ABSTRACT

The complexity of regional water management problems necessitates the summarization of water resource data in a form that is easily analyzed visually. Computer-generated maps are well suited for displaying complex relationships since they are easy to create and modify and are relatively inexpensive compared to traditional techniques. Development of new display techniques creates questions about the most effective display of data used for generic assessments.

Recent attempts at displaying bivariate data geographically have not been entirely successful due to numerous data categories and complex color patterns used in "cross" mapping techniques. This paper offers an alternate method of displaying bivariate data which uses the degree of differences between two variables (e.g., water supply and water demand) to create a scale in which shades of two primary colors are used for positive and negative differences while a third color is used for the null case (i.e., within the confidence limits of the statistical model).

INTRODUCTION

The complex problems faced in regional water management require geographical display techniques which provide information about several variables simultaneously. Attempts at displaying bivariate data have been made by the U.S. Census Bureau (1975) through the use of two-variable color "cross" maps. Recent assessments indicate that interpretation of "cross" maps at an acceptable level of accuracy is not possible (Wainer & Fracolini, 1980). Thus, Wainer et al. (1980) encourage the development of alternate display strategies which overcome some of the difficulties in portraying complex environmental data.

Computer-generated maps provide an effective means to produce and evaluate different mapping strategies. The use of color maps is still experimental with current research identifying how best to use the emphasis of color for particular regional management needs. Monochrome shading schemes which do not require color have been commonly used in the past and it is uncertain whether color schemes are effective enough to justify the additional expense of color map generation.

This paper addresses some of the questions arising from evaluations of bivariate color maps and attempts to determine how color mapping strategies could be designed to best serve regional management needs. Water use in Florida was chosen as an example of a management problem which would benefit from a bivariate geographical display strategy. Water supply and demand were approximated for each county from data stored in the Geocology data base (Olson, Emerson, & Nungeeser, 1980) on surface area of water and irrigation demand.

"CROSS" MAPS

"Cross" mapping is a popular use of computer color cartography. These complex color maps were used by the U.S. Census Bureau (1975) to show the spatial patterns of two demographic variables. In these maps a separate color scale is used for each variable. The two scales are subsequently "crossed" using an overlay process which results in 16 shades representing all the combinations of the four categories of each variable. The result is a very complex map which is difficult to decipher (Wainer et al., 1980). Several explanations of this difficulty exist. One problem with this type of mapping strategy lies in its use of an "ordered" color spectrum. Most maps use a natural visual metaphor, such as increasing intensity of shading to correspond to a quantitative variable.
The lightest shades of gray usually indicate the smallest values of the variable, while the darkest shades represent the largest values. Using the color spectrum alone to indicate bivariate relationships does not produce any obvious natural order. Another problem with this mapping approach is the number of color discriminations required. Bertin (1973) suggests that only six selective degrees of color are identifiable if one excludes variations in shade. These criticisms may explain the difficulty associated with interpreting the 16 category "cross" map.

**ALTERNATIVE COLOR MAPPING STRATEGIES**

One suggestion for improving color mapping schemes is to use different shades of a color (a monochrome configuration) for different levels of a variable to produce a naturally ordered variable. If this is to be a viable solution, then it is questionable why color is needed at all, since a monochrome shading scheme can be achieved as effectively without color by varying shades of gray. Cuff (1973) used several shades of blue to display a variable and then used yellow for the lowest values of the variable. Giving the lowest degree a different color has been criticized for setting this category visually apart from the rest of the categories (Wainer et al., 1980). However, emphasizing or setting apart certain categories is used advantageously in this paper in displaying water supply and demand data.

Our approach to displaying bivariate water supply and demand data is to calculate the difference between the two variables to produce a scale of the differences ranging from negative values of available water (supply is less than demand) to positive values (supply is greater than demand). This method lacks the ability of the "cross" map to display both the univariate information for each variable and the bivariate information. However, this approach is more effective in conveying meaningful information than the "cross" map and is probably superior for many regional management purposes.

County level data for Florida were obtained from the Geocology data base (Olson et al., 1980). Available standing water supply was estimated from surface area of water by multiplying surface hectares of water by an 8 meter depth (calculated average depth for standing water bodies) to obtain water volume. It was assumed that a withdrawal of 1% of the water volume was reasonable for the area under study, since the majority of irrigation demand is obtained from groundwater. Partial water demand was estimated from the available data on irrigation water used. Many factors are involved in water supply and demand and different assumptions can be used to obtain more accurate estimates. For the purpose of illustrating geographical display strategies, we used a few simple assumptions relating irrigation water demand and surface water supplies.

Two different methods of displaying categories of available water were attempted using Procedure GNAP (SAS Institute, 1981). In the first method, we separated negative value categories, the null category, and positive value categories by using three colors to highlight relationships between water supply and demand estimates. Subsequently, the degree of difference between water supply and demand was indicated by varying shading intensities. Red and blue were used to indicate water deficits and water abundance, respectively. Solid shading indicates a substantial difference between supply and demand and crosshatching indicates a moderate difference. The null category, shown in green shows counties where water supply is within 10% of water demand. White was used to indicate missing data to minimize the influence of data base inadequacies. The choice of colors can divert attention to geographical areas of concern. For example, the areas of water shortage are highlighted by red, a color which emphasizes the deficient available water estimates. Hence, the natural ordering of a monochrome shading scheme using two shades of both red and blue, and the contrasting and highlighting abilities of colored are effectively used together to increase the perception of differences between water supply and demand.

Our experience has been that regional management is usually most concerned with conflict and/or limited resource areas. For water management purposes, water deficient areas might be of most concern as critical "problem" areas needing directed decision making. This method can easily be adapted to highlight these sub-areas. Using the previous example, Fig. 2 shows a mapping system in which three categories are made on the water deficit end of the scale, while all the categories with sufficient water are combined. Many other manipulations of the size and placement of categories could be made which would display geographical data to serve other regional management needs.
SUMMARY

Despite overly complex initial attempts at bivariate color maps, alternative approaches to color mapping offer an effective tool for regional environmental management. Bivariate color maps appear to be more effective at displaying the relationships between two variables by combining the contrasting and highlighting abilities of color with the ordering abilities of monochrome shading techniques. Bivariate data presentation is simplified by expressing two variables on a single difference scale. Color adds a new dimension to monochrome shading schemes and affords regional managers additional flexibility for data display.

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LITERATURE CITED


Figure 2. County level analysis of the relationship between water supply and demand as indicated in Fig. 1. Categories have been changed as follows:

1 = water demand exceeds water supply in excess of 1000%.
2 = water demand exceeds water supply by 100% to 999%.
3 = water demand exceeds water supply by 25% to 99%.
4 = water supply is greater than or equal to water demand.
5 = data base missing supply and/or demand data for county.
Figure 1. County level analysis of the relationship (percent) between water supply (.01 * standing water volume) and water demand (irrigation volume) for Florida. Percent = 1 - (irrigation demand / (.01 * standing water volume)). Definition of data categories is as follows:

1 = water demand exceeds water supply in excess of 90%.
2 = water demand exceeds water supply by 26% to 89%.
3 = water supply equals water demand (+/- 25%).
4 = water supply exceeds water demand by 26% to 89%.
5 = water supply exceeds water demand in excess of 90%.
6 = data base missing supply and/or demand data for county.