. For the subjects who performed differently on the different types, the continuous tone maps were more effective than the isarithm maps or block diagrams. Performance differences on the two three-color continuous tone maps were examined; whereas a substantial number performed better on the CVM scheme than on the YGB scheme, small sample sizes prevented the rejection of the possibility that the difference occurred by chance. The subjects preferred the continuous tone technique; 73% of the respondents identified one of the two spectral continuous tone maps as their favorite.

Discussion

In the course of carrying out this research a number of other observations were made. The decision to test students in courses outside the geography department was sound. The professors were intrigued with the study and more than willing to cooperate. The students had a variety of backgrounds and appeared to welcome the interruption in the class schedule. None of the subjects refused to take the test; many commented on how interesting the study was.

Informal conversations with some of the subjects after the test shed additional light on the results. One student thought the exercise was easy and could not imagine how people could have trouble reading the maps. Many other students were perplexed by the block diagrams and questioned how they were supposed to be used; several commented that they had never seen such illustrations before.

The selection of a viewing angle and azimuth for perspective block diagrams is often subjective. The angles for the surfaces in this study were chosen to present the surface with as few hidden areas as possible, while retaining the illusion of three-dimensionality. It is quite possible that the subjects would have performed differently on different perspectives of the surfaces.

One student commented that she found the spectral continuous tone maps easy to use because "you simply match the color on the map to the color in the legend and read the figure." While this comment suggests that the number of colors in the scheme may be important to the effectiveness of the scheme, it also raises the issue of the importance of a legend. The continuous tone maps that had white isolines superimposed did not have an accompanying legend, whereas the continuous tone maps without isolines did have a small legend bar to the side of the map. The difference in performance on these two maps might be attributable to the absence of isolines or to the presence of a legend. Although the addition of a legend to an isarithm map with uniform or continuous shading might at first seem unnecessary, this study suggests that it might assist some map readers.

Finally, the overwhelming preference for the spectral continuous tone technique was encouraging but was undoubtedly influenced by the presence of multiple brilliant colors. An interesting study that could stem from this research would compare spectral continuous tone maps to isarithm maps with similarly colored bands. This type of map is becoming increasingly popular and is used in many newspapers to illustrate daily temperatures.

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

Representing the smooth statistical surface has been a challenge to cartographers for many years. The isarithmic technique is one of the oldest, and has been modified in many ways. The sheer number of proposed modifications is evidence that a better method is needed. In recent years, a number of techniques have been proposed that represent the surface value with continuous changes in tone. These techniques have shown promise but have been hindered by production difficulties. The purpose of this study was to develop a technique for producing more nearly continuous tone maps of smooth statistical surfaces and to evaluate the effectiveness of the technique by testing a number of map readers.

The new technique relies upon a very dense, regular rectangular grid of data values. The values in this very dense grid can be translated into colors or shades and displayed on a high resolution color graphics system. The resultant image appears visually continuous; areas with high values blend smoothly and continuously into areas with low values.

Once displayed on the computer monitor, the images can be reproduced. A number of reproduction techniques are possible, including conventional offset lithography. The necessary color separations can be prepared digitally; the composite negatives can be made directly from the monitor with a standard darkroom copy camera. Many images were prepared in this manner, including a number of maps to be used in a test of the effectiveness of the technique.

To determine whether maps employing this technique would effectively represent a continuous statistical surface, a number of map readers were tested. The effectiveness of the continuous tone representation was compared to two more conventional representations -- isarithm maps and block diagrams. A series of questions was developed to measure how well the subjects could interpret four aspects of the surface configuration. The subjects were asked to identify the surface extrema, estimate the relative and exact values of specific points, and determine the slope between two points. The subjects answered the same questions about the same points on different representations of the same surface. Two different, real surfaces were tested.

The results of the test indicate that the continuous tone technique can be used effectively. The subjects performed significantly better on the continuous tone representation when attempting to locate the surface extrema or estimate the relative or exact values of specific points on the surface. The continuous tone technique was more effective than the isarithm technique at representing the slope between two points and was as effective as the block diagram of the same surface. The continuous tone technique can also be used effectively in conjunction with the isarithmic technique; the subjects performed better on the maps using both techniques than on the maps using only the isarithm technique. A variety of color schemes were tested on the continuous tone maps; the subjects performed better on a spectral scheme involving several colors than on either of two three-color schemes. When asked to select a favorite map from those in the test booklets, the majority of the subjects selected one of the continuous tone maps with a spectral color scheme. A large number identified the block diagram representation as their least favorite.

Conclusions

The mapping of smooth surfaces with continuous tone maps is feasible. Their production has been automated on a high resolution color graphics system, and their reproduction is possible with conventional photographic and printing techniques.

Continuous tone maps have the four basic qualities of the ideal representation of a smooth surface. The data are accurately represented, as accurately as with isarithm maps or block diagrams produced from the same gridded data. Planimetric accuracy is preserved; there are no distortions or disorientations resulting from oblique views of the surface. The general configuration of the surface is obvious to the map reader; testing of sixty-four subjects has shown that the continuous tone technique is more effective than traditional techniques at representing the smooth surface. Finally, the surface representation has smooth visual changes; the tones in the image progress smoothly and continuously from point to point, in accordance with the data values.

The continuous tone technique is a viable alternative to other existing techniques for representing smooth statistical surfaces. It can be used effectively by map readers, alone or in conjunction with the isarithmic technique. Continuous tone maps should be used more often by cartographers attempting to represent smooth surfaces.

APPENDICES

Appendix A

Computer Program GRDTOPXL

```
'GRDTOPXL
'Written by Mark P. Kumler in 1988.
'
'This BASIC program converts GRD files into PXL files (hence its name).
'
'The user will be prompted to enter the name of a file containing a grid
'generated by SURFER; this file should be in ascii format and have a .grd
'extension. The user will be informed of the current size of the grid and will
'be asked to specify the maximum dimensions of the output grid. The actual
'dimensions of the new grid will be computed and displayed, and the user
'will be prompted for the name of a .pxl file to contain the new, dense grid.
'
'The program then densifies the input grid. This is accomplished by
'calculating values for new rows and columns between the existing rows and
'columns. The values for the intersections of this grid are linearly
'interpolated from the original values. All values are scaled into a range of
'zero to maxintensity (250), and truncated to integers.
'
'The files created by this program are intended to be used as input to
'PXLTOAED or PXLTORGB.
'

defint a-z
dim thisrow! (1000)
dim nextrow! (1000)
dim col! (500,20)

maxintensity = 250          'maximum value to appear in output grid
endoffile = 26              'ascii value for end of file character
flag = 253                  'artificial value for cells that should be 26

m$ = "####"                 'format for outputting intensities
n$ = "#####.#"              'format for displaying original grid values

print : input "What file contains the original grid? ", infile$ : print

open infile$ for input as #1
input #1, junk$                 'to peel off DSAA
input #1, cols, rows            'number of columns, rows

for i = 3 to 4
  input #1, junk$               'to peel off remainder of header
next

input #1, zmin!, zmax!          'extrema of input grid
zrange! = zmax! - zmin!         'compute the range of z-values
factor! = maxintensity/zrange!  'conversion factor for pixel intensity
```

```
print "The original grid contains"; cols; "columns and"; rows; "rows."
print
print "The z-values in this grid range from"; zmin!; "to"; zmax!; "."
print
input "Maximum size of new grid? (columns, rows) ", mcols, mrows
print

'The following determines the number of rows and columns that will be
'inserted between the existing rows and columns while retaining the
'original proportions.

desaddlrows = mrows - rows          'desired number of additional rows
desaddlcols = mcols - cols          'desired number of additional
columns
rowgaps = rows - 1                  'number of gaps in which to add rows
colgaps = cols - 1                  'number of gaps in which to add cols

desintrows! = desaddlrows/rowgaps
desintcols! = desaddlcols/colgaps
ninterps = int(min(desintcols!,desintrows!))

'ninterps is the number of rows and columns to be interpolated between all
'of the rows and columns in the original grid

trows = rows + ninterps*(rows-1)    'total number of rows
tcols = cols + ninterps*(cols-1)    'total number of columns

print "The new grid will contain"; tcols;"columns and"; trows; "rows.": print

input "What file should contain the new grid? ", outfile$: print
open outfile$ for output as #2

print #2, tcols
print #2, trows

for col = 1 to cols                 'read in very first row
  input #1, value!
  thisrow!(col) = value!
next col
input #1, cr$
```

```
for i = 1 to rows - 1

  locate 20,1: print "Currently processing original row     of"; rows; "."
  locate 20,34: print i

  for col = 1 to cols                          'read in nextrow
    input #1, value!
    nextrow!(col) = value!
  next col
  input #1, cr$

  for j = 1 to cols
    temp! = thisrow!(j)
    col!(j,1) = temp!
    gap! = nextrow!(j) - temp!
    unit! = gap!/(ninterps+1)
    for k = 1 to ninterps
      col!(j,k+1) = temp! + k*unit!
    next k
  next j

  for j = 1 to ninterps + 1                    'new, "thin" rows
    for k = 1 to cols - 1
      intensity = int((col!(k,j) - zmin!) * factor!)
      if intensity = endoffile then intensity = flag
      print #2, chr$(intensity);
      gap! = col!(k+1,j) - col!(k,j)
      unit! = gap!/(ninterps+1)
      for m = 1 to ninterps
        intensity = int((col!(k,j) + m*unit! - zmin!) * factor!)
        if intensity = endoffile then intensity = flag
        print #2, chr$(intensity);
      next m
    next k
    intensity = int((col!(cols,j) - zmin!) * factor!)
    if intensity = endoffile then intensity = flag
    print #2, chr$(intensity);
  next j

  for col = 1 to cols                          'make new thisrow this nextrow
    thisrow!(col) = nextrow!(col)
  next col

next i
```

```
 for i = 1 to cols - 1
   intensity = int((thisrow!(i) - zmin!) * factor!)
   if intensity = endoffile then intensity = flag
   print #2, chr$(intensity);
   gap! = thisrow!(i+1) - thisrow!(i)
   unit! = gap!/(ninterps+1)
   for j = 1 to ninterps
     intensity = int((thisrow!(i) + j*unit! - zmin!) * factor!)
     if intensity = endoffile then intensity = flag
     print #2, chr$(intensity);
   next j
 next i

intensity = int((thisrow!(cols) - zmin!) * factor!)
if intensity = endoffile then intensity = flag
print #2, chr$(intensity);

print : print "The new grid has been written to the file "; outfile$; "." : print

close #1
close #2

end
```

Appendix B

Computer Program PXLTOAED

```
'PXLTOAED
'Written by Mark P. Kumler in 1988.
'
'This BASIC program displays PXL files on the AED (hence its name).
'
'The user is prompted to enter the name of a .pxl file created by GRDTOPXL.
'The user is also prompted to enter the name of an outline file, if one exists.
'
'The .pxl file is assumed to contain the base matrix for a continuous tone
'image;  each number is interpreted as a value in the AED color table.  For the
'initial display, a spectral temperature scheme is assumed.  Once the image
'has been displayed the color scheme can be changed by resetting the color
'table.  The user is prompted with a number of options for resetting the color
'table.  If an outline file exists, an outline will also be drawn on the display.
'Once an outline has been drawn, the area outside the outline can be set to a
'background color.
'
'This program is designed to display full-color continuous tone images on the
'AED monitor.  If the image is to digitally separated into its component colors,
'PXLTORGB and RGBTOAED should be used.
'
'This program requires the Quickbasic library of AED routines, written by Jim
'Moore.

defint a-z
dim value(1024)                 'to hold color table values for a row of pixels
dim x(1000), y(1000)            'to hold outline coordinates

min = 0                         'minimum brightness
max = 250                       'maximum brightness
flag = 253                      'artificial value for cells that should be 26
endoffile = 26                  'ascii value for end of file character
xwidth = 1023                   'screen width in pixels
yheight = 765                   'screen height in pixels

print : print
print "This program displays a continuous tone image on the AED monitor."
print : print "                    RESET the AED !!!" : print
input "       What file contains the image (.pix file)? ", filename$ : print
input "          Enter the name of the outline file? ", outlinefile$ : print

open filename$ for input as #2
if outlinefile$ <> "" then open outlinefile$ for input as #3
input #2, ncols
input #2, nrows
```

```
lmargin = int((xwidth-ncols)/2)        'to center image horizontally
bmargin = int((yheight-nrows)/2)       'to center image vertically

gosub setupaed
gosub temperature                      'set default color scheme for initial
display

'input "Should a legend and crosshairs be drawn? ", landc$
'   if landc$ = "" then landc$ = "y"
'   landc$ = left$(landc$,1)
landc$ = "y"

cls: print: print
print "The image is being displayed in a temperature scheme.  When the"
print "image is complete you will have the opportunity to reset the color "
print "table.  You will be able to select the colors that will represent "
print "the lowest and highest values, respectively.  Intermediate values "
print "will be calculated."

locate 14,12: print "Row number     of"; nrows; "is being processed."

for row = 1 to nrows
   locate 14,22:print row
  call mov(lmargin, row+bmargin)
  for col = 1 to ncols
     b$ = input$(1,#2)
     intensity = asc(b$)
     if intensity = flag then intensity = endoffile
     value(col) = intensity
  next
  call whc(ncols,value())
next

close #2

if outlinefile$ <> "" then gosub outline
if landc$ = "y" then gosub landc

call mov(0,900)               'move the cursor off the visible screen
gosub resettable              'will loop within resettable until time to quit
call alf                      'set the AED to alphanumeric mode
call tapdon                   'done with the AED
cls
end
```

```
setupaed:
  call tapint                     'set up the Qbasic-AED link.
  call sct(252,0,0,0)             '252 = near black
  call sct(253,255,255,255)       '253 = background (initially white)
  call sct(254,127,127,127)       '254 = grey
  call sct(255,0,0,0)             '255 = near black
  call sbc(252)                   'set background color
  call ers                        'erase the screen
return

outline:
  i=1
  input #3, x(i), y(i)
  xmin = x(i)
  xmax = x(i)
  ymin = y(i)
  ymax = y(i)
  while not eof(3)
    i = i + 1
    input #3, x(i), y(i)
    if x(i) < xmin then xmin = x(i)
    if x(i) > xmax then xmax = x(i)
    if y(i) < ymin then ymin = y(i)
    if y(i) > ymax then ymax = y(i)
  wend
  close #3

  npoints = i
  xrange = xmax - xmin :  yrange = ymax - ymin
  call sec(255)

  startx = lmargin + ((x(1)-xmin)/xrange)*ncols
  starty = bmargin + ((y(1)-ymin)/yrange)*nrows
  call mov(startx, starty)
  for pt = 2 to npoints
    xpix = lmargin + ((x(pt)-xmin)/xrange) * ncols
    ypix = bmargin + ((y(pt)-ymin)/yrange) * nrows
    call dva(xpix, ypix)
  next pt
  call dva(startx,starty)
  call mov(1,340)
  call sec(253)

  print : input "          Do you want the exterior blanked??? ", junk$
  if junk$ = "y" then call bfl(255)
return
```

```
resettable:
  while c$ <> "q"
  r  = min:  g = min:  b = min
  rr = min: gg = min: bb = min

  cls
  print
  print
  print "You are in a loop that will allow you to repeatedly reset the color"
  print "table.  This will allow you to experiment with different color"
  print "progressions or schemes.  You may select colors for the extreme"
  print "values from the list below or define your own (intermediate values"
  print "will be interpolated).  You may also chose one of two predefined"
  print "color schemes:  temperature or elevation."
  print
  print
  print "    r = red      y = yellow     w = white    n = brown"
  print "    g = green    c = cyan       a = gray     e = elevation"
  print "    b = blue     m = magenta    k = black    t = temperature"
  print
  print "    d = define own colors        s = superimpose 'contours' "
  print "    z = change background        q = quit  "
  print
  print "Please specify a color to represent the lowest value in the"
  print "image (or an e or t for a predefined scheme, or a q to quit): "

 c$ = input$(1)
 if c$ = "q" then : return
 elseif c$ = "e" then : gosub elevation
 elseif c$ = "t" then : gosub temperature
 elseif c$ = "d" then : gosub defineowncolors
 elseif c$ = "f" then : gosub experimentalelevation
 elseif c$ = "u" then : gosub experimentaltemperature
 elseif c$ = "s" then : gosub superimposecontours
 elseif c$ = "z" then : gosub changebackground
 else
   if c$ = "r" then : r = max
   elseif c$ = "y" then : r = max: g = max
   elseif c$ = "g" then : g = max
   elseif c$ = "c" then : g = max: b = max
   elseif c$ = "b" then : b = max
   elseif c$ = "m" then : r = max: b = max
   elseif c$ = "w" then : r = max: g = max: b = max
   elseif c$ = "a" then : r = (max-min)/2: g = r: b = r
   elseif c$ = "n" then : r = max * .6: g = max * .33: b = max * .25
   end if      'color assumed to be k (black) and rgb remain at min
```

```
      print : print "Please specify a color to represent the highest value: "
      c$ = input$(1)

      if c$ = "r" then : rr = max
      elseif c$ = "y" then : rr = max: gg = max
      elseif c$ = "g" then : gg = max
      elseif c$ = "c" then : gg = max: bb = max
      elseif c$ = "b" then : bb = max
      elseif c$ = "m" then : rr = max: bb = max
      elseif c$ = "w" then : rr = max: gg = max: bb = max
      elseif c$ = "a" then : rr = (max-min)/2: gg = rr: bb = rr
      elseif c$ = "n" then : rr = max * .6: gg = max * .33: bb = max * .25
      end if

     call setcolortable(r,g,b,rr,gg,bb)
   end if
 wend
 return        'from resettable

 elevation:
     g =  0 : y =  65 : n = 250
     gyexp! = 1.0 : ynexp! = 1.0
     for i = g to y
        red = int(((i-g)/(y-g)) ^ gyexp! * max)   'red increased from 0 to 250
        call sct(i,red,max,min)
     next
     for i = y to n
       prange! = ((i-y)/(n-y)) ^ ynexp!
       red     = max - int(prange! * max / 2.5)
       green   = max - int(prange! * max / 1.5)
       blue    =       int(prange! * max / 4.0)
       call sct(i,red,green,blue)
     next
return

temperature:
  pi! = 3.141593
  m =  0 : b =  75 : g = 125 : y = 175 : r = 250
  x! = 4 :  tlim! = tan(pi!/x!)
  for i = m to b
    prange! = (tan((((i-m)/(b-m)*2)-1)*pi!/x!)/2*tlim!)+0.5
    if prange! < 0 then prange! = 0
    if prange! > 1 then prange! = 1
    red = max - int(prange! * max)     'red decreased from 250 to 0
   call sct(i,red,min,max)
  next
```

```
for i = b to g
  prange! = (tan((((i-b)/(g-b)*2)-1)*pi!/x!)/2*tlim!)+0.5
  if prange! < 0 then prange! = 0
  if prange! > 1 then prange! = 1
  blue = max - int(prange! * max)        'blue decreased from 250 to 0
  green = int(prange! * max)             'green increased from 0 to 250
  call sct(i,min,green,blue)
next

for i = g to y
  prange! = (tan((((i-g)/(y-g)*2)-1)*pi!/x!)/2*tlim!)+0.5
  if prange! < 0 then prange! = 0
  if prange! > 1 then prange! = 1
  red = int(prange! * max)               'red increased from 0 to 250
  call sct(i,red,max,min)
next

for i = y to r
  prange! = (tan((((i-y)/(r-y)*2)-1)*pi!/x!)/2*tlim!)+0.5
  if prange! < 0 then prange! = 0
  if prange! > 1 then prange! = 1
  green = max - int(prange! * max)  'green decreased from 250 to 0
  call sct(i,max,green,min)
next
return

defineowncolors:
  locate 21,1 : print "Enter the red, green, and blue components for the color"
  input "to represent the lowest values: ", r, g, b
  locate 22,1: print space$(80) : locate 22,1
  input "represent the highest values: ", rr, gg, bb
  call setcolortable(r,g,b,rr,gg,bb)
return

'The following subprogram sets up the color table.
sub setcolortable(rlo,glo,blo,rhi,ghi,bhi) static
  rinc! = (rhi-rlo)/250 : ginc! = (ghi-glo)/250 : binc! = (bhi-blo)/250
  for i = 0 to 250
    red  = rlo + (i*rinc!) : green = glo + (i*ginc!) : blue  = blo + (i*binc!)
    call sct(i,red,green,blue)
  next
end sub
```

```
superimposecontours:
  print : print "White (w), gray (g), or black (b)? " : ccolor$ = input$(1)
  if ccolor$ = "w" then shade = 255
  if ccolor$ = "g" then shade = 127
  if ccolor$ = "b" then shade = 0
  for i = 0 to 250 step 25
    call sct(i,shade,shade,shade)
    call sct(i+1,shade,shade,shade)
  next
return

changebackground:
  print : print "White (w), gray (g), or black (b)? " : ccolor$ = input$(1)
  if ccolor$ = "w" then shade = 255
  if ccolor$ = "g" then shade = 127
  if ccolor$ = "b" then shade = 0
  call sct(253,shade,shade,shade)
return

experimentalelevation:
  g =  0 : n = 250
  locate 21,1: input "What position should be yellow: (e.g. 60) ", y
  locate 22,1: input "Magic green-to-yellow exponent: (e.g. .4) ", gyexp!
  locate 23,1: input "Magic yellow-to-brown exponent: (e.g. .9) ", ynexp!
  for i = g to y
    red = int(((i-g)/(y-g)) ^ gyexp! * max)   'red increased from 0 to 250
    call sct(i,red,max,min)
  next
  for i = y to n
    prange! = ((i-y)/(n-y)) ^ ynexp!
    red    = max - int(prange! * max / 2.5)
    green  = max - int(prange! * max / 1.5)
    blue   =       int(prange! * max / 4.0)
    call sct(i,red,green,blue)
  next
return

experimentaltemperature:
  pi! = 3.141593
  m =  0 : b =  75 : g = 125 : y = 175 : r = 250

  locate 21,1: input "Enter positions for b, g, and y: (e.g. 75, 125, 175) ", b, g, y
  locate 22,1: input "Enter denominator for magic tangentiation: ", x!
  locate 23,1: input "Enter intensity correction exponent: (e.g. 0.8) ", y!
```

```
if x! < 2.01 then x! = 2.01
tlim! = tan(pi!/x!)

for i = m to b
   prange! = (tan((((((i-m)/(b-m))^y!)*2)-1)*pi!/x!)/2*tlim!)+0.5
   if prange! < 0 then prange! = 0
   if prange! > 1 then prange! = 1
   red = max - int(prange! * max)      'red decreased from 250 to 0
   call sct(i,red,min,max)
next

for i = b to g
   prange! = (tan((((((i-b)/(g-b))^y!)*2)-1)*pi!/x!)/2*tlim!)+0.5
   if prange! < 0 then prange! = 0
   if prange! > 1 then prange! = 1
   blue = max - int(prange! * max)     'blue decreased from 250 to 0
   green = int(prange! * max           'green increased from 0 to 250
   call sct(i,min,green,blue)
next

for i = g to y
   prange! = (tan((((((i-g)/(y-g))^y!)*2)-1)*pi!/x!)/2*tlim!)+0.5
   if prange! < 0 then prange! = 0
   if prange! > 1 then prange! = 1
   red = int(prange! * max             'red increased from 0 to 250
   call sct(i,red,max,min)
next

for i = y to r
   prange! = (tan((((((i-y)/(r-y))^y!)*2)-1)*pi!/x!)/2*tlim!)+0.5
   if prange! < 0 then prange! = 0
   if prange! > 1 then prange! = 1
   green = max - int(prange! * max)    'green decreased from 250 to 0
   call sct(i,max,green,min)
next
return

landc:        'The following is a feeble attempt at a legend.
  blegend = 60 : llegend = 970
  if lmargin < rlegend then rlegend = lmargin - 3

  for i = 0 to 250
     call mov(llegend,i+blegend)
     call sec(i)
     call dva(xwidth,i+blegend)
  next
```

```
'The following draws crosshairs for optical registration.
r = 15        'radius
 if lmargin < bmargin then
   if bmargin < r*2 then r = int(bmargin/2 - 2)
else
   if lmargin < r*2 then r = int(lmargin/2 - 2)
end if

d = r*2       'diameter
call sec(254)   'plot in grey

xl = r: xr = xwidth-r: yb = r: yt = yheight-r

call mov(0,yb): call dva(d,yb): call mov(xl,0): call dva(xl,d)

call mov(xr,0): call dva(xr,d)
call mov(xwidth,yb): call dva(xwidth-d,yb)

call mov(0,yt): call dva(d,yt)
call mov(xl,yheight): call dva(xl,yheight-d)

call mov(xr,yheight): call dva(xr,yheight-d)
call mov(xwidth,yt): call dva(xwidth-d,yt)
return                          'from landc
```

Appendix C

Computer Program PXLTORGB

```
'PXLTORGB
'Written by Mark P. Kumler in 1988.
'
'This program separates a PXL file into its red, green, and blue components.
'
'The user is prompted to enter the name of a .pxl file created by GRDTOPXL.
'This particular version of PXLTORGB assumes that the image is to follow a
'temperature color scheme; if another scheme is to be followed, the
'appropriate subroutine from PXLTOAED should be substituted for the
'temperature subroutine in this program. Once the red, green, and blue
'values for each position in the color table have been determined, the .pxl
'image is opened. The numbers in the .pxl file are assumed to correspond to
'values in the color table, and the red, green, and blue components of those
'colors are written to three new files with .r, .g, and .b extensions.
'
'This program generates three new files corresponding to the red, green, and
'blue components of the input .pxl file. These three files are to intended to be
'used as input to RGBTOAED.

defint a-z
dim shared red(250), green(250), blue(250)
max = 250 : flag = 253
cls : input "What .pxl file should be separated? ", main$ : print

pixfile$ = main$+".pxl"
rfile$ = main$+".r" : gfile$ = main$+".g" : bfile$ = main$+".b"
open pixfile$ for input as #1 : input #1, ncols : input #1, nrows
open rfile$ for output as #2 : print #2, ncols : print #2, nrows
open gfile$ for output as #3 : print #3, ncols : print #3, nrows
open bfile$ for output as #4 : print #4, ncols : print #4, nrows

gosub temperature          'set default color scheme for initial display

locate 14,12 : print "Row number     of"; nrows; "is being processed."
for row = 1 to nrows
  locate 14,22 : print row
  for col = 1 to ncols
    b$ = input$(1,#1)
    intensity = asc(b$)
    if intensity = flag then intensity = 26
    x = intensity
    print #2, chr$(red(x));
    print #3, chr$(green(x));
    print #4, chr$(blue(x));
  next
next
```

```
   close #1 : close #2 : close #3 : close #4
   print "All done." : cls
   end

   temperature:
     m =  0 :   b =  70 :   c = 105 :   g = 140 :   y = 175 :   r = 250
     for i = m to b
       prange! = (i-m)/(b-m)
       red = max - int(prange! * max)        'red decreased from 250 to 0
       call setrgb(i,red,min,max)
     next

     for i = b to c
       prange! = (i-b)/(c-b)
       green = int(prange! * max)            'green increased from 0 to 250
       call setrgb(i,min,green,max)
     next

     for i = c to g
       prange! = (i-c)/(g-c)
       blue = max - int(prange! * max)       'blue decreased from 250 to 0
       call setrgb(i,min,max,blue)
     next

     for i = g to y
       prange! = (i-g)/(y-g)
       red = int(prange! * max)              'red increased from 0 to 250
       call setrgb(i,red,max,min)
     next

     for i = y to r
       prange! = (i-y)/(r-y)
       green = max - int(prange! * max)      'green decreased from 250 to 0
       call setrgb(i,max,green,min)
     next
   return

sub setrgb(position, r, g, b) static
  red(position)   = r
  green(position) = g
  blue(position)  = b
end sub
```

Appendix D

Computer Program RGBTOAED

```
'RGBTOAED
'Written by Mark P. Kumler in 1988.
'
'This BASIC program displays .R, .G, and .B files on the AED.
'
'The user will be prompted to enter the name of an image to be displayed.
'The three files associated with this image (created by PXLTORGB) are opened
'and displayed sequentially on the AED monitor.  A legend and 'grey-scale'
'are also displayed.  Once the individual components are on the AED display,
'they can be photographed.
'
'This program requires the Quickbasic library of AED routines, written by Jim
'Moore.

defint a-z
max = 250
flag = 253
xwidth = 1023                    'screen width
yheight = 765                    'screen height
greywidth = 350                  'width of grey scale
greyheight = 50                  'height of grey scale

blegend =  200                   'these parameters are good for ust93645
llegend =  800
rlegend = 1023
skew   =  10
scale!  =  .68

dim value(1024)                  'to hold color table values for a row of pixels
dim shared red(250) : green(250) : blue(250)

cls : locate 10,18 :  input "What image should be displayed? ", main$

rfile$ = main$ + ".r" : open rfile$ for input as #2
gfile$ = main$ + ".g" : open gfile$ for input as #3
bfile$ = main$ + ".b" : open bfile$ for input as #4

print : print "      The three component files of this image will be displayed"
print "      in succession (red, then green, then blue).  You will be "
print "     prompted to signal that you are ready for the next component."
print : print "           Press any key after you have reset the AED."
proceed$ = input$(1)

cls : locate 10,1 : print "The image will start to appear in about 10 seconds..."
```

```
input #2, ncols : input #2, nrows
input #3, ncols : input #3, nrows
input #4, ncols : input #4, nrows

lmargin   = int((xwidth-ncols)/2)          'to center image horizontally
bmargin   = int((yheight-nrows)/2)         'to center image vertically

greyleft  = int((xwidth-greywidth)/2)
greyright = int((xwidth+greywidth)/2)
greytop   = bmargin - 50
greybottom = greytop - greyheight

gosub setupaed          'prepare AED to receive image(s)
gosub setcolortable     'set color table to shades of green
gosub templegend        'prepare r, g, b arrays according to temperature
scheme

cls : locate 14,17: print "   Red row     of"; nrows; "is being processed."
for row = 1 to nrows
   locate 14,27:print row
   call mov(lmargin, row+bmargin)
   for col = 1 to ncols
      intensity = asc(input$(1,#4))
      if intensity = flag then intensity = 26
      value(col) = intensity
   next
   call whc(ncols,value())
next
close #2

gosub redlegend
gosub greyscale

locate 18,13: print "Press any key when ready for the next component."
proceed$ = input$(1)

cls : call ers
locate 14,17: print " Green row     of"; nrows; "is being processed."
for row = 1 to nrows
   locate 14,27:print row
   call mov(lmargin, row+bmargin)
   for col = 1 to ncols
      intensity = asc(input$(1,#4))
      if intensity = flag then intensity = 26
      value(col) = intensity
   next
```

```
    call whc(ncols,value())
  next
  close #3

  gosub greenlegend
  gosub greyscale

  locate 18,13: print "Press any key when ready for the next component."
  proceed$ = input$(1)

  cls
  call ers
  locate 14,17: print "  Blue row     of"; nrows; "is being processed."
  for row = 1 to nrows
    locate 14,27:print row
    call mov(lmargin, row+bmargin)
    for col = 1 to ncols
      intensity = asc(input$(1,#4))
      if intensity = flag then intensity = 26
      value(col) = intensity
    next
    call whc(ncols,value())
  next
  close #4

  gosub bluelegend
  gosub greyscale

  call alf
  call tapdon
  end

setupaed:
  call tapint              'set up the Qbasic-AED link.
  call sct(255,0,0,0)      '255 = near black
  call sbc(255)            'set background color
  call ers                 'erase the screen
return

setcolortable:                  'sets color table for black to green scheme
  for i = 0 to 250
    call sct(i,0,i,0)
  next
return
```

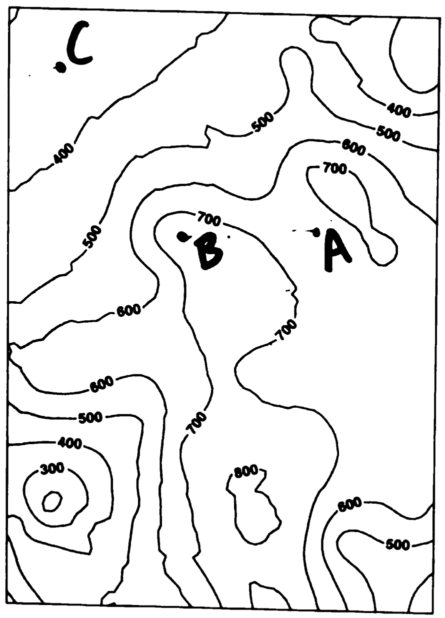
```
templegend:
  m =  0 :  b = 70 :  c = 105 :  g = 140 :  y = 175 :  r = 250

  for i = m to b
    prange! = (i-m)/(b-m)
    red = max - int(prange! * max)            'red decreased from 250 to 0
    call setrgb(i,red,min,max)
  next

  for i = b to c
    prange! = (i-b)/(c-b)
    green = int(prange! * max)                'green increased from 0 to 250
    call setrgb(i,min,green,max)
  next

  for i = c to g
    prange! = (i-c)/(g-c)
    blue = max - int(prange! * max)           'blue decreased from 250 to 0
    call setrgb(i,min,max,blue)
  next

  for i = g to y
    prange! = (i-g)/(y-g)
    red = int(prange! * max)                  'red increased from 0 to 250
    call setrgb(i,red,max,min)
  next

  for i = y to r
    prange! = (i-y)/(r-y)
    green = max - int(prange! * max)          'green decreased from 250 to 0
    call setrgb(i,max,green,min)
  next
return

sub setrgb(position, r, g, b) static
  red(position)  = r
  green(position) = g
  blue(position)  = b
end sub
```

```
redlegend:
  for i = 0 to 250
    dy = int(i*scale!)
    call mov(llegend,dy+blegend)
    call sec(red(i))
    call dva(rlegend,dy+blegend-skew)
  next
return

greenlegend:
  for i = 0 to 250
    dy = int(i*scale!)
    call mov(llegend,dy+blegend)
    call sec(green(i))
    call dva(rlegend,dy+blegend-skew)
  next
return

bluelegend:
  for i = 0 to 250
    dy = int(i*scale!)
    call mov(llegend,dy+blegend)
    call sec(blue(i))
    call dva(rlegend,dy+blegend-skew)
  next
return

greyscale:
  call sec(max)
  for i = greybottom to greytop
    call mov(greyleft, i)
    call dva(greyright, i)
  next
return
```

Appendix E

Sample Pages from the Test Booklets

Goodhope



1. Draw an **H** at the highest point on the map.

2. Draw an **L** at the lowest point on the map.

3. Point **A** is ______ point **B**.

   a) higher than
   b) lower than
   c) about the same elevation as

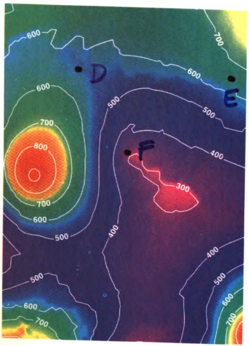
4. A straight line from point **B** to point **C** is generally:

   a) uphill
   b) downhill
   c) level

5. Estimate the elevation at point **A**.

   ____

Hanover



1. Draw an **H** at the highest point on the map.

2. Draw an **L** at the lowest point on the map.

3. Point **D** is _______ point **E**.

   a) higher than
   b) lower than
   c) about the same elevation as

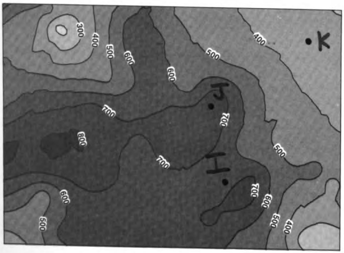
4. A straight line from point **E** to point **F** is generally:

   a) uphill
   b) downhill
   c) level

5. Estimate the elevation at point **D**.

   ____

Ingram



1. **Draw an H at the highest point on the map.**

2. Draw an **L** at the lowest point on the map.

3. Point **I** is ________ point **J**.

    a) higher than
    b) lower than
    c) about the same elevation as

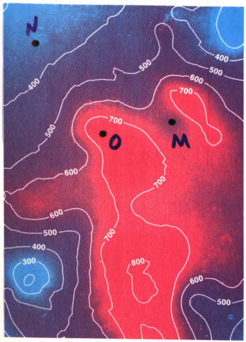
4. A straight line from point **J** to point **K** is generally:

    a) uphill
    b) downhill
    c) level

5. Estimate the elevation at point **I**.

    ____

Johnstown



1. **Draw an H at the highest point on the map.**

2. Draw an **L** at the lowest point on the map.

3. Point **M** is ________ point **N**.

   a) higher than
   b) lower than
   c) about the same elevation as

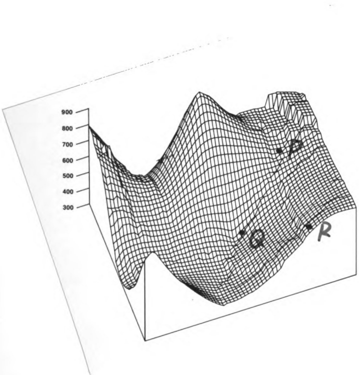
4. A straight line from point **N** to point **O** is generally:

   a) uphill
   b) downhill
   c) level

5. Estimate the elevation at point **M**.

   ____

Keene



1. **Draw an H at the highest point on the map.**

2. Draw an **L** at the lowest point on the map.

3. Point **P** is ________ point **Q**.

   a) higher than
   b) lower than
   c) about the same elevation as

4. A straight line from point **Q** to point **R** is generally:

   a) uphill
   b) downhill
   c) level

5. Estimate the elevation at point **P**.

   ____

Appendix F

The Oral Instructions and Supplementary Questions

The Oral Instructions and Supplementary Questions

"My name is Mark Kumler. I'm a graduate student in the Department of Geography and am carrying out this study to compare different types of maps. Your cooperation is most appreciated. Please read the instructions on the cover of the test booklet; when you're finished reading them please open the booklet and begin."

(after two minutes)

"You should be finishing up the first map and starting on the second. There are seven maps in the test."

(after ten minutes, the following questions were written on the board...)

1. Your class level?
2. Any experience/training reading maps?
3. Your favorite map?
4. Your least favorite map?
5. Any comments?

(immediately after writing the questions on the board)

"You have a few more minutes. When you finish, please turn to the back cover and answer the five questions I've just written on the board."

(after collecting the last test booklet)

"Thank you for your time and participation. I'll be in the hallway after class if any of you have any questions or additional comments."

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LIST OF REFERENCES

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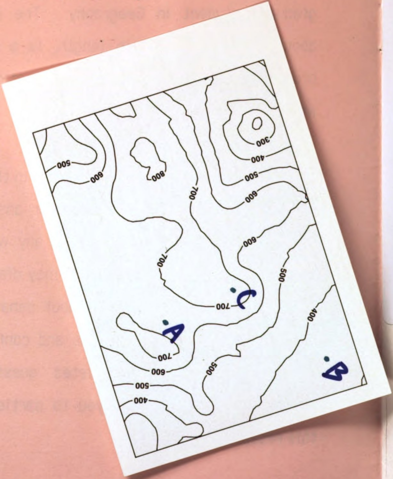
This exercise, involving maps and map reading skills, is being conducted by Mark Kumler, a graduate student in Geography. The exercise, about fifteen minutes in length, is a research project designed to provide information about improving maps.

The exercise is not part of your work in this class nor will your participation or your answers to questions influence your grade in any way. You may decline to participate or you may discontinue the exercise at any time without penalty. All results will remain anonymous and confidential. Your return of the completed questionnaire constitutes agreement by you to participate in this research.

You are about to see seven maps. Each map will be accompanied by five questions. Please read the questions carefully, and answer them as best you can.

Goodhope



1. Draw an **H** at the highest point on the map.

2. Draw an **L** at the lowest point on the map.

3. Point **A** is ________ point **B**.

   a) higher than
   b) lower than
   c) about the same elevation as

4. A straight line from point **B** to point **C** is generally:

   a) uphill
   b) downhill
   c) level

5. Estimate the elevation at point **A**.

   ____

Hanover

1. Draw an **H** at the highest point on the map.

2. Draw an **L** at the lowest point on the map.

3. Point **D** is ________ point **E**.

   a) higher than
   b) lower than
   c) about the same elevation as

4. A straight line from point **E** to point **F** is generally:

   a) uphill
   b) downhill
   c) level

5. Estimate the elevation at point **D**.

   ____

Ingram

1. Draw an **H** at the highest point on the map

2. Draw an **L** at the lowest point on the map.

3. Point **I** is ________ point **J**.

   a) higher than
   b) lower than
   c) about the same elevation as

4. A straight line from point **J** to point **K** is generally:

   a) uphill
   b) downhill
   c) level

5. Estimate the elevation at point **I**.

   ____

Johnstown

1. Draw an **H** at the highest point on the map

2. Draw an **L** at the lowest point on the map

3. Point **M** is ________ point **N**

   a) higher than
   b) lower than
   c) about the same elevation as

4. A straight line from point **N** to point **O** is generally:

   a) uphill
   b) downhill
   c) level

5. Estimate the elevation at point **M**.

   ____

Keene

1. Draw an **H** at the highest point on the map.

2. Draw an **L** at the lowest point on the map.

3. Point **P** is ________ point **Q**.

   a) higher than
   b) lower than
   c) about the same elevation as

4. A straight line from point **Q** to point **R** is generally:

   a) uphill
   b) downhill
   c) level

5. Estimate the elevation at point **P**.

   ____

Lancaster

1. Draw an **H** at the highest point on the map.

2. Draw an **L** at the lowest point on the map.

3. Point **S** is ________ point **T**.

   a) higher than
   b) lower than
   c) about the same elevation as

4. A straight line from point **T** to point **U** is generally:

   a) uphill
   b) downhill
   c) level

5. Estimate the elevation at point **S**.

   ____

Vernon

1. Draw an **H** at the highest point on the map.

2. Draw an **L** at the lowest point on the map.

3. Point **X** is ________ point Y.

    a) higher than
    b) lower than
    c) about the same elevation as

4. A straight line from point **Y** to point Z is generally:

    a) uphill
    b) downhill
    c) level

5. Estimate the elevation at point **X**.

    ____

114
740
THS
Booklet 4

MICHIGAN STATE UNIVERSITY LIBRARIES
3 1293 03149 2337

114740 THS
Kumler, Mark Philip

SUPPLEMENTARY
MATERIAL

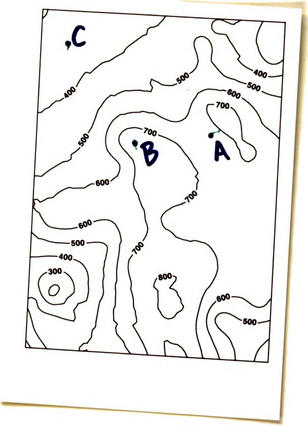
LIBRARIES
MICHIGAN STATE UNIVERSITY
EAST LANSING, MICH. 48824-1048

This exercise, involving maps and map reading skills, is being conducted by Mark Kumler, a graduate student in Geography. The exercise, about fifteen minutes in length, is a research project designed to provide information about improving maps.

The exercise is not part of your work in this class nor will your participation or your answers to questions influence your grade in any way. You may decline to participate or you may discontinue the exercise at any time without penalty. All results will remain anonymous and confidential. Your return of the completed questionnaire constitutes agreement by you to participate in this research.

You are about to see seven maps. Each map will be accompanied by five questions. Please read the questions carefully, and answer them as best you can.

Goodhope



1. Draw an **H** at the highest point on the map.

2. Draw an **L** at the lowest point on the map.

3. Point **A** is ________ point **B**.

   a) higher than
   b) lower than
   c) about the same elevation as

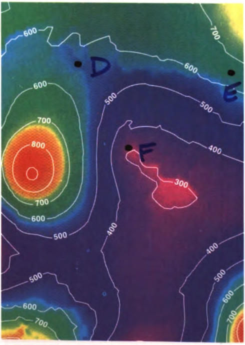
4. A straight line from point **B** to point **C** is generally:

   a) uphill
   b) downhill
   c) level

5. Estimate the elevation at point **A**.

   ____

Hanover



1. Draw an **H** at the highest point on the map.

2. Draw an **L** at the lowest point on the map.

3. Point **D** is ________ point **E**.

   a) higher than
   b) lower than
   c) about the same elevation as

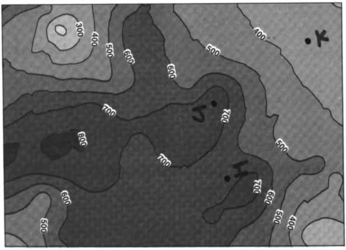
4. A straight line from point **E** to point **F** is generally:

   a) uphill
   b) downhill
   c) level

5. Estimate the elevation at point **D**.

   ____

Ingram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K
700
J
700
800
500
700
H
700
600
600
500
500
400

1. Draw an **H** at the highest point on the map

2. Draw an **L** at the lowest point on the map

3. Point **I** is ________ point **J**

   a) higher than
   b) lower than
   c) about the same elevation as

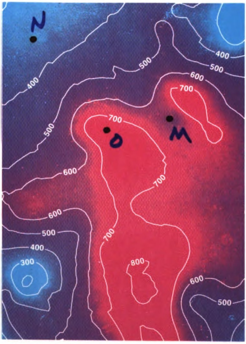
4. A straight line from point **J** to point **K** is generally

   a) uphill
   b) downhill
   c) level

5. Estimate the elevation at point **I**.

   ____

Johnstown



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1. Draw an **H** at the highest point on the map.

2. Draw an **L** at the lowest point on the map.

3. Point **M** is ________ point **N**.

   a) higher than
   b) lower than
   c) about the same elevation as

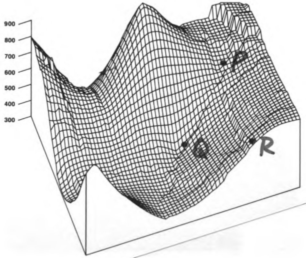
4. A straight line from point **N** to point **O** is generally:

   a) uphill
   b) downhill
   c) level

5. Estimate the elevation at point **M**.

   ____

Keene



1. Draw an **H** at the highest point on the map.

2. Draw an **L** at the lowest point on the map.

3. Point **P** is ________ point **Q**.

   a) higher than
   b) lower than
   c) about the same elevation as

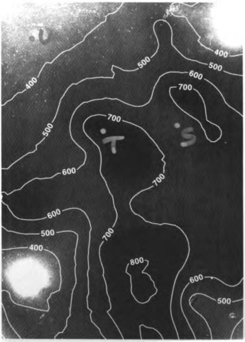
4. A straight line from point **Q** to point **R** is generally:

   a) uphill
   b) downhill
   c) level

5. Estimate the elevation at point **P**.

   ____

Lancaster



1. Draw an **H** at the highest point on the map.

2. Draw an **L** at the lowest point on the map.

3. Point **S** is ________ point **T**.

   a) higher than
   b) lower than
   c) about the same elevation as

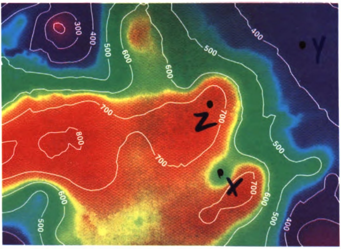
4. A straight line from point **T** to point **U** is generally:

   a) uphill
   b) downhill
   c) level

5. Estimate the elevation at point **S**.

   ____

Vernon



300
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Z
X
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1. Draw an **H** at the highest point on the map.

2. Draw an **L** at the lowest point on the map.

3. Point **X** is ________ point **Y**.

   a) higher than
   b) lower than
   c) about the same elevation as

4. A straight line from point **Y** to point **Z** is generally:

   a) uphill
   b) downhill
   c) level

5. Estimate the elevation at point **X**.

   ____

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This exercise, involving maps and map reading skills, is being conducted by Mark Kumler, a graduate student in Geography. The exercise, about fifteen minutes in length, is a research project designed to provide information about improving maps.

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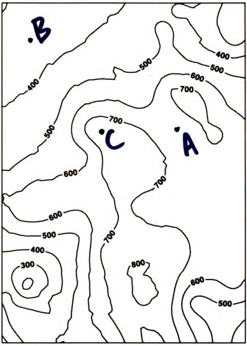
You are about to see seven maps. Each map will be accompanied by five questions. Please read the questions carefully, and answer them as best you can.

Goodhope



1. Draw an **H** at the highest point on the map.

2. Draw an **L** at the lowest point on the map.

3. Point **A** is ________ point **B**.

   a) higher than
   b) lower than
   c) about the same elevation as

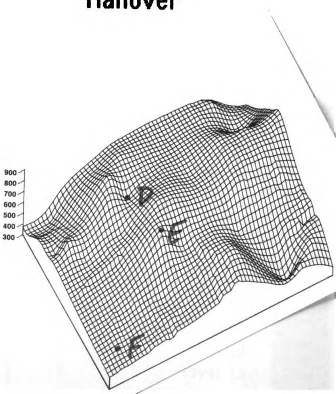
4. A straight line from point **B** to point **C** is generally:

   a) uphill
   b) downhill
   c) level

5. Estimate the elevation at point **A**.

   ____

Hanover



1. Draw an **H** at the highest point on the map.

2. Draw an **L** at the lowest point on the map.

3. Point **D** is ________ point **E**.

   a) higher than
   b) lower than
   c) about the same elevation as

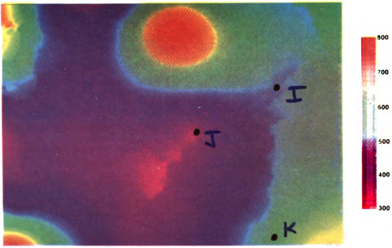
4. A straight line from point **E** to point **F** is generally:

   a) uphill
   b) downhill
   c) level

5. Estimate the elevation at point **D**.

   ____

Ingram



1. Draw an **H** at the highest point on the map.

2. Draw an **L** at the lowest point on the map.

3. Point **I** is ________ point **J**.

   a) higher than
   b) lower than
   c) about the same elevation as

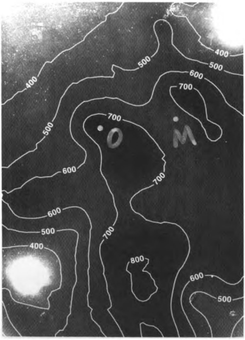
4. A straight line from point **J** to point **K** is generally:

   a) uphill
   b) downhill
   c) level

5. Estimate the elevation at point **I**.

   ____

Johnstown



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1. Draw an **H** at the highest point on the map.

2. Draw an **L** at the lowest point on the map.

3. Point **M** is ________ point **N**.

   a) higher than
   b) lower than
   c) about the same elevation as

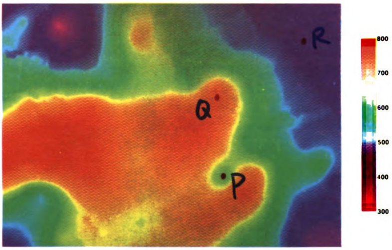
4. A straight line from point **N** to point **O** is generally:

   a) uphill
   b) downhill
   c) level

5. Estimate the elevation at point **M**.

   ____

Keene



1. Draw an **H** at the highest point on the map.

2. Draw an **L** at the lowest point on the map.

3. Point **P** is ________ point **Q**.

   a) higher than
   b) lower than
   c) about the same elevation as

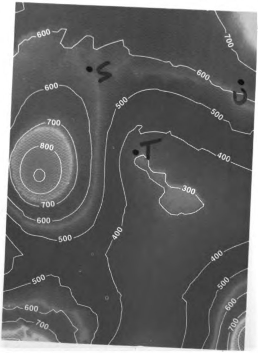
4. A straight line from point **Q** to point **R** is generally:

   a) uphill
   b) downhill
   c) level

5. Estimate the elevation at point **P**.

   ____

Lancaster



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700

1. Draw an **H** at the highest point on the map.

2. Draw an **L** at the lowest point on the map.

3. Point **S** is _______ point **T**.

   a) higher than
   b) lower than
   c) about the same elevation as

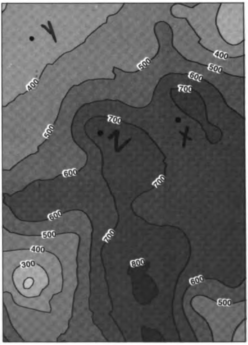
4. A straight line from point **T** to point **U** is generally:

   a) uphill
   b) downhill
   c) level

5. Estimate the elevation at point **S**.

   ____

Vernon



1. Draw an **H** at the highest point on the map.

2. Draw an **L** at the lowest point on the map.

3. Point **X** is ________ point **Y**.

   a) higher than
   b) lower than
   c) about the same elevation as

4. A straight line from point **Y** to point **Z** is generally:

   a) uphill
   b) downhill
   c) level

5. Estimate the elevation at point **X**.

   ____

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You are about to see seven maps. Each map will be accompanied by five questions. Please read the questions carefully, and answer them as best you can.

Goodhope

1. Draw an **H** at the highest point on the map.

2. Draw an **L** at the lowest point on the map.

3. Point **A** is ________ point **B**.

    a) higher than
    b) lower than
    c) about the same elevation as

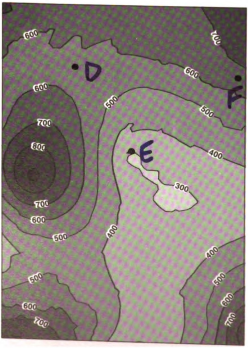
4. A straight line from point **B** to point **C** is generally:

    a) uphill
    b) downhill
    c) level

5. Estimate the elevation at point **A**.

    ____

Hanover



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700

1. Draw an **H** at the highest point on the map.

2. Draw an **L** at the lowest point on the map.

3. Point **D** is ________ point **E**.

   a) higher than
   b) lower than
   c) about the same elevation as

4. A straight line from point **E** to point **F** is generally:

   a) uphill
   b) downhill
   c) level

5. Estimate the elevation at point **D**.

   ____

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Goodhope

1. Draw an **H** at the highest point on the map.

2. Draw an **L** at the lowest point on the map.

3. Point **A** is ________ point **B**.

   a) higher than
   b) lower than
   c) about the same elevation as

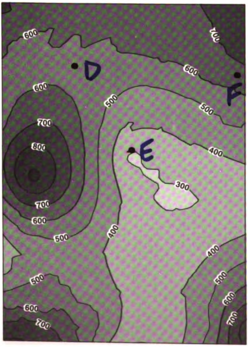
4. A straight line from point **B** to point **C** is generally:

   a) uphill
   b) downhill
   c) level

5. Estimate the elevation at point **A**.

   ____

Hanover



1. Draw an **H** at the highest point on the map.

2. Draw an **L** at the lowest point on the map.

3. Point **D** is ________ point **E**.

   a) higher than
   b) lower than
   c) about the same elevation as

4. A straight line from point **E** to point **F** is generally:

   a) uphill
   b) downhill
   c) level

5. Estimate the elevation at point **D**.

   ____

Ingram

1. Draw an **H** at the highest point on the map

2. Draw an **L** at the lowest point on the map.

3. Point **M** is _________ point **N**.

   a) higher than
   b) lower than
   c) about the same elevation as

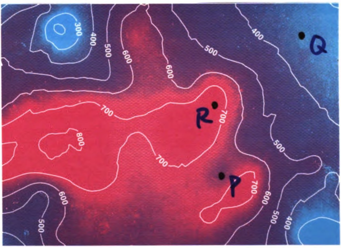
4. A straight line from point **N** to point **O** is generally:

   a) uphill
   b) downhill
   c) level

5. Estimate the elevation at point **M**.

   ____

Keene



1. Draw an **H** at the highest point on the map

2. Draw an **L** at the lowest point on the map.

3. Point **M** is ________ point **N**.

   a) higher than
   b) lower than
   c) about the same elevation as

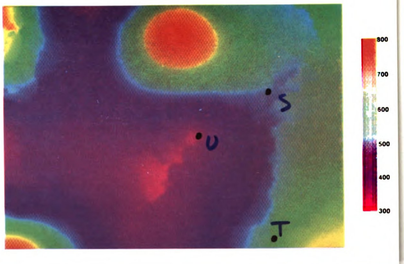
4. A straight line from point **N** to point **O** is generally:

   a) uphill
   b) downhill
   c) level

5. Estimate the elevation at point **M**.

   ____

Lancaster



1. Draw an **H** at the highest point on the map.

2. Draw an **L** at the lowest point on the map.

3. Point **S** is ________ point **T**.

   a) higher than
   b) lower than
   c) about the same elevation as

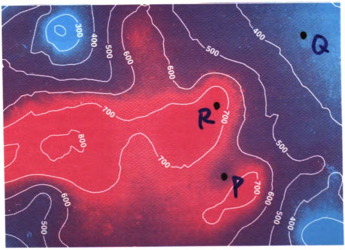
4. A straight line from point **T** to point **U** is generally:

   a) uphill
   b) downhill
   c) level

5. Estimate the elevation at point **S**.

   ____

Keene



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R
P
Q

1. Draw an **H** at the highest point on the map.

2. Draw an **L** at the lowest point on the map.

3. Point **P** is ________ point **Q**.

   a) higher than
   b) lower than
   c) about the same elevation as

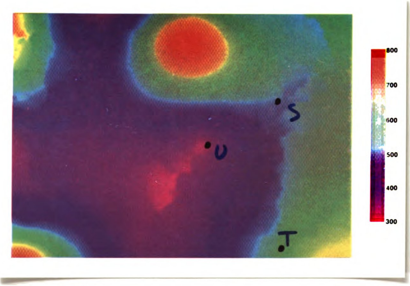
4. A straight line from point **Q** to point **R** is generally:

   a) uphill
   b) downhill
   c) level

5. Estimate the elevation at point **P**.

   ____

Lancaster



1. Draw an **H** at the highest point on the map.

2. Draw an **L** at the lowest point on the map.

3. Point **S** is ________ point **T**.

   a) higher than
   b) lower than
   c) about the same elevation as

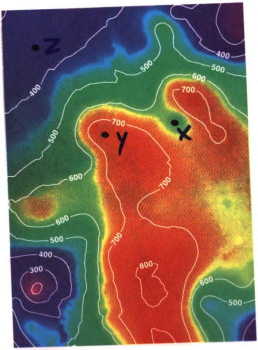
4. A straight line from point **T** to point **U** is generally:

   a) uphill
   b) downhill
   c) level

5. Estimate the elevation at point **S**.

   ____

Vernon



1. Draw an **H** at the highest point on the map.

2. Draw an **L** at the lowest point on the map.

3. Point **X** is ________ point **Y**.

   a) higher than
   b) lower than
   c) about the same elevation as

4. A straight line from point **Y** to point **Z** is generally:

   a) uphill
   b) downhill
   c) level

5. Estimate the elevation at point **X**.

   ____

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