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A Dot Matrix Printer Method
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A DOT MATRIX PRINTER METHOD FOR REPRESENTING SMOOTH STATISTICAL SURFACES

by

William Fouracre Johnson

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ABSTRACT

A DOT MATRIX PRINTER METHOD FOR REPRESENTING SMOOTH STATISTICAL SURFACES

by

William Fouracre Johnson

This research examines methods of representing statistical surfaces and problems with their use, particularly the conceptual and perceptual problems associated with conventionally used representations of smooth statistical surfaces. Development of a symbolization model using random dot matrices is discussed prior to introducing a new method of producing that symbolization with dot matrix printers. The random dot matrix symbolization is then tested against its equivalent isarithmic symbolization in a psychophysical experiment involving the perception of surface form with smooth surface representations. The test includes semantic differential questions to measure map reader attitudes towards these two symbolizations. Two groups of map readers are tested: those familiar and those unfamiliar with the isarithmic symbolization. Results from this paired difference test show that both groups of map readers favor the isarithmic symbolization over the random dot matrix symbolization, but the difference in surface form perception between the two symbolizations is not statistically significant. It is concluded that dot matrix symbolization is as effective as isarithmic symbolization, but its application to statistical mapping may be hindered by negative map reader impressions.

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CHAPTER I

INTRODUCTION

MAPPING STATISTICAL SURFACES

Statistical mapping is the symbolic display of numeric data on a map to show the extent, form, and spatial characteristics of that data over two dimensional (x,y) space. The symbols used to represent the data can be thought of as giving the map a third visual dimension, that of height (or z-value) corresponding to the assignment of data values to areas on the map. The conceptual surface of data elevations is referred to as a statistical surface [Robinson, et al, 1978, p 181, 218].

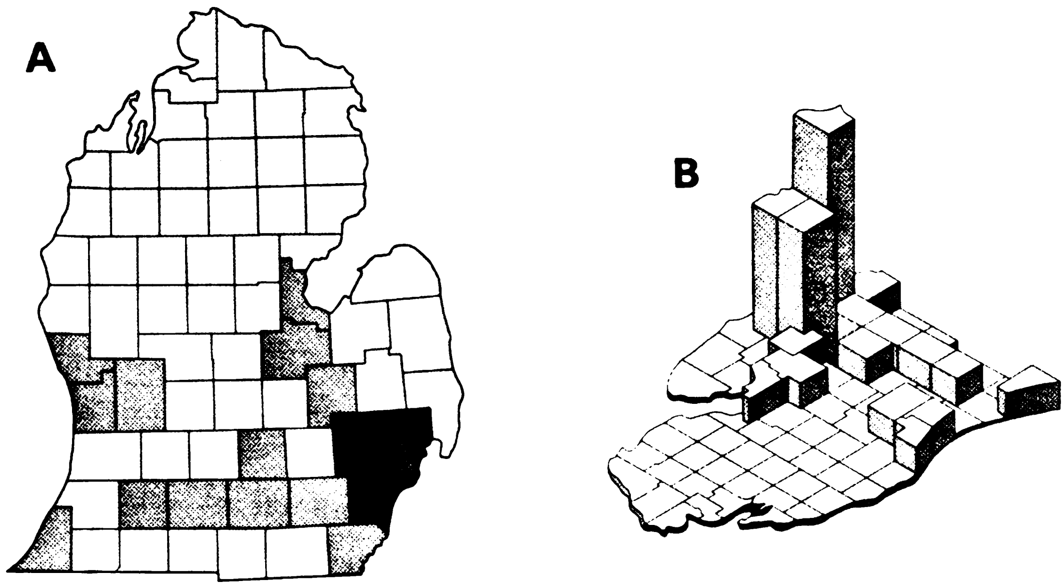
A statistical surface can take one of two basic forms. If data are collected by areas and are assumed to have uniform value throughout each area, the surface will consist of a number of steps, each having the shape of its collection area and a height proportional to the data value for that area. These are known as stepped, or discontinuous, statistical surfaces and are commonly associated with census-type data gathered by enumeration areas [Monmonier, 1977, p 23; Jenks, 1963, p 16].

Data that are sampled at points from a continuous population and are not assumed to have uniform value over areal units will lead to a smoothly undulating surface. This type of surface, called a smooth statistical surface, has continuously changing slope, which is a measure of the relative changes in value over space. Weather data, such as temperature or air pressure, as well as many types of ratio data, are examples that can be thought of as having smooth change across the surface. Construction of a smooth surface is based on the interpolation of values between sample data points, since it is impossible to obtain values for all points in a continuous distribution [Robinson, 1961, p 54; Jenks, 1963, p 16].

The basic decision in the statistical mapping process is the form of the statistical surface to be represented. Once decided, the secondary decision of appropriate symbol can be made. The most accurate representations of statistical surfaces are produced with symbologies which have characteristics suited to the form of the surface [Jenks, 1963, p 16]. Stepped statistical surfaces should be symbolized with areal symbols that are uniform within each data collection area and show steps or discontinuities at the boundaries of units. Smooth statistical surfaces should be represented such that they have visually continuous slope over the map surface. Cartographers have at their disposal a variety of symbol types suitable for illustrating either form of statistical surface; each of these symbol types suffers from limitations which may deter their use.

Stepped statistical surfaces are most commonly represented with choropleth symbology (Figure 1a), where data collection units are shaded in a graded series such that the shading for a unit is proportional in appearance to its data value or class of data values. Alternatively, block diagrams (Figure 1b) may be used which provide a perspective volumetric view with each data collection unit elevated in

Stepped Statistical Surfaces



Smooth Statistical Surfaces

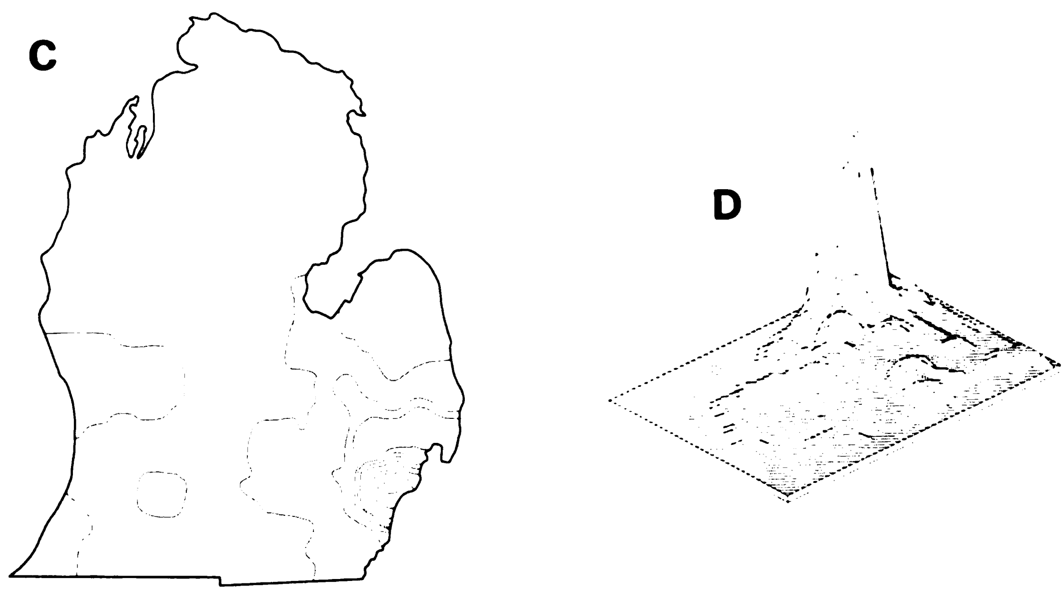


Figure 1. Statistical surface representations: a. choropleth map b. block diagram c. isarithmic map d. perspective transect model [from Groop and Smith, 1982, p 124].

proportion to its value. Smooth statistical surfaces are most commonly represented with isarithms (Figure 1c), despite evidence suggesting that they provide less easily recognized surface representations [Phillips, et al, 1975, p 45-6; Griffin and Locke, 1979, p 71]. Smooth surfaces may also be represented with different types of block diagrams, such as perspective transect models (Figure 1d) or "fishnet" models which use perpendicular transect lines across the data surface. Perhaps more familiar is plastic hill shading, often used to represent the land surface.

Problems with Existing Methods of Surface Representation

Since the purpose of representing a statistical surface is to provide an accurate visual counterpart to the conceptual data surface, there are several objectives that a successful illustration should achieve. First, the data should be accurately represented on the map so that the values of the original distribution can be retrieved. Second, the map should be planimetric, that is, the symbols on the map should be in their correct x,y position so that all data values are correctly associated with their true positions. Third, the form and configuration of the surface should be apparent; stepped statistical surfaces should appear stepped, and smooth surfaces should appear smooth and continuous [Groop and Smith, 1982, p 123-4; Robinson, 1961, p 54]. The traditional symbologies vary in the degree to which they meet these objectives. What follows is a discussion of the perceptual problems associated with surface representation using these symbologies.

The choropleth method of representing stepped statistical surfaces is among the most widely used cartographic symbologies. Until Tobler's introduction of "unquantized" choropleth maps in 1973, the main research questions concerning choropleth maps were appropriate class intervals for dividing the data set into generalized groupings and equal appearing tone steps for symbolizing the classes on the map. Proper class interval selection not only affects the look of the map, but largely determines the spread of error in the symbolization [Jenks, 1963, 1967, 1977]. Tobler's unclassed choropleth maps challenged the established ideas that generalized data classes are necessary for consistent map communication. Studies by Peterson [1979] and Muller [1979] confirmed the contention that the greater informational content of unclassed choropleth maps does not reduce their effectiveness.

Block diagrams, an alternative to choropleth representation of stepped surfaces, offer an impression of the surface as it would appear in perspective view. The primary drawbacks to their use are loss of planimetry and the likelihood of obscuring at least some part of the surface by units elevated in the foreground. Further, the look of a block diagram is dependent on the view azimuth and inclination of the viewing point [Monmonier, 1977, p 24; Groop and Smith, 1982, p 125].

The existing methods of portraying smooth surfaces vary considerably in ability to show surface form. Perspective diagrams such as the "fishnet" or surface transect models provide a good visual impression of smooth slope changes that occur with this type of surface, but like block diagrams and other perspective illustrations, the lack of planimetry and the selection of a view azimuth and inclination to minimize hidden parts of the surface are important drawbacks. A study by Rowles [1978] showed that while view angle and inclination do not in themselves determine the interpretability of the surface, they may contribute to perceptual errors.

View angle problems are absent from isarithmic maps, as isarithmic maps are planimetric representations of surfaces. The isarithmic symbology consists of a series of lines or isarithms formed by the intersection of horizontal planes with the surface such that isarithms are always perpendicular to slope directions. The slope characteristics of a surface are not shown directly with isarithms, but are represented by the spacing between adjacent isarithms. To facilitate slope interpretation, the isarithmic interval is usually constant on a map, but there are exceptions to this convention, especially if the surface has unusually prominent peaks. Since isarithms provide a series of sample intersections with a surface, the form of the surface can only be inferred. A further complication is that the isarithms themselves are usually based on values interpolated from a limited pool of known data values, very few of which are likely to be coincident with any of the isarithms. The isarithms are thus a "second generation" representation of the surface, and the form of the surface that must be visually inferred from the isarithms is, in a sense, "three steps removed" from the original data surface.

Because isarithms are traces of intersections with the surface at given intervals, surface representation is increasingly generalized as isarithmic interval increases. That is, as the surface is sampled at fewer levels, the amount of information suggesting surface form is deteriorating. This is analagous to data classification, where fewer classes result in greater classification error. The isarithmic model thus has a built-in generalization error which is interval dependent.

In addition to the problems of isarithmic generalization, there are demonstrated problems with visual interpretation of the surface. A study by Griffin and Locke [1979] identified eight types of errors in the interpretation of an isarithmic transect profile. The most dominant error was found to be slope reversal, i.e. the perception of a concave slope despite the isarithmic depiction of a convex slope or vice versa. Interestingly, convex slopes were found to result in consistently greater interpretation errors. The authors concluded that this was a perceptual error caused by texture gradient creating an illusion of depth, rather than a conceptual error. Other researchers have found that isarithms are useful in determining spot values, but are difficult for untrained readers to interpret, especially for visualizing surface form [Phillips, et al, 1975, p 46; Potash, et al, 1978, p 34]. The difficulty of visualizing surface form with isarithmic maps may be due to the lack of information in peripheral vision with this symbology. Interpretation of isarithmic surface representations involves focusing on a limited viewing area where the lines can be seen distinctly [Phillips, 1979, p 75]. The addition of shading tones between isarithms increases the interpretability of the map [Castner and Wheate, 1979, p 83; Potash, et al, 1978, p 34] but creates the impression of discrete steps, an effect contradictory to the objectives in portraying smooth surfaces.

Plastic hill shading does not suffer from the complex perceptual and conceptual difficulties of isarithms. With this technique, a smooth and continuous shading is applied to the map with respect to an assumed illumination direction [Yoeli, 1966; Brassel, 1974]. The surface thus depicted appears as it would with an illumination source striking surfaces that face toward the light and creating shadows on surfaces that face away from the light. This provides a realistic-looking planimetric surface portrayal, but because the illustration is modelling illumination, different points with the same elevation may not receive the same shading tone, depending on their position relative to the illumination source [Smith, 1980, p 12]. This problem limits its usefulness in representing statistical surfaces, since data values cannot generally be retrieved.

In this study, an automated method for portraying smooth statistical surfaces that uses continuous tonal variation will be suggested as an alternative to existing symbologies. The effectiveness of this surface representation will be evaluated in a comparative psychophysical test of surface visualization with the "continuous-tone" method and isarithmic method. Results from this experiment should show whether the continuous tone method of smooth statistical surface representation offers any significant improvement over conventional symbologies.

Continuous Tone Methods for Representing Smooth Surfaces

The modelling of smooth statistical surfaces with continuous tonal variation is based on the assignment of shading values scaled directly to data values at every point on the map surface. In this way, high data values receive a proportionally darker tone than low data values to create a continuously shaded surface. The gray-tone symbol is thus a continuous function of z-value. Since the symbols are related directly to individual data values, there is no classification error. Planimetry is maintained, and the form of the original data surface is preserved with a minimum of information loss.

A method for representing smooth statistical surfaces using continuous-appearing tonal variation was developed by Smith and Groop [Smith, 1980; Groop and Smith, 1982]. Their automated surface representation employed a lattice of finely graduated point symbols to create the visual impression of continuous gray-tone variation across the mapped surface (Figure 2). At each intersection in the lattice, a data value was represented with a point symbol graduated in size proportional to that value. The range of sizes for individual point symbols varies such that the highest data values produce symbols that fill their lattice positions and therefore create maximum tonal density. With a fine enough lattice, the visual effect is not an assemblage of graduated point symbols, but rather a continuous variation in gray-tone. Preliminary testing showed that slope direction can be accurately interpreted with this symbology [Smith, 1980, p 41].

The authors noted several advantages of modelling smooth statistical surfaces with this method. First, there is no depth illusion problem resulting from textural differences in symbol density, such as there is with isarithmic maps. Second, since there is no classification error with the model, the symbolization takes its form directly from the available data rather than from arbitrary decisions such as isarithmic interval. Third, the map remains planimetric, and all data points are accurately scaled. Finally, the conception of continuous tonal variation is consistent with the type of statistical surface it represents [Groop and Smith, 1982, p 129].

Despite these advantages, the symbology was of limited utility

Figure 2. Sample map from the Smith/Groop method for representing smooth statistical surfaces [from Groop and Smith, 1982, p 128].

because of implementation problems. To produce an impression of continuous tonal variation rather than an impression of an array of graduated point symbols, the lattice used to generate the symbols must be very fine. But since the minimum increment of standard digital plotters is not sufficiently small to produce the necessary fine graduations in point symbol size, the maps were plotted at a very large size and subsequently reduced using photographic methods. Plotting times were generally quite long and expensive, as the pen plotter drew and filled each point symbol at its appropriate size. A further problem with this symbology was the undesirable appearance of visual steps in parts of the surface where steep gradient was present. This was caused by the interpolation routine used to generate the lattice of data values, and it was a significant barrier to the application of this mapping technique [Groop and Smith, 1982, p 129].

Gray tone symbols can also be constructed using randomly placed dots. The automated use of randomly placed dots is not new to cartography. A program from the Harvard Laboratory for Computer Graphics and Spatial Analysis called DOT.MAP (later improved and renamed MIRAGE) which uses random dot placement matrices has been available since the mid-1970's [Dutton, 1978]. This program has not had wide application among the cartographic community, since the output devices, pen plotters or CRT screens, are inefficient at providing reproducible output.

More recent efforts by Groop [1982] have resulted in the application of random dot placement matrices to the model for representing smooth statistical surfaces (Figure 3). This symbology used a lattice of cells, each filled with a number of randomly placed dots in proportion to a data value, rather than a lattice of individual point symbols. By keeping the cell size very small relative to map size, variation in tone across the map surface appears to change in a smooth and continuous manner. Data are only generalized to the extent that a sample data point is represented with a cell of dots instead of a single point symbol. Generalization is thus a function of cell size. As cell size approaches zero, the degree of generalization also tends toward zero.

Figure 3. Sample map using a random dot matrix method with pen plotter output [Groop, 1982].

The advantages of this symbology were readily apparent. The increment in tonal variation could be reduced to a finer level than with the previous method, since the output device did not have to draw symbols in a limited range of sizes. This helped to reduce the effects of unwanted visual steps in the output, as well as increase the overall "smoothness" of the surface. The practical resolution limit was instead determined by the ability of the pen in a pen plotter to consistently create small dots. Since the size of individual symbols on the surface was greatly reduced by the dot matrix method, maps did not have to be plotted at such large sizes and be drastically reduced to achieve the effect of continuous tonal variation. A more modest reduction of the original pen plotter output was sufficient to create continuous-appearing gray tone variation.

The new method was limited by the technical characteristics of the output device, as pen plotters are not well suited to the task of plotting large quantities of dot symbols with consistency and reliability. The dots which form the symbology varied in size and density due to inconsistencies in the flow of ink from the pen. In addition, the dots could not be plotted at a size small enough to eliminate the need for photographic reduction. Further, the output was very slow, with small maps taking several hours to plot, while most maps required an "overnight" plot.

In an extension of this symbology, Frohnert created unclassed choropleth maps symbolized with the dot matrix technique. While her research was aimed at effectively portraying stepped statistical surfaces, the method she used to create gray-tones is similar to the method used for smooth statistical surfaces. After experiments using random dot matrix unclassed choropleth maps to determine consistency of region generalization and pattern recall, she concluded that "...the dot matrix method holds potential as an effective mapping technique..." [Frohnert, 1983, p 61].

RESEARCH PROBLEM

The purpose of this thesis is the development of an effective automated method for representing smooth statistical surfaces using a random dot matrix model and dot matrix printer technology. There are two primary objectives. The first involves the technical development of a continuous-tone mapping technique for representing conceptually smooth data surfaces. Technical development is focused on providing a mapping symbology that satisfies the visual/cartographic objectives for illustrating smooth statistical surfaces, as well as meeting technical requirements such as fast, high-resolution output.

The second objective is to discover, through psychophysical testing of map users, whether the desired visual/cartographic characteristics are indeed present in the symbology. One of the essential characteristics of smooth statistical surfaces is continuous slope, which can be constant (linear) or, more likely, variable from concave to convex. Map readers should be able to distinguish these various slope types on the cartographic surface representations to fully understand the map. It is reasoned that if map readers can visualize slopes (and thus surface form) more easily with the proposed dot matrix representations than with the counterpart isarithmic representations, then the dot matrix mapping technique is a more appropriate cartographic symbology for illustrating the basic form of smooth statistical surfaces.

CHAPTER II

A PROPOSED METHOD FOR REPRESENTING SMOOTH SURFACES

The evolution of a dot matrix method for portraying smooth statistical surfaces progressed to the current level on the basis of pen plotter output, a method with inherent production weaknesses. For the technique to see wide-spread application, a different method of producing hardcopy is needed. CRT screens allow fast and efficient plotting times, but do not lend themselves to hardcopy duplication. To copy an image, a photograph of the screen must be taken either directly or with a matrix camera that electronically exposes a film emulsion with the screen image. Neither option is practical for the dot matrix method, especially since the resolution of many screens is too coarse to produce continuous tone maps worthy of duplication.

Dot matrix printers create images, usually alphanumeric characters, by filling a predefined print matrix cell (character space) with an appropriate combination of dots. The sports stadium scoreboard and electronic time/temperature signs found outside of many banking institutions are familiar examples of dot matrix technology. Early dot matrix printers printed only fixed character fonts, but a new generation of dot matrix printers can be used to create graphics as well as characters. With these "addressable" dot matrix printers, images of almost any description can be assembled as combinations of individual dots. The print matrix cell is not fixed on these printers, so larger cell images may be printed in successive printing passes as the paper advances through the printer. One of the greatest attractions of these printers is their low cost and almost universal availability. Nearly every microcomputer is capable of driving one, and computer users are far more likely to have access to a dot matrix printer than other output devices such as matrix cameras or pen plotters.

Technical Objectives

Dot matrix printers are designed to print dot image graphics quickly, accurately, and consistently. Add to these advantages their low cost and wide availability, and it should be clear that the adaptation of the random dot matrix technique to dot matrix printer technology is a logical step. Given the limits and capabilities of dot matrix printer technology, the development of a new method for producing continuous-tone surface representations has these primary technical objectives:

1. Create a dot matrix symbology with continuous-appearing tonal variation which possesses visual/cartographic characteristics suitable for representing smooth statistical surfaces.
2. Provide fast, easy, hardcopy output which does not require subsequent photographic steps to reach final (useable) form.
3. General adaptability of the method -- use of the method should not depend on specific brands or models of computer equipment to operate successfully. The method should also be flexible enough to create random dot areal patterns for other mapping needs, such as unclassed choropleth maps similar to those investigated by

Frohnert. This is the least critical of the objectives, though it remains a desireable goal.

The Dot Matrix Printer Method

The technical development of the method is based on a family of programs written in BASIC for use with an IBM Personal Computer. Two of the programs are used for entering data and laying out the map cell structure, respectively. In addition, there is an interpolation program used to compute a matrix of data values from known control point values. These programs are essentially peripheral to the method, as they are used only to prepare input files needed to run the main program. Input files need only be prepared only once; program runs can be made as often as desired using prepared files.

The heart of the method is in a program tentatively titled DOTMATRX, which computes the map pattern and drives a dot matrix printer. The dot matrix printer used to develop this technique is a GEMINI-15, which is similar to many other currently available dot matrix printers. In order to understand how the method creates a continuous-tone symbology, it is important to consider the operation of the printer.

The printer has a small print head with a single column of 9 pins spaced 1/72 inch apart. Each pin has a diameter of 1/72 inch, such that each pin is very nearly tangent to its neighbors. A printing ribbon is positioned between the print head and the paper so that when a pin is "fired" the impression of the pin head on the ribbon creates a dot on the paper with a nominal diameter of 1/72 inch. The print head is driven horizontally across the paper by a pulse motor capable of moving in increments as fine as 1/120 inch. The print head cannot move vertically, so the paper must be advanced relative to the print head. Vertical control of the platten rollers (or tractor feed sprockets) that advance the paper is accomplished with another pulse motor, this one capable of movements as fine as 1/144 inch. The highest resolution of the printer is thus 120 by 144 dots per square inch. At this resolution, dots overlap by 50% vertically and 40% horizontally, effectively filling all interstices to create total ink coverage. The pin firings and pulse motor movements are controlled by a stream of codes sent to the printer from the attached computer. Generally, the print head advances across the paper, firing the pins selectively to create characters or graphics. At the end of a printing pass, the paper advances and another row is printed. But, if total ink coverage is needed, the paper must be advanced by 1/144 inch at the end of a row to line up the print head pins with the dot interstices and print the row again. Using this strategy, the printer can create a range of dot densities from zero percent-area-inked (i.e. no dots) to 100 percent-area-inked (Figure 4).

The continuous-appearing tone variation that this method creates is based on filling a matrix of small cells with randomly placed dots.

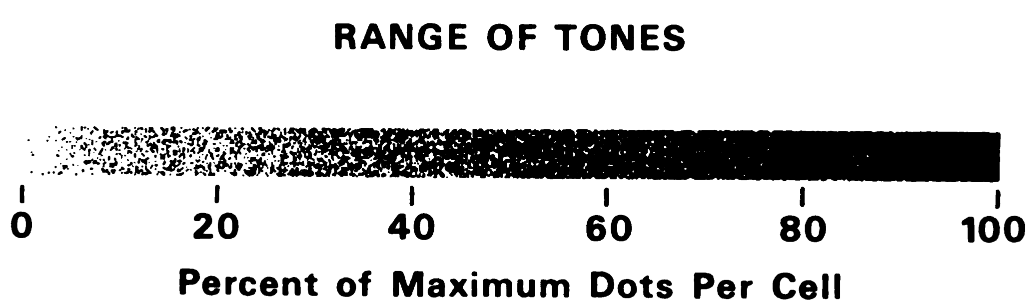


Figure 4. Gray-tone range with the dot matrix printer method.

Each of the cells may be thought of as the graphic equivilent of a character space. Since each cell is covering a small area on the map with a relatively uniform dot density, the symbology is actually modelling a stepped statistical surface. But because the cells are quite small and the values of neighboring cells progress in a smooth manner, and since randomly placed dots do not provide clear cell edge definition, the visual effect is a smoothly changing surface.

The size of individual cells used in the symbology is 1/12 inch square, or 10 dots wide by 12 dots high. Maximum dot coverage in cells of this size is thus 120 dots, and there is a corresponding maximum tonal range of 120 steps. Other cell sizes are possible, but there is a trade-off between cell size (and therefore tonal steps, as well) and coarseness of the cell matrix. If the cells are made larger, there are more possible tone steps, but this comes at the expense of a coarser cell structure -- one that approaches a stepped statistical surface. The problem can also be reversed. If the cells are too small, there are few tonal steps, and the surface texture may not appear smooth across adjoining cells. The 1/12 inch cell size was chosen as a reasonable compromise for these conditions.

The placement of dots in each cell is based on the data value for that cell. During computation, a 10 by 12 array is used to store the positions of dots in the cell. Dot placements are performed by a random sampling process without replacement. Since the printer must make two passes to print maximum dot density, an entire row of cell matrices are computed before a row is printed. The first pass prints odd numbered cell matrix rows. The second pass, 1/144 inch lower, prints the even numbered cell matrix rows. The internal memory of the computer only needs the capacity to store an array with the dot pattern for a single row. Since this is seldom a large memory demand (maximum row length is fixed due to the width of the printer), the technique can be used on small microcomputers.

Gray tones with the dot matrix printer symbology range in density from white to full optical density of the printing ink where maximum dot coverage is obtained. The function of optical density change associated with increasing the dot coverage per cell can be determined by measuring the reflectance densities of cells having known dot coverages. Optical reflectance density is a measure of the amount of incident light that reflects back from a surface. When light strikes a printed page, for example, part of the light is absorbed, while the remainder is reflected. Dark areas, which have high optical densities, do not reflect as much light as light-toned areas. The ratio of the amount of light reflected from a given tone area and the amount of light reflected from a white area on the same paper is the measured optical reflectance density of that tone [Blair and Shapiro, 1980, p 5:9-10]. The density function of the dot matrix symbology was measured with a digital reflectance densitometer on an incremented set of cells with dot coverages ranging from no dots to 100% of the maximum dots per cell. The graph of this function (Figure 5) shows a nearly linear increase in optical density associated with increasing dot coverage. It is not known whether linear reflectance scaling of the dot matrix symbology results in linear <u>perceptual</u> response to changes in dot densities. Following the example of Stoessel [1972, p 708-713], who derived a linear perceptual scaling function for graphic arts dot screens, a perceptual scaling function could be determined for the dot matrix printer symbology.

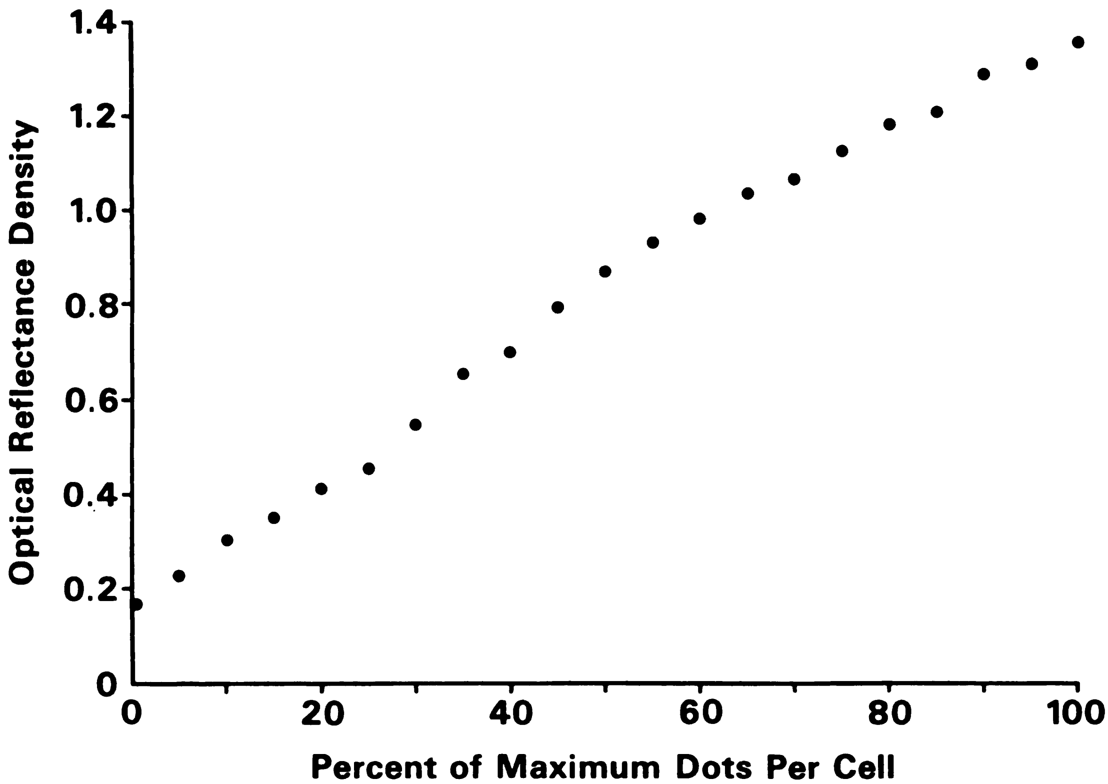


Figure 5. The density function of the dot matrix printer method.

One of the stated design objectives of the method is to provide fast, easy, hardcopy output. Failure of previous methods to meet this objective was an important barrier to their general acceptance. This method offers significant improvements in execution speed over previous methods, due largely to the efficiency of dot matrix printers as output devices. In addition, program DOTMATRX was "streamlined" wherever possible to increase computation speed. Two program features which result in significantly reduced execution time are noteworthy.

The first of these involves the random sampling method used to position dots within a cell. Each dot's position is determined by sampling a random number sequence to obtain x,y cell coordinates. Since the random sample is performed without replacement (i.e. no two dots with common cell coordinates), as the number of dots in a cell approaches maximum density, the probability of randomly finding the coordinates for the remaining "empty" cell positions rapidly decreases. Program DOTMATRX avoids this problem in cells with greater than 50% dot coverage by initially assigning dots to all cell positions and subsequently deleting dots through the random sampling process.

A second important feature that significantly improves program execution speed is compilation into machine language through a BASIC compiler. Uncompiled programs must be translated into machine language by an interpreter as the program executes. Repeated use of an uncompiled program requires translation each time. Compiled programs, on the other hand, are already in machine language so no translation occurs during run-time. Use of a compiled version of DOTMATRX reduces run time to about 1/6 to 1/10 of that required for both compilation and execution, the exact amount depending of the characteristics of the data set used.

The data file needed to run DOTMATRX is a rectangular matrix of interpolated data values set up so that cells outside of the map area have null (zero) data values. The program prints a cell of random dots for each matrix value, so non-zero values outside of the desired map area would result in unwanted printed cells. The data matrix is structured during interpolation through use of a run-encoded raster map outline file that directs the interpolation program to place zeros in cells outside of pre-defined map boundaries. The interpolation algorithm currently used in the program employs an inverse distance weighting function based on the nearest six control points [Tobler, 1970].

Program output is a hardcopy map at final size printed directly on the dot matrix printer (Figure 6). The sample map shown has 2135 individual cells, corresponding to non-zero values in the interpolated data matrix. Program execution time for this map was 22 minutes, excluding the necessary preparation of the input matrix.

The improvements of this method over previous dot matrix methods can be summarized briefly:

1. Improved resolution; resulting in smoother texture, fewer visible surface steps, and greater range of available grey tones.
2. Hardcopy produced directly at final size, eliminating the need for subsequent photographic reduction.
3. Increased execution speed; maps are produced in minutes, rather than hours.

Other Applications of the Method

The method has several other potential applications beyond the representation of monovariate smooth statistical surfaces. One of these is the extension of the symbology to multivariate smooth statistical surfaces. Multivariate symbologies could consist of different colored dots to represent different variables. Eilertson-Rogers and Groop [1981] showed that multicolor dot maps are at least as effective as separate monovariate dot maps for representing regional data. Their maps were conventional dot maps in which each dot represents a given number of objects, but the same concept of overlaying multiple variables can be extended to the dot matrix

MEAN ANNUAL SNOWFALL – Michigan

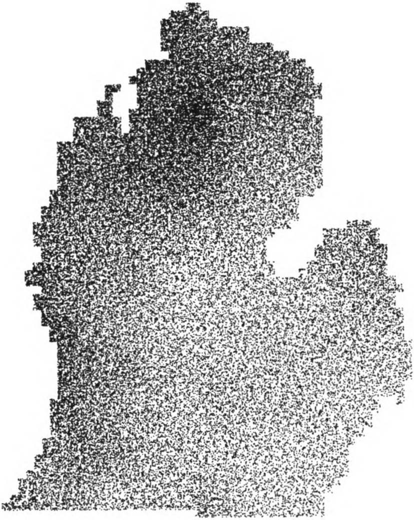


Figure 6. Sample map showing the dot matrix printer symbology.

symbology. In a similar vein, Eyton [1984] has experimented with designs for unclassed multivariate maps symbolized with continuous color gradients in complementary colors. His maps are similar in concept to the multivariate dot matrix maps suggested here. Creating a multicolor dot matrix map would be easiest with a color dot matrix printer. The author has not attempted this, due to lack of access to such a printer. In the absence of a color dot matrix printer, multicolor maps can be created by producing each statistical surface as a separate monochrome map by using the method in standard fashion. The separate maps can then be used to make photographic negatives, each one used to print a different color on a composite map. This method, though less efficient, has been used successfully to create two-variable maps of smooth statistical surfaces (Figure 7). Another possible use of the method is unclassed choropleth mapping of stepped statistical surfaces, such as those researched by Frohnert [1983]. This would require a different structure of the input matrix; values would not be interpolated as for smooth statistical surfaces. Unclassed choropleth mapping has not yet been attempted with the method. An additional application of the method is nominal class mapping, where gray tones would represent different classes of features, rather than differences in value of a single phenomenon. Preliminary work in this area has been done by R. Smith and Groop [1980].

One interesting example of nominal class mapping that has potential for further research is the creation of dot matrix LANDSAT images from digital spectral reflectance data. Each LANDSAT pixel, with its spectral reflectance value, is represented as a cell of random

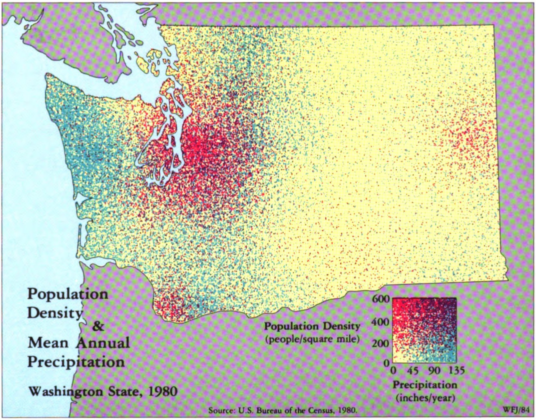


Figure 7. A color-encoded two variable map using the dot matrix symbology.

dots. In this way, the spectral reflectance of a scene is shown with gray tone variation. This is conceptually similar to the black and white photographic images that are commonly produced from LANDSAT data. LANDSAT scenes created with the dot matrix method are considerably magnified (Figure 8). The example shown was created from a 60 row by 60 column section of a scene imaged by LANDSAT's Thematic Mapper in band 5 (near-infrared wavelengths). Each LANDSAT TM pixel represents a 30-meter by 30-meter ground area, and is represented by a 1/12 inch square cell. The nominal scale of the image is 1:14,000 -- a magnification of about 53 times over the standard scale of 1:750,000. The scene shows part of the airport at Traverse City, Michigan, with buildings appearing light in tone (high reflectance) while vegetation and asphalt paved surfaces (note the runways in the lower part of the scene) appear dark. Dot matrix images of this type could prove useful as inexpensive and easily produced images of variously modified (i.e. density sliced, edge enhanced, contrast stretched, etc.) LANDSAT data sets.

In summary, the dot matrix printer sybology holds potential for illustrating a variety of cartographic products. The ready availability of microcomputers and dot matrix printers necessary for producing the symbology should facilitate the use and continued experimentation of dot matrix mapping applications. The greatest attention in this thesis is placed on designing dot matrix maps to represent smooth statistical surfaces so that map readers can readily distinguish surface form. Chapter 3 deals with an evaluation of the symbology to determine if map readers can indeed use these maps to effectively visualize the surface form of smooth statistical surfaces.

TRAVERSE CITY AIRPORT

TM band 5 - contrast stretched

Figure 8. An example of a dot matrix LANDSAT image.

CHAPTER III

THE EXPERIMENT

Preliminary testing of a dot matrix symbology was conducted by P. Smith [1980], who determined that slope direction could be accurately seen on an early version of dot matrix symbology (Figure 2). His testing was conducted using variously rotated circular maps having a linear slope profile. Subjects were asked to orient an axis through the maps identifying the direction of greatest tonal gradient. While his results were important to the continued development of an effective dot matrix symbology, they did not indicate whether subjects were able to see differences in slope form on smooth statistical surfaces. Further, the linear slopes modelled in his test maps are not characteristic of most 'real' continuous data surfaces. A more thorough evaluation of the continuous tone model can be made in a test using actual data surfaces and determining if map users can visualize the essential form of the surface.

Method of Testing

Much has been published in the cartographic literature pertaining to test designs for cartographic research. Investigators warn that the validity of many testing procedures hinges upon careful selection of test instruments and testing instructions. Shortridge and Welch [1980, p 22] determined that slight changes in emphasis within testing instructions produce markedly different results. They also advise cartographic researchers to acknowledge the fact that map reading involves not only perception but a variety of non-perceptual factors such as the readers' expectations. The degree of task specificity in psychophysical test instructions can also affect test results. Cole [1980, p 65] noted that as test instructions become increasingly task-specific, there is a decline in the amount of response error. The issue of designing experiments with the perspective of the map user was also discussed by McCleary [1975, p 248]. He warns that inappropriate or mis-applied techniques are often the result of overlooking the motivation of the map reader. Experience, too, becomes a factor in test results. Test subjects in cartographic testing may perform differently on a test if they are given task-specific training prior to the test. Olson [1975] performed psychophysical tests involving map comparisons to discover that a small amount of task-specific reader training clarified the test concept and led to greater response accuracy. Finally, psychologists Thorndyke and Stasz [1980] cataloged learning strategies for knowledge acquisition from maps, and found that successful learners relied on a structured procedure to encode map information. This suggests that cartographic tests should provide instructions that facilitate this structured strategy.

In light of these findings, it is clear that testing instructions and administration procedures, as well as test instruments, must be thoughtfully designed if test results are to be meaningful and valid. The testing method used in this study is modelled, in part, after a technique used by Griffin and Locke [1979], who addressed the visualization of slope form on isarithmic maps by asking map readers to match the slope of surface transects with one of five graphic profile choices.

Surface form may be described as the nature of the surface, including slope characteristics (convexities and concavities), smoothness, and complexity of gradient changes. For the present study, a paired difference test was used to compare the effectiveness of the random dot matrix representations of smooth statistical surfaces with corresponding isarithmic surface representations. The paired difference test employs responses for both map types from each test subject to facilitate a direct comparison of the difference between these paired responses. Perception of surface form was tested by asking map readers to compare transect lines drawn on test maps with a selection of graphic surface profiles. Additional insights to the perception of surface form were obtained by asking subjects to compare spot elevations on the maps and to identify the "landform" (hill, valley, etc.) at selected points.

In addition to the transect/profile matching and point questions, a short series of semantic differential questions was asked of each subject for both the isarithmic and dot matrix maps. The semantic differential (S-D) procedure consists of a series of questions or statements, each followed by a bipolar word pair (i.e. good/bad, interesting/boring, etc.) separated by a scale bar. Subjects respond to each question by placing a mark on the scale bar between the word pair to indicate their relative evaluation of the map on the quality indicated. For example:

The effectiveness of the maps at showing overall surface form:

excellent I——I——I——I—/—I——I——I——I poor

A response mark in this position on the line indicates that a map reader is neutral in judgement of the effectiveness of the maps for showing surface form. Responses are quantified by assigning numeric values to segments of the line. A mark in the center segment is scored as '0', while segments closer to "excellent" are scored as '1', '2', and '3', respectively. Segments in the direction of "poor" are scored with negative values. S-D word pairing has gained acceptance in cartographic research as a quantitative tool for measuring subjective responses of maps as whole entities [Petchenik, 1974; Dent, 1975; Gilmartin, 1978; Olson, 1981].

The S-D questions used in this test were aimed at evaluating the difficulty of the experimental task and the overall effectiveness of the two different symbolizations at communicating the form of smooth statistical surfaces. Five S-D questions were used. The same set of questions followed both the dot matrix maps and the isarithmic maps in each test so that subjects indicated attitudes about both map types. The five S-D questions used were:

1. The ease of matching the transect lines to the profiles:

   easy/difficult

2. The ease of comparing spot elevations on the maps:

   easy/difficult

3. The effectiveness of the maps at showing overall surface form:

   excellent/poor

4. The aesthetic appeal of the map symbolization:

   very nice/awful

5. The texture of the map symbolization:

   smooth/coarse

S-D questions are an effective tool for measuring attitudes and subjective responses, but test subjects may feel strongly about some aspect of a test that the S-D questions do not address. To overcome this, the test used in this study ended with a page for subjects to write comments.

Hypothesis

It is hypothesised that map readers can distinguish surface form of conceptually smooth surfaces more effectively with the proposed dot matrix symbology than with the corresponding isarithmic symbology. The hypothesis will be supported if the difference in paired responses is significantly different from zero, in the direction favoring the dot matrix maps. The null hypothesis, to be accepted or rejected in the statistical analyses, states that the difference in means of paired responses is equal to zero. The significance level for acceptance or rejection is 0.95, indicating that there is only a 5% chance of rejecting the null hypothesis if it is indeed true (i.e., of "accepting" the working hypothesis when it is false).

Design of the Test Maps

Five different pairs of dot matrix and corresponding isarithmic test maps were produced for the testing experiment. The maps portrayed a variety of surface configurations to reduce the possibility of the test results being map-specific or surface-specific. Real data sets, such as the percentage of cropland used for corn in Michigan or population density in Washington state, were used so that the test would simulate normal map reading conditions. Corresponding isarithmic maps were matched as closely as possible to their random dot matrix counterparts by using the same data control points to create similarly interpolated data matrices, and by producing the maps with the SURFACE II computer mapping package. A pair of corresponding test maps is shown in Figure 9.

Test maps were constructed using a 4 inch square format which allowed the corresponding pairs to be rotated relative to each other so that test subjects would be less likely to recognize the map patterns. Titles, scales, legends, and other peripheral map information were omitted from the maps to help maintain test subjects' attention on the map symbolizations. Random letter codes were affixed to each different test map so that no order was implied in the sequence of maps in the test booklets. Each test map included two transects with labelled end-points and three labelled spot elevation points. Labels for the transects and spot elevations were typeset and printed on the maps with white "casing" surrounding each label to improve legibility. Transect lines and labelled points were drawn with red transparent ink to add contrast to the black printed map symbolization and to allow the symbolization to "show through". Profile choices for the transect/profile matching were constructed by systematically reversing the slope characteristics of the correct profile. For example, the profile choices for a linear slope transect would include a convex and a concave profile choice. The true profile choices were determined by graphing the values of all known or interpolated values along a transect. Labelled points for the "landform" identification questions were placed on the maps in locations selected to avoid ambiguities. The test questions and response choices for each pair of corresponding

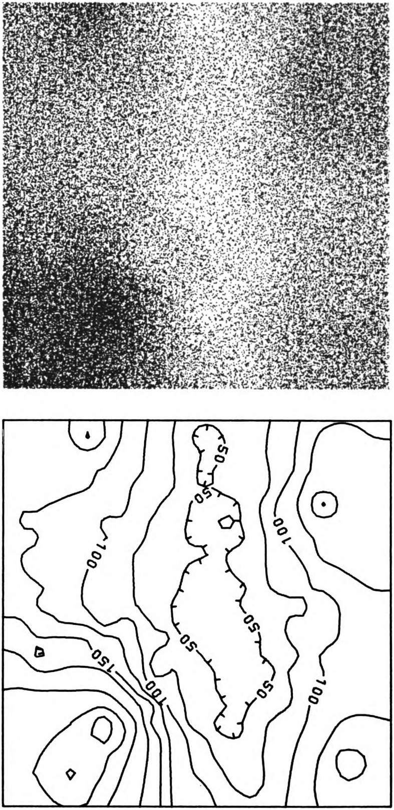


Figure 9. Corresponding dot matrix and isarithmic maps.

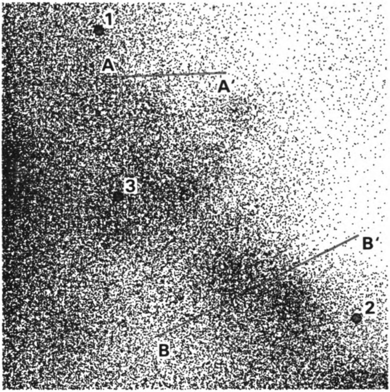
maps were identical so that each test subject responded to the same questions on both map symbolizations (Figures 10 and 11).

Test Administration

The test was conducted on sample groups of students enrolled in undergraduate Geography and English classes at Michigan State University. Two general groups of map readers were targeted in the experiment: those who were familiar with isarithmic map reading and those who were unfamiliar with it. The two separate groups were not identified before the testing, but were instead identified by including a question in the test booklets asking if they had used maps like those in the test. Responses from these two general groups of map readers were separated to determine whether familiarity with isarithmic mapping affects the difference in surface form perception between the two mapping symbologies.

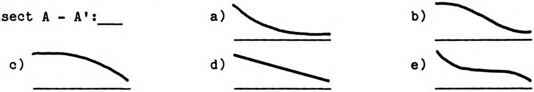
A preliminary version of the test was conducted with four subjects to aid in determining the final format of the test. Results of the preliminary test showed that the experiment took too long (approximately 25 - 30 minutes) and that the physical size and thickness of the test booklets intimidated some test subjects. To overcome these problems, the test was shortened and the test booklets were reduced to half-page format. Five pairs of test maps were still used in the test, but instead of placing all five pairs in each test booklet, five different combinations of three map pairs were used. Each test booklet began with a series of three dot matrix or isarithmic maps, each with the transect/profile matching questions, spot elevation comparisons, and "landform" identification questions. The maps were

J

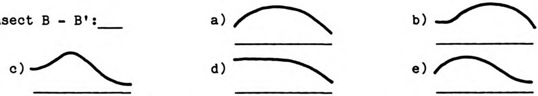


Part I Match each transect line on the map to the profile that most closely resembles the form of the surface along that transect. Mark your selection in the space provided.

Transect A - A':___



Transect B - B':___



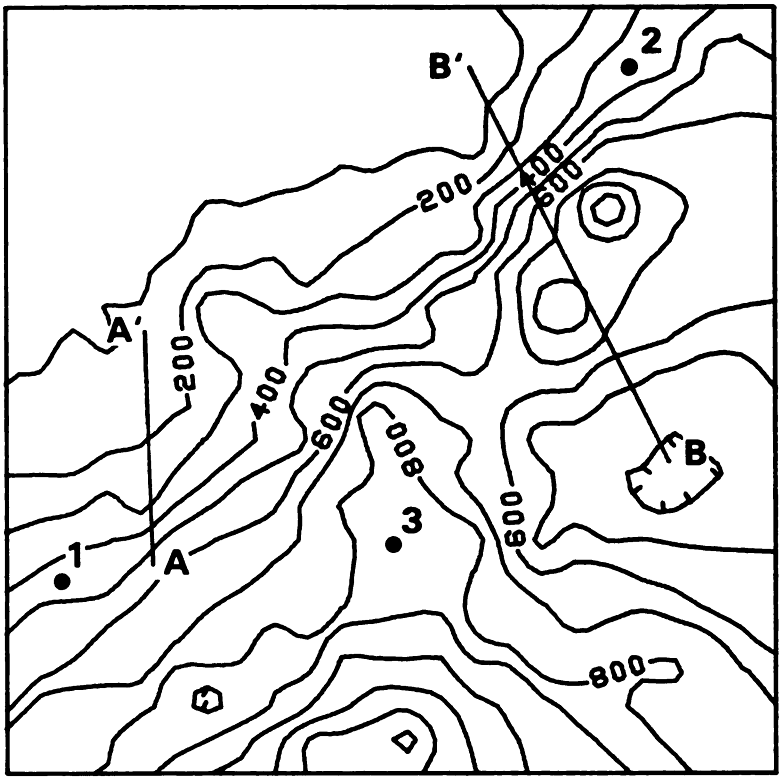
Part II Refer to the numbered points on the map for these questions.

Point #1 is ___ point #2.
- a) higher than
- b) lower than
- c) same elevation as

Point #3 is situated ___
- a) on a "ridge"
- b) in a "valley"
- c) can't determine

Figure 10. Sample dot matrix test map and response choices.

K



Part I Match each transect line on the map to the profile that most closely resembles the form of the surface along that transect. Mark your selection in the space provided.

Transect A - A':___

a) 

b) 

c) 

d) 

e) 

Transect B - B':___

a) 

b) 

c) 

d) 

e) 

Part II Refer to the numbered points on the map for these questions.

Point #1 is ___ point #2.
- a) higher than
- b) lower than
- c) same elevation as

Point #3 is situated ___
- a) on a "ridge"
- b) in a "valley"
- c) can't determine

Figure 11. Sample isarithmic test map and response choices.

followed by the series of five S-D questions. Then another set of three maps corresponding to the first three, but rotated to prevent recognition, appeared with identical questions, followed by another set of S-D questions. Finally a page for comments was included at the end of the booklet.

Test booklets were distributed to test subjects from a colated stack arranged so that each booklet contained a combination of maps different from the booklets preceding and following it. Further, half of the test booklets began with three dot matrix maps, while the remainder began with isarithmic maps. In total, ten permutations of test booklets were used: five combination of three maps, isarithmic or dot matrix appearing first.

Test subjects were given a brief introduction prior to the experiment to familiarize them with the experimental tasks. An example of a statistical surface representation was shown to them on an overhead projector, and the transect/profile matching exercise was demonstrated. The map shown to them did not resemble any of the experimental maps. A sample S-D question was then shown to them on another overhead transparency and the proper response method was demonstrated. After the introductory demonstrations, subjects were given test booklets and asked to begin the test. No time limit was imposed, but subjects were advised every two minutes that they should be advancing to the next map. The test took an average of fifteen minutes to complete.

Since it was impossible to predict beforehand how many test subjects in a given group would claim familiarity with isarithmic maps, the test was conducted on several small groups which had reasonably predictable ratios of experienced vs. inexperienced map readers. Thus it was possible to obtain a total sample with roughly half of the respondents familiar with isarithmic map reading.

A total of 109 test subjects participated in the experiment. One test booklet was removed from the sample due to incomplete responses, leaving an adjusted sample of 108: 62 familiar with isarithmic maps, and 46 unfamiliar with isarithmic maps.

CHAPTER IV

RESULTS

Responses from the profile/transect matching, spot elevation comparisons, and "landform" identification questions were scored on the basis of correct responses. Response totals were paired from each test booklet by scoring the dot matrix and the isarithmic maps separately. S-D responses were also paired for each test booklet. Paired responses were tabulated separately for experienced vs. inexperienced isarithmic map readers. In total, twelve paired samples were tabulated: two for differences in surface form perception (experienced and inexperienced with isarithms), and five sets of S-D questions for both experienced and inexperienced isarithmic map readers.

Data analysis for paired samples involves the determination of differences between pairs. Each sample has parameters that describe the data population from which it was drawn. In paired sample analysis, these parameters can be used to generate statistics which inferentially indicate whether the paired samples belong to the same population or were drawn from different populations. Paired sampling has the advantage of reducing the influences of extraneous variables, especially the effect of subject-to-subject variability [Nie, et al, 1975, p 270]. In this study, we are interested in determining if the responses for the dot matrix maps are significantly different from the responses for the isarithmic maps. A comparison of paired sample means using the T-test is appropriate for this analysis. The paired T-test is used to calculate the probability that the difference in sample means is equal to zero. If the difference in paired sample means is significantly different from zero, then it can be inferred that the samples were not drawn from a common population. The T-test in this analysis is two-tailed. That is, if the difference in paired sample means is significantly different from zero, we would like to know in which direction the difference differs from zero. This information can be used to determine which symbology leads to significantly "better" results.

An important assumption of the T-test is that sample data are normally distributed. Failure to use normally distributed data may lead to spurious results, since the T-test computes the probability of a normally distributed sample -- the difference in sample means for a paired T-test -- belonging to a normally distributed population. To check the sample data for normality, a Kolmogorov-Smirnov (K-S) goodness-of-fit test was used. This non-parametric test compares the sample distribution with a theoretical normal distribution and computes the probability of the sample being normally distributed. Table 1 summarizes the results of K-S tests for the twenty-four individual samples (paired samples were split for the K-S tests). The null hypothesis for the K-S test is that the sample distributions are normally distributed. The surface form perception questions -- profile/transect matching, spot elevation comparisons, and "landform" identification -- for both symbologies with both experienced and inexperienced isarithmic map readers were within acceptable normality limits. Several of the samples for S-D responses with experienced

Table 1. K-S test for Normality of Samples

H_0: Sample distribution = Normal distribution   Significance = 0.05

Sample Data	Sample Size	Two-tailed Probability	Decision
I. Respondents experienced with isarithmic mapping:			
A. Dot Matrix symbology:			
Surface Form perception	62	0.070	Accept H_0
S-D question #1	59	0.015	*Reject H_0
S-D question #2	59	0.009	*Reject H_0
S-D question #3	59	0.075	Accept H_0
S-D question #4	59	0.038	*Reject H_0
S-D question #5	58	0.084	Accept H_0
B. Isarithmic symbology:			
Surface Form perception	62	0.389	Accept H_0
S-D question #1	59	0.052	Accept H_0
S-D question #2	59	0.000	*Reject H_0
S-D question #3	59	0.000	*Reject H_0
S-D question #4	59	0.030	*Reject H_0
S-D question #5	58	0.025	*Reject H_0
II. Respondents inexperienced with isarithmic mapping:			
A. Dot Matrix symbology:			
Surface Form perception	46	0.172	Accept H_0
S-D question #1	45	0.059	Accept H_0
S-D question #2	45	0.068	Accept H_0
S-D question #3	45	0.275	Accept H_0
S-D question #4	45	0.096	Accept H_0
S-D question #5	45	0.319	Accept H_0
B. Isarithmic symbology:			
Surface Form perception	46	0.661	Accept H_0
S-D question #1	45	0.344	Accept H_0
S-D question #2	45	0.198	Accept H_0
S-D question #3	45	0.069	Accept H_0
S-D question #4	45	0.040	*Reject H_0
S-D question #5	45	0.198	Accept H_0

isarithmic map readers differed significantly from normality. The remaining S-D samples were acceptably normal.

Differences in Surface Form Perception

The responses to the transect/profile matching, spot elevation comparisons, and "landform" identification questions were used in this study to measure surface form perception with the two symbologies. To test the hypothesis that one of the symbologies leads to fewer errors in surface form perception, and thus provides the average map reader with a more effective surface representation, a paired T-test was used on the differences between paired responses. The difference in paired responses was found by subtracting the number of correct responses on the isarithmic maps from the number of correct responses on the dot matrix maps for each respondent. The null hypothesis with the paired T-test states that the mean difference in paired responses is equal to zero. If the mean difference is significantly greater than zero, then the dot matrix maps facilitate greater response accuracy; if the mean difference is significantly less than zero, then the isarithmic maps offer better response accuracy. Table 2 summarizes the results of the paired T-test for the surface perception questions.

The T-test shows that the differences in response accuracy between the two symbolizations are not significant with either experienced or inexperienced isarithmic map readers. Neither symbolization facilitated significantly greater response accuracy. However, there was a negative mean difference in paired responses with experienced isarithmic map readers, while the mean paired difference with inexperienced isarithmic map readers was positive. This indicates that

Table 2. Paired T-test with Surface Perception Responses

H_0: Mean Paired Difference = 0 — Significance = 0.05

Paired Sample	Mean Difference (d.m.-is.)	T Value	Two-tailed Probability	Decision
Respondents experienced with Isarithmic maps	-0.338	-0.98	0.332	Accept H_0
Respondents inexperienced with Isarithmic maps	0.304	0.59	0.556	Accept H_0

map readers experienced with isarithmic maps made fewer errors using those maps than with the dot matrix maps. The reverse was true for inexperienced isarithmic map readers; they made fewer errors in surface perception on the dot matrix maps than on the isarithmic maps. This suggests that the map readers familiar with isarithmic maps may not be part of the same population as the map readers unfamiliar with isarithmic maps.

To test this hypothesis, a standard T-test was used on the difference in response means between groups, rather than on the difference in responses paired between map symbolizations. The null hypothesis in this case is that the means are equal, i.e. drawn from the same population, at the 0.05 significance level. Rejection of the null hypothesis would indicate that the experienced and inexperienced isarithmic map readers are not members of a common population. Results of this T-test are shown in Table 3.

The isarithmic-experienced map readers made fewer surface perception errors than their inexperienced counterparts on both symbolizations. The difference in response means between these groups was significantly different for both map symbolizations. This supports

Table 3. T-test for Difference in Means Between Map Reader Groups

H_0: $Mean_{experienced\ w/isar.} = Mean_{inexperienced}$ Significance = 0.05

Sample Group	Group Mean	T Value	Two-tailed Probability	Decision
I. Dot Matrix maps:				
Experienced with isarithms	7.742	2.24	0.027	*Reject H_0
Inexperienced with isarithms	6.544			
II. Isarithmic maps:				
Experienced with isarithms	8.081	4.02	0.000	*Reject H_0
Inexperienced with isarithms	6.239			

the hypothesis that map readers experienced with isarithmic maps do not belong to the same population as map readers inexperienced with isarithmic maps.

Differences in Map Reader Preferences

An important aspect of the evaluation of the dot matrix printer symbology is to compare map reader attitudes and preferences between isarithmic and dot matrix maps. For this study, the S-D questions and written comments were included to measure these subjective responses. S-D questions were paired for each respondent; the same five questions were asked after the surface form perception questions for the dot matrix maps and again after the surface form perception questions for the isarithmic maps. Responses for the paired S-D questions were scored such that positive responses (neutral to "easy", neutral to "excellent", etc.) were given positive values ranging from zero to three, while negative responses (neutral to "difficult", neutral to "poor") were scored from zero to negative three. The mean response for each question thus indicates a generally positive or negative response attitude towards a particular S-D stimulus. A paired T-test was used to test the difference in means between paired responses for each of the five S-D questions. The difference in means was computed by subtracting the mean response to an S-D question for the isarithmic maps from the mean response to that same S-D question for the dot matrix maps. The null hypothesis states that the difference in means between paired responses is equal to zero. If the mean difference is greater than zero, then the dot matrix maps were favored by map readers, while a negative mean difference indicates that the isarithmic maps were prefered, relative to a particular S-D question. Table 4 shows the results of paired T-tests for the five S-D questions. The five S-D questions are listed below.

1. The ease of matching transect lines to the profiles:

    easy/difficult

2. The ease of comparing spot elevations on the maps:

    easy/difficult

3. The effectiveness of the maps at showing overall surface form:

    excellent/poor

4. The aesthetic appeal of the map symbolization:

    very nice/awful

5. The texture of the map symbolization:

    smooth/coarse

Results of the paired T-test show that the difference in responses for the two maps types were significantly different for all five S-D questions when the map readers were experienced with isarithmic maps. Map readers inexperienced with isarithmic maps responded significantly

Table 4. Paired T-test with S-D Responses

H_0: Mean Paired Difference = 0 — Significance = 0.05

Paired Sample	Mean Difference (d.m.-is.)	T Value	Two-tailed Probability	Decision
I. Respondents experienced with isarithmic maps:				
S-D question #1	-0.746	-2.71	0.009	*Reject H_0
S-D question #2	-1.068	-4.46	0.000	*Reject H_0
S-D question #3	-1.831	-6.61	0.000	*Reject H_0
S-D question #4	-1.661	-5.97	0.000	*Reject H_0
S-D question #5	-1.241	-4.51	0.000	*Reject H_0
II. Respondents inexperienced with isarithmic maps:				
S-D question #1	0.311	0.84	0.404	Accept H_0
S-D question #2	0.244	0.77	0.446	Accept H_0
S-D question #3	-0.467	-1.58	0.122	Accept H_0
S-D question #4	-0.667	-2.42	0.020	*Reject H_0
S-D question #5	-0.533	-1.76	0.085	Accept H_0

differently to the two map symbolizations only on S-D question number four (aesthetic appeal of the symbolization). It is interesting to note that there was a positive difference in paired means in only two cases for the inexperienced reader group; S-D questions one and two (ease of matching transect/profiles; ease of comparing spot elevations). It appears that map readers are united in their general preference for isarithmic maps. Questions three and four (the effectiveness of surface form portrayal; aesthetic appeal of the symbolizations) show the greatest differences in paired response means. These mean differences are negative for both map reader groups, again favoring the isarithmic maps.

The striking division of null hypothesis rejections and acceptances by map reader experience groups lends support to the general hypothesis that the experienced and inexperienced map readers are not from the same response population. To test this hypothesis, a between-groups T-test was used. This test indicates for each S-D question whether the response means for the two map reader groups are likely to belong to a common population. The null hypothesis for this T-test is that the means between groups are equal. As Table 5 shows, there is a sharp division in acceptance and rejection of this hypothesis. The difference in responses between the two map reader groups was not significantly different for any of the S-D questions for the dot matrix maps, but there was a significant difference between groups for all five S-D questions for the isarithmic maps. This indicates that map readers experienced with isarithmic maps have a greater margin of preference for isarithmic maps than inexperienced isarithmic map readers. More importantly, it shows that the two groups do not differ significantly in attitude towards the dot matrix maps. Map readers are indeed united in their reactions to the dot matrix maps.

Results of the T-tests for some of the S-D response samples may be clouded by a violation of the T-test assumption for normally distributed data. The K-S test results (Table 1) revealed that several of the response samples for S-D questions with experienced map readers differ significantly from normality. However, the margins of acceptance or rejection with T-tests using these samples were not close to the critical probability level, so the effect of non-normality in the data may have been minimal. If the margins of rejection or acceptance had been close to the critical probability level, there would be a much greater risk in accepting the T-test results where the normality assumption was violated.

Table 5. Between-Groups T-Test for S-D Questions

H_0: $Mean_{experienced\ w/isar.} = Mean_{inexperienced}$ Significance = 0.05

Sample Group	Group Mean	T Value	Two-tailed Probability	Decision
I. Dot Matrix maps:				
S-D question #1				
Experienced with isarithms	0.136	1.05	0.298	Accept H_0
Inexperienced with isarithms	-0.222			
S-D question #2				
Experienced with isarithms	0.407	-0.17	0.862	Accept H_0
Inexperienced with isarithms	0.467			
S-D question #3				
Experienced with isarithms	-0.542	-0.03	0.977	Accept H_0
Inexperienced with isarithms	-0.533			
S-D question #4				
Experienced with isarithms	-0.848	0.42	0.673	Accept H_0
Inexperienced with isarithms	-0.978			
S-D question #5				
Experienced with isarithms	-0.638	0.71	0.480	Accept H_0
Inexperienced with isarithms	-0.844			
II. Isarithmic maps:				
S-D question #1				
Experienced with isarithms	0.881	4.90	0.000	*Reject H_0
Inexperienced with isarithms	-0.533			
S-D question #2				
Experienced with isarithms	1.475	4.68	0.000	*Reject H_0
Inexperienced with isarithms	0.222			
S-D question #3				
Experienced with isarithms	1.288	5.00	0.000	*Reject H_0
Inexperienced with isarithms	-0.067			

(cont'd next page)

Table 5. (cont'd)

H_0: $Mean_{experienced\ w/isar.} = Mean_{inexperienced}$			Significance = 0.05	
Sample Group	Group Mean	T Value	Two-tailed Probability	Decision
II. Isarithmic maps:				
S-D question #4				
Experienced with isarithms	0.814	4.16	0.000	*Reject H_0
Inexperienced with isarithms	-0.311			
S-D question #5				
Experienced with isarithms	0.603	3.26	0.002	*Reject H_0
Inexperienced with isarithms	-0.311			

Written comments on the last page of the test booklets offer additional insights to map reader reactions to the test maps. Many test subject left this page blank, but there were recurring themes in the comments from the remaining test subjects. Several map readers expressed their dislike for the dot matrix maps, calling them "vague", "dizzying", and "inaccurate". A few labelled them "dumb" and "ugly". Some subjects liked the dot matrix symbolization. One subject stated that "the [dot matrix] maps appeal directly to the senses, while the [isarithmic] maps require careful study". A more common theme was the need for a legend on the dot matrix maps. Many of the comments indicated that subjects were not sure whether dark areas represented high or low data values. This theme was also echoed in comments that pointed to the greater measurement accuracy of isarithmic maps due to explicitly labelled isarithms. The remaining comments fell into two broad categories; admissions of not knowing much about maps (presumably as an excuse for inaccurate answers), or interest in the outcome of the study.

Discussion of Results

Surface form perception, as measured in this study by transect/profile matching, spot elevation comparisons, and "landform" identification questions, did not differ significantly between isarithmic and dot matrix symbologies. Map readers who claimed familiarity with isarithmic maps made fewer errors on the isarithmic maps, while map readers unfamiliar with isarithmic maps made fewer errors on the dot matrix maps, though neither difference was statistically significant. One of the factors that may have affected the results is the difference in the way the two symbologies are visually interpreted. Dot matrix maps offer the map reader a "whole" image of the surface with less metric information for specific locations, while isarithmic maps provide an abundance of metric information but do not provide an easily visualized surface, especially for inexperienced map readers. The test design used in this study was aimed at surface form perception, but the tasks involved in the experiment may have been too "local" to show a significant difference in surface form visualization between the two symbologies. Despite this, the dot matrix maps proved to be as useful as their isarithmic counterparts in local map surface interpretation tasks.

One design change in the dot matrix test maps that might have led to a difference in the test results is the addition of a legend to the dot matrix maps. Written comments on several test booklets indicated that some map readers were unsure if dark tone areas represented high data values or vice versa. Legends could range from a simple statement that dark areas indicate higher values to a combination continuous-tone and sample density boxes legend similar in concept to those suggested by Brassel and Utano [1979 p 40-42] for unclassed choropleth maps. Since isarithmic maps have a "built-in" legend in the form of value labels on isarithms, perhaps the dot matrix maps would have been more equivilent if they had included a simple legend.

Another factor which may have affected the test results is the difference in time needed to interpret the two symbologies. The dot matrix maps very likely require less time to answer form questions, since map readers respond to a nearly "instant image", rather than the more metric interpretation process likey employed with isarithmic maps. Under unlimited time conditions, it seems reasonable that many map readers could eventually answer surface form questions correctly with isarithmic maps, while additional time might not benefit similar surface form interpretations with dot matrix maps. This "time problem" was not accounted for in the test.

Semantic differential questions showed that map readers generally preferred the isarithmic symbology. Test subjects who were familiar with isarithmic maps indicated that transect/profile and spot elevation comparisons were easier on the isarithmic maps than on the dot matrix maps, while map readers inexperienced with isarithmic maps indicated the opposite condition. For the remaining S-D questions, both groups of map readers indicated their preferences for isarithmic maps. The responses to S-D questions regarding the effectiveness of the maps at showing surface form and the aesthetic appeal of the map symbolizations were especially revealing of a preference for isarithmic maps. A partial explanation for this may lie in the "newness" of the dot matrix symbology. Isarithmic maps have the advantage of some "inertia" associated with their long standing in the arsenal of cartographic symbolizations. This explanation, however, fails to account for the lack of appeal of the dot matrix symbology to map readers who claimed unfamiliarity with isarithmic maps. Perhaps map readers in general just found the symbology visually unpleasant.

Dot matrix maps were shown to be as effective as isarithmic maps at communicating the form of smooth statistical surfaces. The characteristics of the random dot matrix symbology that provide visual cues to the form of surfaces include continuous tonal gradient, peripheral viewing information, and intuitively simple interpretation. One of the primary differences between dot matrix and isarithmic maps is the "instant" image of the map surface with dot matrix maps versus the greater metric accuracy of isarithmic maps. For this reason, the dot matrix symbology may be especially useful for general representations of surfaces where metric accuracy is less important or for inexperienced map readers interested in regional data concepts. These advantages, however, are tempered by the preference of map readers for isarithmic maps. Negative map reader reaction to dot matrix symbology may be the most significant barrier to the successful application of this symbology to cartographic representation of continuous data surfaces.

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

This study involved the development of an improved method to produce continuously shaded maps using a random dot matrix model, and an evaluation of dot matrix symbology in a comparative test of surface form perception with the corresponding isarithmic symbology. Development of an improved method to produce the random dot matrix symbology followed a discussion of perceptual problems associated with surface representations with traditional symbologies and a review of previous efforts to develop the dot matrix symbology. The proposed method for producing dot matrix symbology employs dot matrix printer technology; a more feasible technology than that used in previous development efforts for the dot matrix model. Cartographic applications with this method extend beyond the representation of single-variable smooth statistical surfaces to multivariate surface representations, unclassed choropleth mapping, and nominal class mapping including dot matrix LANDSAT images.

The effectiveness of the dot matrix symbology at communicating the form of conceptually smooth data surfaces was tested in a paired comparison psychophysical testing experiment using dot matrix and corresponding isarithmic surface representations. Surface form perception was tested by asking map readers to match transect lines on map symbolizations with graphic profile choices, discriminate point elevations, and identify the "landform" of selected points on the map symbolizations. The experiment also included paired semantic differential questions to measure the preferences of map readers with these symbologies. The test was given to 108 undergraduate students, 62 of whom claimed familiarity with isarithmic mapping. Paired responses from the test were analyzed to determine if there was a significant difference in surface form perception between the two symbologies. In addition, test results of subjects claiming familiarity with isarithmic maps were compared with results of subjects claiming no familiarity with isarithmic maps.

Paired T-tests showed that the difference in response accuracy to surface form questions between dot matrix and isarithmic symbolizations was not significantly different from zero. Between-groups T-tests showed that map readers experienced with isarithmic map reading made significantly fewer errors on both symbolizations than those inexperienced with isarithmic mapping. Preferences of map readers towards the two map symbolizations were measured with paired semantic differential questions. Responses to these questions were evaluated with paired T-tests to determine if map readers exhibited a significant preference for one of the symbologies. Both groups of map readers, those experienced with isarithmic map reading and those inexperienced with isarithmic map reading, showed marked preference for the isarithmic symbology.

Conclusions

The dot matrix symbology possesses several characteristics that make it suitable for representing continuous data surfaces. First, changes in tonal gradient are scaled directly to data values. Second, the form of the surface symbolization follows the form of the data without being affected by arbitrary decisions such as isarithmic interval. Third, the map remains planimetric so that all areas of the map surface are shown without graphic distortion. Finally, since the symbology offers an immediatly impression of the surface, interpretation may be made in peripheral viewing areas as well as local viewing areas. These characteristics led to the hypothesis that dot matrix maps would be significantly more effective than corresponding isarithmic maps in communicating the form of smooth statistical surfaces.

The test results failed to substantiate this hypothesis, but while the dot matrix symbology did not prove significantly more effective than the corresponding isarithmic symbology, neither did it prove significantly less effective. An important result of the testing experiment was the negative map reader reactions to the dot matrix symbology. Map readers seem to be more comfortable with the greater metric accuracy of isarithmic maps than with the non-metric, "instant image" of dot matrix maps. This conclusion was supported especially by the low evaluation both experienced and inexperienced map readers made of the aesthetic appeal of the dot matrix symbolization and its effectiveness at showing overall surface form.

In light of these findings, it seems unlikely that the dot matrix symbology will ever replace isarthmic mapping for illustrations of smooth statistical surfaces. However, cartographers should consider using dot matrix maps to represent continuous data in situations where metric accuracy is not expected by the intended map audience, especially if that audience is not experienced at map interpretation. The advantages of easy, low-cost production, and intuitively simple interpretation weigh favorably towards dot matrix maps in these circumstances.

Some improvements to dot matrix maps that may increase surface form interpretability as well as improve map reader reactions include the addition of legend information, finer dot resolution to reduce image "coarseness", and possibly the superimposition of isarithms to improve the metric accuracy of the symbolization. Further research in this direction is needed if the dot matrix method is to become an accepted alternative to traditional symbologies.

APPENDIX A

TEST INSTRUMENT

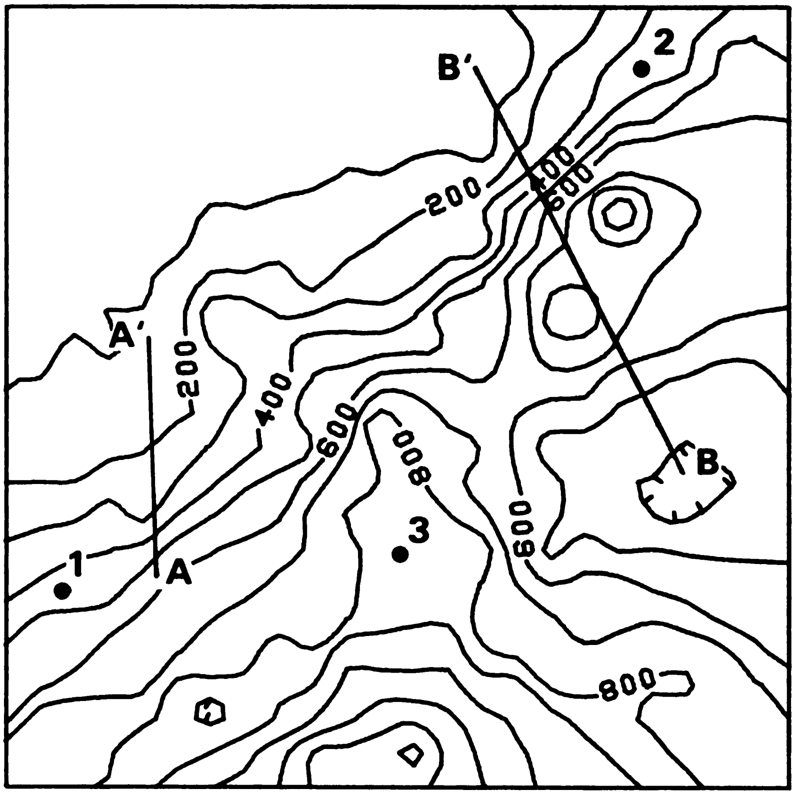
APPENDIX A

TEST INSTRUMENT

The contents of this appendix are not arranged as they were in the actual test instrument. The test instrument consisted of three dot matrix maps with associated profile and spot elevation questions, five semantic differential questions about those three maps, three corresponding isarithmic maps with questions identical to those used for the dot matrix maps, another set of semantic differential questions for the isarithmic maps, and finally a page for comments. Test booklets were half-page size (8 1/2" wide x 5 1/2" high) to conserve paper and duplicating costs. A total of five corresponding pairs of maps were used. Since each test booklet used only three pairs of maps, a series of fixed test map combinations was used to ensure that all five maps were distributed in roughly equal numbers. In the test booklets, isarithmic maps were rotated 1/4 turn from their dot matrix counterparts to reduce the likelihood of test subjects recognizing the map surfaces. Half of the booklets began with isarithmic maps while the remainder began with dot matrix maps. The transects used on corresponding map pairs were identical, as were the profile choices and spot elevation questions.

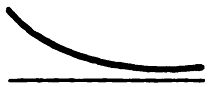
The ten different test booklets are listed below, identified by map letter codes: 1) JYC/KZD 2) YCL/ZDM 3) CLQ/DMR 4) LQJ/MRK 5) QJY/RKZ 6) KZD/JYC 7) ZDM/YCL 8) DMR/CLQ 9) MRK/LQJ 10) RKZ/QJY

K



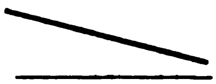
Part I Match each transect line on the map to the profile that most closely resembles the form of the surface along that transect. Mark your selection in the space provided.

Transect A - A':___

a) 

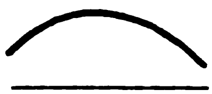
b) 

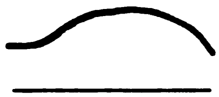
c) 

d) 

e) 

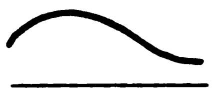
Transect B - B':___

a) 

b) 

c) 

d) 

e) 

Part II Refer to the numbered points on the map for these questions.

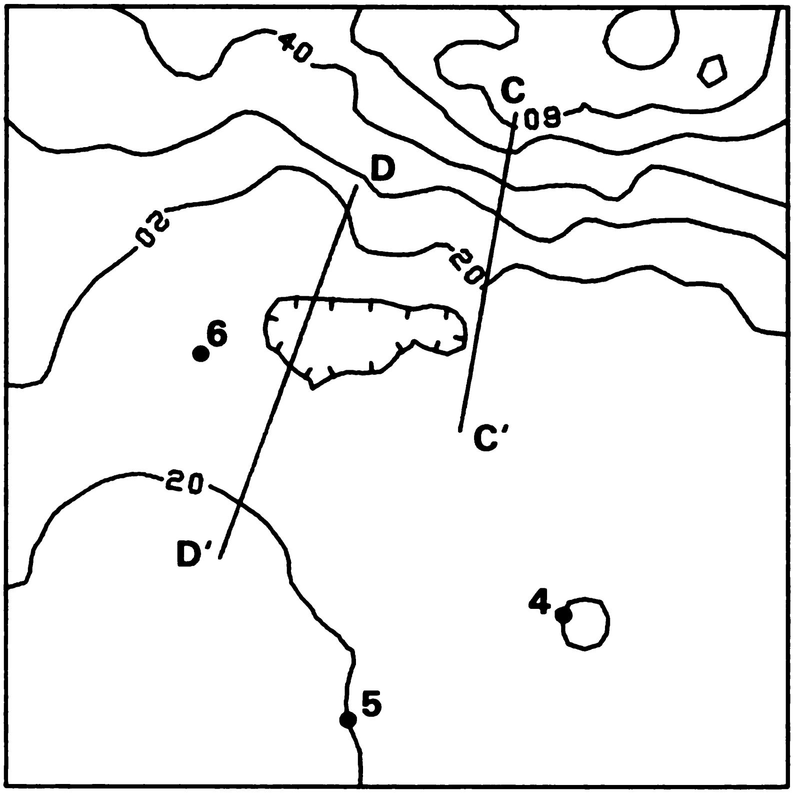
Point #1 is ___ point #2.

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

Point #3 is situated ___

a) on a "ridge"
b) in a "valley"
c) can't determine

Z

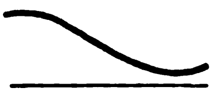


Part I Match each transect line on the map to the profile that most closely resembles the form of the surface along that transect. Mark your selection in the space provided.

Transect C - C':___

a) 

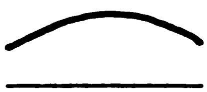
b) 

c) 

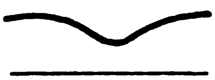
d) 

e) 

Transect D - D':___

a) 

b) 

c) 

d) 

e) 

Part II Refer to the numbered points on the map for these questions.

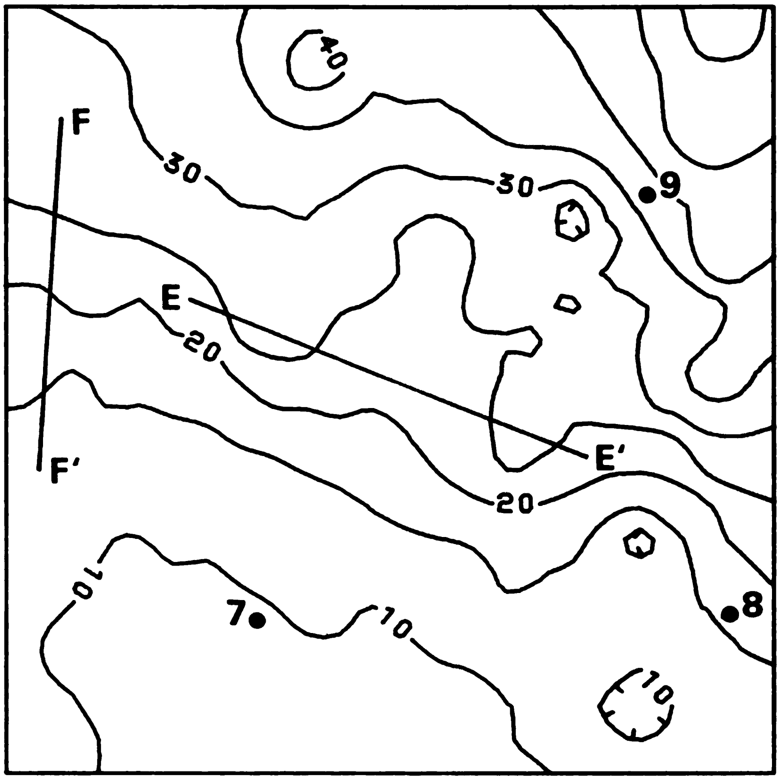
Point #4 is ___ point #5.

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

Point #6 is situated ___

a) on a "hill"
b) in a "lowland"
c) can't determine

D



Part I Match each transect line on the map to the profile that most closely resembles the form of the surface along that transect. Mark your selection in the space provided.

Transect E - E':___

a) 

b) 

c) 

d) 

e) 

Transect F - F':___

a) 

b) 

c) 

d) 

e) 

Part II Refer to the numbered points on the map for these questions.

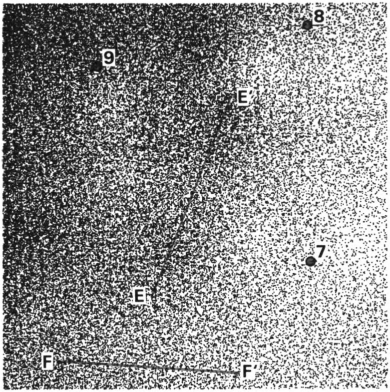
Point #7 is ___ point #8.

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

Point #9 is situated ___

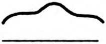
a) on a steep slope
b) on a flat area
c) can't determine

C



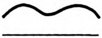
Part I Match each transect line on the map to the profile that most closely resembles the form of the surface along that transect. Mark your selection in the space provided.

Transect E - E':___

a) 

b) 

c) 

d) 

e) 

Transect F - F':___

a) 

b) 

c) 

d) 

e) 

Part II Refer to the numbered points on the map for these questions.

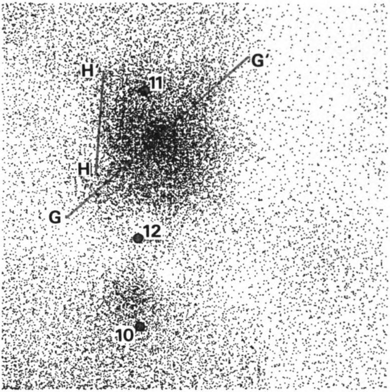
Point #7 is ___ point #8.

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

Point #9 is situated ___

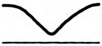
a) on a steep slope
b) on a flat area
c) can't determine

L



Part I Match each transect line on the map to the profile that most closely resembles the form of the surface along that transect. Mark your selection in the space provided.

Transect G - G':___

a) 

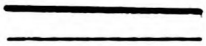
b) 

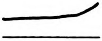
c) 

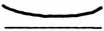
d) 

e) 

Transect H - H':___

a) 

b) 

c) 

d) 

e) 

Part II Refer to the numbered points on the map for these questions.

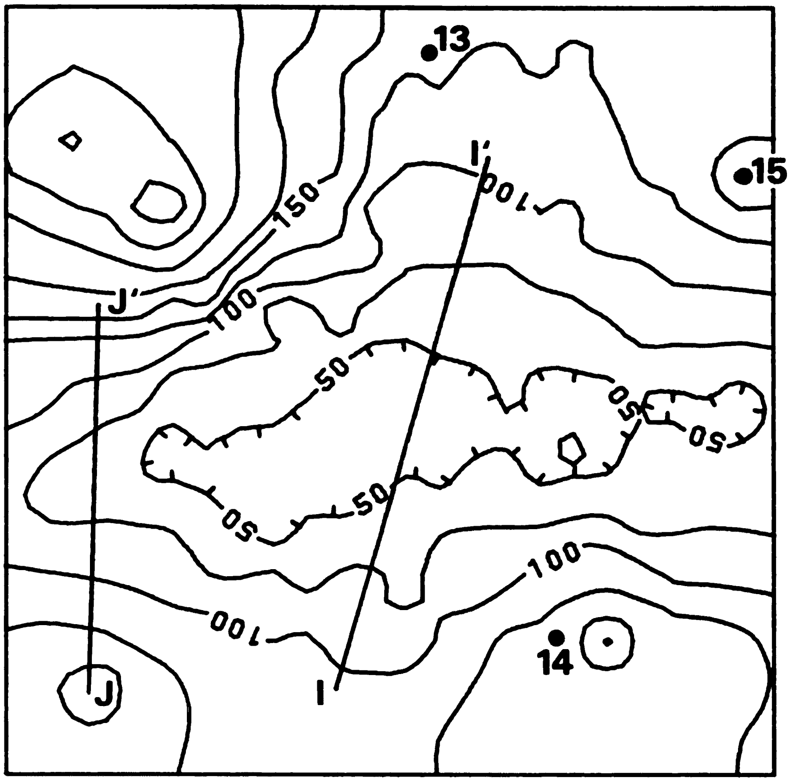
Point #10 is ___ point #11.

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

Point #12 is situated ___

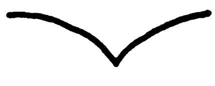
a) on a "ridge"
b) in a "valley"
c) can't determine

R



Part I Match each transect line on the map to the profile that most closely resembles the form of the surface along that transect. Mark your selection in the space provided.

Transect I - I':___

a) 

b) 

c) 

d) 

e) 

Transect J - J':___

a) 

b) 

c) 

d) 

e) 

Part II Refer to the numbered points on the map for these questions.

Point #13 is ___ point #14.

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

Point #15 is situated ___

a) on a "hill"
b) in a "lowland"
c) can't determine

Part III After you have completed the questions for the preceeding three maps, respond to the following statements by placing a mark on the line between each word pair. Base each response on your initial reaction.

1. The ease of matching the transect lines to the profiles:

   easy I____I____I____I____I____I____I____I difficult

2. The ease of comparing spot elevation on the maps:

   easy I____I____I____I____I____I____I____I difficult

3. The effectiveness of the maps at showing overall surface form:

   excellent I____I____I____I____I____I____I____I poor

4. The aesthetic appeal of the map symbolization:

   very nice I____I____I____I____I____I____I____I awful

5. The texture of the map symbolization:

   smooth I____I____I____I____I____I____I____I coarse

*Have you used maps like these before (yes/no)? _____

Use the space below to make any comments about the maps or the test.

***** Thank you for your help! *****

APPENDIX B

ORAL TEST INSTRUCTIONS AND DEMONSTRATION MATERIALS

APPENDIX B

ORAL TEST INSTRUCTIONS AND DEMONSTRATION MATERIALS

[read aloud to test subjects prior to testing] I'm doing my Master's thesis research on the effectiveness of two types of map symbolizations. To do this, I need to know how people perceive the information shown on maps. The symbolizations I'm testing are used to represent something called Statistical Surfaces. [show top half of first overhead] A statistical surface is an abstraction -- it shows the height of data values over an area. This example shows annual snowfall data for Michigan's lower penninsula. We can see, for example, that it snows the most in the northwestern part of the state.

The test consists of 6 maps; 3 of one type, and 3 more of another type. There is no particular order to the maps in each test booklet. You'll be matching transect lines on the maps with profiles [show bottom half] like these. Each map has two transect lines on it. [read intructions from overhead] Each map also has several numbered points [show on overhead] like these. There will be questions like: 'Is point #1 higher or lower than point #2?'. If you're not sure about an answer; just guess, but don't skip any questions or leave anything blank. OK?

After the the first 3 maps, you'll come to a short series of Impression Questions [show second overhead]. There will be another set of questions like these after the second set of 3 maps. These questions apply only to the 3 maps that precede them. Answer these questions by making a single vertical mark on the line [show on overhead]. Mark the line with your FIRST IMPRESSION. You shouldn't spend much time on these questions, just read them and quickly mark your responses. In this example, I've responded to the statement 'The color scheme of this overhead' by making a mark between 'neutral' (the middle of the line) and 'beautiful'. Are we clear on this?

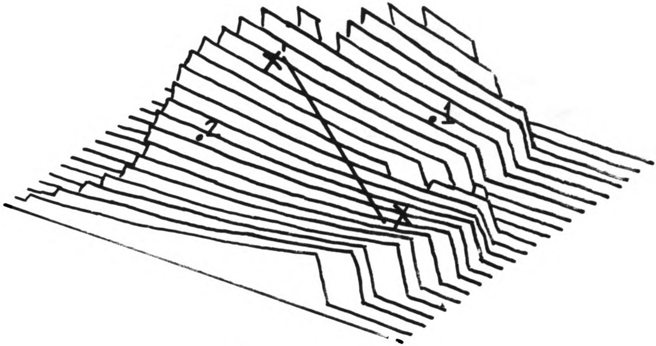
The last page of the test asks for any comments about the test or the maps. I encourage you to write down your comments.

[begin passing out the test booklets] As soon as everyone has a test booklet, you may begin. There's no fixed time limit, but I'll help you pace yourself by telling you approximately when you should be starting the next map. Don't panic if you're a bit behind, just pick up the pace and try to catch up with everyone else. If you're COMPLETELY confused about the whole thing, raise your hand and I'll come over to you -- otherwise don't ask any questions during the test. Bring your test booklet up here when you're finished.

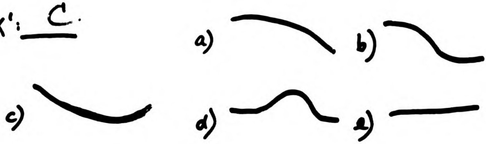
[when everyone has a test booklet] OK, please begin.

[at 2 minute intervals] You should now be finishing up the (first, second, etc) map and starting on the next one. If you're behind, don't panic and don't skip any questions, just try to pick up the pace.

"MICHIGAN SNOWFALL"



Transect X-X': C



To match a transect to a profile, look at the map along the transect line and form a mental image of the map surface along that line. Then choose the profile that most closely matches your mental image. Write your answer in the space provided.

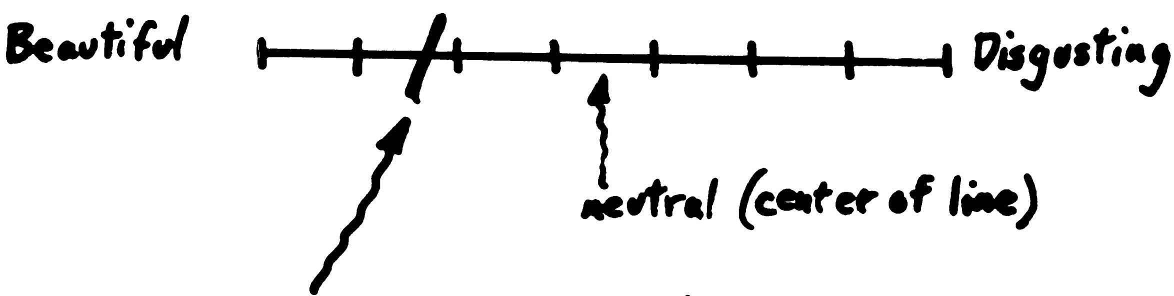
Overhead transparency #1 for test instructions.

Impression Questions

- short series of questions following each set of 3 maps; questions apply to those 3 maps ONLY.
- mark the line between each pair of words according to your FIRST REACTION to the statement.

for example:

The Color Scheme of this Overhead Transparency:



a mark here indicates that I think the color scheme is "pretty good" — not beautiful, but better than neutral.

Overhead transparency #2 for test instructions.

APPENDIX C

PROGRAM "DOTMATRX" AND PERIPHERAL PROGRAMS

APPENDIX C

PROGRAM "DOTMATRX" AND PERIPHERAL PROGRAMS

Program "DOTMATRX"

```
10 REM This program prints a "random dot matrix - smooth symbology" map
     on a dot matix printer.  The map will show a smooth gradation in
     grey tone, consistent with the notion of a smooth statistical
     surface.
20 REM The input data is a matrix of values interpolated from known
     "control point" values.  The output is a matrix of cells, each
     containing randomly placed dots in proportion to a data value.
30 REM This program uses graphics printing codes for a GEMINI-15
     printer.  The resolution (dots/cell) is either 10 x 12 (high res.)
     or 5 x 6 (low res.).  The cell size is the same (1/12" square) in
     either case.
40 REM Program stored as "DOTMATRX.WFJ" in ASCII code.  Program written
     for compatability with BASIC compiler.  Compiling the program
     greatly increases the speed of execution.  Written 3-29-84 by
     Bill Johnson.
50 REM-------------------------------------------------------------------
60 REM Initialize variables, set constants, prompt inputs
70 CLEAR: PRINT: PRINT "Turn printer ON" 'clear memory, printer message
80 LPRINT CHR$(27);"@"                   'initialize printer mode
90 WIDTH "LPT1:",255                     'initialize width of printout
100 FOR I%=1 TO 24: PRINT: NEXT          'scroll to clear screen
110 OPTION BASE 1                        'minimum array subscript=1
120 LMARGIN%=0: NONZERO=0
130 PRINT "This program will produce a random dot matrix map.  The
     output is a"
140 PRINT "matrix of grid cells, each one containing randomly placed
     dots in"
150 PRINT "proportion to a data value.  The output can be produced in
     either"
160 PRINT "high or low resolution.  High resolution (120 x 144 dots/sq.
     in.)"
170 PRINT "looks better than low resolution (60 x 72 dots/sq. in.) but
     takes"
180 PRINT "about two and a half times longer to produce.": PRINT
190 INPUT "Do you want the output in high (1) or low (2)
     resolution";RES: PRINT
200 IF RES=1 OR RES=2 THEN 210 ELSE 190
210 INPUT "Enter the maximum blackness of a cell (20-100%):",MAXBLK
```

```
220 IF MAXBLK>100 OR MAXBLK<20 THEN 210
230 PRINT: INPUT "Do you want to set a new left margin on printer
    (Y/N)";Y$
240 IF Y$="n" OR Y$="N" THEN 270
250 PRINT: INPUT "Enter new left margin for printer (0 - 6 inches):
    ",INCHES
260 IF INCHES <0 OR INCHES>6 THEN 250
270 PRINT:PRINT "Disk containing data matrix should now be in drive
    'a'.":PRINT
280 INPUT "What diskfile contains your data matrix (a:________.mtx)";N$
290 Q=LEN(N$): IF Q<=8 THEN 300 ELSE PRINT "Name must be 8 characters
    or less.": GOTO 280
300 P$="a:": S$=".mtx": A$=P$+N$+S$:     'concatenate string (fn)
310 PRINT: INPUT"How many ROWS in your data matrix";NROWS%
320 PRINT: INPUT "How many COLUMNS in your data matrix";NCOLS%
330 PRINT: INPUT "What is your map title (up to 50 characters)";H$
340 Q=LEN(H$): IF Q<=50 THEN 350
350 IF RES=1 THEN R$="High resolution mode (120 x 144 dots/sq. in.)"
    ELSE R$="Low resolution graphics mode (60 x 72 dots/sq. in.)"
360 FOR I%=1 TO 24: PRINT: NEXT: PRINT "You have selected ";R$;"."
370 PRINT "Your data set (";A$;"), has";NROWS%;"rows and";
    NCOLS%;"columns."
380 PRINT "Maximun cell blackness=";MAXBLK;"%.  Left margin=";
    INCHES;"inches.
390 PRINT "Your map title is '";H$;"'."
400 PRINT: INPUT "Is this correct (Y/N)";Y$: PRINT
410 IF Y$="n" OR Y$="N" THEN 190
420 IF RES=1 THEN LMARGIN%=CINT(INCHES*120) ELSE
    LMARGIN%=CINT(INCHES*60)
430 IF RES=1 THEN NTONES%=CINT(120*(MAXBLK/100)) ELSE
    NTONES%=CINT(30*(MAXBLK/100))
440 T$="00:00:00": TIME$=T$
450 IF RES=1 THEN CELLCOLS%=NCOLS%*10 ELSE CELLCOLS%=NCOLS%*5
460 N1%=(LMARGIN%+CELLCOLS%) MOD 256: N2%=INT((LMARGIN%+CELLCOLS%)/256)
470 REM-------------------------------------------------------------
480 REM Find range of data values, compute scaling factor for number of
        tones
490 PRINT "Finding ranges of data set -- Please be patient"
500 MINVAL=9.000001E+09
510 MAXVAL=-9.000001E+09
520 OPEN A$ FOR INPUT AS #1              'open diskfile to read data
530 FOR ROW%=1 TO NROWS%
540     FOR COL%=1 TO NCOLS%
550             INPUT #1,VALUE
560             IF VALUE>MAXVAL THEN MAXVAL=VALUE ELSE 570
570             IF VALUE<MINVAL THEN MINVAL=VALUE ELSE 580
580             IF VALUE>0 THEN NONZERO=NONZERO+1 ELSE 590
590     NEXT
600 NEXT
610 CLOSE#1
620 IF MINVAL>0 THEN RANGE=MAXVAL ELSE RANGE=MAXVAL-MINVAL
630 FACTOR=NTONES%/RANGE                 'compute scaling factor
640 REM-------------------------------------------------------------
```

```
650 REM Print title on map (8.5 cpi, double-strike), centered over map
      area
660 LM%=INCHES*10+(NCOLS%/2*8.5/12)-(Q/2*8.5/10): IF LM%<1 THEN LM%=1
670 LPRINT CHR$(27);CHR$(77);CHR$(LM%)   'set left margin: center title
680 LPRINT CHR$(15);CHR$(14);CHR$(27);CHR$(71); 'set to 8.5 cpi,
                                                  double-strike
690 LPRINT H$: LPRINT: LPRINT: LPRINT
700 REM-----------------------------------------------------------------
710 REM Compute number of random dots for each cell
720 IF RES=1 THEN MINUTES=CINT((NONZERO/120)+.5) ELSE
     MINUTES=CINT((NONZERO/300)+.5)
730 FOR I%=1 TO 24: PRINT: NEXT          'scroll to clear screen
740 PRINT "Computing dot pattern for each cell.  Please wait for
     printout."
750 PRINT: PRINT "This map should take about";MINUTES;"minute(s) to
     print."
760 PRINT "Do not handle paper while printer is in operation.  Slight
     gaps"
770 PRINT "will show on your output if the paper is moved during
     printout."
780 OPEN A$ FOR INPUT AS #1
790 IF RES=2 THEN 1380
800 REM************************* HIGH RESOLUTION **********************
810 DIM MATRXROW(12,1200)             'row storage array for dot pattern
820 LPRINT CHR$(27);"@";CHR$(27);CHR$(51);CHR$(1)  'set carriage
                                                    return: 1/144"
830 FOR ROW%=1 TO NROWS%                 'rows in data matrix
840     FOR COL%=1 TO NCOLS%             'columns in data matrix
850             INPUT #1,VALUE
860             NDOTS%=CINT(VALUE*FACTOR)  'compute # of dots for cell
870             IF NDOTS%>60 THEN 880 ELSE 1020
880             NDOTS%=120-NDOTS%
890             FOR I%=1 TO 12           'fill cell array with 1's
900                 FOR J%=1 TO 10
910                     MATRXROW(I%,((COL%-1)*10+J%))=1
920                 NEXT
930             NEXT
940             RANDOMIZE (ROW%*COL%)    'reseed random # generator
950             FOR DOT%=1 TO NDOTS%     'find random dots for a cell:
                                          ndots>60
960                     X%=CINT((RND(DOT%)*12)+.5)
970                     Y%=CINT((RND(DOT%)*10)+.5)
980                     IF MATRXROW(X%,((COL%-1)*10+Y%))=0 THEN 960
990                     MATRXROW(X%,((COL%-1)*10+Y%))=0
1000             NEXT
1010            GOTO 1090
1020            RANDOMIZE (ROW%*COL%)    'reseed random # generator
1030            FOR DOT%=1 TO NDOTS%     'find random dots for a cell:
                                          ndots<60
1040                    X%=CINT((RND(DOT%)*12)+.5)
1050                    Y%=CINT((RND(DOT%)*10)+.5)
1060                    IF MATRXROW(X%,((COL%-1)*10+Y%))=1 THEN 1040
1070                    MATRXROW(X%,((COL%-1)*10+Y%))=1
```

```
1080            NEXT
1090        NEXT COL%
1100        REM-----------------------------------------------------------
1110        REM Print out row in two passes
1120        FOR PASS%=1 TO 2                    'loop for two printing passes
1130            LPRINT CHR$(10);CHR$(27);CHR$(76);CHR$(N1%);
                    CHR$(N2%);          'graphics
1140            FOR BLANK%=1 TO LMARGIN%        'move to left margin
1150                LPRINT CHR$(0);
1160            NEXT
1170            FOR SPACE%=1 TO CELLCOLS%
1180                    PIN1%=0: PIN2%=0: PIN3%=0: PIN4%=0: PIN5%=0:
                        PIN6%=0
1190                    IF MATRXROW(PASS%,SPACE%)=1 THEN PIN1%=128
1200                    IF MATRXROW(PASS%+2,SPACE%)=1 THEN PIN2%=64
1210                    IF MATRXROW(PASS%+4,SPACE%)=1 THEN PIN3%=32
1220                    IF MATRXROW(PASS%+6,SPACE%)=1 THEN PIN4%=16
1230                    IF MATRXROW(PASS%+8,SPACE%)=1 THEN PIN5%=8
1240                    IF MATRXROW(PASS%+10,SPACE%)=1 THEN PIN6%=4
1250                    LPRINT CHR$(PIN1%+PIN2%+PIN3%+PIN4%+PIN5%
                            +PIN6%);
1260            NEXT
1270        NEXT
1280        LPRINT: LPRINT: LPRINT: LPRINT: LPRINT    'carriage return for
1290        LPRINT: LPRINT: LPRINT: LPRINT: LPRINT: LPRINT 'next row
                                                            (9 x 1/144")
1300        FOR I%=1 TO 12              'reset row storage array to zeros
1310            FOR J%=1 TO CELLCOLS%
1320                MATRXROW(I%,J%)=0
1330            NEXT
1340        NEXT
1350 NEXT ROW%
1360 CLOSE #1
1370 GOTO 1920
1380 REM************************** LOW RESOLUTION **********************
1390 DIM MATRXCEL(6,5)                'cell storage array for dot pattern
1400 LPRINT CHR$(27);"@";CHR$(27);CHR$(65);CHR$(6)  'set carriage
                                                        return: 6/72"
1410 ROW%=1: COL%=1: BLANK%=1: I%=1: J%=1: DOT%=1: SPACE%=1
1420 FOR ROW%=1 TO NROWS%                   'rows in data matrix
1430     LPRINT CHR$(27);CHR$(75);CHR$(N1%);CHR$(N2%);  'low res.
                                                            graphics
1440     FOR BLANK%=1 TO LMARGIN%           'move to left margin
1450         LPRINT CHR$(0);
1460     NEXT
1470     FOR COL%=1 TO NCOLS%               'columns in data matrix
1480             INPUT #1,VALUE
1490             NDOTS%=CINT(VALUE*FACTOR)  'compute # of dots for cell
1500             IF NDOTS%>15 THEN 1510 ELSE 1650
1510             NDOTS%=30-NDOTS%
1520             FOR I%=1 TO 6              'fill cell array with 1's
1530                 FOR J%=1 TO 5
1540                     MATRXCEL(I%,J%)=1
```

```
1550                NEXT
1560            NEXT
1570            RANDOMIZE (ROW%*COL%)     'reseed random # generator
1580            FOR DOT%=1 TO NDOTS%      'find random dots for cell:
                                           ndots>15
1590                    X%=CINT((RND(DOT%)*6)+.5)
1600                    Y%=CINT((RND(DOT%)*5)+.5)
1610                    IF MATRXCEL(X%,Y%)=0 THEN 1590
1620                    MATRXCEL(X%,Y%)=0
1630            NEXT
1640            GOTO 1720
1650            RANDOMIZE (ROW%*COL%)     'reseed random # generator
1660            FOR DOT%=1 TO NDOTS%      'find random dots for cell:
                                           ndots<15
1670                    X%=CINT((RND(DOT%)*6)+.5)
1680                    Y%=CINT((RND(DOT%)*5)+.5)
1690                    IF MATRXCEL(X%,Y%)=1 THEN 1670
1700                    MATRXCEL(X%,Y%)=1
1710            NEXT
1720            REM--------------------------------------------------
1730            REM Print cell with random dots
1740            FOR SPACE%=1 TO 5
1750                    PIN1%=0: PIN2%=0: PIN3%=0: PIN4%=0: PIN5%=0:
                        PIN6%=0
1760                    IF MATRXCEL(1,SPACE%)=1 THEN PIN1%=128
1770                    IF MATRXCEL(2,SPACE%)=1 THEN PIN2%=64
1780                    IF MATRXCEL(3,SPACE%)=1 THEN PIN3%=32
1790                    IF MATRXCEL(4,SPACE%)=1 THEN PIN4%=16
1800                    IF MATRXCEL(5,SPACE%)=1 THEN PIN5%=8
1810                    IF MATRXCEL(6,SPACE%)=1 THEN PIN6%=4
1820                    LPRINT CHR$(PIN1%+PIN2%+PIN3%+PIN4%+PIN5%
                               +PIN6%);
1830            NEXT
1840            FOR I%=1 TO 6        'reset cell storage array to zeros
1850                FOR J%=1 TO 5
1860                    MATRXCEL(I%,J%)=0
1870                NEXT
1880            NEXT
1890    NEXT COL%
1900    LPRINT                 'carriage return for next row (6/72")
1910 NEXT ROW%
1920 REM------------------------------------------------------------
1930 REM Restore printer mode, end program execution
1940 CLOSE #1
1950 LPRINT CHR$(27);"@": WIDTH "LPT1:",80    'restore printer mode
1960 LPRINT: LPRINT: LPRINT: LPRINT
1970 PRINT: PRINT: PRINT "Program execution completed.": PRINT
1980 V$=TIME$: PRINT "Total time of program execution: ";V$
1990 END
```

Program "INTERP"

```
10 REM Program to interpolate values into a grid from scattered control
     points.
20 REM The interpolation is done with Tobler's algorithm (value at a
     point "P" is based on the values of the nearest 6 control points,
     each weighted by the inverse of their distance from "P").
30 REM The input data is a set of scattered control points, identified
     by their position (row,col) in a rectangular gridcell matrix.  The
     empty positions in the matrix will be filled with interpolated
     values.
40 REM Also input is a data set to clip non-map areas from the matrix.
     This suppresses interpolation of values outside of the map area.
     These non-map areas are given values of zero in the matrix.
50 REM The matrix is partitioned during the search for the nearest 6
     control points to save search time.  Partitioning is based on a
     box (1/3 number of rows x 1/3 number of columns) surrounding the
     current matrix position.
60 REM The completed grid of values is written to a diskfile.
70 REM Program stored as "INTERP.WFJ" in ASCII code.  Program written
     for compatability with BASIC compiler.  Compiling the program
     greatly increases the speed of execution.   Written 3-31-84 by
     Bill Johnson.
80 REM-----------------------------------------------------------------
90 REM Initialize variables, prompt inputs, dimension arrays, open
     diskfiles
100 CLEAR: PRINT
110 OPTION BASE 1                          'minimum array subscript = 1
120 DIM R%(110),C%(110),VALUE(110),MATRIX(110,110),NEARDIST(6),
     PTDIST(6)
130 PRINT "This program will interpolate values into a grid from
     scattered control points."
140 PRINT "The interpolation is done with Tobler's algorithm (value at
     a point"
150 PRINT "is based on the values of the nearest 6 control points,
     each"
160 PRINT "weighted by the inverse of their distance from that point)."
170 PRINT "     The completed data grid will be written to a
     diskfile.": PRINT
180 PRINT "Disk containing data files should now be in drive 'a'."
190 PRINT: INPUT "What file contains your control points
     (a:________.dat)";N$
200 Q=LEN(N$): IF Q<=8 THEN 210 ELSE PRINT "Name must be 8 characters
     or less": GOTO 190
210 P$="a:": S$=".dat": A$=P$+N$+S$      'concatenate string (filename)
220 PRINT: INPUT "How many control points in your file";NPOINTS%
230 PRINT: INPUT "What file contains your map outline data
     (a:________.dat)";O$
240 Q=LEN(O$): IF Q<=8 THEN 250 ELSE PRINT "Name must be 8 characters
     or less": GOTO 230
250 PRINT: INPUT "How many ROWS in your matrix";NROWS%
```

```
260 PRINT: INPUT "How many COLUMNS in your matrix";NCOLS%
270 PRINT: INPUT "What name for your output diskfile
    (a:________.mtx)";M$
280 Q=LEN(M$): IF Q<=8 THEN 290 ELSE PRINT "Name must be 8 characters
    or less": GOTO 270
290 B$=P$+O$+S$: T$=".mtx": C$=P$+M$+T$ 'concatenate strings (filename)
300 PRINT: PRINT"You will be interpolating a";NROWS%;"rows
    by";NCOLS%;"columns"
310 PRINT "matrix from";NPOINTS%;"control points.  Your control points
    will be"
320 PRINT "read from file '";A$;"'.  Your map outline data will be read
    from"
330 PRINT "file '";B$;"'.  Your matrix will be written to file
    '";C$;"'."
340 PRINT: INPUT "Is this correct (Y/N)";Y$
350 IF Y$="n" OR Y$="N" THEN 190
360 OPEN A$ FOR INPUT AS #1          'open file for control points
370 OPEN B$ FOR INPUT AS #2          'open file for map outline
380 OPEN C$ FOR OUTPUT AS #3         'open file to write matrix data
390 T$="00:00:00": TIME$=T$          'initialize timer
400 REM-----------------------------------------------------------------
410 REM interpolate grid
420 PRINT: PRINT "Interpolation begins. . . ."
430 FOR I%=1 TO NPOINTS%                  'input control points (v,r,c)
440     INPUT #1,VALUE(I%),R%(I%),C%(I%)
450 NEXT
460 CLOSE #1
470 COUNT%=0
480 FOR ROW%=1 TO NROWS%                  'rows in matrix
490     V$=TIME$: PRINT
500     PRINT "---------------------------------------","Time so far:
        ";V$
510     PRINT "Row","Column","Value",NROWS%;"rows,";NCOLS%;"columns in
        matrix"
520     INPUT #2,BLANKCELLS%
530     COL%=1                            'initialize column counter
540     FOR COL%=COL% TO ((COL%-1)+BLANKCELLS%) 'assign zeros to non-
                                                 map areas
550             MATRIX(ROW%,COL%)=0
560             WRITE #3,MATRIX(ROW%,COL%)    'write value to diskfile
570             PRINT ROW%,COL%,MATRIX(ROW%,COL%)
580     NEXT
590     IF BLANKCELLS%=NCOLS% THEN 1040         'if row is blank go to
                                                 next row
600     INPUT #2,MAPCELLS%
610     FOR COL%=COL% TO ((COL%-1)+MAPCELLS%)   'interpolate values in
                                                 map area
620             FOR NEAR%=1 TO 6          'initialize nearest 6 distance
630                     NEARDIST(NEAR%)=9000!
640                     PTDIST(NEAR%)=0
650             NEXT
660             FOR SEARCH%=1 TO NPOINTS%  'search for nearest 6 points
670                     IF NPOINTS%<20 OR (NCOLS%<20 AND NROWS%<20)
```

```
                    THEN 700
680                 IF R%(SEARCH%)>(ROW%+NROWS%/3) OR
                    R%(SEARCH%)<(ROW%-NROWS%/3) THEN 860
690                 IF C%(SEARCH%)>(COL%+NCOLS%/3) OR
                    C%(SEARCH%)<(COL%-NCOLS%/3) THEN 860
700                 PTNUM%=SEARCH%
710                 IF ROW%<>R%(SEARCH%) OR COL%<>C%(SEARCH%)
                    THEN 760
720                 MATRIX(ROW%,COL%)=VALUE(SEARCH%) 'control point
                                                      value
730                 WRITE #3,MATRIX(ROW%,COL%)  'write to diskfile
740                 PRINT ROW%,COL%,MATRIX(ROW%,COL%)
750                 GOTO 960
760                 DIST=SQR((ROW%-R%(SEARCH%))^2+
                    (COL%-C%(SEARCH%))^2)
770                 FOR NEAR%=1 TO 6        'sort nearest 6 points
780                         IF DIST>NEARDIST(NEAR%) THEN 850
790                         SHORTDIST=NEARDIST(NEAR%)
800                         NEARDIST(NEAR%)=DIST
810                         DIST=SHORTDIST
820                         PTDIST1=PTDIST(NEAR%)
830                         PTDIST(NEAR%)=PTNUM%
840                         PTNUM%=PTDIST1
850                 NEXT
860             NEXT SEARCH%
870             V1=0: V2=0
880             FOR NEAR%=1 TO 6          'weight values by distance
890                     V1=V1+VALUE(PTDIST(NEAR%))/
                        (NEARDIST(NEAR%))^1.5
900                     V2=V2+1/(NEARDIST(NEAR%))^1.5
910             NEXT
920             MATRIX(ROW%,COL%)=V1/V2  'interpolated matrix value
930             WRITE #3,MATRIX(ROW%,COL%)  'write value to diskfile
940             PRINT ROW%,COL%,MATRIX(ROW%,COL%)
950             COUNT%=COUNT%+1
960     NEXT COL%
970     INPUT #2,BLANKCELLS%
980     IF BLANKCELLS%>0 THEN 540
990     FOR COL%=COL% TO NCOLS%           'assign zeros to non-map areas
1000            MATRIX(ROW%,COL%)=0
1010            WRITE #3,MATRIX(ROW%,COL%)   'write value to diskfile
1020            PRINT ROW%,COL%,MATRIX(ROW%,COL%)
1030     NEXT
1040 NEXT ROW%
1050 CLOSE #2: CLOSE #3
1060 PRINT "End of program execution."
1070 PRINT COUNT%;" values interpolated from ";NPOINTS%;" control
     points."
1080 TOTAL%=COUNT%+NPOINTS%: PRINT "Matrix has";TOTAL%;"values."
1090 V$=TIME$: PRINT "Total time of program execution: ";V$
1100 END
```

Program "CELLGRID"

```
10 REM This program prints a grid cell matrix for the dot matrix map
     symbology.
20 REM The output is printed on the GEMINI-15 printer at whatever size
     is desired.  The matrix cells are 1/12" square, and are used for
     both the low and high resolution versions of the dot matrix smooth
     symbology.
30 REM Program stored as "CELLGRID.WFJ" in ASCII code.  Program written
     for compatability with BASIC compiler.  Compiling the program
     greatly increases the speed of execution.   Written 3-28-84 by
     Bill Johnson.
40 REM---------------------------------------------------------------
50 REM Initialize variables, prompt inputs
60 CLEAR: PRINT
70 LPRINT CHR$(27);"@"                    'initialize printer mode
80 WIDTH "LPT1:",255                      'initialize width of printout
90 PRINT "This program will print a cell grid of 1/12 in. square
     cells."
100 PRINT: INPUT "Enter the desired WIDTH of the cell grid (1-12
     in.):",HOWWIDE
110 IF HOWWIDE<1 OR HOWWIDE>12 THEN GOTO 100 ELSE 120
120 INPUT "Enter the desired LENGTH of the cell grid (1-30
     in.):",HOWLONG
130 IF HOWLONG<1 OR HOWLONG>30 THEN GOTO 120 ELSE 140
140 WIDE%=CINT(12*HOWWIDE): LONG%=CINT(12*HOWLONG)
150 M%=(WIDE%*5)+1:  N1%=M% MOD 256: N2%=INT(M%/256)    'graphics
                                                          parameters
160 REM--------------------------------------------------------------
170 REM Print grid
180 PRINT: PRINT "Please wait for printout.  This may take several
     minutes."
190 PRINT "Do not handle the paper while printer is in operation."
200 LPRINT "Matrix cell grid (";LONG%;"rows x";WIDE%;"columns) for dot
     matrix"
210 LPRINT "smooth symbology.  Each cell is 1/12 inch square.": LPRINT:
     LPRINT
220 LPRINT CHR$(27);"A";CHR$(6)           'set carriage return to 6/72"
230 ROW%=1: COL%=1: SPACE%=1
240 FOR ROW%=1 TO LONG%+1
250     LPRINT CHR$(27);CHR$(75);CHR$(N1%);CHR$(N2%);   'low res.
                                                          graphics mode
260     IF ROW%=LONG%+1 THEN 360
270     FOR COL%=1 TO WIDE%
280             LPRINT CHR$(252);         'print vert. line (6 pins)
290             FOR SPACE%=1 TO 4         'print horiz. line (top pin)
300                     LPRINT CHR$(128);
310             NEXT SPACE%
320     NEXT COL%
330     LPRINT CHR$(252);                 'finish last column (6 pins)
340     LPRINT                            'carriage return for next row
```

```
350 NEXT ROW%
360 FOR SPACE%=1 TO M%                      'finish last row (top pin)
370     LPRINT CHR$(128);
380 NEXT SPACE%
390 LPRINT
400 LPRINT CHR$(27);"@":WIDTH "LPT1:",80: LPRINT  'restore printer mode
410 PRINT: PRINT "Program execution completed."
420 END
```

Program "INPUT"

```
10 REM Program to write data to a file from keyboard input.
20 REM Stored as "INPUT.WFJ".  Written 3-28-84 by Bill Johnson.
30 CLEAR: CLS
40 PRINT "This program is used to write data to a diskfile from
    keyboard"
50 PRINT "entry.  Data will be sent to the disk in drive 'a' and will
    be"
60 PRINT "given the name suffix '.dat'.   ie.(a:________.dat)."
70 PRINT: INPUT "What name do you want for your file";N$
80 A=LEN(N$): IF A>8 THEN 90 ELSE 100
90 PRINT "The file name must be 8 characters or less.": GOTO 70
100 PRINT: PRINT "Your data file will be named '";N$;"'."
110 PRINT: INPUT "Is this correct? (Y/N)";Y$
120 IF Y$="n" OR Y$="N" THEN 70
130 P$="a:": S$=".dat": A$=P$+N$+S$
140 OPEN A$ FOR OUTPUT AS #1
150 PRINT: PRINT "What type of data will you be entering?": PRINT
160 INPUT "Enter (1) for numeric data or (2) for character data:",T
170 IF T=1 OR T=2 THEN 180 ELSE 150
180 IF T=1 THEN T$="numeric" ELSE T$="character"
190 PRINT: PRINT "You will be entering ";T$;" data.  ";
200 INPUT "Is this correct (Y/N)";Y$: PRINT
210 IF Y$="n" OR Y$="N" THEN 160
220 CLS: PRINT "You may now enter data after each prompt (?)."
230 PRINT "If you make a mistake, backspace and correct it before
    entering it."
240 PRINT "You can also edit your data set after data entry is
    completed."
250 IF T=2 THEN 280
260 PRINT: PRINT "Enter '999' when finished.": PRINT
270 GOTO 290
280 PRINT: PRINT "Enter 'end' when finished.": PRINT
290 COUNT=0
300 IF T=2 THEN 390
310 DIM D(1000)
320 FOR I=1 TO 1000
330     PRINT I;"  ";
340     INPUT D(I)
350     IF D(I)=999 THEN 460
360     COUNT=COUNT+1
```

```
370 NEXT I
380 GOTO 460
390 DIM D$(1000)
400 FOR I=1 TO 1000
410     PRINT I;"  ";
420     INPUT D$(I)
430     IF D$(I)="end" OR D$(I)="END" THEN 460
440     COUNT=COUNT+1
450 NEXT I
460 PRINT "End of data entry.  You can now list your data set to check
      for"
470 PRINT "errors.  Each data value will be listed with a number.  Note
      the"
480 PRINT "numbers of data values to be corrected.  You can halt the
      listing"
490 PRINT "by pressing CTRL + NUM LOCK.  Listing will resume when any
      key is"
500 PRINT "pressed.": PRINT
510 INPUT "Press RETURN to list your data on the screen",R$: CLS
520 IF T=2 THEN 570
530 FOR I=1 TO COUNT
540     PRINT I;"  ";D(I)
550 NEXT I: PRINT
560 GOTO 600
570 FOR I=1 TO COUNT
580     PRINT I;"  ";D$(I)
590 NEXT I
600 INPUT "Do you want to make any corrections (Y/N)";Y$
610 IF Y$="n" OR Y$="N" THEN 800
620 PRINT: GOTO 650
630 INPUT "Another correction (Y/N)";Y$
640 IF Y$="n" OR Y$="N" THEN 770
650 IF T=2 THEN 680
660 INPUT "Enter the number of a data value to be corrected: ";I
670 GOTO 690
680 INPUT "Enter the number of a character string to be corrected: ";I
690 IF I>COUNT OR I<1 THEN 660
700 IF T=2 THEN 740
710 PRINT "Current value:";D(I)
720 INPUT "Enter the new data value: ";D(I)
730 GOTO 630
740 PRINT "Current string :";D$(I)
750 INPUT "Enter the new character string: ",D$(I)
760 GOTO 630
770 PRINT: INPUT "Do you want to list your data set again (Y/N)";Y$
780 IF Y$="y" OR Y$="Y" THEN 790 ELSE 800
790 IF T=1 THEN 530 ELSE 570
800 CLS: PRINT "Data are now being sent to diskfile '";N$;"'."
810 PRINT "Note: identifier numbers are not included in your data
      file."
820 IF T=2 THEN 870
830 FOR I=1 TO COUNT
840     WRITE #1,D(I)
```

```
850 NEXT I
860 GOTO 900
870 FOR I=1 TO COUNT
880     WRITE #1,D$(I)
890 NEXT I
900 CLOSE #1
910 IF T=2 THEN 940
920 ERASE D
930 GOTO 950
940 ERASE D$
950 CLS: INPUT "Do you want to enter another data set (Y/N)";Y$
960 IF Y$="y" OR Y$="Y" THEN 30
970 PRINT: PRINT "End of program run."
980 END
```

LIST OF REFERENCES

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