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The Development of
Process-Printed Munsell Charts for
Selecting Map Colors

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THE DEVELOPMENT OF
PROCESS-PRINTED MUNSELL CHARTS FOR
SELECTING MAP COLORS

By

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ABSTRACT

THE DEVELOPMENT OF
PROCESS-PRINTED MUNSELL CHARTS
FOR SELECTING MAP COLORS

By

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Color charts aid cartographers in the difficult task of choosing colors for maps. The perceptual organization of Munsell color charts presents many potential map color schemes. The Munsell charts, however, are painted and many maps are printed with process colors. The printed combinations of percentages of yellow, magenta, cyan, and black process-color inks that approximate the Munsell organization were developed using color measurement followed by systematization of percentage progressions and visual adjustment. Ten color charts were designed and printed. They each show colors of a constant hue that change in value vertically and in chroma horizontally across the chart.

Interviews with sixteen cartographers who design color maps were also conducted to gather background information on their use of color charts and investigate the potential usefulness of Munsell-based printed charts. The majority of interviewed cartographers felt these charts would be useful when selecting colors for maps, especially thematic maps.

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My other committee members deserve thanks. Dr. David Lusch made many practical suggestions on interpolation, systematization, and other problems. He also had a sharp eye for treacherous errors and points that needed further elaboration. I thank Dave for his advice.
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information that should be omitted, and the general organization of the thesis. His comments prompted major reordering that produced welcome simplification of the thesis.

The Department of Geography at Michigan State University devoted many resources to this research and I thank Dr. Gary Manson for this support. Printing my charts (one of many contributions) was tremendously important to the thesis.

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Chapter 1

INTRODUCTION

The objective of this study is to produce process-printed Munsell color charts. The purpose of these charts is to aid cartographers in the selection of colors for printed maps.

Color selection is one of the most difficult problems in map design (Castner, 1980), but there are many advantages to using color on maps. Well chosen colors increase both the attractiveness of a map and the effectiveness with which it communicates spatial information. Color affords map clarity and simplicity (Robinson 1967) while simultaneously allowing greater detail and complexity in hierarchical structure (Robinson and others 1984). Color also enhances important graphic communication elements such as figure-ground relationships and perceptual grouping (Dent 1985).

To aid in the selection of colors for maps, cartographers commonly use "lithographers' color charts" which show all colors that result from systematically combining percentages of the process inks. My experience in designing color schemes for process printed maps and assisting other students with color selection has left me greatly dissatisfied with these conventional lithographers' charts. A systematic selection of every nth color from such charts, for example, does not produce equal visual differences between colors. In addition, colors that form a logical scheme are often located pages apart, which makes it difficult to find the colors and to decide whether differences between them are appropriate. Difficulties such as these seem to be a common problem among cartographers; Castner (1980) and Brown (1982) also state that selecting colors from lithographers' charts is difficult.

Recommendations for color selection are often made using phrases such as "values of one hue," "spectral progression," "distinctive hue," "differences in value and intensity," and "more intense colors" (Robinson and others 1984, p. 186). Since cartographers should be thinking about color using the dimensions of hue, value, and intensity (or hue, value, and chroma), they should also be using charts with colors arranged according to these dimensions. Given cartographers' difficulties selecting colors and the importance of the perceptual dimensions of color in map design, a perceptually organized color chart should be an aid to cartographers when selecting map colors.

Kimerling's (1980) statement offers insight into why the Munsell system, based on the dimensions used to describe color, has not been employed in map color selection:

> Research cartographers are devising map design guidelines for the employment of color based on the CIE or Munsell color systems, while printers and cartographers involved in map construction rely on color charts showing tint screen combinations. To date, no method for converting among systems, other than visual comparison, has appeared in the cartographic literature (p. 139).

The final result of this thesis research will be printed color charts with corresponding tables of screen percentages that approximate the colors in the Munsell Student Set (1984).

1.1

Objectives

Although the objective of this study is to print Munsell charts for selecting map colors, I will be approximating the highly standardized painted Munsell charts rather than trying to produce a precise replication of them. Castner (1980) warns that "because of the large number of variables in the photographic, plate making and printing processes, it will be impossible to furnish a precise translation system for any color notation system" (p. 377). Similarly, Brown (1982) states that the conversion to Munsell would require a prohibitively large number of screen percentages. Approximating the Munsell charts is a worthwhile task because the end product should be useful to cartographers and because conventional charts differ so drastically from the ideal of perceptual organization.

My understanding of the usefulness of printed Munsell charts was based on personal experience and the vocabulary used for color selection guidelines in the cartographic literature. However, little is known about the actual practices of cartographic designers while choosing colors and using charts. Although simply asking "would you use these charts" would not produce a realistic assessment of my Munsell approximations, it seemed foolish to assume that printed Munsell charts fit into the general practices of cartographic designers. Therefore, as a secondary part of this research, I conducted interviews with sixteen cartographers who design color maps. The first objective of these interviews was to gather background information on the current use of color charts by these cartographers. The second objective was to examine the perceived potential usefulness of printed Munsell charts by asking the cartographic designers about uses of the charts within the context of their specific color selection problems.

1.2

Organization

Following this introduction, the second chapter of this thesis begins with detailed descriptions of the color systems of Munsell and process-printing. Chapter 2 then continues with a review of color in the cartographic literature and color systems in cartography. The color system descriptions provide necessary background for understanding the specific methods used to convert Munsell to printed color. Chapters 3, 4, and 5 each include method, results, and discussion sections. Chapter 3 presents the use of color measurement as an objective color matching technique. The results of the color matching in Chapter 3 necessitated further subjective systematization and visual adjustment of the color matches, and these refinements are described in the Chapter 4. Chapter 5 presents the interviews with cartographic designers, which included discussion of the charts developed in Chapters 3 and 4. Finally, my concluding comments are presented in Chapter 6.

Chapter 2

BACKGROUND AND LITERATURE REVIEW

Color systems and color in the cartographic literature are reviewed in this chapter. First, a general discussion of color systems and the dimensions of color offers definitions that will help the reader to understand the color concepts used in this thesis. The specifics of Munsell color and printed color, the two systems used for this research, are then described. The discussion of color is followed by a review of the cartographic literature on color and color systems.

2.1
Color Systems

A general definition provided by Billmeyer (1984) is that a color system is an orderly arrangement of colors represented with examples. The quality of "orderly" is approached in three ways by Judd and Wyszecki (1975): colorant-mixture, color-mixture, and color-appearance systems. With colorant mixture, a limited number of pigments or dyes are combined. Colors are varied with

rotating-sector disks or a tristimulus colorimeter for color-mixture. For these two types of systems, colors are mixed in systematically varied proportions to provide examples of the range of colors, or color gamut, possible with these materials. Color-appearance systems are systematic collections of color examples organized according to the perception of color.

The basic ideas used in organizing a color-appearance system are to provide a uniform sampling of the psychological color space and to show by example the psychological attributes of color perception (Judd and Wyszecki 1975). The attributes, or dimensions, of color are the qualities used to that specify colors (Agoston 1979). Judd and Wyszecki define the psychological attributes of color as hue, lightness, and saturation (the terms used by other authors vary). Under ordinary viewing conditions, the psychological attributes correlate roughly with the psychophysical attributes: hue with dominant wavelength, lightness with luminous reflectance, and saturation with purity (Evans 1948, Judd and Wyszecki 1975).

Hue is difficult to define precisely though the concept is readily understood. Hue is often described as the color sensation that gives rise to color names such as red and green (Agoston 1979, Judd and Wyszecki

1975). The most appropriate geometric organization of hue for a color system is a circle (Judd and Wyszecki). The colors are arranged around the circle in the sequence of the colors in the visible spectrum (red, orange, yellow, green, and blue) with red and blue joined by the non-spectral purples.

The lightness dimension is also referred to as brightness. Judd and Wyszecki (1975) distinguish between these two terms, using brightness to refer to objects that are self-luminous and lightness for nonself-luminous objects. In general, this dimension refers to the amount of light that an object emits, reflects, or transmits. For objects that reflect light, lightness ranges from white to black. In most color systems, the neutral colors (from white, through grays, to black) are represented along a central, vertical axis (Wright 1984). The term "value" is used is used for the lightness dimension in the Munsell system.

Saturation is the most common term for the third perceptual dimension of color, but a many other terms with similar meanings are also used, such as chroma, chromatic content, chromaticity, colorfulness, vividness, and intensity (Robertson 1984). Generally, this dimension is used to describe the degree to which colors differ from neutral, or achromatic (Robertson). Saturation, when distinguished from chroma, is linked with lightness: as lightness increases, saturation also increases. Chroma, on the other hand, holds constant with changes in lightness. At one lightness level, chroma and saturation describe the same quality of color change. With increasing lightness, however, a series of colors with constant saturation will increase in chroma (Judd and Wyszecki 1975).

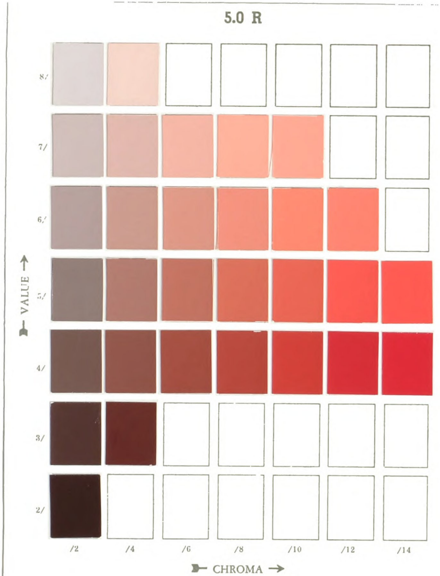
2.1.1

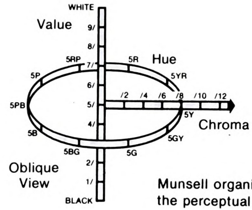
The Munsell Color System

Judd and Wyszecki (1975) describe the Munsell Book of Color (1976) as the most prominent example of a color-appearance system. The collections of Munsell color chips from the Macbeth Company offer different numbers of chips, different chip sizes, and a matte or glossy finish. Munsell notation has been incorporated into the Standards of the American National Standards Institute (ANSI) and the American Society for Testing and Materials (ASTM). Japanese color standards and standard paint designations of the British Standards Institute also use Munsell notations (Agoston 1979). The Munsell system is used to establish color standards and acceptable ranges of color deviation for many types of commercial products (Parker 1984) and to classify colors, as with the Munsell Soil Color Charts (1975).

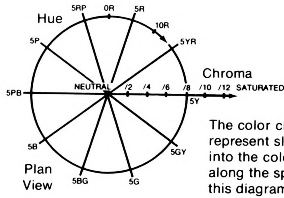
The Munsell system provides one model of color perception space. The dimensions of color used in the Munsell system are hue, value, and chroma. Under ordinary viewing conditions, Munsell Hue and Munsell Value correspond to hue and lightness, as defined previously in Section 2.1. Munsell Chroma corresponds to the perceptual dimension of chroma and is an approximate counterpart of perceived saturation. Munsell Chroma describes the difference between a color and a gray of the same value (Agoston 1979).

The organization of the hue, value, and chroma dimensions in the Munsell system is cylindrical (Figure 2.1) and steps between colors along each dimension are intended to be perceptually uniform when observed on a middle gray to white background. The value dimension forms the vertical, central core of the Munsell color solid with white at the top and black at the bottom. Horizontal slices through the Munsell solid pass through colors of intended equal value. Intended uniform perceptual steps in hue are arranged circularly, in equal angular sectors, around the value axis. Planes radiating from the central axis pass through colors of equal hue. Colors of intended equal chroma are located at equal distances from the value axis and chroma increases





Munsell organization of the perceptual dimensions



The color charts represent slices into the color solid along the spokes in this diagram.

◀ Example color chart from the Munsell *Student Set*

Figure 2.1 Organization of the Munsell Color System

as the distance from the center increases. A vertical cylinder passes through all equal-chroma colors.

The hue and value dimensions of the Munsell system are divided using a decimal system. The extremes in value are assigned the notations of zero for black and ten for white. The ten steps between black and white are associated with progressively lighter grays. The hue circle is divided into ten hue ranges and each range is divided into ten sections. Therefore, there are 100 hue radii altogether (Figure 2.2).

Each hue range is labelled with one or two letters: R (red), YR (red-yellow), Y (yellow), GY (green-yellow), G (green), BG (blue-green), B (blue), PB (purple-blue), P (purple), and RP (red-purple). The fifth radius within each designated hue (for example, 5 YR) is the "major hue" and is located in the middle of the hue range. In the Munsell Book of Color (1976) pages of color chips are provided for the 2.5, 5, 7.5, and 10 radii in each hue range and, thus, there are 40 hue pages in the two-volume set, which contains up to 1,550 chips. Alternatively, hue may be designated using 100-hue notation. Zero corresponds with 0 R, 10 to 10 R, 20 to 10 YR, 30 to 10 Y, and this correspondance continues until 100 coincides with 10 RP, which is the same as 0 R. If the 100 hue steps are divided

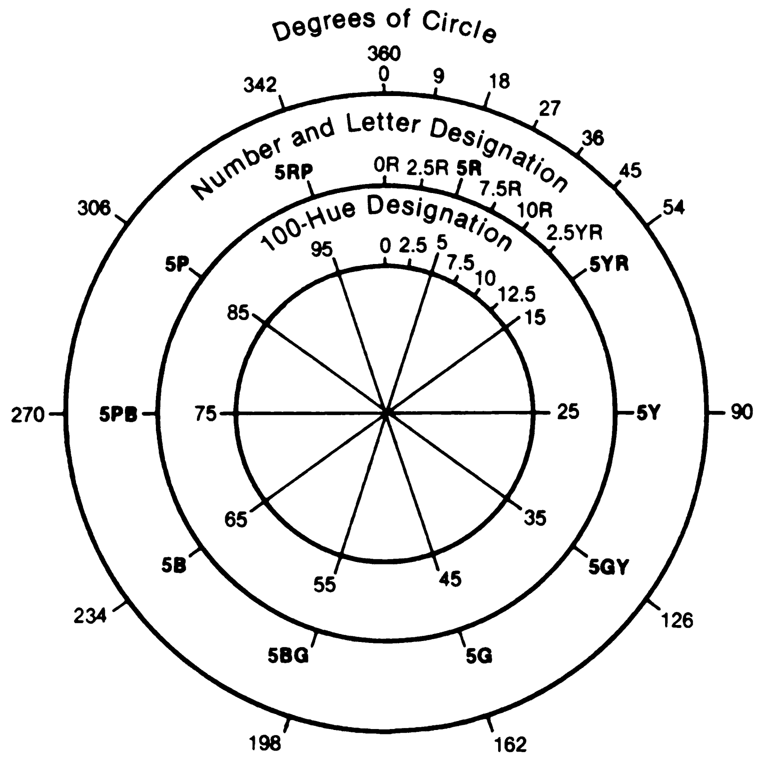


Figure 2.2 Relationships Between Three Methods of Designating Munsell Hue

into the 360 degrees of a circle, each step requires 3.6 degrees and the difference between the pages in the Munsell Book of Color is 9 degrees. The relationships between these methods of designating hue are displayed in Figure 2.2.

Chroma notations begin with zero at the neutral center of the Munsell color space and increase outward with steps of two between chips (0, 2, 4, 6, 8...). The maximum chroma at each hue and value combination is limited by the existence of pigments of acceptable permanency (Agoston 1979). Thus, the range of the Munsell chips has been periodically extended as new pigments become available (Bond and Nickerson 1942).

Because the maximum chromas attained in the chips vary with hue and value, the Munsell color solid has an irregular shape. For example, the color solid bulges in the high-value yellows and in the low-value purples (Figure 2.3). Therefore, the arrangements of chips on the hue pages in the Munsell Book of Color (1976) are different shapes.

A Munsell color notation lists the hue, value, and chroma of a color. The hue notation is given first followed by the value and chroma notations, which are separated by a slash. An example Munsell notation

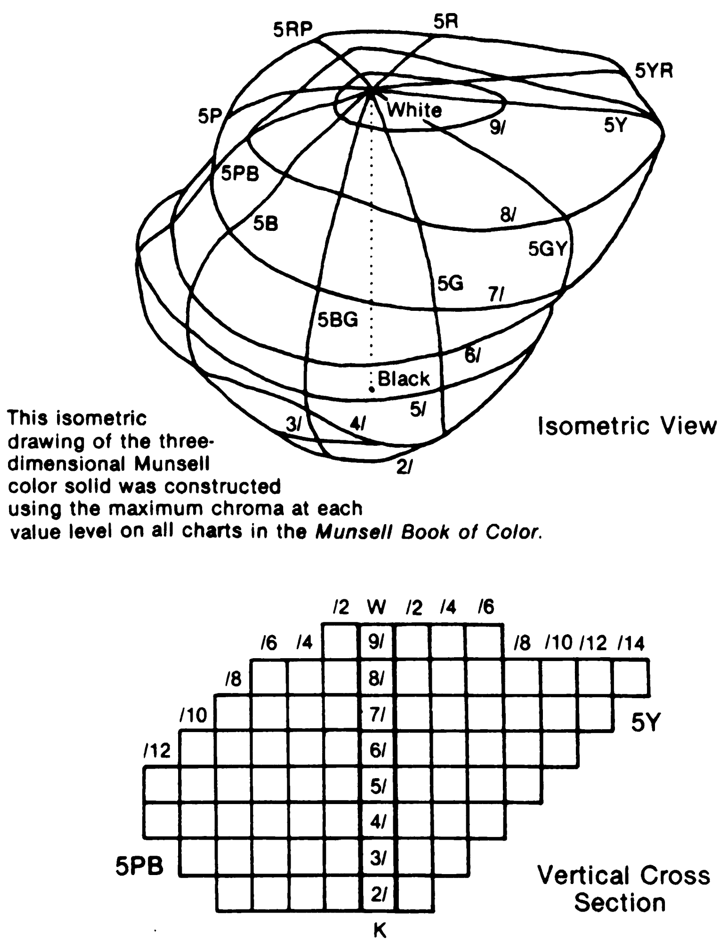


Figure 2.3 The Munsell Color Solid

for a mid-value, saturated red would be 5 R 5/12. Neutrals have no hue or chroma and thus have shortened forms, such as N 5/. This method of notation provides a concise description of the psychological attributes of a color.

As mentioned in the earlier definitions, the Munsell system is designed to show equal changes in color along each dimension. The steps of one Munsell dimension, however, are not equal to the steps in another. One value unit equals approximately 1.5 chroma units and 25 hue units at chroma 1/ or 3 hue units at chroma 5/ (Agoston 1979).

2.1.2
Printed Color Systems

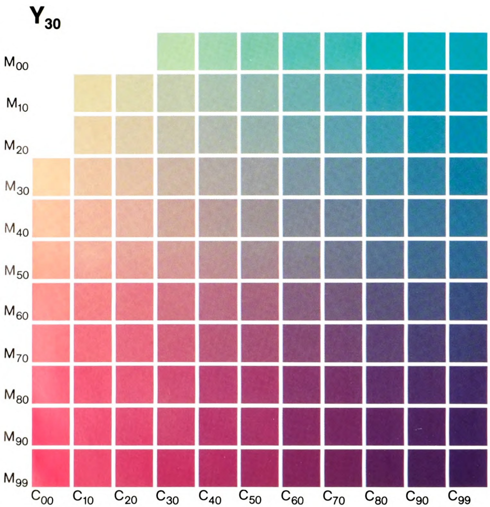
A colorant-mixture system can be constructed using systematic variations of the four process-color printing inks: screenings of yellow, magenta, cyan, and black. As the screened percentages of an ink increase from zero to 100, progressively greater amounts of the paper are covered with ink. The colors in this series range from the color of the paper to the color of the printed, solid ink. Process-color charts, which show examples that represent the color system, are produced by printing rows of the series from 0 to 100 percent of one ink with columns of this series in another ink. This approach is expanded by printing a series of charts with a constant percentage of one, or two, inks over each entire chart and varying the percent of those constant inks from chart to chart.

The entire gamut of hues is produced by the systematic variation of overprinted, screened percentages of the four process inks. Subtractive color mixture occurs where the small, screened dots of different ink are printed on top of each other. The resulting small patches of color are not resolved by the eye and also produce colors by perceptual color averaging (Agoston, 1979). Color averaging occurs with the small dots and pieces of dots in combinations of up to 9 colors: white (paper), each ink (yellow, magenta, cyan, and black), and the subtractive mixtures of the overprinted inks (yellow plus magenta, yellow plus cyan, magenta plus cyan, and yellow plus magenta plus cyan). The color of reflected light from combinations of the process colors, which result from averaging the above-mentioned colors, can be predicted using the Neugebauer equations (Kimerling 1980, 1981).

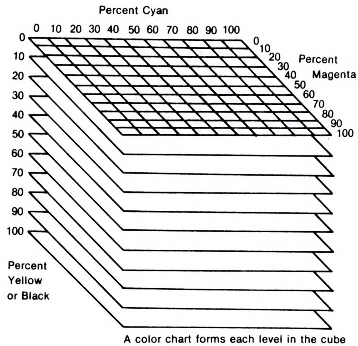
The Kueppers Color Atlas (1982) provides examples of process-color charts and represents a color system. There are four sets of color charts in the Atlas.

They show all combinations of ten percent increments of yellow, magenta, and black; yellow, cyan, and black; cyan, magenta, and black; and yellow, magenta, and cyan. Each set of three inks shown in all combinations can be represented as a cube (Figure 2.4). There are 121 colors on each chart, 11 charts in each set, 1,331 colors in each set, and, therefore, 5,324 colors in the four sets of charts in the Atlas. Thus, the systematic mixture of the four process inks produces 5,324 colors and a comprehensive catalog of the colors resulting from combining screens of these four inks.

The differences between pairs of adjacent colors on the Atlas charts are not perceptually uniform. Some neighboring colors look very similar. For example, differences of 80, 90, and 100 percent of an ink cause little change in color. In each set, the charts overprinted with 80, 90, and 100 percent black (or yellow, in the case of the yellow, magenta, and cyan combinations) differ little from each other. Conversely, the change in color with a change from zero to ten percent ink is perceptually large. Many colors in perceptual color space are not represented in these areas of the color charts.



◄ Example color chart from the Kueppers *Color Atlas*



▲ Organization of a Kueppers color cube

Figure 2.4 Organization of the Kueppers *Color Atlas*

2.2

The Cartographic Literature on Color

The background information presented up to this point deals specifically with color systems and is derived from the color literature. There is also a small amount of literature in cartography that deals with color in mapping.

A brief history of color research in cartography is provided by Robinson (1966). He explains that the period before World War I produced much research on the use of colors on maps, especially landform representation maps. Because color reproduction techniques became more complex after the war and because cartographers were not competent in these methods, the lithographers and engravers became responsible for color map reproduction. "While little if anything was done to further [color] research, a great deal that had been accomplished was forgotten, at least in American cartography" (p. 78).

The literature on color use in cartography, since Robinson's (1966) writing, has examined a variety of topics. A review and comparison of equal value gray scale research is provided by Kimerling (1985). Specific choropleth color schemes have been examined by Eyton (1984), Olson (1981, 1975), Wainer and Francoli (1980), and Cuff (1974a, 1973, 1972), and further studies of hypsometric colors have also been conducted (Phillips 1982, Patton and Crawford 1977).

The discussions of color that appear in the cartography texts (Dent 1985, Robinson and others 1984, Imhof 1982, Keates 1978) and summary articles (Cuff 1974b, Feeken 1972, Wood 1968, Robinson 1967, Keates 1962, Saunders 1961-2) present fairly similar series of topics with different degrees of completeness. Color is invariably introduced with a reminder of the complexity and uncertainty involved in using color on maps. The distinctions between physical, psychophysical, and psychological color dimensions are usually defined and a variety of color systems are usually described. Other topics presented by the authors include visual acuity and sensitivity, contrast and color interaction, advance and retreat of colors, individuality of hues, symbolic connotations and conventions, color preferences, and the concept of color harmony.

General guidelines for selecting map colors are provided in cartography textbooks. In the texts by Dent (1985) and Robinson and others (1984), the precision of hue descriptions in their guidelines is limited to basic hue names such as red, yellow, and brown. The authors advocate simple value progressions, explain

the use of the equal value gray scale, and include warnings about highly saturated colors. Unfortunately, these guidelines only address a portion of the color use problems faced by cartographers. Shellswell (1976) notes the lack of studies directed toward offering "basic, objective guidance to the cartographer for color specification" (p. 72). The actual process of choosing colors for a specific map is often based on subjective judgment and involves knowledge and skills that are quite complex.

2.2.1

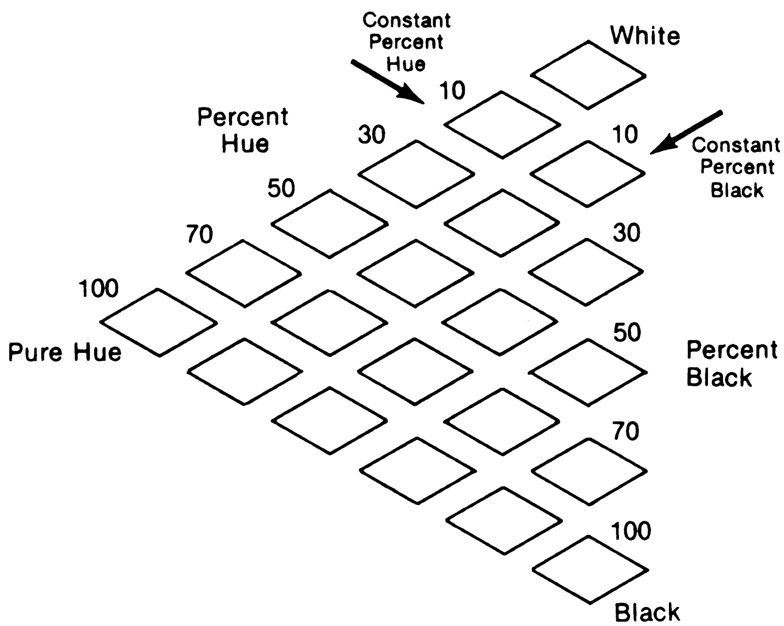
Color Systems in Cartography

In the cartographic literature, the most thorough treatments of color systems and color designation are found in the recent texts by Dent (1985) and Robinson and others (1984). The CIE coordinate system, Munsell system, and printed color system are described in the chapters on color in both texts. In addition, Dent describes the Ostwald system and ISCC-NBS color designations and Robinson and others describe the red-green-blue color cube. The specific problems of how to use the system or a comparison of their relative usefulness in cartography are rarely dealt with in the cartographic literature on color. The exceptions are articles by

Brown (1982), Kimerling (1981, 1980), Castner (1980), and Shellswell (1976).

Kimerling (1980, 1981) sifts through the color theory research and presents the pieces relevant to printing color maps. The culmination of his work is the description of the positions of process-color screen combinations in the CIE-xyY chromaticity diagram. The relationship between the CIE coordinate system and printed color is clearly represented with two- and three-dimensional diagrams.

Castner (1980) makes a number of suggestions about the qualities that a color chart should have to be useful to cartographers. He stresses the importance of the perceptual ordering of the dimensions of color (hue, value, and chroma). He also suggests that colors presented on a chart be "sufficiently far apart so that they will be distinctly different under all but the worst conditions of simultaneous contrast" (p. 374). These sufficient differences are also necessary to maintain distinctions between colors with printing variations. Castner recommends the design of a printed color chart with an Ostwald system arrangement (Figure 2.5).



Suggested color chart form for map design
(Castner 1980, p. 376)

Figure 2.5 Castner's Chart Based on the Ostwald Color System

Echoing Castner's (1980) views, Brown (1982) discusses the design of a color chart specifically for cartographers (the negatives for this chart are sold by ITC). He points out that color charts based on slices through the color cube (such as the 1982 Kueppers Color Atlas) are difficult to use when choosing map color schemes and that the perceptual dimensions of color play little part in the organization of those charts. The organization of the colors on the ITC chart is based on the Ostwald system and hue, value, and chroma are arranged in a usable, orderly manner.

2.2.2 Perceptually Uniform Color Systems in Cartography

Cartographers' interest in uniform perceptual steps in a color system is shown by the extensive research on: equal value gray scales (Kimerling 1985); Shellswell's (1976) extension of this idea to hues; and the use of perceptually equal screen increments by the DMA (Stoessel 1980). The Munsell color system discussed in Section 2.1.1, as well as the OSA Uniform Color Scales (MacAdam 1974) and the CIE-L*u*v* coordinate system (Hunt 1975), are examples of perceptually uniform systems (none have been converted to process printing specifications).

Shellswell (1976) recommends sizes for easily discerned color difference steps of red, cyan, yellow, and magenta using the CIE-L*u*v* coordinate system. His small sample of colors limits the practical usefulness of the results, but his approach is very relevant to cartographic color choice problems. He suggests the practical tool of screen percentages of individual colors that produce perceptually equal spacings of cartographic usefulness, meaning that color differences are large enough to withstand simultaneous contrast effects and variations in printing.

Because many cartographers are limited to five and ten percent screen increments for printing, it is difficult for them to print colors with the degree of precision required to attain uniformly spaced colors. In addition to this limitation, Castner (1980) warns that any printing process "will be plagued by the problem of quality control" (p. 371). Similarly, Monmonier (1980) discusses the hopelessness of pursuing uniformly scaled grays because printing is a significant source of error along with perceptual variability among map viewers. On the other hand, the ability of advanced technology (such as the computer-driven, scanning laser platemaker developed for the U.S. Defense Mapping Agency (Kimerling 1980)) to produce precise screens of any density indicates that cartographers may be able to better approximate a uniformly-scaled color system.

Even without the ability to reproduce colors precisely, the general concept of equal perceptual steps is useful when designing effective progressions of color for maps. Equal differences between colors in a choropleth progression are particularly appropriate. Shellswell (1976) states that "any facility to measure perceptual color difference will supplement knowledge of the mechanisms by which color operates to achieve map clarity" (p. 77).

2.3

Choosing Between Ostwald and Munsell

Munsell and printed color are the systems used in this research. The first part of this chapter provided descriptions of these two color order systems. The cartographic literature on color and specifically on color systems was then reviewed. In this review, two primary articles by Castner (1980) and Brown (1982) present work with the Ostwald color system. Therefore, I will elaborate on why I chose to approximate the Munsell charts with process printing rather than working with the Ostwald system.

The Munsell and Ostwald systems are compared by Bond and Nickerson (1942). Briefly, the Ostwald solid is shaped as two cones base to base which gives each hue chart an identical triangular form. The pure hues are located on the outer apex with neutrals from white to black along the central edge of each triangular chart. Thus, all colors on a horizontal slice through the solid do not have constant value because the pure hues have inherently different values. Yellow, for example, has a much higher value than purple and they both appear at the same level. The regular structure of the system requires an equal number of steps between white and yellow as between white and purple. These are not visually equal steps since white is much more similar to yellow than to purple.

In comparison to Munsell, the Ostwald system is easier to adapt to process printing because of the regularity of its format. However, all three of the perceptual dimensions of color would be systematically arranged on printed Munsell charts whereas the Ostwald system does not present colors of constant value across horizontal slices. The Ostwald system also does not have perceptually equal spacing between colors. The relationships among the three dimensions and equal visual differences between colors are important in map color selection. For these reasons, I have chosen to work with the Munsell system.

Chapter 3

COLOR MATCHING USING COLOR MEASUREMENT METHODS, RESULTS, AND DISCUSSIONS

3.1

Introduction

The primary focus of this research is to determine the percentages of the process inks needed to print color charts approximating the Munsell color system. There are two main stages in developing these color charts:

1) computerized color matching based on spectrophotometric readings
2) systematizing and visually refining the matches

This chapter presents methods, results, and discussion for the first stage. Chapter 4 presents the second stage in which the final printing specifications are developed for the Munsell approximations.

Alternatives to my approach to matching the Munsell chips with process colors would have been visual comparison (from the beginning) or the use of equations. Visually matching the 238 colors in the Munsell Student Set (1984) would be a tedious task and the quality of the matches would be affected by human error and inconsistency. The second approach requires the conversion from Munsell to CIE-xyY notation with the software available from Davidson Colleagues or the ASTM (1980) tables. The CIE coordinates would then be converted to percentages of process inks using the inverted Neugebauer equations (Pobboravsky and Pearson 1972). This two stage conversion was not used in part because Dr. Pobboravsky expressed a lack of confidence in the mathematical approach during a telephone conversation (1984). He felt that my proposed combination of color measurements, interpolation, and visual matching was an equally accurate, if not superior, method of converting between Munsell and process colors.

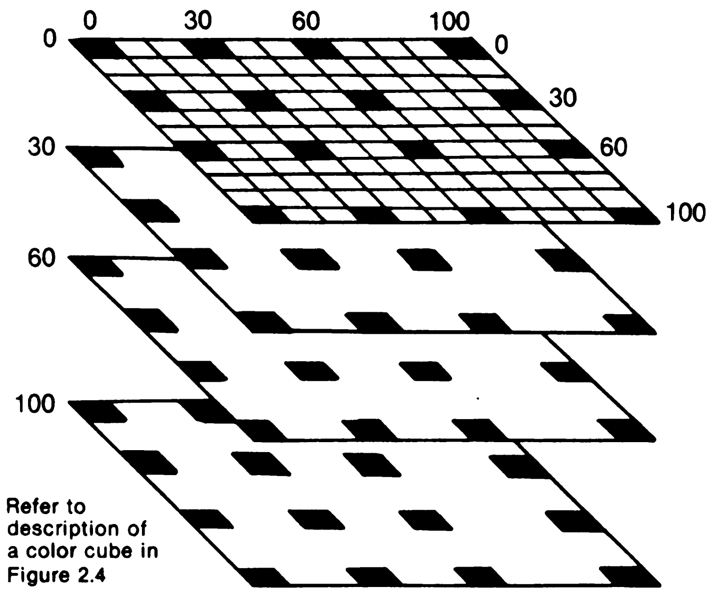
3.2
Method

3.2.1
Measurements

The Kueppers Color Atlas (1982) was used as a physical example of printed colors and is described in Section 2.1.2. This collection of color charts was used because it is commercially available and relatively inexpensive ($10.95 in 1984). The Atlas contains four sets of color charts that show all combinations of ten percent increments of: yellow, magenta, and black (YMK); yellow, cyan, and black (YCK); magenta, cyan, and black (MCK); and yellow, magenta, and cyan (YMC).

There are 5,324 colors in these four sets of charts, which would take over 90 hours to measure with the spectrophotometer. I did not have access to the equipment for this length of time and, therefore, a sample of colors was measured from the Atlas charts. Measurements were made from colors printed with combinations of 0, 30, 60, and 100 percent screenings of the process-colors. A regular sampling (Figure 3.1) was used to facilitate the linear interpolation of notations for the remaining colors on the charts, as discussed in the next section.

The instrument used for the measurements was a Macbeth Color-Eye Spectrophotometer connected to a microcomputer. Software by Davidson Colleagues used the measurements from the spectrophotometer to calculate the CIE-xyY coordinates for each measured color. The software then used the xyY coordinates in a "table lookup" procedure that converted them to Munsell notations. Thus, the final result of the measurement of a color with the spectrophotometer was the Munsell notation



Measurements provided Munsell notations for all colors in the Kueppers *Color Atlas* that are printed with combinations of 0, 30, 60, and 100 percent of the process inks.

Figure 3.1 Sample of Colors Measured from Each *Atlas* Color Cube

for that color. Example output from these measurements is provided in Table 3.1. A test of the accuracy of these measurements is presented in Appendix A.

3.2.2
Interpolations

After measuring the Munsell notations for the regular sampling of colors from the charts in the Kueppers Atlas, the next step was to interpolate the Munsell notations for the remaining colors in the Atlas. The Munsell notations of the colors change gradually across the Atlas charts and, conversely, the grid relationships between the colors on an Atlas chart are retained (in a distorted form) when the colors are plotted in the Munsell color space (Figure 3.2). This consistency across and between charts should allow interpolation to predict the Munsell notations for the Atlas colors positioned between the measured colors.

Simple linear interpolation was used to calculate the remaining notations. Before the calculations were made, two mathematical transformations of the data were performed to simplify the mathematics of the interpolations. Hue was converted to degrees and a conversion from cylindrical to rectangular coordinates was performed.

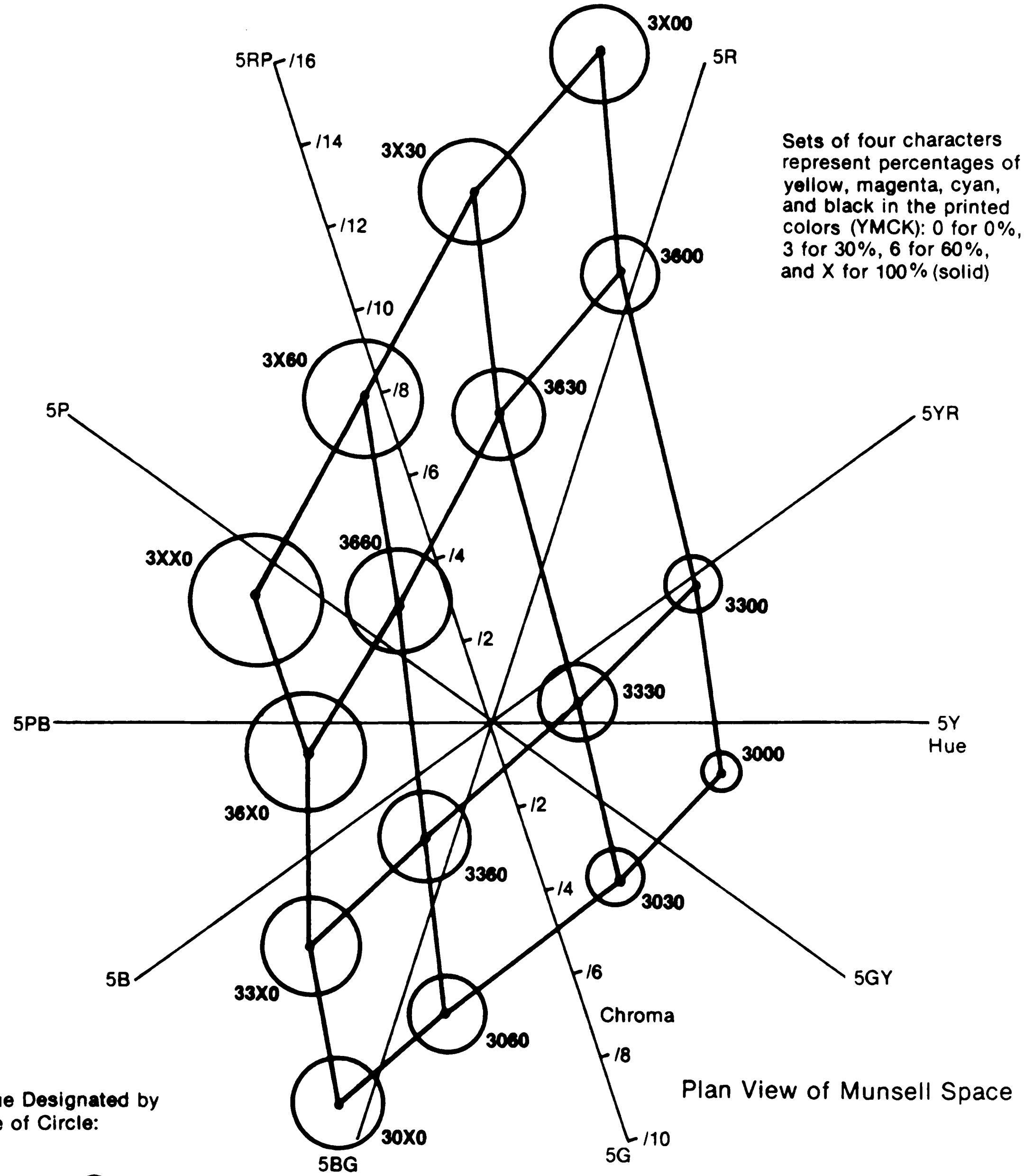
Table 3.1 Example Output from the Spectrophotometer and Davidson Software

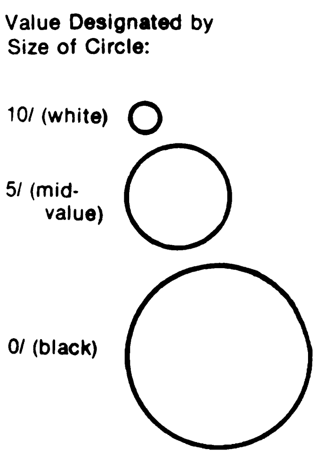
This table lists the notations for the sample of colors measured on the Atlas page that shows magenta and cyan combinations overprinted with 30 percent yellow. The YMCK specifications list the percentages of yellow, magenta, cyan, and black process inks in the Atlas colors. A '0' represents 0 percent, '3' is 30 percent, '6' is 60 percent, and 'X' is 100 percent.

Process Notation:	CIE Notation:			Munsell Notation:		
YMCK	x	y	Y	Hue	Value	/ Chroma
3000	0.3726	0.4047	81.33	8.40 Y	9.13	/ 5.40
3300	0.3961	0.3666	52.95	5.51 YR	7.64	/ 5.59
3600	0.4593	0.3205	28.22	4.36 R	5.84	/ 10.82
3X00	0.5364	0.2833	16.51	2.41 R	4.62	/ 15.66
3030	0.3203	0.3845	53.56	9.05 GY	7.68	/ 4.46
3330	0.3458	0.3483	34.58	0.96 Y	6.38	/ 1.95
3630	0.4052	0.3008	17.84	0.39 R	4.78	/ 7.15
3X30	0.4805	0.2625	10.57	9.46 RP	3.78	/ 12.24
3060	0.2478	0.3468	32.83	2.54 BG	6.24	/ 6.73
3360	0.2713	0.3155	22.37	7.69 BG	5.28	/ 2.84
3660	0.3188	0.2728	12.03	9.78 P	4.01	/ 3.57
3X60	0.3824	0.2338	6.54	4.18 RP	3.00	/ 8.04
30X0	0.1939	0.3190	21.57	6.23 BG	5.20	/ 9.32
33X0	0.2054	0.2822	14.74	0.87 B	4.40	/ 6.53
36X0	0.2320	0.2431	7.74	2.23 PB	3.26	/ 4.27
3XX0	0.2677	0.1952	3.86	2.67 P	2.27	/ 6.16

The details of the instrument settings are necessary for repeating the measurements but their explanation would require more technical color theory than is appropriate for this thesis. The spectrophotometer was a 45-0 geometry machine used with "DOEON status". This code signifies that tile calibration was used, reflectance measurements were made, specular reflectance was excluded, and the ultraviolet component was excluded. The calculations were made using illuminant C (daylight) and the 2 degree observer.

The CIE to Munsell conversion software is available from Davidson Colleagues, P.O. Box 157, Tatamy, PA 18085 (1984).





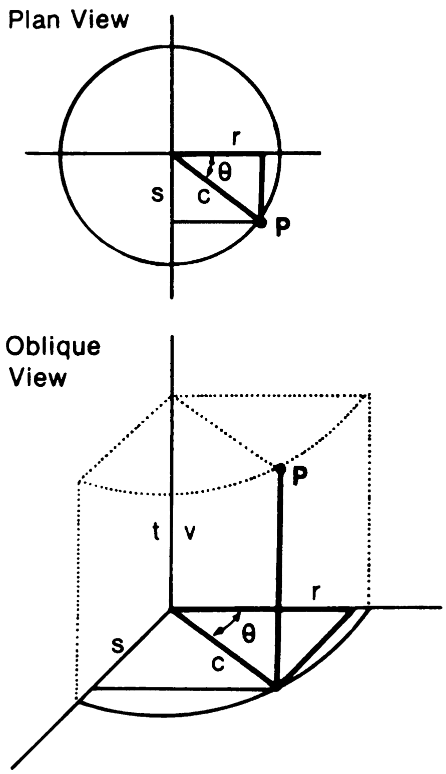
Munsell locations of the 16 colors measured from the Kueppers *Color Atlas* chart of magenta and cyan combinations with 30 percent yellow in all colors.

Figure 3.2 Measured *Atlas* Colors Plotted in Munsell Space

The Munsell hue notations were changed from letter and number designations to degrees around the circle. For example, 5 YR equals 54 degrees. Zero degrees lies at 0 R and there are 100 hue steps around the 360 degree hue circle, which makes one hue step equal to 3.6 degrees (Figure 2.2).

The cylindrical hue, value, and chroma coordinates of the measured Munsell notations were temporarily transformed into rectangular coordinates to make the linear interpolation straightforward. This was not a conversion to another color solid: a rectangular, three-dimensional grid was simply superimposed on the Munsell solid and each color was renamed with rectangular coordinates, arbitrarily labeled r, s, and t. After the interpolations were completed, the rectangular coordinates were converted back into cylindrical Munsell coordinates for use in the next stage of the analysis. The transformation formulae are explained in Figure 3.3.

Interpolations of the Munsell notations for all of the colors in the Atlas were made in three passes through each set of charts, or each color cube. The result of each pass is explained in Figure 3.4. The following formulae were used to interpolate the coordinates for the Atlas colors between every two Atlas colors



Point **P** has the coordinates θ v/c, for Hue (in degrees) Value / Chroma, in the Munsell system and (r,s,t) in a rectangular coordinate system superimposed on Munsell color space.

The relationships between the rectangular and cylindrical coordinate systems are:

$\theta = \text{ARC TAN } s/r$ (TAN $\theta = s/r$)

$c = \sqrt{s^2 + r^2}$ (Pythagorean Theorem)

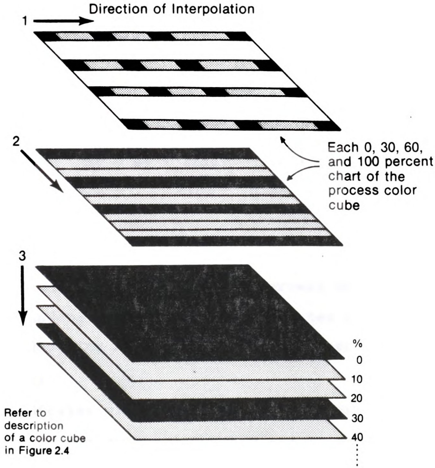
$v = t$

$r = c(\text{COS } \theta)$ (COS $\theta = r/c$)

$s = c(\text{SIN } \theta)$ (SIN $\theta = s/c$)

$t = v$

Figure 3.3 Conversion Between Munsell and Rectangular Coordinate Systems



Interpolations are used to generate Munsell notations for all colors in the Kueppers *Color Atlas.*

Black areas represent colors with known notations. Screened areas are those notations interpolated during pass.

Figure 3.4 Results of Three Interpolation Passes Through *Atlas* Color Cubes for which coordinates had been measured or calculated (in the second and third passes of the interpolation). For differences of 0 to 30 and 30 to 60 percent between colors with known coordinates:

$dr = (r_3 - r_6)/3$	$ds = (s_3 - s_6)/3$	$dt = (t_3 - t_6)/3$
$r_4 = r_3 + dr$	$s_4 = s_3 + ds$	$t_4 = t_3 + dt$
$r_5 = r_3 + 2(dr)$	$s_5 = s_3 + 2(ds)$	$t_5 = t_3 + 2(dt)$

Where:

r_3, s_3, and t_3 are the r, s, and t known coordinates of an Atlas color (e.g. 30 percent cyan)

r_6, s_6, and t_6 are the known coordinates of a neighboring Atlas color (e.g. 60 percent cyan)

the coordinates with subscripts 4 and 5 are those of the two colors between 3 and 6 (e.g. 40 and 50 percent cyan)

dr, ds, and dt are the r, s, and t differences between each color in this sequence of four colors (e.g. differences between 30 and 40, 40 and 50, and 50 and 60 percent cyan)

When a difference of 60 to 100 percent exists between colors, the above formulae are changed to accommodate the extra step between the two colors with known coordinates. The difference between coordinates is divided by four instead of three and a third addition step is added. Example interpolated notations are provided in Table 3.2 and a test of the accuracy of the interpolation is presented in Appendix A.

3.2.3

Matching

The measurement of the sample of colors in the Kueppers Color Atlas (1982) and the subsequent interpolations led to a Munsell notation for every color in the Atlas. This list of 5,324 Munsell notations was then repeatedly searched for the printed colors closest to each of the 238 chips on the charts in the Munsell Student Set (1984).

The Student Set (1984) was used because it provides a sample of ten hue charts, is commercially available, and is inexpensive ($16.75 in 1984). In comparison, the much larger Munsell Book of Color (1976), with its more detailed sampling of color space, costs over $500 (1984). The price of the larger book may make it inaccessible to cartographers interested in the Munsell color system and the results of this study. It also seemed logical to attempt an approximation of the more manageable student charts before the larger volumes. The potential usefulness of the Munsell system

Table 3.2 Example Interpolation Results

This table lists the interpolated notations for all of the colors from part of the Atlas chart that shows combinations of magenta and cyan with 30 percent yellow overprinted. The same chart was used as an example in Table 3.1 and Figure 3.2. Yellow is constant at 30 percent in each color. Magenta ranges from 0 to 30 percent and cyan ranges from 0 to 100 percent. The measured colors on which the interpolated notations are based are underlined.

Process Color Specifications for the Atlas Colors:

YMCK			
3000	3100	3200	3300
3010	3110	3210	3310
3020	3120	3220	3320
3030	3130	3230	3330
3040	3140	3240	3340
3050	3150	3250	3350
3060	3160	3260	3360
3070	3170	3270	3370
3080	3180	3280	3380
3090	3190	3290	3390
30X0	31X0	32X0	33X0

Munsell Notations for the Atlas Colors:

Hue Value/Chroma			
8.40 Y 9.13 / 5.40	4.11 Y 8.63 / 5.07	9.59 YR 8.14 / 5.14	5.51 YR 7.64 / 5.59
1.44 GY 8.65 / 4.85	6.96 Y 8.17 / 4.24	1.57 Y 7.70 / 4.06	6.31 YR 7.22 / 4.34
5.08 GY 8.16 / 4.53	0.98 GY 7.71 / 3.62	4.89 Y 7.25 / 3.08	7.75 YR 6.80 / 3.12
9.05 GY 7.68 / 4.46	6.19 GY 7.25 / 3.30	0.69 GY 6.81 / 2.35	0.96 Y 6.38 / 1.95
4.79 G 7.20 / 4.76	3.85 G 6.80 / 3.43	1.73 G 6.41 / 2.13	3.89 GY 6.01 / 0.97
9.34 G 6.72 / 5.58	9.73 G 6.36 / 4.22	0.50 BG 6.00 / 2.87	2.61 BG 5.65 / 1.53
2.54 BG 6.24 / 6.73	3.43 BG 5.92 / 5.39	4.89 BG 5.60 / 4.08	7.69 BG 5.28 / 2.84
3.70 BG 5.98 / 7.33	4.78 BG 5.67 / 6.08	6.41 BG 5.37 / 4.87	9.07 BG 5.06 / 3.74
4.68 BG 5.72 / 7.97	5.86 BG 5.43 / 6.81	7.50 BG 5.13 / 5.69	9.91 BG 4.84 / 4.67
5.52 BG 5.46 / 8.64	6.72 BG 5.18 / 7.55	8.31 BG 4.90 / 6.53	0.47 B 4.62 / 5.60
6.23 BG 5.20 / 9.32	7.43 BG 4.93 / 8.32	8.94 BG 4.67 / 7.38	0.87 B 4.40 / 6.53

to cartographers lies in the way it is organized, and this is clearly reflected in the student charts.

Two criteria were used to evaluate the similarity between the Munsell notation of an Atlas color and a student set color. The first criterion was that the notation of the Atlas color had to be closer to the Munsell notation that was being matched than any other Munsell chip notation (within 1.25 hue steps, 0.5 value step, and 1.0 chroma step). Then, all the Atlas color notations that met this criterion were compared to the Munsell chip notation using the Godlove equation (Appendix A). The Atlas color and Munsell chip with the smallest Godlove difference were considered (tentatively) to be the best match. Some Munsell colors, however, were not matched with Atlas colors because the first criterion could not be met.

Each Munsell chip from the Munsell Student Set (1984) was matched with two colors from the Kueppers Color Atlas (1982). One color was from the yellow, magenta, and cyan set of charts in the Atlas, and I will refer to these as "YMC matches." The other color was from the three sets of charts that include black ink (YMK, YCK, and MCK), and I will refer to these as "black matches."

The two separate sets of matches were selected because using combinations of YMC matches and black matches on one Munsell chart would require extremely precise printing to retain the correct color relationships in progressions of color (if it could be maintained at all). In addition, the interpolations of the Munsell notations for the Atlas colors were not sufficiently accurate to establish whether the YMC or black match was better.

The selection of only two matches from a number of close colors was an arbitrary decision. However, it would not be advantageous to try to allow for the level of inaccuracy in the interpolations when performing the matches. In addition, consideration of colors more than one half notation away might capture accurate matches that are inaccurately labeled, but it would also cause many even poorer matches to be considered. If all colors within one half notation of the Munsell chip notations or all colors within a set Godlove distance are chosen, many matches occur for many colors. For many low-value colors, as an example, about ten colors are within one half Munsell chip and up to 50 or 60 colors are within three Godlove units. If this many matches were accepted for these colors the purpose of using the computer to perform the matching would be defeated. If one must sift through 60 colors for a match, visual matching may as well have been used in the first place.

3.3

Results and Discussion

The computer matches of process colors to the chips in the Munsell Student Set (1984) are presented in Appendix B. Both the YMC and black matches are shown. At the start of the project I had naively expected that the computer matches would be reasonably accurate and systematic and that they would be the final step in finding the printed approximations of Munsell colors. The level of accuracy of the interpolated notations (Appendix A) indicated that these computer matches would not be perfect and they definitely were not. Many colors were not assigned matches with the selected matching criteria and some colors were obviously poorly matched. In addition, these matched colors may be the best mathematical matches with individual Munsell chips, but the collections of colors for each chart only roughly represent the systematic perceptual organization of a Munsell chart as a whole.

3.3.1

The Matches

The inequality of the steps between colors can be seen by examining the percentages of the process inks for the matched colors listed in Appendix B, even without printed examples of the computer matches. For example, in the chroma /6 column of 5 YR, the progression of YMC matches is 3300, 5410, 5420, X640, and - (no match). The change in color between 3300 and 5410 is 20 percent yellow, 10 percent magenta, and 10 percent cyan. In comparison, the change between 5410 and 5420 is only 10 percent cyan and is visually smaller. The next step to X640 is a larger change of 50 percent yellow, 40 percent magenta, and 20 percent cyan. Similarly, the changes between the black matches in the chroma /6 column of 5 PB (0260, 0261, 0352, 0463, and 0595) are limited to 10 percent differences in the inks until the last color which makes a jump of 10 percent magenta, 30 percent cyan and 20 percent black. This also creates a shift in hue toward cyan. The colors in both these /6 columns increase in value downward, but the increase occurs unevenly rather than in a smooth progression of equal steps.

The rough progressions of colors can be seen along the rows as well. For example, in the value 5/ row of 5 R (Appendix B) part of the sequence of matched colors is 3505, 4703, 4702, 5901, and 5900. Yellow and magenta increase and black decreases as chroma increases. These changes cause the colors to increase in chroma but there is a jump in the percentages of three inks between 3505 and 4703, and then there is only a change of 10 percent black between 4703 and 4702. All three inks change again in percentage between 4702 and 5901 and there is another change of only ten percent black between 5901 and 5900. This row is another example of an uneven progression of color in the matches.

The hues of some of the matched colors are incorrect, especially in the low chroma colors where an interpolation error can result in a shift to an entirely different hue. An example of this occurs in the chroma /2 column of 5 G (Appendix B) where the sequence of colors is 1205, 3045, 1009, 3058, and 4079. This progression of ink combinations is jumbled and it is not likely that the specification for even a very desaturated green should be 10 percent yellow, 20 percent magenta, and 50 percent black. Likewise, 5 Y 8/2 is matched with 2401 which contains too much magenta for a desaturated yellow. Similarly, the values and chromas of some colors are poorly matched.

These examples of inconsistent changes between successions of matched colors and incorrect color matches demonstrate the rough nature of the color matches. On the other hand, some of the color sequences are very even and many of the color matches are very close. The color changes on the 5 RP chart (Appendix B) are smooth and the matches are consistently good.

3.3.2

The Missing Matches

Examination of the missing color matches shows that matching the Munsell chips with process colors containing black was more successful than matching with the YMC colors. Twenty-four percent of the chips in the Munsell Student Set (1984) were not assigned black matches whereas 42 percent were not matched with YMC colors. This is partly because there are three times as many Atlas colors that include black (3,993) compared to the one set of 1,331 YMC colors. In addition, the use of black allows many more Atlas colors to be matched with the near-neutral Munsell colors. This is particularly important because there are more chips in the near-neutral region of the Munsell color solid than in the high chroma areas. The colors on the YMC charts are combinations of percentages of three saturated color inks and most of the colors have a definite hue.

Combinations of near equal proportions of the three inks should theoretically be neutral but they print as browns and purples in the Color Atlas (Kueppers 1982). This lack of neutrals results because the process inks are not pure subtractive primaries and because a correct color balance was not maintained during printing.

The proportion of the Munsell chips without matches varies from chart to chart. The number of matches missing on each chart and the number of missing matches as a percentage of the total number of chips on each chart are presented in Table 3.3. On the 5 Y and 5 RP charts, all of the chips have black matches. Except for 5 B and 5 BG, the percentage of the chart that is not matched is lower for the black matches than for the YMC matches.

The blue chart was particularly hard to match, with 75 percent of the black matches and 65 percent of the YMC matches missing. I do not know why the computer matching was so drastically unsuccessful for this chart, although matching blue Munsell chips visually with process blue is also difficult. It seems that the hue of process blue is different enough from Munsell blue that screening it or desaturating it does not produce colors with notations that are near enough to 5 B notations and adding 10 percent yellow shifts the hue too far from 5 B to produce good matches.

Table 3.3 <u>Distribution of Missing Color Matches</u>

	Matches Containing Black		YMC Matches	
Munsell Chart	Number Missing	Percent of Chart	Number Missing	Percent of Chart
5 R	7	23	10	33
5 YR	6	25	12	50
5 Y	0	0	10	48
5 GY	3	15	8	40
5 G	5	23	9	41
5 BG	10	50	6	30
5 B	15	75	13	65
5 PB	5	19	15	56
5 P	5	19	8	31
5 RP	0	0	10	36

Most of the colors without an assigned match are low-chroma or high-value colors. Table 3.4 shows the percentages of the total number of missing matches that fall into these categories separately and combined. Ninety-one percent of the missing black matches and eighty percent of the YMC matches fall into one or both of these two categories.

There are many missing high-value matches because there are not many high-value colors in the Atlas.

The jump from 0 to 10 percent in each ink is visually quite large and any combinations of this smallest percentage of ink further decrease the value of a color.

There are many missing low-chroma colors because of the way the matching criterion of one half chip notation couples with the cylindrical construction of the Munsell system. Near the neutral core of the Munsell system, the colors separated by a few degrees still look fairly similar. These reasonably good visual matches are rejected by the matching criterion of being within one half notation, which is a much smaller distance than one half notation at high chroma (Appendix A). It was, however, not acceptable to relax this criterion because more incorrect hues would become matches as well.

The problem of many missing color matches, compounded by inaccuracy and unevenness in the matches, lead me to refine the color measurement and interpolation results. Through this refinement process, discussed in the next chapter, I arrived at the final printed-color matches for the Munsell charts.

Table 3.4 Locations of Missing Color Matches

Region of Munsell Charts	Number of Munsell Chips Occurring in Region	Number of Missing Matches in Region	Percent of Occurrences Missing	Percent of Total Missing Matches
	Matches Containing Black (Total Missing Matches: 56)			
High Value OR Low Chroma	161	51	32 % (51/161)	91 % (51/56)
High Value (7/ or 8/)	74	31	42	55
Low Chroma (/2 or /3)	127	41	32	73
High Value AND Low Chroma	40	21	53	38
	YMC Matches (Total Missing Matches: 101)			
High Value OR Low Chroma	161	81	50	80
High Value (7/ or 8/)	74	38	51	38
Low Chroma (/2 or /3)	127	71	56	70
High Value AND Low Chroma	40	28	70	28

The region of "High Value OR Low Chroma" comprises all notations that include 7/, 8/, /2, or /3.

The region of "High Value AND Low Chroma" comprises all notations that include 7/2, 8/2, 7/3, or 8/3.

Chapter 4

REFINEMENT OF THE COLOR MATCHES

METHODS, RESULTS, AND DISCUSSION

4.1

Introduction

This chapter presents the second stage in the development of the process-color approximations of the Munsell charts. The specifications derived in the previous chapter are used as a starting point from which final matches are determined by systematizing the progressions of percentages across the charts and performing visual adjustments. These refinements were made using cut-out Kueppers Atlas colors initially and were reworked using Color Key proofs. These final matches were printed at Michigan State University (with other process-color maps for the Department of Geography).

The refinements were performed with only colors from the three sets of charts that include black. The black matches (Appendix B) produced by the computer matching were used as guidance for constructing systematic progressions of percentages that represent the Munsell charts as wholes. I did not ignore matching individual chip colors when considering the charts as wholes, but now emphasized the construction of smooth progressions of value and chroma within a given chart and approximating correct visual hue over whole charts.

In addition to using only colors from the charts that include black, I worked with the same three inks on any one chart. This is a logical restriction for two reasons. Purples (5 P), for example, are matched with only colors from the MCK charts because colors from the YMK or YCK charts should contain no purples. Secondly, even if a given color from one of the omitted Atlas charts was a close match to an individual chip, it would look out of place relative to the Munsell chart as a whole. For 5 Y, which could be matched with small amounts of cyan in some yellows, only YMK colors were used because additions of cyan to some yellows and magenta to others would cause disturbing shifts in hue with variability in printing. The black matches from the computerized matching in the previous chapter generally keep to one set of three inks for each chart with only a few deviations to matches from another set (Appendix B). The three process inks used to match each Munsell chart are: YMK for 5 R, 5 YR, and 5 Y; YCK for 5 GY, 5 G, 5 BG, and 5 B; and MCK for 5 PB, 5 P, and 5 RP.

4.1.1

Rationale for Continuing with Only Black Matches

The matching was continued with colors from only the charts that include black for three reasons.

1) Fewer missing matches:

The number of YMC matches missing (42 percent) was almost twice the number of missing black matches (24 percent). The more complete black matches provided more information with which to begin filling out and refining the process-color Munsell charts.

2) More colors available:

There were more colors to choose from in the three sets of charts that include black than in the YMC set (3,993 compared to 1,331 colors). With a greater choice of colors, good color matches are more likely to be found.

3) Maintaining color balance:

Color balance is easier to maintain when colors are desaturated with black rather than with the third primary, as in the YMC charts (Bruno 1985). For example, a dark orange (or brown) can be created by desaturating a combination of yellow and magenta with black or cyan. If cyan is used and it is overinked during printing, the orange will shift to greenish, bluish or purplish. This will also occur if either the magenta or yellow, or both, are underinked. If black is used to desaturate the orange and the black is overinked, the orange will become darker but will still be orange. Similarly, underinking magenta and yellow will create a more neutral color but it will still be orange.

The hues of desaturated colors are the most vulnerable to changes in color balance (Bruno 1985). The Munsell charts include many desaturated colors and, therefore, the durability of the color balance is a particularly important consideration. A color scheme chosen from the black matches and then reproduced with poorly controlled printing will not match the Munsell chart colors, but hues will be roughly the same and progressions of change in value and chroma will be retained.

4.1.2

Preliminary Systematizing and Visual Adjustment

By using the "computer matches" from Chapter 3 as a starting point, I improved the matches between the process and Munsell colors. The irregular progressions in the ink percentages were made systematic in all directions. For example, the value 5/ row of 5 R produced by the computer matching is 0236, -, 3505, 4703, 4702, 5901, and 5900 (Appendix B). Note that generally yellow and magenta increase, cyan appears only in the first, and black decreases as chroma increases. A systematization of the progressions of ink percentages would yield 0306, 1405, 2504, 3603, 4702, 5801, and 6900. The yellow and magenta increase by 10 percent increments, there is no cyan, and black decreases by 10 percent increments.

I then cut out the colors for these new systematic progressions from a Kueppers Color Atlas (1982) and arranged them as the Munsell chart colors are arranged. The next step was to compare the Atlas colors to the original Munsell colors using my visual judgement. Differences between the Atlas colors and Munsell colors

were noted, the Atlas was checked for process colors that were better visual matches, and a new set of systematically changing percentages was designed. This was an iterative process that was repeated until I reached the most visually accurate compromise I could find between matching individual colors and reproducing the chart as a whole with smoothed changes in color in all directions.

Constructing the charts of cut-out Atlas colors was an enlightening process. The irregularities in the printing of the Atlas became readily apparent as colors from different pages were placed together in the Munsell arrangements. For example, the yellow was underinked on the 10 percent black page in the YMK set. This caused a diagonal strip across the systematic matches to be inconsistent with the visual progression of colors across the chart. Thus, the charts composed of cut-out colors looked generally correct, but the progressions of colors across rows, columns, and diagonals were slightly irregular. These charts of systematic matches would not make a very convincing demonstration of printed Munsell charts, but one would not construct conventional printed charts in such a fashion either.

4.1.3

Printing the Charts

Before printing the charts, I went through the process of rethinking the matched specifications once again. Small irregularities had been incorporated in the progressions of percentages to improve the visual match between the cut-out Kueppers Atlas colors and the Munsell charts. These irregularities may well be inappropriate when all of the colors are printed simultaneously. A diagonal organization was the general trend of the progressions of individual ink percentages in the cut-out systematic matches. The primaries (yellow, magenta, and cyan) usually increased in percentage downward and to the right. This is logical because more color is needed to increase the chroma and lower the value. The percentages of black usually increased downward and to the left. The proportion of black in a color must increase as chroma decreases and the value of colors decrease as the amount of black increases. Using this diagonal strategy, which emerged from the computer matches and cut-out systematic matches, new "final matches" were derived that eliminated departures from regular progressions of screen percentages.

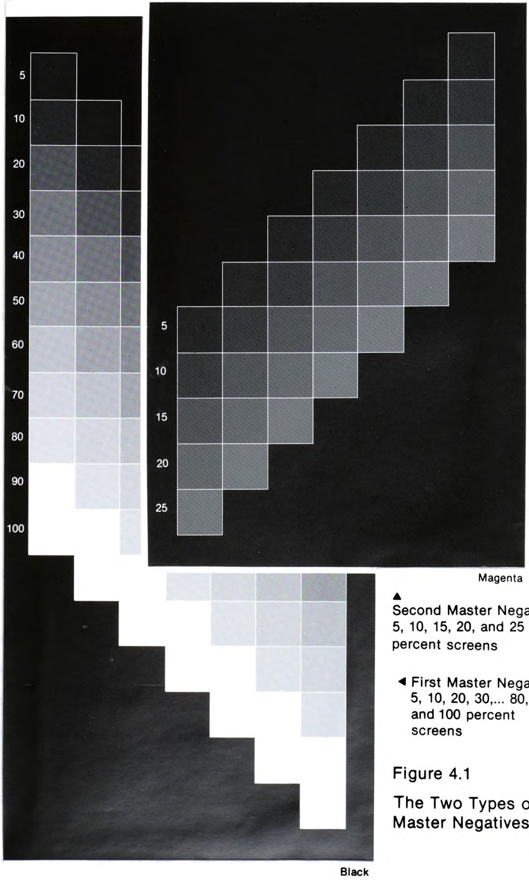
Another change made while designing the final set of matches was the use of 5, 15, and 25 percent screens (available in our production center) in addition to the ten percent increments available in the Atlas. The use of a 5 percent screen made it easier to restrict the organization of the percentages to diagonals by avoiding the abrupt visual jump from 0 to 10 percent when an ink was introduced into a sequence. Such abrupt jumps were a major problem when trying to match the Munsell charts with the Kueppers Atlas colors because the addition of an ink often changes the whole nature of the hue. The additional 5 percent screen almost eliminates this problem.

Color Key (a 3M product) was the color proofing method that I used while performing final adjustments of the matched percentages and preparing the negatives for printing the charts. Color Key results are very consistent and this allows systematic progressions of percentages to look systematic on a Color Key proof, which was not the case with the cut-out Kueppers colors (Section 4.1.2). The consistency of the proofing materials was an advantage that far outweighed the problem of discrepancies between the proof and the printed product. I knew that the colors of the printed charts would vary slightly from the proof colors, but the systematic nature of the color progressions would be retained. Likewise, when color schemes selected from the charts are printed, they may vary both from the Color Key proofs and my printed charts, but if they are printed reasonably well they should still be systematic.

4.2
Method

The first step in making the final adjustments in the matched specifications and in producing the negatives to print the charts was to make master negatives of diagonal percentages. Two types of master negative were made. The first set of masters had tint-screen percentages 0, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 arranged on diagonals. The second set had the percentages 0, 5, 10, 15, 20, and 25 on diagonals (Figure 4.1).

These two masters were created for each of the four process colors using the appropriate screen angles for each color (90 degrees for yellow, 75 for magenta, 105 for cyan, and 45 for black). The diagonals for yellow, magenta, and cyan were arranged to increase in percentage to the right and down and the diagonals for black increased to the left and down. ByChrome screens with 133 lines per inch were used in contact with diazo duplicating film to produce these master negatives. A master Color Key proof in the corresponding process color was made from each of these negatives.



▲
Second Master Negative: 5, 10, 15, 20, and 25 percent screens

◀ First Master Negative: 5, 10, 20, 30,... 80, 90, and 100 percent screens

Figure 4.1

The Two Types of Master Negatives

The Munsell chips in the Student Set are approximately 12 by 17 millimeters with separations of 1 to 2 millimeters. This size could not be duplicated with the printed process-color charts because the amount of space available on the printing plate was limited. A negative of 1 cm by 1 cm boxes with 2 millimeter separations between boxes was created. Ten Peelcoats were exposed using this negative and the boxes corresponding to chips on each of the ten Munsell charts were removed from these Peelcoats. Thus, an open-window negative was created for the arrangement of colors on each Munsell chart (Figure 4.2).

The open-window negatives for each Munsell chart were used with the Color Key proofs of the master negatives to examine the combinations of diagonally arranged screen percentages. The master proofs were registered with each other and the open-window was used to mask away all but the colors that would appear on the printed Munsell chart. By sliding the Color Keys vertically, I compared many combinations of the process colors with the original Munsell Student Set (1984) (Figure 4.3). The first master negatives (with 5 percent and increments of 10 percent) were used unless a satisfactory match was not obtained. If there was an unsatisfactory match, the second (5, 10, 15, 20, 25 percent) master

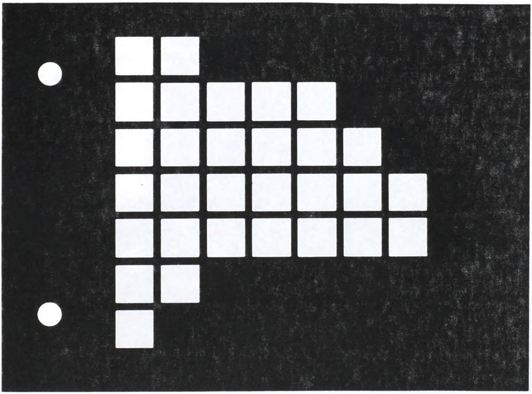


Figure 4.2 Example Open Window Negative for a Munsell Chart

Slide the master negative beneath the open window to select the correct percentages.

Expose Color Key (for proof) or duplicating film (for final composite negative) in contact with the master and open window combination.

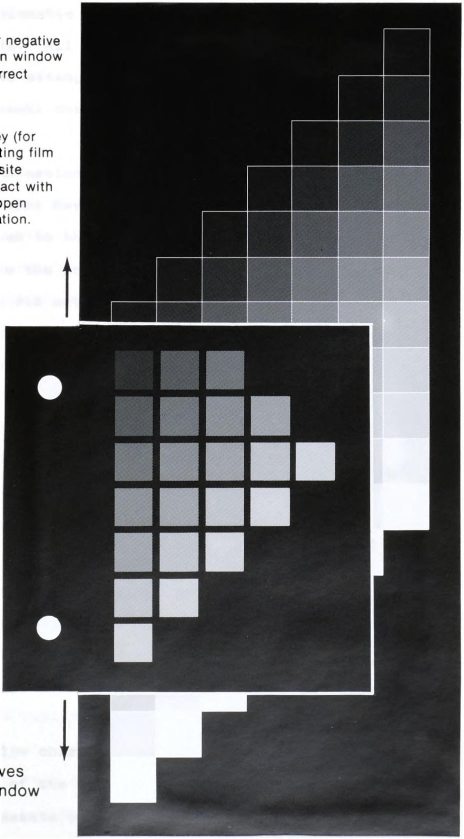


Figure 4.3

The Use of Master Negatives With Open Window Negatives for the problematic process color was used with the first masters. All or part of the second master was used in these attempts to improve the visual match with the Munsell charts.

The combinations of colors created by shifting the master Color Key proofs were judged visually by comparing them to the Munsell charts. The lighting conditions in the production center and the red Peelcoat open-windows did not provide optimum viewing conditions. However, tentative decisions on combinations of diagonal progressions were made and then new Color Key proofs were made with the open-window and the master negatives for each process color. The original Munsell chips are glued onto white paper and, therefore, these Color Key proofs of the charts were viewed against white paper. Final comparisons of the chart proofs were made in sunlight from a north facing window to provide daylight illumination. Correcting, proofing, and visual checking were repeated until the best overall visual match between the Color Key and Munsell charts were obtained.

The yellow chart is the only one on which I deviated from the use of the diagonal master negatives. Twenty percent increments of the systematic matches were used because yellow ink, which changes relatively little in appearance with increasing percentages, controls much of the color change on this chart (Appendix B).

4.3

Results and Discussion

Appendix C contains the pages of a booklet that presents the printed charts and corresponding process-color specifications. The final matches are also listed by individual ink percentages in Appendix B.

Table 4.1 presents my judgments of the problems with the printed charts shown in the Appendix. The differences between the printed colors and the painted chips in the Munsell Student Set (1984) are noted in the first column of the table. The differences between the Color Key proofs, on which my initial visual judgments of the color matches were based, and the Munsell charts are listed in the second column. Color matches are good unless otherwise stated in these columns. The third column is labeled "Deviations from the perceptual organization of the Munsell system." This heading refers to how well the perceptual organization of the Munsell system is represented by the printed chart, independent of the match between the Munsell Student Set chart and the printed chart. In the case of hue, the colors on the chart should all be of a consistent hue. When the value dimension is correctly represented, the colors along individual rows are of the same value and value decreases down each column. Chroma is properly represented when the colors in each column are of the same chroma and chroma increases to the right, away from the neutral core of the Munsell solid. Chart colors visually fulfill these requirements unless otherwise noted in this column.

My judgments of the color matches and chart characteristics were made in a north-facing window on a cloudy day at mid-day to approximate standard daylight illumination (ASTM 1980). General terms, such as "too little" and "too much," are used to describe the differences between colors. While it would be interesting to quantify these differences with colorimetric measurements or to see how others perceive the differences, the variability with which these colors will print partly justifies limiting the current discussion to the general observations of one person.

Examination of the problems listed in the first column of Table 4.1 indicates that many of the hue matches are weaker at the extremes of the charts. The proportions of the inks that provide a good match for the majority of the chart colors often do not generate proper matches towards the edges of the chart. This problem causes inaccuracies in the matches at the extremes: high value, low value, high chroma, low chroma and maximum chroma. For example, the 5 YR matches contain too much magenta in the high chroma colors, too little magenta in the low chroma colors, and too much yellow in the high value colors. Maintaining the diagonal strategy, to ensure smooth progressions in color across entire charts, required compromises in the accuracy of the hue matches.

The slight problems in the color matches between the Color Key and Munsell charts are often exaggerated on the printed charts. This exaggeration occurs because of differences between the Color Key pigments and process inks, the different paper stocks used, and the slight density of the film in each Color Key layer.

On most of the printed charts, the high-value colors are darker than those on the Munsell charts and this problem is less pronounced on the Color Key proofs. On the 5 Y, 5 GY, and 5 G charts, the low-value colors are too light. These two problems cause the range in values on the charts to be diminished. Because 5 percent was the lowest percentage of ink used, it was often impossible to obtain colors of value 8/ that retained the correct hue and differed in chroma. The correct value level at the extremes in value was often compromised to retain the desired hue and chroma of the colors.

The /2 column is usually too high in chroma when compared to the Munsell charts. This limits the range in chroma across the charts. It was difficult to obtain neutral colors of chroma /2 because the percentages of the primary inks that fit in with the diagonal organization and generate the correct hue and value cause the chroma of these near-neutral colors to increase. This is another compromise in the accuracy of the matching that was made to limit the percentages to the diagonal arrangement and thus keep progressions smooth.

Table 4.1 Visual Evaluation of the Printed Charts

Color matches and the perceptual organization of the colors are good unless otherwise noted.

Problems With the Match Between the Printed Charts and the Munsell Student Set Charts	Problems With Matches Between Color Key Proofs and the Munsell Charts	Deviations of the Printed Charts from the Perceptual Organization of the Munsell System
5 R Hue		
(1) too much yellow in 4/10, 4/12, 5/10, and 5/12 (2) too little yellow in remaining colors, except 2/ and 3/	problem (2) less pronounced, better match with Munsell chart	problem (1)
5 YR Hue		
(1) too much magenta /12 and /14 (2) too much yellow in 8/ (3) too little magenta in /2 and /4	problems (1) and and (2) less pronounced, better match	slight problems in (1) and (2)
5 Y Hue		
(1) all colors need some magenta except the diagonals of first and second maximum chroma	problem (1) less pronounced, better match	slight problem (1)

Table 4.1 (continued)

Problems With Matches Between Printed and Munsell Charts	Problems With Matches Between Color Key and Munsell charts	Deviations from Munsell Perceptual organization
5 GY Hue		
(1) too much yellow in most colors, except (2) too much cyan in maximum chroma colors	problems (1) and (2)	problem (2) at 5/8
5 G Hue		
(1) too much yellow in most colors, except 8/2, 8/4, 8/6, 7/2, 7/4, and 6/2	problem (1) less pronounced, better match	
5 BG Hue		
(1) too much yellow in /6 and /8	problem (1) less pronounced, better match	
5 B Hue		
(1) too little yellow in 7/ and 8/ (2) too much yellow in maximum chroma colors of 6/, 5/, 4/, and 3/	problems (1) and (2) less pronounced, better match	7/8 too cyan and shift in hue at the diagonal where yellow is introduced
5 PB Hue		
(1) too much magenta in all colors, except (2) 8/2 contains no magenta and the hue is incorrect	problem (1) less pronounced and therefore (2) is less pronounced, better match	problem (1) at 3/8 and 4/10 problem (2)

Table 4.1 (continued)

Problems With Matches Between Printed and Munsell Charts	Problems With Matches Between Color Key and Munsell Charts	Deviations from Munsell Perceptual Organization
5 P Hue		
(1) too little magenta in 8/2, 8/4, and 7/2	problem (1) less pronounced, better match	problem (2)
(2) too much magenta in remaining colors		
5 RP Hue		
(1) too much magenta in 8/ and 7/	problem (1)	
5 R Value		
(1) 8/, 7/, and 6/ are too dark	problem (1)	too little difference between rows at /12 and /14
5 YR Value		
(1) /2 is too dark	problem (1)	8/2 and 7/2 are too dark
5 Y Value		
(1) 6/, 5/, 4/ and 3/ are too light	problem (1) less pronounced, better match	6/2, 7/2, 7/10 8/2, and 8/12 are darker than other colors in the same rows

Table 4.1 (continued)

Problems With Matches Between Printed and Munsell Charts	Problems With Matches Between Color Key and Munsell Charts	Deviations from Munsell Perceptual Organization
5 GY Value		
(1) 8/ and 7/ are too dark (2) 4/ and 3/ are too light	problem (1), better match without problem (2)	
5 G Value		
(1) 8/ too dark (2) 3/ and 2/ too light	problem (1) less pronounced, better match	
5 BG Value		
(1) 8/ is too dark	problem (1) less pronounced, better match	
5 B Value		
(1) 8/ and 7/ are too dark	problem (1) less pronounced, better match	
5 PB Value		
(1) 8/, 7/, and 6/ are too dark	problem (1) less pronounced, better match	values too similar down columns because of problem (1)

Table 4.1 (continued)

Problems With Matches Between Printed and Munsell Charts	Problems With Matches Between Color Key and Munsell Charts	Deviations from Munsell Perceptual Organization
5 P Value		
(1) 8/ and 7/ are too dark	problem (1) less pronounced, better match	
5 RP Value		
		/8 and /10 columns too similar
5 R Chroma		
		4/10, 4/12, 4/14, and 5/10, 5/12, 5/14 sequences too similar in chroma
5 YR Chroma		
5 Y Chroma		
(1) /2 is too neutral	problem (1) less pronounced, better match	/2 and /4 are too different because of problem (1)
5 GY Chroma		
(1) /2 and /4 are too high in chroma	problem (1)	problem (1) causes chroma steps to be too small

Table 4.1 (continued)

Problems With Matches Between Printed and Munsell Charts	Problems With Matches Between Color Key and Munsell Charts	Deviations from Munsell Perceptual Organization
5 G Chroma		
5 BG Chroma		
(1) /2 is too high in chroma	problem (1)	
5 B Chroma		
(1) /2 is too high in chroma		problem (2)
(2) 7/8 is too high in chroma		
5 PB Chroma		
(1) /2 is too high in chroma	problems (1) and (2) are less pronounced, better match	
(2) /10 is too neutral		
5 P Chroma		
(1) /2 is too high in chroma	problem (1) less pronounced, better match	
5 RP Chroma		
(1) /2 is too high in chroma	problem (1)	

Chapter 5

THE INTERVIEWS

METHOD, RESULTS, AND DISCUSSION

5.1

Introduction

Though development of the charts themselves was the major goal in this project, additional research on color charts in general and the potential usefulness of the Munsell-based charts was conducted using telephone interviews. The design of the interviews and the cartographers' responses are discussed in this chapter. These interviews are a secondary part of the research, but relate the finished charts to mapping problem.

Two main objectives controlled the design of the interviews. The first objective was to gather background information on the use of color charts by cartographers who experience with color-map design and their degree of satisfaction with those charts. The second objective of the interviews was to examine the perceived potential usefulness of the Munsell-based process color charts to these cartographers within the context of their particular design problems and experiences. The practices and views of the cartographers who are interviewed will assist me in drawing conclusions about the potential usefulness of the charts as aids for color selection in cartography.

5.2
Method

5.2.1
Sample Selection

Because of the nature of my subject matter, color charts for map color selection, I am interested in the practices and views of cartographers experienced with color-map design. It would be irrelevant to interview inexperienced people, or "naive subjects," to gain useful information on charts in the context of current mapmaking practices. The people I interviewed were selected because Dr. Olson or I knew that they, or their organization, were involved in the design of color maps. To avoid biasing the responses toward any particular type of organization or type of experience, five people from academic institutions, five from government agencies, and five from private firms were interviewed (Appendix D). I did not attempt to ensure that the sample was perfectly representative of all color-map designers nor did I use a statistically large sample. Likewise, I do not intend to make generalizations about the population of color-map designers.

One pilot interview was conducted to test the interview materials and questions for any unforeseen problems. Richard Groop, at Michigan State University, was interviewed for this pilot. His interview was conducted in the same manner as the interviews that followed and he was not previously aware of the details of my research. Therefore, his responses will also be included in the discussion of the results. All cartographers interviewed are referenced Appendix D, with their permission, to give credit for the valuable information they contributed to the research.

5.2.2

Interview Questions

The interview questions focus on the objectives outlined in Section 5.1 and are as follows:

1. How many color maps were you involved in designing in the last two years and what percentage is this of all the maps you were involved in designing in those two years?

2. What method do you use to specify printed colors on maps?

3. Do you have color charts available to you?

   If yes...

   3.1 Were your charts developed within your own organization, acquired as negatives to be printed, or acquired as finished printed charts?

   3.2 Do you use color charts while selecting map colors?

   If yes...

   3.2.1 Please name and describe the color charts you use.

   3.2.2 How do you use color charts: do you look for schemes in the chart colors, check the specifications of colors that are already decided, combine these approaches, or use the charts in a different manner?

3.2.3 What problems do you have with the use of your color charts?

3.2.4 Are you generally satisfied with the color charts you use?

4. The enclosed booklet [see Appendix] contains printed approximations of Munsell color charts. Were you previously familiar with the Munsell color system?

5. Have you ever used the Munsell system for color selection, color description, or any other purpose?

6. Do you see potential uses for these printed Munsell charts when selecting map colors? Please elaborate on your answer.

The first interview question is included to gauge the cartographers' experience with color-map design. Question 2 and the seven parts of Question 3 address the first objective: to gather background information on the use of color charts by cartographers. Questions 4 and 5 are used to assess the cartographers' experience with the Munsell system. The second objective, to examine the perceived potential usefulness of the charts, is addressed by Question 6.

The relationship of Question 2 to the first objective is less direct than for the questions in 3, which refer directly to color charts. However, the method by which the cartographers specify printed colors should have great influence on the charts they use. For example, if they print with PMS (Pantone Matching System) of many ink colors, they are probably using Pantone charts. A process color chart is appropriate if they print with process colors, including possibly the charts developed during this research. PMS colors include, but are not limited to, the process colors yellow, magenta, cyan, and black. With four-color process printing, a range of hues is produced by overprinting screens of only these four inks as opposed to mixing inks of each desired hue with the Pantone Matching System. I use "process" and "PMS" to simplify terminology when distinguishing between these two approaches to color printing.

Responses to Question 3.1 will indicate the importance to the cartographers of the accuracy of the printed colors on the charts. A chart that is printed with the same combination of inks, paper, and press with which the maps are printed will be much more accurate, and more expensive, than a pre-printed commercial chart.

Questions 3.2.1, 3.2.2, and 3.2.3 focus on the specific color charts the cartographers use, how they use them, and the problems they have with them. If they are using color charts to search for color schemes, the Munsell organization may be very useful. If they are using them to look up the specifications for colors that have already been decided, conventional color charts that present all available colors may be more appropriate. The question of problems with the use of their color charts (Question 3.2.3) may bring out information on how color charts can be improved for use by cartographers. The organization of the Munsell-based charts may solve some of these problems.

Question 3.2.4 follows up on the question of problems with the use of color charts (Question 3.2.3) by ascertaining whether or not the cartographers are generally satisfied with their charts. The satisfied cartographers would not necessarily reject new color selection aids, but the dissatisfied cartographers would probably be more receptive to alternative color charts.

The remainder of the interview questions center on the Munsell system. Questions 4 and 5 were used to collect preliminary information on whether the cartographers are familiar with the Munsell system and whether they have used it for any purpose. Question 6 was designed to address the second objective of the interviews: to examine the perceived potential usefulness of the printed Munsell charts for selecting map colors. This question relates most directly to the bulk of this research work, summarized in Chapters 3 and 4. The Munsell-based printed color charts were developed specifically for cartographers and these experienced cartographic designers were asked to judge the usefulness of these charts. I was interested whether or not other cartographers agreed with my feeling that the Munsell organization of the perceptual dimensions of color could be useful for selecting map color schemes.

The investigation of color charts, addressed in the first part of the interviews, can be used to gauge how the Munsell-based charts fit into the current practices of cartographic designers and whether these charts avoid or share the problems the cartographers have with their color charts. The responses to the final question, on the usefulness of the Munsell-based charts, will provide key information on the potential of these charts. While the cartographers' answers will not be taken as final judgment on whether the charts can be useful, the perceived potential usefulness of the charts to practicing cartographers will be an important factor in the success of the charts and in guiding further research relating to color charts for cartography.

5.2.3

Interview Materials

Each person interviewed received a packet of information in the mail approximately one week before the interview. The materials in the packet were a bound set of the final printed color charts (Appendix C), a letter of introduction, a list of the interview questions, and a postcard which they were asked to return (Appendix D).

At an agreed upon date, I telephoned the participants and conducted the interviews. The use of the telephone allowed the structure of the interviews to be flexible. All questions that are listed in Section 5.2.2 were addressed and additional comments and information were welcomed during the interviews. Conducting the interviews by telephone minimized the effort required of the participants and also permitted any necessary question clarifications during the discussions.

With the exception of one, the interviews were recorded on tapes (to be later erased). The cartographers were not quoted from these tapes, but the recordings are valuable because they provided an accurate record of the discussion. By eliminating the need for extensive note taking, the recording also allowed the interviews to go quickly and increased my freedom to pursue interesting details with additional impromptu questions.

5.3
Results and Discussion: Interviews

The responses of the sixteen interviewed cartographic designers are summarized and discussed in this section. They are credited for their comments and ideas offered during the interviews (see Appendix D for their names and affiliations). It should be noted that a problem or technique mentioned by some interviewees might have been mentioned by others if their discussion had focused on that particular topic. Beyond the interview questions themselves, however, additional information was not solicited from each person in a structured manner.

5.3.1
Question 1: Number of Maps

Estimates of the number of color maps designed in the last two years ranged from 5 to 2500. Color maps made up 5 to 100 percent of the map design work of the cartographers in those two years. I did not require precise responses to Question 1 from the participants, and I wanted to avoid making the terms of the question so specific that many map projects were excluded. The responses are, therefore, difficult to compare because number of maps and involvement took a variety of forms. There were questions of how to count atlas maps, series of maps with the same color scheme, revisions, color pen-plotter maps, two-color maps, student projects, and projects given minimal attention. If questioned, I asked people to include all maps and count the number of individual maps in atlases and series.

Though there were questions on what to include in the estimates of number of color maps and proportion of work in color, I was satisfied that each person's responses to the remainder of the questions were based on personal experience selecting map colors.

5.3.2

Question 2: Color Specification

Percentages of the process inks were used by 12 of the 16 cartographers for printing maps. Two mentioned that they did not use standard dot screens in increments of 5 and 10 percent. The variations described were: a series of screen percentages that began with 7, 13, 20 and continued in increments of 10 (Borrowdale screens, Wray); a wide variety of screen percentages available with computer-produced negatives (Zebarth, Wray); mezzotint screens to avoid problems with moiré (Zebarth); collections of percentages that vary for each screen angle (for example, 5, 7, 9, 12, 15, 20, 25, 29, 34, 45, 51, 59, 65, and 83 percent for the 45 degree screen angle, Zebarth). Of the 12 who used process inks, three mentioned sometimes substituting a warmer red for the magenta ink (Kimerling, Wiedel, Arvetis).

Half of the cartographers used both percentages of process inks and Pantone Matching System (PMS) inks for printing color maps. PMS was used by eight of the 12 process users, and four of the participants said they used only PMS inks and no process color printing. Two, who used both PMS and process inks, said process color was usually used when the maps were being printed with process-printed color photographs, and thus these inks were already available on the press (Arvetis, name withheld). Four mentioned that a PMS color was sometimes used as a "special" fifth color with the process inks (Zebarth, Petchenik, Caldwell-Lindgren, Brouwer).

Altogether, 12 interviewees used process color printing and 12 used PMS colors. These figures indicate that color charts composed of combinations of process colors will not be useful for every map design problem. However, since process colors are used by the same number that use PMS, they seem to be equally as popular among the cartographers interviewed. Thus, the use of process color inks in this study provides the maximum gamut of hues with four inks and allows the developed charts to be potentially useful to most of these cartographers.

5.3.3

Question 3: Color Charts

Responses to the first three parts of Question three revealed that all of the cartographers had access to and used color charts. Of the 16 participants, 15 had charts that were acquired as finished printed charts. Three rarely used charts other than those developed within their organization. Three had charts developed in-house in addition to their pre-printed charts. Three others mentioned custom charts they had proofed or printed for specific projects and another had samples of these custom charts from the projects of others.

Most of the charts described in response to Question 3.2.1 were conventional printed process charts (books or sheets) that were commercially available, supplied by lithographers, or printed in-house. These showed combinations of the three screened process inks and sometimes included screens of black. Conventional charts are described in Section 2.1.2, but a few variations were mentioned. The black for one set of charts was on a transparent overlay and, for another, three percentages of black were printed over quarters of each color square on the charts. One had a choice of specials printed with conventional YMC combinations. Two people had charts printed with a warm red replacing magenta. Another chart showed the process combinations on a variety of paper types.

The Pantone books and strip charts for PMS inks were also commonly used. Other charts named were the ITC chart (Section 2.2.1), Defense Mapping Agency's color book, U.S. Geological Survey charts, restricted palettes for specific jobs, a computer firm's plotted chart, color wheels with process colors on transparent overlays, and two-color charts with screens of black over screens of one PMS color.

Most of the cartographers interviewed used preprinted, finished charts. Thus, despite their disadvantages (which will be discussed), they are seen as aids of sufficient use that the cost of custom printing is usually not warranted. The use of preprinted charts indicates that the printed charts resulting from this research may be useful color selection aids, even though printed map colors will not replicate the chart colors exactly.

The initial response to Question 3.2.2 from six of the cartographers was that they used color charts to find the specifications for colors they had already decided upon. Nine of the cartographers said they used the charts in a manner that combined looking for schemes in the chart colors and looking for colors already decided upon. This was often described as having a general idea of the color scheme, working out general relationships, or knowing the category of hue desired, and then using the charts to select the exact colors to be printed. The sixteenth person did not answer this question directly. One person also used charts to provide ideas for color schemes.

The organization of the Munsell-based process printed charts is well suited to looking up the desired hue and then selecting the exact color from the choices available. On conventional color charts, each page shows colors of a variety of hues and a specific hue will appear on a number of pages. This arrangement is awkward if cartographic designers do choose colors by deciding on a hue, blue-green for example, and then selecting the exact process-ink percentages from charts. The organization of conventional charts necessitates searching through a series of chart pages that show blue-greens. Examination of the Munsell blue-green chart would be a more efficient approach if the designer has made the hue decision already.

The cartographers usually did not look for color schemes in the chart colors, perhaps because they do not need this type of aid when designing color schemes. However, if the current charts of the cartographers are not organized in a manner that presents useful schemes, then it is not likely that the charts would be looked to for ideas. Though the interviewed cartographers did not say they were using their charts for ideas, the availability of perceptually organized chart might encourage this type of chart use.

Additional specific information on the use of charts surfaced in further comments. Five people said they cut colors from the charts to allow them to align colors in progressions (Weiss, Heidt, Kimerling, Broome, Wiedel). Two people mentioned that they had multiple copies of inexpensive sheet charts to cut up (Broome, Weiss) and Heidt used disks punched from chart colors to set up progressions. Others spoke of putting pairs of chart colors side by side by folding and overlapping the charts (Arvetis) or using a punched hole to look through to another color (Petchenik). Wiedel used a video camera to view selections in black and white to check value differences between colors for the visually impaired.

The use of color charts in the iterative fine-tuning process of minimizing the number of percentages of each ink for a job was described by three people (Kimerling, Caldwell-Lindgren, Zebarth). Common percentages of individual inks are used in as many different map colors as possible while retaining a desirable color scheme. This refining requires much rechecking of colors on charts and reduces the complexity and cost of a job by simplifying production. Castner and Petchenik discussed the advantage of printing or proofing a separate chart showing combinations of a restricted set of percentages. Castner continued that the variety of colors including a common percentage are often found in widely separated locations on the charts which makes colors difficult to compare.

The cartographic designers also mentioned a variety of other considerations while using charts to select map colors: the strength of a color in relation to its area (Zebarth, Castner, Brouwer, Wray), coordination with nearby colors (Chu, Groop, Arvetis), legibility of overprinted information (Wray), appropriateness to the map theme (Brouwer, Groop, Wray), emphasizing map theme information more than background information (Zebarth), and using colors from either the warm or cool sides of the charts (Weiss).

Question 3.2.3 elicited discussions of many interesting problems that the cartographers had while using their color charts. Only one person said they had no problems with their charts (name withheld). The most common problem mentioned (Weiss, Petchenik, Arvetis, Chu, name withheld, Kimerling, Zebarth, Heidt, Wiedel) was that chart colors did not match printed map colors. These differences were ascribed to differences between printers (inks and presses), different papers, and fading with age. Colors also appear different on maps because the colors in small areas on the chart looked different over large areas (Petchenik, Groop, Zebarth). Simultaneous contrast with surrounding colors on the chart or map caused differences in color appearance as well (Heidt, Brouwer, Wiedel, Weiss). Brouwer and Wiedel said that they used masks to isolate colors on the chart pages to reduce distraction from surrounding colors.

Three of the cartographers wanted larger color samples (Groop, Wiedel, Arvetis). Arvetis wanted color areas of 1 to 1.5 inches square and Wiedel had very specific wishes: 2 by 2 inch chips separated by a gray surround of at least one-quarter inch to combat simultaneous contrast effects. Three people expressed the desire for moveable chips to lay side by side in progressions of color (Wiedel, Groop, Heidt). As additional information on a chart, Koch found type and line weights in color useful (as shown in Pantone and DMA books respectively, which do not show combinations of screened process inks).

The cartographers commented on the difficulty of using charts in general. Two said their charts showed too many colors (Wray, Chu) and Wray wanted screen percentages in a geometric progression (5, 10, 20, 40, 80) if the number of screens of each ink were reduced. Castner felt that the many colors on conventional charts complicates the problem of selecting colors and therefore he occasionally tapes out alternating rows and columns to simplify his charts. Petchenik did not use charts with many colors; through experience she designs limited palettes of 10 or 12 colors for specific projects from which to select colors for individual maps.

With four variables, the four screened inks, the necessity of flipping through many pages of charts was termed cumbersome (Caldwell-Lindgren). To avoid this awkward arrangement, Caldwell-Lindgren sometimes used a color wheel (process colors on rotating transparencies). On the other hand, Koch mentioned that he was not satisfied with color wheels because the density of the film layers grayed colors. Weiss and Arvetis preferred all colors together on one sheet. However, these sheet charts show fewer colors because screens of black are not included, and the omission of black was seen as a shortcoming (Weiss, Arvetis, Broome). Similarly, Petchenik felt that conventional charts did not show a wide enough selection of colors to see the subtle differences possible in the lower percentages.

The wide variety of maps made, resources available, and personal preferences created a range of chart-use problems and desired chart qualities. It would be impossible to design one chart that satisfied all of these requirements. The chart-use problems that were discussed in the interviews focused on printing and physical format rather than the organization of the specific colors. People mentioned wanting to move colors around, but only one mentioned wanting the colors on the chart in a different order. The organizations of the available charts may be the most generally useful, but the necessity of folding, lapping, cutting out, punching holes, creating limited palettes, and masking out indicate that a different organization, possibly perceptual, should be useful to cartographic designers. A perceptual organization will aid map color selection by bringing useful sets of colors closer together on the charts and assist in locating colors with desired hue, value, and chroma characteristics.

During the discussions of problems with color charts, comments were qualified with acknowledgements of the limitations of charts. They were not seen as a substitute for experience (Arvetis, Zebarth). Zebarth stated that the experienced map designer knows how to compensate for differences in color appearance with changes in area, for example. He continued that, after using a chart for a while, the designer will learn the ways in which the chart is inaccurate and how to compensate for these problems while using it. This view was echoed in Arvetis's statement that one needs years of experience before being able to anticipate the color results from the printer. Chu noted that color schemes must be designed with differences between colors that hold up with deviations from the chart colors. This design consideration was also described by Zebarth as building in a tolerance factor.

To sum up their feelings about the charts they use, seven participants said they were satisfied with their charts. Four others said they were satisfied, but qualified the statement with comments such as: satisfied, except for problems of simultaneous contrast and non-moveable swatches; they could be improved; they are not substitutes for experience; and they all leave something to be desired. Five said they were not generally satisfied with the color charts they used.

In general, many problems with color charts were discussed, but the cartographers also recognized the limits of charts as an aid for color selection. Approximately half said they were not satisfied with their charts and, given the many problems discussed, I suspect that almost all of those interviewed would welcome useful alternatives.

5.3.4

Questions 4 and 5: Munsell System

Responses to the preliminary questions on the Munsell system revealed that 15 of the 16 cartographers interviewed were familiar with the Munsell system (Question 4) but nine had never used the system for any purpose (Question 5). Weiss stated that the Munsell system was not of use because cartographers need process color specifications for printing colors. A number of cartographers did not use actual Munsell color chips but said they used the system indirectly. Four used a mental construct of the Munsell dimensions of color when designing progressions (Chu, Castner, Kimerling, Heidt). These comments indicate that the Munsell system may be useful to the cartographers but the format in which it is currently available (painted chips) is not. If the perceptual organization of the Munsell system is used as a mental construct during design, a physical representation in process inks ought to be welcome.

In addition, the person with name withheld had experience with a computerized slide production system that used the Munsell dimensions (hue, value, chroma) for color designation. Wiedel and Wray stated they may use Munsell indirectly through the U.S. Geological

Survey color charts. (A further contact at U.S.G.S. said they had no Munsell-based charts, though I have seen a 1975 version that includes circular charts similar to slices through the Ostwald solid.) Castner and Heidt used the Munsell system in teaching about color and Castner also used paints with Munsell designations which are distributed throughout the color solid, as a teaching aid. Other uses of the Munsell system were during production of a book dealing with color solids (Heidt) and for describing soil sample colors (Groop).

5.3.5

Question 6: Printed Munsell-Based Charts

The final question of the interviews focused on the Munsell-based process color charts developed in the first part of this research (Appendix C). Twelve of the 16 cartographers interviewed saw potential uses for these printed charts when selecting map colors. Two felt the charts would not be useful (one uses limited palettes and the other had no problems with current charts). Two others gave intermediate answers: one was not sure and the other saw very limited use of the charts (this person used only PMS inks). Many interesting comments were made in the elaborations for Question 6 and the remainder of this section provides a summary of these comments.

Six of the cartographers stated that the Munsell-based process charts would be useful for selecting choropleth or thematic map progressions (Wiedel, Heidt, Castner, Kimerling, Groop, Weiss). Kimerling was the most emphatic about the usability of the charts. He felt they were a very logical approach that all cartographers could use and that choropleth progressions could be designed by using colors from diagonals on the charts. Color sequences of one hue that change in value and chroma simultaneously are positioned on diagonals. Heidt also mentioned the useful gradations along diagonals and pointed out that, by using progressions that change in both value and chroma, color differences would be more apparent when colors were intermixed on a map and simultaneous contrast affected appearance. Castner also discussed the logical sequences along diagonals and the great value of any chart that provides a translation of the perceptual dimensions. He also felt that the layout of conventional charts is not of help to the designer or in the design process.

With respect to the progressions on the charts, Weiss questioned whether naive users would know they should skip chips because adjacent colors were too similar. On the other hand, Groop said he saw no problem with the small differences between adjacent colors because, as an experienced designer, he could decide which colors to use from progressions on the charts. This comment is consistent with responses to Question 3 warning that a chart is not a replacement for experience.

The charts were not seen as useful for all thematic mapping situations; Chu observed that too few hues are shown and too much page flipping would be required when designing complex land-use and geologic maps. On the other hand, Castner felt that the perceptual organization should aid in selecting colors for qualitative maps. For example, only value 7/ colors could be chosen for one style of map or, as another example, value 4/ colors could be used for tiny map areas to balance larger areas. Petchenik agreed that the charts would be useful for choropleth mapping but said that they would not be of use to her because 95 percent of commercially produced maps are not choropleth maps. The interviewee with name withheld felt that designers would continue to use the charts with which they are familiar.

Castner and Heidt saw the charts as a useful teaching aid for color selection. Castner discussed the simple and powerful tool of using value changes to represent amounts of things and hue changes for kinds of things. Heidt felt it was important to understand the three dimensions of color and their relationships, and that it helped to see the system printed. Zebarth had already begun using the charts in an unexpected instructional manner. Because the charts provide a range of values and chromas for individual hues, he was able to use the charts to show others, with less experience in process color work, the range of colors that would appear in two-color reliefs. In this case, the organization of the colors along perceptual dimensions was the key to the usefulness of the charts.

Four people said they liked the organization of the booklet (Groop, Broome, Caldwell-Lindgren, Zebarth) and two felt that a good range was shown in the small number of color choices (Caldwell-Lindgren, Groop). Heidt, however, would like to have seen the omitted screen combinations since he was accustomed to working with the full set of screen combinations. Zebarth liked the small, convenient size of the booklet because it occupied little desk space but two others preferred all of the colors on one sheet to ease comparison between colors (Weiss, Arvetis).

Another comment on format was that the white space around each chart color had the advantage of reducing contrast effects from surrounding colors (Wiedel). Castner suggested that the squares should be tilted to emphasize the sequences along the diagonals (Munsell charts with diamond-shaped chips). He acknowledged that the horizontals and verticals are important in conceptualizing the dimensions of color but felt that the schemes along diagonals are more important during practical use.

Two people felt that the hue, value, and chroma numbers were not needed on the pages (Caldwell-Lindgren, Brouwer) and Brouwer continued that these numbers were an obstruction for the average person because they gave the charts an overly scientific appearance. Weiss felt that more descriptive labels of the color dimensions would be of greater help than hue, value, and chroma. Two people said that looking to the left to check the percentages in each color was a problem because too much comparison and hesitation was involved (Caldwell-Lindgren, Arvetis). They both observed that it would be helpful to have the percentages of ink on the colors, possibly on an overlay. Castner suggested using four digit codes (as used in Appendix B) instead of four two-digit numbers for each color specification.

Kimerling cautioned that the charts would be useful if the colors matched his printed colors. Printing mismatches were the main problem with color chart use mentioned in response to Question 3. To guard against inaccuracies in the printing of a chart, Zebarth stated that he looks at the size of the screen dots under magnification when specifying percentages from chart colors instead of using the percentages given on the chart. Castner stated that it was not necessary to worry about differences of a few percent because colors must be much farther apart to maintain differences through all stages of production.

The problem of chart colors not matching printed colors seems to be one that the cartographers tolerate because of the expense required to custom print charts. It is a problem inherent in using preprinted charts and applies to the Munsell-based charts of this research as well as commercial charts.

Two people saw problems with the many screens needed to print progressions of colors from the charts if the cost of a job was a constraint (Petchenik, Kimerling). Similarly, too few choices were shown to allow fine-tuning of a color scheme to simplify production (Koch). The perceptual organization does not lend itself to quickly looking-up specific screen percentage combinations, which is repeatedly required during fine-tuning. However, conventional charts do act as well organized catalogs of screen combinations and the Munsell-based charts are not meant to replace these charts but to function as an additional color selection aid.

Petchenik and Koch commented that 80 to 90 percent of the colors were too saturated or dark for them to use on a map, except with rare small symbols. In addition, Petchenik uses no more than two inks in colors to avoid registry problems and to reduce the number of screen angles used. Drop-outs are used to avoid moiré if more than four screen angles are required in a set of overprinted colors or if background colors will adversely alter an overprinted color, and drop-outs also contribute to registry problems. Most of the colors on the Munsell-based charts are composed of three inks, but she would only use screens of three inks over large areas with few drop-outs to confidently avoid registry problems. This practical restriction limits the usefulness of the Munsell-based charts for these commercial maps.

Almost all of the colors on the Munsell-based charts include a percentage of black. Two people mentioned that they did not use screens of black in their map colors. Black was reserved for type, which often underwent late revisions on Petchenik's maps. Zebarth did not use black screens because they interfered with the crispness of black type in gravure printing. Castner mentioned that some people felt a black screen made colors look dirty. On the other hand, Broome said that the greatest benefit of the charts was the presence of black and six mentioned they frequently used screens of black to darken or enrich colors (Arvetis, Broome, Castner, Wiedel, Weiss, Caldwell-Lindgren).

Generally, the Munsell-based process color charts were judged as potentially useful, especially for thematic map color progressions. The Munsell-based charts shared some of the problems of other color charts: the colors will not match future printings; page flipping is required; the chips are small; and the colors are not moveable. Some cartographers felt that the labeling of the screen percentages was awkward and that too few colors were shown for fine-tuning schemes. These were new problems created by the Munsell organization. Other problems were avoided such as lacking space between color samples. Conflicting desires, such as the presence or absence of black screens and the preferred number of colors shown, leave the charts useful for some tasks and not useful for others.

Chapter 5

CONCLUDING COMMENTS

The primary objective of this research was to print an approximation of Munsell color charts with process inks. Given the variability of process printing and the precise perceptual spacing between Munsell colors, producing an exact replica was neither realistic nor anticipated. The attempt produced a set of charts which are easily recognized as approximating a Munsell Student Set (1984) despite numerous observable differences. It also produced interesting, useful information about the relationship between the Munsell system and process ink combinations.

The general trends in ink percentages when colors are organized by the perceptual dimensions of value and chroma are consistent from hue to hue. Constant percentages are arranged on diagonals, with black and the primary colors (yellow, magenta, and cyan) increasing in opposite directions (Appendix B). The proportions of the primaries are adjusted to produce a constant hue. The simultaneous increase in the percentages

of each primary produce decreasing value and increasing chroma diagonally (down and to the right). The increasing percentages of black on the opposite diagonal cause decreasing value and decreasing chroma (down and to the left). Intersecting these two trends causes decreasing value downward with approximately constant chroma in each column and increasing chroma to the right with approximately constant value along each row.

The exact hue, value, and chroma of corresponding Munsell colors (especially for high-value and low-chroma colors) and the constancy of the visual steps between adjacent colors in the Munsell system were not maintained. However, the basic perceptual order of the Munsell system, a quality that makes the printed Munsell-based charts potentially useful to cartographers, was duplicated.

6.1
Using the Munsell-Based Charts

The majority of the cartographic designers interviewed (Chapter 5) felt that the Munsell-based color charts would be useful for selecting map colors, especially for thematic maps. The organization of the perceptual dimensions on the Munsell-based charts make good color choices easier to find because the colors are ordered in the manner we think about color. Different types

of schemes are found in different orientations on the charts and a variety of these are presented in Figure 6.1. Many of the schemes are usable and some are innovative schemes that designers may not think of without seeing them printed in sequence. On the other hand, some of the these schemes are not usable, but no chart can guarantee the choice of correct colors (Karssen 1975).

6.1.1

Quantitative Sequences

Color sequences of changing value with constant hue and chroma are aligned vertically on each chart. Sequences with value decreasing and chroma increasing are arranged on the diagonals that run down and to the right. Both of these types of color scheme are appropriate for choropleth maps that present a range of magnitudes (quantitative information).

Robinson and others (1984) designate chroma as the least significant dimension of color. It also seems to be the most difficult dimension to understand, probably because of the lack of perceptually organized color aids and the imprecise color terms we use in everyday speech. However, chroma is certainly important enough that its disregard or misuse may lead to poor communication of map information (Cuff 1972).

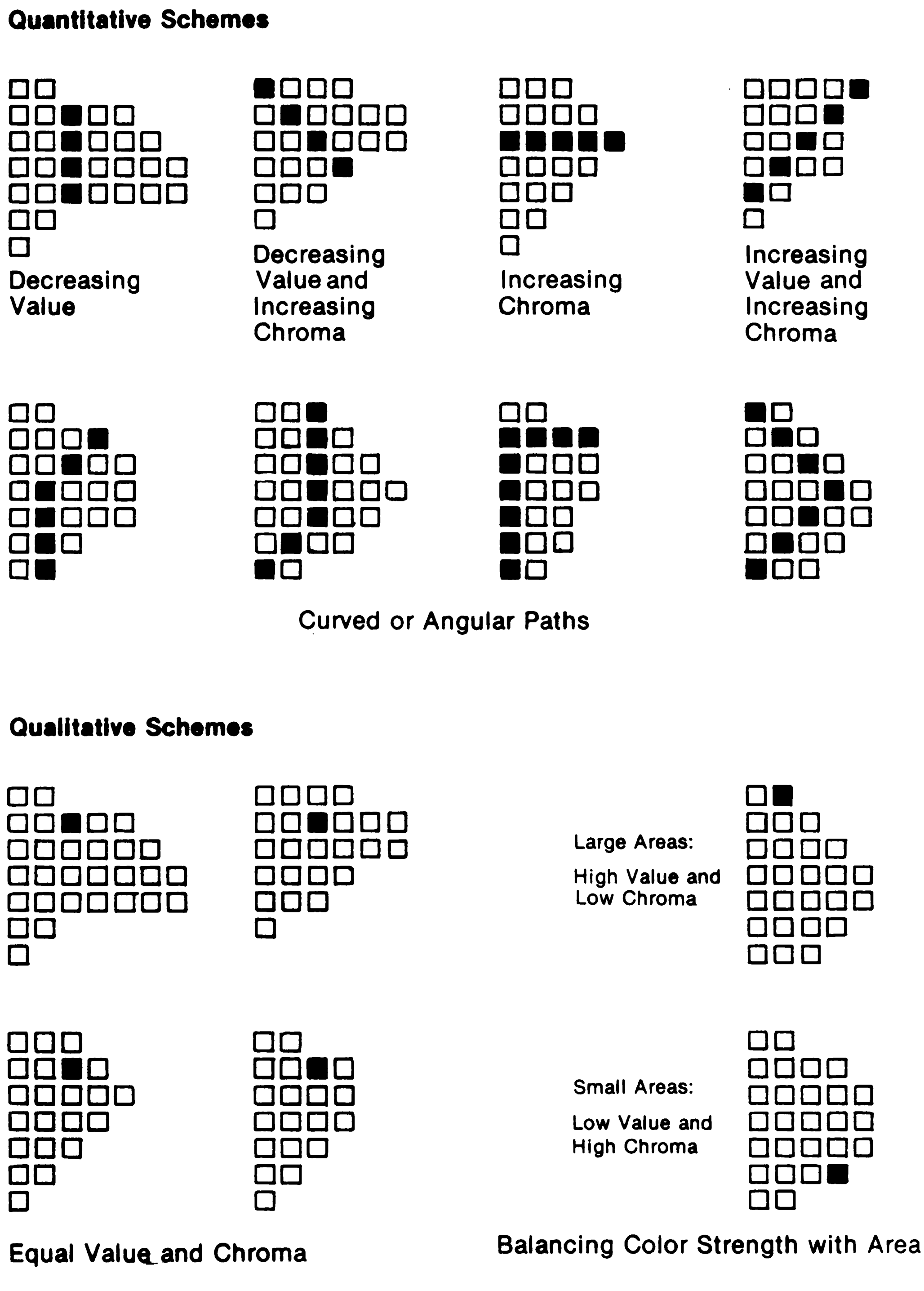


Figure 6.1 Examples of Color Scheme Types on Munsell Charts

Sequences of changing chroma with constant hue and value are arranged horizontally. Some of these schemes may be useful for presenting quantitative information. The diagonals running upward to the right show value and chroma increasing simultaneously. It may be that magnitude representation with the latter type of scheme should be avoided because low value and high chroma may both be interpreted as representing greatest magnitude. However, these schemes do have a definite logic in their structure and again some may be useful on maps representing quantitative information. If the maximum chroma in the sequence is not composed of high ink percentages and the progressions of value and chroma are both systematic, the higher chroma colors should not compete visually with the dark colors in the sequence (as did the 100 percent yellow in Cuff's 1972 test).

6.1.2

Lengths of Sequences

The limited number of colors along the verticals, horizontals, and diagonals is disappointing. With reference to his Ostwald-based charts, Castner (1980) states that this "simply reinforces the fact that there are real limitations in our freedom to select sequences with uniformly changing but perceptually related characteristics, particularly when they must be more than just noticeably different" (p. 376). Castner uses intersecting screen percentages of 0, 10, 30, 50, 70, and 100 to compose his theoretical chart (Figure 2.5). My Munsell-based charts are printed with 5 and 10 percent increments and therefore adjacent colors are perceptually more similar than his would be. Depending on map type and chosen sequence, it will often be necessary to skip colors in a sequence to ensure adequate perceptual differences between colors. Selecting every other color, for example, would further restrict the number of colors in a sequence.

On conventional charts with ten percent increments in screens it is necessary to skip unequal numbers of colors if following a column, row, or diagonal because the perceptual spacing between high percentages is much smaller than between low percentages. This inconsistency makes it difficult to decide whether one, two, three, or more percentages should be skipped between consecutive colors in a sequence.

I attempted to duplicate the perceptually equal spacing between colors of the Munsell system on the printed Munsell-based charts. The resulting differences between colors are much more consistent than on conventional charts. Therefore, if it is necessary to skip colors in a sequence, using every other color along the entire sequence will produce a near equally stepped scheme. In addition, the colors in schemes with value and chroma changing simultaneously are more easily differentiated because the perceptual spacing between colors is larger along diagonals and changes along two dimensions occur between colors.

Sequences with a greater number of colors that change logically in value and chroma can be constructed by following curved or angular paths across the charts. Castner (1980) recommends a similar strategy with his perceptually organized charts. There are a wide variety of approaches that may be taken. For example, moving downward through colors of changing value and constant chroma and then diagonally with both value and chroma decreasing may provide a sequence with a greater number of useable colors. Similarly, upward through equal chroma, lower value colors and then on a diagonal to lighter, higher chroma colors also produces a logical scheme. More sharply curved paths that begin vertically and finish horizontally or switch diagonals may also be useful. A variety of possible routes are shown in the top section of Figure 6.1 but their usefulness for an individual map must be examined on the charts.

6.1.3

Qualitative Sequences

On maps presenting nominal classifications (qualitative information such as land use), the color schemes should not imply a hierarchy of magnitude (Robinson and others 1984). As discussed in the interviews and described by Wray (1983), nominal classifications may also be designed by balancing the strength of colors with their relative areas on a map. Assigning low-value, high-chroma colors to small areas aids their identification and giving large areas high value and low chroma helps prevent these colors from overwhelming the map.

Nominal color schemes are not arranged in a particular order on the Munsell-based charts, but the organization of the Munsell system does allow colors with desired hue, value, and chroma characteristics to be easily located on the charts. Nominal schemes can be designed by selecting colors that have similar value and chroma levels from different hue charts. Alternatively, if area is compensated for by color strength then, as an example, a dark red for tiny map areas and a pale orange for wide expanses may be desired. These colors can be easily located on the Munsell charts because they appear at the bottom of the 5 R chart and the top of the 5 YR chart respectively and they appear only in these places (not on a variety of other pages as with conventional color charts). The ease of locating colors on the Munsell-based charts should also aid the specification of desired colors for reference maps.

6.1.4

Color Selection Experience

During the interviews, a number of cartographers remarked that a color chart cannot replace experience when selecting colors. I do not contest this point because color selection is a complex process, but the difficulty of using color charts is one posible reason that much experience is needed to select map colors effectively. Experience and an especially good understanding of color are required to select perceptually logical schemes from perceptually illogical charts. If cartographers had well designed, perceptually organized charts, the map design process would be made less complex. The cutting, folding and other tactics described during the interviews to get color schemes together indicate that a different color chart organization would be useful.

The perceptual ordering of process ink combinations should also be useful in teaching novices about the

relationships between the colors they want and the percentages needed to print these colors. For example, a scheme may include a brown that the cartographer would like to change to a richer brown (higher chroma and lower value). If the brown is 5 YR 5/4 (50 percent yellow, 30 magenta, and 40 black; see Appendix) the cartographer can see that moving to the right and down on the chart provides that richer brown, which is composed of 70 percent yellow, 50 magenta, and 40 black. This type of adjustment may be obvious to an experienced designer but the novice gains the information that both yellow and magenta need to be increased by quite a bit (20 percent) but the black percentage remains constant. This information is valuable, since the novice may be inclined to change the black percentage, (which would interfere with the desired increase in chroma) and not change the yellow and magenta enough (to produce the desired decrease in value and increase in chroma). This type of problem is certainly not the only one encountered when designing a color map. However, the printed approximations of the Munsell color charts, as one of many charts available, should assist in gaining color selection skills and experience.

6.2

Ideal Versus Practical Results

Ideally this research should have started with extremely well printed conventional process charts (or well tested equations) and an unlimited range of screen percentages. However, the use of the Kueppers Color Atlas (1982) and five and ten percent screens bring the project into the realm of real map production problems and the results into the realm of practical use. Printed Munsell charts with rigid printing requirements and unusual screen percentages, which are not commercially available, would be hardly more useful to cartographers than the original painted Munsell chips. Likewise, it would not be useful to specify a 13 percent instead of 15 percent screen, for example, if the variability in printed results encountered by cartographers exceeds that two percent difference. On the other hand, beginning with precise data and gaining an unadulterated understanding of the process ink percentages that could print a Munsell chart would have been a tremendous academic insight, even though the results may not have been of immediate practical use.

The problems of printing variability and screen choices encouraged the distillation of the diagonal trends in the percentages. The intersecting diagonals are a generally useful approach to constructing perceptually organized charts. In addition, the systematic, diagonal organization will allow the retention of the perceptual logic in schemes printed with conditions that cause colors to stray from those shown on the printed charts. The use of black in desaturating colors facilitates retention of the perceptual organization of schemes because printing variability will not cause large hue shifts (Section 4.1.1). The use of black instead of the third primary to desaturate and darken colors may also reduce the cost of printing by eliminating one ink color (depending on the range of hues on the map).

6.3

Extending the Printed Charts

The shape of each Munsell chart is partly restricted by the maximum chroma attainable with permanent paints. This restriction seems irrelevant to printing with process inks, since the limit on maximum chroma is already imposed by 100 percent ink. The Munsell chart format was followed for this research because the printed charts were designed to simulate existing Munsell charts. It would be interesting to examine the usefulness of more complete Munsell-based process charts. The percentage trends on the Munsell-based charts can be extended

past the Munsell page formats until one of the inks in the combinations reaches either zero or 100 percent.

Munsell-based charts with fully extended percentages are triangular in shape and are very similar to Castner's (1980) suggested form for a color chart. His chart organization is based on the mechanical intersection of a fixed set of screen percentages of black and a hue on opposite diagonals. Hue compositions were not defined in Castner's article, but during our interview he indicated that the hue dimension was intended to be percentages of one PMS ink.

With this research on the Munsell system, consistency in hue with process inks (for hues other than straight yellow, magenta, and cyan) is created with percentages of two primaries changing in the same direction and, in some cases, at different rates. Problems that I had maintaining the correct hues at edges of the Munsell-based charts suggest that the constancy of hues may be compromised on the extended charts mentioned in the previous paragraphs. It is questionable whether controlling these variations would be worthwhile in the context of map design, but they would vary from the ideal of perceptual organization.

6.4

Summary and Recommendations

This thesis presents the development of process-printed approximations of Munsell color charts. The organization of the perceptual dimensions of color (hue, value, and chroma) on my printed charts duplicate the general arrangement of the Munsell system. This Munsell organization is produced by intersecting diagonals of increasing screen percentages of black and the primary process inks. I recommend that differences between the original Munsell charts and my printed charts be quantified and evaluated with further research.

The Munsell-based printed charts are useful for selecting both quantitative and qualitative color schemes for maps. This statement is supported by the cartographic designers interviewed; the majority agreed that the charts are potentially useful for selecting map colors. A better understanding of the relative ease of selecting map color schemes from different types of charts should be sought through future testing.

In addition to discussion of my charts, cartographers made practical suggestions about the format of color charts in general during interviews. These interviews were ripe with information on how color charts are used, and they provide background and a starting point for further research and development work with color charts.

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APPENDICES

Appendix A

ACCURACY CHECKS

This Appendix presents the accuracy checks of measurements and interpolation discussed in Chapter 3.

A.1

Measurement Accuracy Check

To check the accuracy of the Munsell notations produced by the instrument and software combination (Section 3.2.1), measurements were made of a sample from the Munsell Book of Color (1976). The production of the color chips in this volume is carefully controlled and the chips are intended for precise visual matching and the precise specification of colors. If the Munsell notations from measurements of the color chips in the Munsell Book of Color match the original notations of the chips, then my measurements of the colors in the Kueppers Atlas should also be reasonably accurate. While one would expect the software to function "well," it is also expected that error will creep in due to the variation from desired color in the Munsell chips,

inherent limitation in the lookup tables, and other uncontrolled variables. It seemed unwise to blindly accept the machine results without a check on accuracy.

A.1.1

Method

Two sessions with the spectrophotometer were needed to complete the measurements of the printed colors. Samples of colors from the Munsell Book of Color (1976) were measured at the beginning of each session. For the first session, the sampling was conducted in an ad hoc random manner. For the second session, a stratified random sample was designed to ensure that each segment of the color solid was represented. The number of measurements taken in segments of the color solid was proportionate to the number of colors in that segment. The first sample consisted of 44 measurements, and 33 colors were measured for the second sample.

I will relate the differences between measured and original notations to the three key magnitudes discussed below. These three color difference standards are listed in Table A.1 and used in Tables A.2 and A.3 to summarize the results of the measurement check.

1) Closest to correct chip:

If the measured notation is closer to the correct chip notation than any other chip notation, it will be within 1.25 hue steps (one half of the 2.5 hue steps between pages in the 1976 Munsell Book of Color), 0.5 value step (half of the value difference between chips), and 1.0 chroma step (half of the chroma difference between chips).

2) Within visual matching limits:

The American Society for Testing and Materials states that the "estimated precision within which a [Munsell] color notation can be determined by visual comparison is 0.5 hue step, 0.1 value step, and 0.4 chroma step" (ASTM 1980, p. 3).

3) The NBS unit:

One NBS (National Bureau of Standards) unit is equal to approximately 2.5 hue steps at chroma /1, 0.1 value step, and 0.15 chroma step (Judd and Wyszecki 1975). One NBS unit is also equal to approximately five just-perceptible color differences (Agoston 1979). A color difference of one NBS unit or less is usually disregarded in commercial transactions (Judd and Wyszecki 1975).

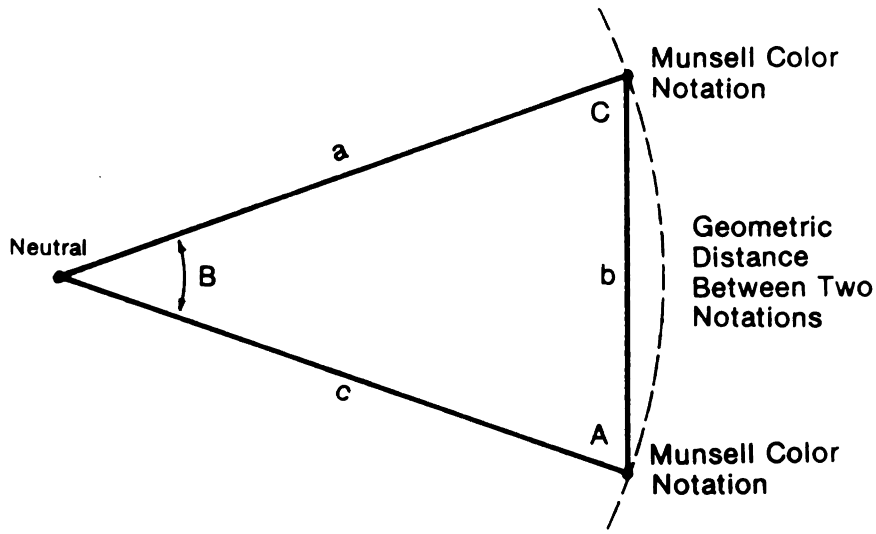
Table A.1 Three Color Difference Standards

	One Half Munsell Chip	ASTM Visual Precision	One NBS Unit
Hue	1.25	0.5	2.5 at /1
Value	0.5	0.1	0.1
Chroma	1.0	0.4	0.15

Interpreting the accuracy of the hue differences is complicated by the cylindrical organization of the Munsell system. The same-sized measured difference in Munsell hue increases in visual difference with increasing distance from the neutral center of the color solid. Thus, the difference between two hues with very low chromas (near the center of the cylinder) may be many degrees but they will look very similar. At a high chroma, however, the same difference in degrees of hue will cause a visually great difference in color. Value steps and chroma steps, on the other hand, are designed to be visually equal throughout the color solid.

Geometric distances between two hues correspond to approximate visual differences (in a simplistic treatment of Munsell space). Geometric distance between two hues can be calculated with the cosine law using the separation between the hues, in degrees, at a specific chroma level (Figure A.1). Godlove (1951) also applied the cosine law to Munsell color space to develope his color difference equation. The category "Hue (chroma corrected)" in Tables A.2 and A.3 lists the accuracy of the hue measurements weighted by the chroma of the corresponding original notation using the formula in Figure A.1. The use of this formula provides a rough compensation for the increase in visual difference with increasing chroma.

The cosine law formula (Figure A.1) is also used to compare hue differences to one NBS unit in Tables A.2 and A.3. If the hue difference of one NBS unit (2.5 hue steps, or 9 degrees, at chroma /1) is substituted into the formula derived in Figure A.1, the result is 0.16. This geometric distance should represent one NBS unit at all chroma levels if one assumes that visual spacing is roughly constant throughout the Munsell solid. The ASTM visual estimation limit and the NBS unit may be compared to provide an example of the relationship between a constant hue difference, which changes in visual size at different chroma levels, and a constant visual difference. When the ASTM limit of 0.5 hue step is substituted into the Figure A.1 formula, the result at chroma /1 is approximately 20



In the Munsell system:

B = hue difference in degrees

a = c = chroma

b = linear distance between two Munsell notations at A and C vertices

Cosine Law: $b^2 = c^2 + a^2 - 2ac(\text{COS B})$

Solve for b:

$$b = \sqrt{2c^2 - 2c^2(\text{COS B})}$$

$$b = \sqrt{2c^2(1 - \text{COS B})}$$

Figure A.1 Application of the Cosine Law to the Munsell System

percent of the NBS distance of 0.16 and 280 percent of 0.16 at chroma /14 (Figure A.2).

A.1.2

Results and Discussion

The two samples taken at the beginning of each measurement session have been combined for this discussion. The results of the measurement accuracy check are listed in Table A.2.

Table A.2 Measurement Accuracy

Percent of differences between measured and original notations that are equal to or closer than:

	One Half Munsell Chip	ASTM Visual Precision	One NBS Unit
Hue	83	49	53
Value	100	79	79
Chroma	96	75	46

Mean and standard deviation of differences between measured and original notations (n = 77):

	Mean	Standard Deviation
Hue	-0.32	0.92
Hue (chroma corrected)	0.19	0.16
Value	-0.02	0.07
Chroma	-0.07	0.42

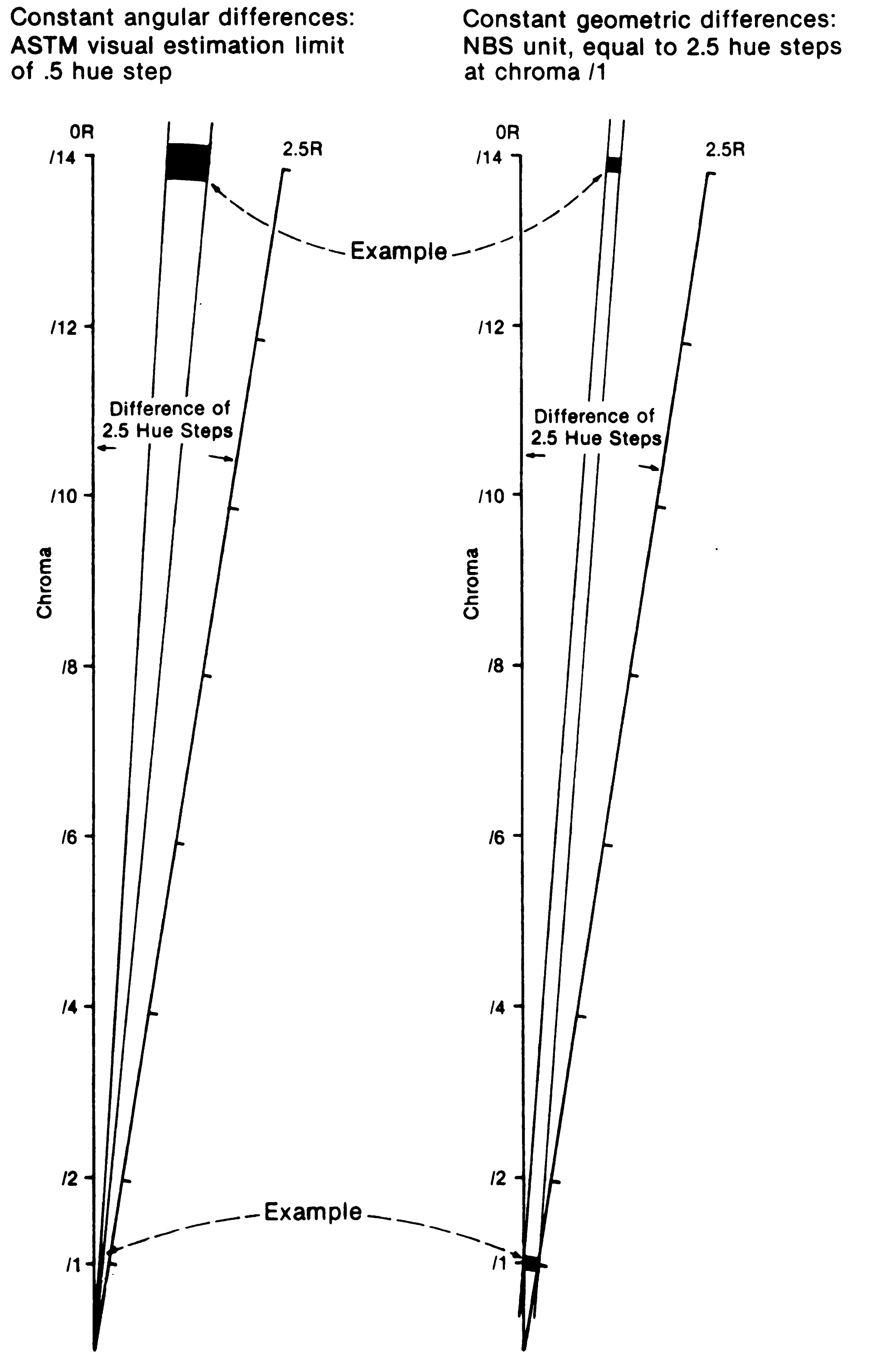


Figure A.2 Relationship Between Two Types of Hue Difference

Table A.2 presents the percentages of the notation measurements that fall within the limits described in Section A.1.1. The value and chroma measurements are almost all closer to the correct chip than any other chip and 79 and 75 percent respectively fall within the visual estimation limits set by ASTM (1980). The means of the differences between the measured and original notations are very small (between zero and -0.1) for both value and chroma. A negative value difference indicates that the original value is lower (darker) than the measured value. A negative chroma difference indicates that the original chroma is less (more neutral) than the measured chroma. The standard deviations of the differences are also small for value and chroma. Ninety-five percent of the measured notations are between -0.16 and 0.12 value step and between -0.91 and 0.77 chroma step of the original notations.

Of the hue differences, 83 percent are closest to the correct chip and 49 percent meet ASTM visual estimation accuracy. Fifty-three percent of the hue measurements are equal to or closer than one NBS unit. Thus, despite the noticeably lower agreement between original and measured hues (than for value or chroma), over half of the inaccuracies in the hue measurements would be commercially disregarded. The mean and standard deviation of the hue differences are −0.32 and 0.92, respectively. A negative hue difference indicates that the original hue is positioned counter-clockwise around the hue circuit from the measured hue. The hue difference mean is less than the ASTM visual estimation accuracy and, considering that there are 2.5 hue steps between pages in the Munsell Book of Color (1976), the standard deviation is about one third of the difference between pages.

A.2
Interpolation Accuracy Check

As described in Section 3.2.2, I interpolated the Munsell notations for all colors in the Kueppers Atlas from a sample of measured notations. The interpolation accuracy is discussed in the remainder of this Appendix.

A.2.1
Method

To check the accuracy of the interpolations, the notations for a sample of Atlas colors were measured and these measured notations were compared with the corresponding interpolated notations. Thirty-three colors were randomly selected from each of the four sets of color charts in the Kueppers Atlas (YMK, YCK, CMK, and YMC). Each color was measured with the spectrophotometer and the Munsell notation was generated by the Davidson software.

To examine the total difference between two notations, the modified form of the Godlove (1951) equation was used (Judd and Wyszecki 1975). This formula is based on the euclidian distance between two points with cylindrical coordinates and includes weightings on the hue, value, and chroma differences which compensate for the visual differences in the units of each dimension. The modified Godlove difference formula is as follows:

$$dE = fs \{ 2 (fh) (c_1) (c_2) [1 - \cos(3.6 (h_1 - h_2))] + (c_1 - c_2)^2 + [4(v_1 - v_2)]^2 \}^{.5}$$

Where:

dE is the Godlove difference

h_1 and h_2 are the hues of the two colors being compared

v_1 and v_2 are the values of the two colors

c_1 and c_2 are the chromas of the two colors

fh and fs are explained as follows:

> For a white to middle-gray surround, fh weights hue differences by twice the weight specified by the [original] Godlove formula. The factor fs expresses the reduction in perceived size of the color difference caused by use of a surround that differs

in color from the average of the two colors being compared (Judd and Wyszecki 1975, p. 316).

$$fh = \{4 / [3 - \cos(3.6(h_1 - h_2))]\}^2$$

$$fs = \frac{15 + [C_m{}^2 + 16(V_m - V_s)^2]^{.5}}{5 + [C_m{}^2 + 16(V_m - V_s)^2]^{.5}}$$

Where:

C_m is the mean chroma, $(c_1 - c_2) / 2$

V_m is the mean value, $(v_1 - v_2) / 2$

V_s is the Munsell value of a gray or white surround; a surround of value 5/ was used as a summary of the many value contexts in which two map colors might appear.

A.2.2

Results and Discussion

The results of comparing the random sampling of measured notations with the corresponding interpolated notations for the combined four sets of color charts are summarized in Table A.3.

Table A.3 Interpolation Accuracy

Percent of differences between measured and interpolated notations that are equal to or closer than:

	One Half Munsell Chip	ASTM Visual Precision	One NBS Unit
Hue	58	35	32
Value	83	34	34
Chroma	77	46	9

(column headings are described in Section A.1)

Mean and standard deviation of differences between measured and interpolated notations (n = 132):

	Mean	Standard Deviation
Hue	-1.40	6.22
Hue (chroma corrected)	0.69	0.87
Value	-0.07	0.40
Chroma	0.10	0.94
Godlove Difference	3.59	3.16

The sizes of the Godlove differences provide a summary of the accuracy of the interpolations of hue, value, and chroma because the formula comprises all three of the dimensions. When the differences between the measured and interpolated notations are substituted into the Godlove equation, the mean Godlove difference is 3.59 with a standard deviation of 3.16. For comparison, if the ASTM limits for visual estimations (0.5 hue,

0.1 value, and 0.4 chroma difference) are substituted into the Godlove formula (with an example value of 5/ and chroma of /8) the result is 1.34. If differences of one half the distance between adjacent Munsell chips in each dimension are substituted into the Godlove formula (using 5/ and /8), the result is 4.54. Therefore, the mean Godlove difference between the interpolated and measured notations is about three times larger than a difference of the ASTM limit in each dimension but about 80 percent of the size of a difference of one half chip in each dimension. As another comparison, the Godlove differences in the measurement accuracy check summarized in Table A.2 have a mean of 1.02 and a standard deviation of 0.60. These are both less than one-third of the size of the Godlove differences that summarize the interpolation accuracy.

This inaccuracy in the interpolations is also seen in the percentages of differences that fall below the three standards for comparison (Tables A.1 and A.3). Eighty-three percent of the value differences and 77 percent of the chroma differences are closer than or equal to half the difference between adjacent Munsell chips in the <u>Munsell Book of Color</u> (1976). The differences between interpolated and measured hues reveal less accuracy along that dimension; 58 percent are within one half chip. The change in the visual

importance of the hue differences with chroma interferes with the interpretation of this statistic. Thirty-two percent are within one NBS unit, which indicates that almost one-third of the interpolations are very accurate. This accuracy rate is about two-thirds of the 53 percent that are within one NBS unit for the instrument accuracy check (Table A.2).

Three factors contribute to the inaccuracies in the interpolations. These are the initial measurements, the use of linear interpolation, and the quality of the printing in the Kueppers Color Atlas (1982).

Inaccuracies in the initial measurements resulted from imperfect accuracy of the measurements from the instrument and software combination. These were discussed in Section A.1.2.

The use of linear interpolation caused inaccuracy when the change between two known notations was not linear. In an example sequence of four colors labeled 3030, 3040, 3050, and 3060, the Munsell notations for 3030 and 3060 are known. Linear interpolation assigns equal differences from 3030 to 3040, 3040 to 3050, and 3050 to 3060. The actual differences may, however, be greater between 3030 and 3040 than between 3050 and 3060. Since the interpolations of later passes

are based on these interpolated notations, this inaccuracy affects later interpolations as well (the notations of colors that do not fall between measured colors are interpolated from two previously interpolated color notations). The impact this type of error has on the notation accuracy is limited, however, because only two or three notations are interpolated between known notations. An alternative interpolation strategy based on a hypothesized consistent trend in the differences between consecutive colors was not investigated. Given the accuracy of the initial measurements, however, this precision would be unwarranted.

Quality of printing contributed to the inaccuracies because the printing of the relatively inexpensive Color Atlas (Kueppers 1982) was not tightly controlled. The difference in cost with increased accuracy is reflected by the difference in price between the Kueppers Atlas, Pantone charts, and ByChrome charts. The Kueppers Atlas costs $10.95 (1984), and the Pantone Four-Color Process Guide - 2, which shows 13,000 colors on coated and uncoated paper, costs $145.00 (1984). Charts that accurately represent the color printing of a specific printer may be produced using the Color Selector Kit, which is available from the ByChrome Company. This kit is a set of negatives for printing process color charts with one's own papers, presses, and inks. Fifteen

press plates are needed to print 132 charts that show all combinations of the 12 percentages of the process inks. The kit costs $41.90 (1984), but the cost of labor, plates, press runs, and paper must also be considered in the price of these charts. They would be much more expensive than either the Kueppers or Pantone charts.

The interpolation check provides a framework in which to judge the level of accuracy of the interpolations. The interpolated Munsell notations are not exact. The inaccuracies in the interpolations will cause inaccurate assignments of process color specifications to the Munsell chips in the next step of the analysis. About 40 percent of the hue notations and about 20 percent of the value and chroma notations will be off by more than one half the difference between adjacent Munsell chips. Nevertheless, it seemed reasonable to use the interpolated notations as a "first cut" in locating printed-color approximations to Munsell chips. The interpolations allow an objective matching process that should at least yield a fair proportion of colors in the neighborhood of close matches.

Appendix B

PROCESS COLOR SPECIFICATIONS FOR COLOR MATCHES

Table B.1 Process Colors Matched Using the Color Measurements

The process colors matched in Chapter 3 with the Munsell Student Set (1984) charts are listed in this table. Each hue chart is labeled with a letter and number designation. For example, 5 R is the red chart in the set. The value notations are assigned to the rows and the chroma notations head the columns for each chart.

At each value and chroma combination there are two process color specifications: the top specification is the matched color that contains a percentage of black and the bottom specification contains only percentages of yellow, magenta, and cyan process inks. Each process color specification is made up of four characters. The characters specify the percentages of yellow, magenta, cyan, and black process ink in that order (YMCK). A '0' represents 0 percent, '1' is 10 percent, '2' is 20 percent, and this pattern continues to '9' for 90 percent. An 'X' represents 100 percent or solid ink. For example, '2X03' represents 20 percent yellow, 100 percent magenta, 0 percent cyan, and 30 percent black. A '-' indicates that no process color met the criteria for matching the Munsell color (see Section 3.2.3).

Table B.1 (continued)

5 R

	/2	/4	/6	/8	/10	/12	/14
8/	- -	2500 2500					
7/	- -	2501 -	- -	3500 3500	- -		
6/	2504 -	- -	3502 3520	3501 3510	3600 3600	4700 4700	
5/	0236 -	- 4540	3503 -	4703 4620	4702 4710	5901 5801	5900 5900
4/	0237 5650	3505 7850	4605 5740	5804 7940	5903 6930	6X03 7X20	- 6X10
3/	3508 9980	4607 XX80					
2/	280X -						

5 YR

	/2	/4	/6	/8	/10	/12
8/	- -	- -	3300 3300	- -		
7/	- -	3301 -	- 5410	5400 5400	6400 6400	7500 7500
6/	- -	3303 -	5402 5420	6502 9520	7501 -	X601 -
5/	3305 5550	5404 -	6503 X640	7503 X630		
4/	3307 X880	7505 X760	8505 -			
3/	6508 -					

Table B.1 (continued)

5 Y

	/2	/4	/6	/8	/10	/12
8/	2401	1013	2023	5101	X200	9200
	-	-	5210	8210	X200	9200
7/	1014	2024	5102	7202	9202	
	-	4220	7320	X320	-	
6/	3104	4104	6203	8203		
	-	8440	X440	-		
5/	3106	6205	8205			
	-	6440	-			
4/	5207	8206				
	X780	-				
3/	2019					
	-					

5 GY

	/2	/4	/6	/8	/10
8/	-	3020	4020	5020	9030
	-	3020	4020	5020	9030
7/	-	4022	5022	7031	
	-	4130	5130	8140	
6/	-	4023	5023	8032	
	-	5240	8250	X250	
5/	3026	5035	6035	X044	
	-	8460	-	-	
4/	3027	5027			
	9680	-			
3/	4028				
	-				

Table B.1 (continued)

5 G

	/2	/4	/6	/8	/10
8/	-	-	-		
	-	-	-		
7/	-	1005	2105	-	
	-	3040	4050	-	
6/	1205	1006	2007	5060	7080
	-	4250	5160	5060	7080
5/	3045	2108	5062	6071	
	5460	5360	6370	8290	
4/	1009	4086	5085		
	6570	95X0	94X0		
3/	3058	50X8			
	-	-			
2/	4079				
	-				

5 BG

	/2	/4	/6	/8
8/	-	-		
	1220	-		
7/	-	-	-	-
	-	-	-	2350
6/	-	-	3061	3060
	-	3260	3170	3060
5/	-	2065	3062	4091
	4460	4380	4290	41X0
4/	2086	3095	40X4	
	5570	5490	54X0	
3/	2088	-		
	7790	76X0		
2/	2099			
	-			

Table B.1 (continued)

5 B

	/2	/4	/6	/8
8/	-	-		
	-	-		
7/	-	-	-	1060
	-	-	-	1060
6/	-	-	-	1071
	-	-	-	1070
5/	-	-	1074	1082
	3470	-	-	-
4/	-	-	10X5	
	4580	3490	-	
3/	-	-		
	7890	57X0		
2/	-			
	-			

5 PB

	/2	/4	/6	/8	/10
8/	-	0130			
	-	0130			
7/	0142	-	0260	-	
	-	-	0260	-	
6/	0143	-	0261	0360	-
	-	1450	0250	0360	-
5/	0145	0264	0352	0361	0390
	-	-	-	0380	0390
4/	0266	0355	0463	0482	05X0
	4680	-	2690	-	05X0
3/	0357	0476	0595	0593	
	5780	37X0	-	-	
2/	0369	05X8			
	-	-			

Table B.1 (continued)

5 P

	/2	/4	/6	/8	/10
8/	0110	-			
	0110	-			
7/	0132	0330	0330		
	-	0330	0330		
6/	0134	0331	0440	0440	
	-	-	0440	0440	
5/	-	-	0441	0550	-
	-	-	2650	0550	-
4/	0256	-	0543	0652	0660
	-	3670	2760	1760	0660
3/	0338	0556	0764	0863	
	6980	4880	3990	1980	
2/	0559	0777	0886		
	7X90	4X90	3X90		

5 RP

	/2	/4	/6	/8	/10	/12
8/	0101	0200	0300			
	0240	0200	0300			
7/	0103	0202	0301	0400		
	-	2520	-	0400		
6/	0104	0303	0403	0502	0501	
	-	-	2620	-	1610	
5/	1405	0404	0504	0603	0602	0720
	-	-	-	2730	1720	0720
4/	0307	0406	0605	0714	0813	
	-	3650	3750	2840	2940	
3/	0408	0617	0826			
	6870	4860	4960			
2/	041X	0948				
	-	6X70				

Table B.2 <u>Process Colors Matched with the Munsell Colors: Percentages for Each Ink Shown Separately</u>

These miniature representations of the Munsell chart arrangements show the percentages of the individual inks for each chart. The percentages of yellow, magenta, cyan, and black in each color are separated from each other and are presented for the computer matches (Chapter 3) and final specifications (Chapter 4 and Appendix C).

The location of a percentage indicates the value and chroma of the color in which it is included:

```
Chroma
/2 /4 /6 /8 /10 /12 /14

Value
  8/    21
  7/    32100
  6/    432100
  5/    5432100
  4/    6543210
  3/    76
  2/    8
```

The characters used to represent the percentages of the inks are defined as follows:

Character:	0	0̲	1	1̲	2	2̲	3	4	5	6	7	8	9	X	-
Percentage:	0	5	10	15	20	25	30	40	50	60	70	80	90	100	no match

Table B.2 (continued)

Yellow	Magenta	Cyan	Black
5 R			
Computer			
-2	-5	-0	-0
-2-3-	-5-5-	-0-0-	-1-0-
2-3334	5-5567	0-0000	4-2100
0-34455	2-57799	3-00000	6-33210
034556-	25689X-	300000-	755433-
34	56	00	87
2	8	0	X
Final			
00	01	00	21
00012	12345	00000	32100
001234	234567	000000	432100
0123456	3456789	0000000	5432100
1234567	456789X	0000000	6543210
23	56	00	76
3	6	0	8
5 YR			
Computer			
--3-	--3-	--0-	--0-
-3-567	-3-445	-0-000	-1-000
-3567X	-34556	-00000	-32211
3567	3455	0000	5433
378	355	000	755
6	5	0	8
Final			
1234	0112	0000	2100
234567	112345	000000	321000
345678	123456	000000	432100
4567	2345	0000	5432
567	345	000	654
6	4	0	7

Table B.2 (continued)

Yellow	Magenta	Cyan	Black
5 Y			
Computer			
2125X9	400122	012000	133100
12579	00122	12000	44222
3468	1122	0000	4433
368	122	000	655
58	22	00	76
2	0	1	9
Final			
02468X	000001	000000	211000
13579	00001	00000	32110
2468	0001	0000	4321
357	001	000	543
46	01	00	65
5	1	0	7
5 GY			
Computer			
-3459	-0000	-2223	-0000
-457	-000	-223	-221
-458	-000	-223	-332
356X	0000	2334	6554
35	00	22	77
4	0	2	8
Final			
45678	00000	01123	21000
5678	0000	1123	3210
6789	0000	1234	4321
789X	0000	2345	5432
89	00	34	65
9	0	4	7

Table B.2 (continued)

Yellow	Magenta	Cyan	Black
5 G			
Computer			
---	---	---	---
-12-	-01-	-00-	-55-
11257	20000	00068	56700
3256	0100	4067	5821
145	000	088	965
35	00	5X	88
4	0	7	9
Final			
123	000	123	100
2345	0000	2345	2100
34567	00000	34567	32100
4567	0000	4567	4321
567	000	567	543
67	00	67	65
7	0	7	7
5 BG			
Computer			
--	--	--	--
----	----	----	----
--33	--00	--66	--10
-234	-000	-669	-521
234	000	89X	654
2-	0-	8-	8-
2	0	9	9
Final			
01	00	12	10
1122	0000	2345	2100
1223	0000	3456	3210
2234	0000	4567	4321
234	000	567	543
34	00	67	65
4	0	7	7

Table B.2 (continued)

5 B

Computer

Yellow	Magenta	Cyan	Black
--	--	--	--
---1	---0	---6	---0
---1	---0	---7	---1
--11	--00	--78	--42
--1	--0	--X	--5
--	--	--	--
-	-	-	-

Final

Yellow	Magenta	Cyan	Black
00	00	12	10
0000	0000	2345	2100
0000	0000	3456	3210
0001	0000	4567	4321
001	000	567	543
01	00	67	65
1	0	7	7

5 PB

Computer

Yellow	Magenta	Cyan	Black
-0	-1	-3	-0
0-0-	1-2-	4-6-	2-0-
0-00-	1-23-	4-66-	3-10-
00000	12333	46569	54210
00000	23445	6568X	65320
0000	3455	5799	7653
00	35	6X	98

Final

Yellow	Magenta	Cyan	Black
00	00	12	10
0000	0112	2345	2100
00000	11223	34567	32100
00000	12234	45678	43210
00000	22345	56789	54321
0000	2345	6789	6543
00	34	78	76

Table B.2 (continued)

Yellow	Magenta	Cyan	Black
5 P			
Computer			
0-	1-	1-	0-
000	133	333	200
0000	1344	3344	4100
--00-	--45-	--45-	--10-
0-000	2-566	5-456	6-320
0000	3578	3566	8643
000	578	578	976
Final			
00	01	01	10
000	123	112	210
0000	2345	1223	3210
00000	34567	22345	43210
00000	45678	23456	54321
0000	5678	3456	6543
000	678	456	765
5 RP			
Computer			
000	123	000	100
0000	1234	0000	3210
00000	13455	00000	43321
100000	445667	000002	544320
00000	34678	00011	76543
000	468	012	876
00	49	14	X8
Final			
000	123	000	100
0000	2345	0000	2100
00000	34567	00001	32100
000000	456789	000112	432100
00000	56789	00112	54321
000	678	011	654
00	78	11	76

Appendix C

FINAL PRINTED CHARTS AND PROCESS COLOR SPECIFICATIONS

This Appendix presents the pages of the booklet used in the interviews (Chapter 5). If you are looking at black and white copies of these charts, and would like to see the color versions, contact me (Cynthia Brewer) through the Department of Geography at Michigan State University. I will send you a set of printed charts, if the supply is not exhausted.

Process Color Charts Based on the Munsell Color System

by

Cynthia A Brewer
Department of Geography
Michigan State University
East Lansing, Michigan
48824

The tint-screen percentages of the process inks in the chart colors are listed on the left side of each page in this booklet. Each open square corresponds to a color square on the adjacent chart and contains four numbers which represent:

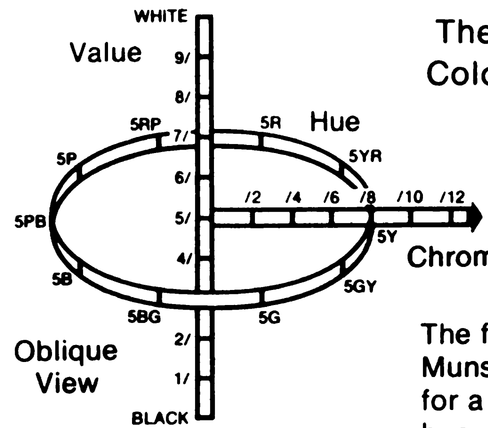
% yellow	50	30	% magenta
% cyan	00	20	% black

00 = 0%, 05 = 5%,
10 = 10%, . . . 80 = 80%,
90 = 90%, and 99 = 100%

The perceptual dimensions of color from the Munsell system (right) are used to organize the colors on the printed charts in this booklet. On each printed chart, hue is relatively constant, value changes vertically, and chroma changes horizontally. The labels 'target hue', 'target value', and 'target chroma' are used because the printed charts do not match the painted Munsell charts exactly. The printed charts have the same arrangements of colors as the ten hue charts in the Munsell Student Set*. By approximating these painted Munsell charts with specified percentages of the process inks, the Munsell system is made accessible for planning printed color schemes.

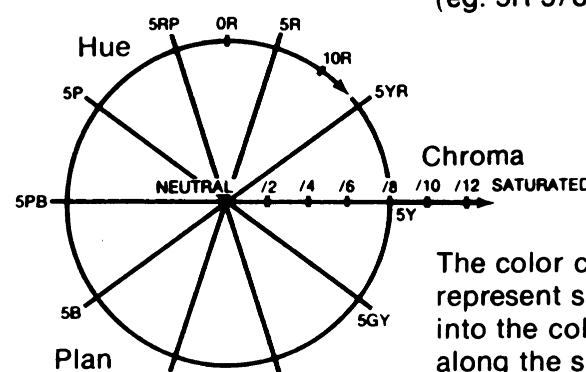
*Munsell Student Sets may be purchased from:
Munsell Color
Macbeth division of Kollmorgen Corp.
2441 North Calvert Street
Baltimore, Maryland 21218

The Munsell Color System



Oblique View

The form of the Munsell notation for a color is: hue value/chroma (eg. 5R 5/8)



Plan View

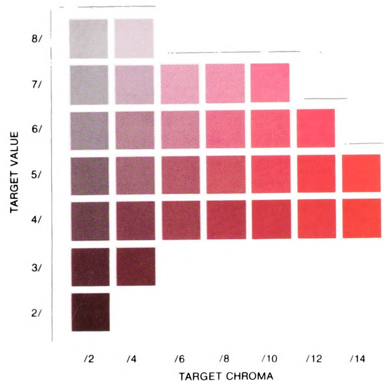
The color charts represent slices into the color solid along the spokes in this diagram.

Red

00 05 00 20	00 10 00 10					
00 10 00 30	00 20 00 20	05 30 00 10	10 40 00 05	20 50 00 00		
00 20 00 40	05 30 00 30	10 40 00 20	20 50 00 10	30 60 00 05	40 70 00 00	
05 30 00 50	10 40 00 40	20 50 00 30	30 60 00 20	40 70 00 10	50 80 00 05	60 90 00 00
10 40 00 60	20 50 00 50	30 60 00 40	40 70 00 30	50 80 00 20	60 90 00 10	70 99 00 05
20 50 00 70	30 60 00 60					
30 60 00 80						

Y M
C K

TARGET HUE 5 R

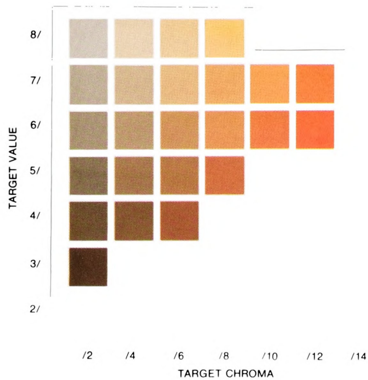


Yellow-Red

10 05 00 20	20 10 00 10	30 15 00 05	40 20 00 00		
20 10 00 30	30 15 00 20	40 20 00 10	50 30 00 05	60 40 00 00	70 50 00 00
30 15 00 40	40 20 00 30	50 30 00 20	60 40 00 10	70 50 00 05	80 60 00 00
40 20 00 50	50 30 00 40	60 40 00 30	70 50 00 20		
50 30 00 60	60 40 00 50	70 50 00 40			
60 40 00 70					

Y M
C K

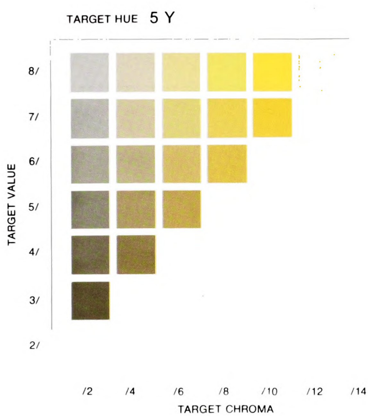
TARGET HUE 5 YR



Yellow

05 00 00 20	20 00 00 15	40 00 00 10	60 00 00 05	80 05 00 00	99 10 00 00
10 00 00 30	30 00 00 20	50 00 00 15	70 05 00 10	90 10 00 05	
20 00 00 40	40 00 00 30	60 05 00 20	80 10 00 15		
30 00 00 50	50 05 00 40	70 10 00 30			
40 05 00 60	60 10 00 50				
50 10 00 70					

Y M
C K

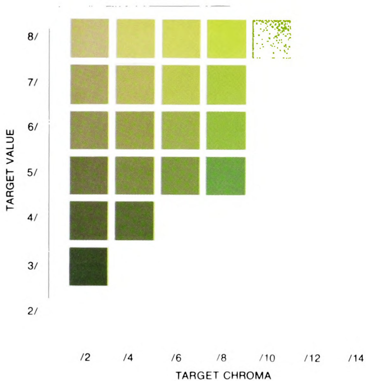


Green-Yellow

40 00 05 20	50 00 10 10	60 00 15 05	70 00 20 00	80 00 30 00
50 00 10 30	60 00 15 20	70 00 20 10	80 00 30 05	
60 00 15 40	70 00 20 30	80 00 30 20	90 00 40 10	
70 00 20 50	80 00 30 40	90 00 40 30	99 00 50 20	
80 00 30 60	90 00 40 50			
90 00 40 70				

Y M
C K

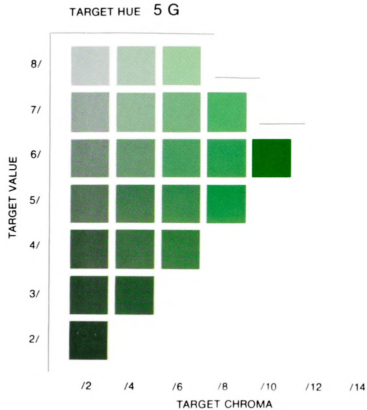
TARGET HUE 5 GY



Green

10 00 10 10	20 00 20 05	30 00 30 00		
20 00 20 20	30 00 30 10	40 00 40 05	50 00 50 00	
30 00 30 30	40 00 40 20	50 00 50 10	60 00 60 05	70 00 70 00
40 00 40 40	50 00 50 30	60 00 60 20	70 00 70 10	
50 00 50 50	60 00 60 40	70 00 70 30		
60 00 60 60	70 00 70 50			
70 00 70 70				

Y M
C K

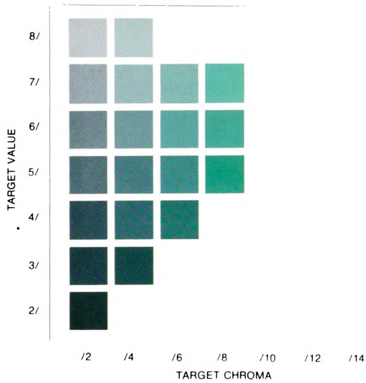


Blue-Green

05 00 10 10	10 00 20 05		
10 00 20 20	15 00 30 10	20 00 40 05	25 00 50 00
15 00 30 30	20 00 40 20	25 00 50 10	30 00 60 05
20 00 40 40	25 00 50 30	30 00 60 20	40 00 70 10
25 00 50 50	30 00 60 40	40 00 70 30	
30 00 60 60	40 00 70 50		
40 00 70 70			

Y M
C K

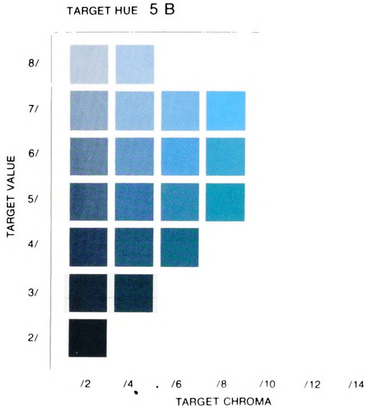
TARGET HUE 5 BG



Blue

00 00 10 10	00 00 20 05		
00 00 20 20	00 00 30 10	00 00 40 05	00 00 50 00
00 00 30 30	00 00 40 20	00 00 50 10	05 00 60 05
00 00 40 40	00 00 50 30	05 00 60 20	10 00 70 10
00 00 50 50	05 00 60 40	10 00 70 30	
05 00 60 60	10 00 70 50		
10 00 70 70			

Y M
C K

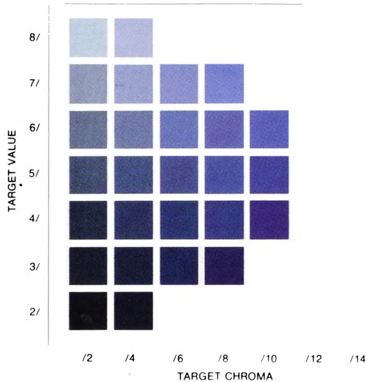


Purple-Blue

00 00 10 10	00 05 20 05			
00 05 20 20	00 10 30 10	00 15 40 05	00 20 50 00	
00 10 30 30	00 15 40 20	00 20 50 10	00 25 60 05	00 30 70 00
00 15 40 40	00 20 50 30	00 25 60 20	00 30 70 10	00 40 80 05
00 20 50 50	00 25 60 40	00 30 70 30	00 40 80 20	00 50 90 10
00 25 60 60	00 30 70 50	00 40 80 40	00 50 90 30	
00 30 70 70	00 40 80 60			

Y M
C K

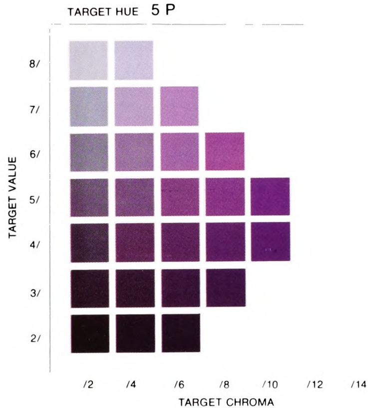
TARGET HUE 5 PB



Purple

00 05 05 10	00 10 10 05			
00 10 10 20	00 20 15 10	00 30 20 05		
00 20 15 30	00 30 20 20	00 40 25 10	00 50 30 05	
00 30 20 40	00 40 25 30	00 50 30 20	00 60 40 10	00 70 50 05
00 40 25 50	00 50 30 40	00 60 40 30	00 70 50 20	00 80 60 10
00 50 30 60	00 60 40 50	00 70 50 40	00 80 60 30	
00 60 40 70	00 70 50 60	00 80 60 50		

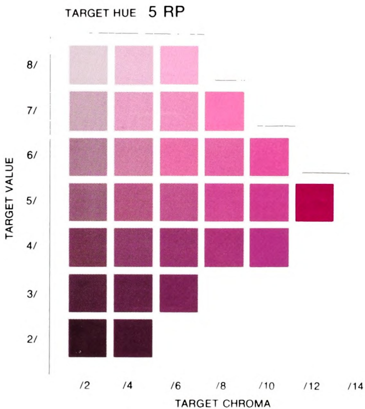
Y M
C K



Red-Purple

00 10 00 10	00 20 00 05	00 30 00 00			
00 20 00 20	00 30 00 10	00 40 00 05	00 50 00 00		
00 30 00 30	00 40 00 20	00 50 00 10	00 60 05 05	00 70 10 00	
00 40 00 40	00 50 00 30	00 60 05 20	00 70 10 10	00 80 15 05	00 90 20 00
00 50 00 50	00 60 05 40	00 70 10 30	00 80 15 20	00 90 20 10	
00 60 05 60	00 70 10 50	00 80 15 40			
00 70 10 70	00 80 15 60				

Y M
C K



Appendix D

INTERVIEW PARTICIPANTS AND MATERIALS

A list of the cartographic designers interviewed and the information they recieved in the mail before the interviews are provided in this Appendix, which supplements Chapter 5.

The interviewed cartographers were referenced, with their permission, during the discussion of the results in Chapter 5. The people that were interviewed are:

Academic

Onno Brouwer, Associate Director, Cartography Lab, Department of Geography, University of Wisconsin - Madison

Henry Castner, Professor, Department of Geography, Queen's University

Gregory Chu, Cartography Laboratory, Department of Geography, University of Minnesota

Richard Groop, Associate Professor, Department of Geography, Michigan State University (pilot interview)

A. Jon Kimerling, Associate Professor, Department of Geography, Oregon State University

Joseph Wiedel, Associate Professor, Department of Geography, University of Maryland

Government

Frederick Broome, Chief, Mapping Operations Branch, Geography Division, U.S. Bureau of the Census

Ted Koch, Mapping Technologist, Mapping Services Bureau, New York State Department of Transportation

Carolyn Weiss, Research and Development Officer, Geocartographics Division, Statistics Canada

James Wray, Research Geographer (retired), National Mapping Division, U.S. Geological Survey

A graphic designer at the U.S. Central Intelligence Agency (name withheld by request)

Private

Chris Arvetis, Vice President, Creative Director, Rand McNally & Company

Herb Heidt, President, Map Works

Patricia Caldwell Lindgren, President, Caldwell and Associates

Barbara Petchenik, R.R. Donnelley & Sons Company

Alfred Zebarth, Assistant Supervisor, Cartographic Division, National Geographic Society

November Date, 1985

Name
Address
Phone Number

LETTER

Dear Name:

I am working on my master's thesis with Prof. Judy Olson. The enclosed booklet of printed color charts is a product of my thesis research, and I would like your assistance in evaluating the potential usefulness of the charts. Although the development of the charts themselves was the major goal of my research, I am also investigating the use of color charts in general by cartographic designers and the reactions of cartographic designers to the enclosed charts. Your insight will provide me with information for this portion of my thesis.

I would like to interview you by telephone and I have attached a page of questions that will form the basis of the interview. There is no need for a written response to these questions, but I do need to know the following (which can be answered on the enclosed postcard):

1) Are you willing to be interviewed?

2) May I tape the phone call?
This is to avoid my having to take notes and should help keep the interview short (about fifteen minutes).

3) May I paraphrase and reference you in my thesis?
Any "direct quotes," should I wish to use them, would be sent to you for editing, since statements made in conversation are not always worded as one would want to see them in print.

Assuming your response is positive, I would like to set a tentative date of Day, Date, Time for the interview, and I will use the number listed with your address at the beginning of this letter. If this suggested date, time, or phone number are inconvenient for you, please use the space on the postcard to alter these specifics.

I look forward to talking with you.

Sincerely Yours,

Cynthia Brewer

Interview Questions

1. How many color maps were you involved in designing in the last two years and what percentage is this of all the maps you were involved in designing in those two years?

2. What method do you use to specify printed colors on maps?

3. Do you have color charts available to you?

If yes...

3.1 Were your charts developed within your own organization, acquired as negatives to be printed, or acquired as finished printed charts?

3.2 Do you use color charts while selecting map colors?

If yes...

3.2.1 Please name and describe the color charts you use.

3.2.2 How do you use color charts: do you look for schemes in the chart colors, check the specifications of colors that are already decided, combine these approaches, or use the charts in a different manner?

3.2.3 What problems do you have with the use of your color charts?

3.2.4 Are you generally satisfied with the color charts you use?

4. The enclosed booklet contains printed approximations of Munsell color charts. Were you previously familiar with the Munsell color system?

5. Have you ever used the Munsell system for color selection, color description, or any other purpose?

6. Do you see potential uses for these printed Munsell charts when selecting map colors? Please elaborate on your answer.

POSTCARD TO RETURN

<u>Name</u>

Cynthia Brewer
Department of Geography
315 Natural Science Building
Michigan State University
East Lansing, Michigan
48824-1115

Front

1) Are you willing to be interviewed? _____

2) May I tape the phone call? _____

3) May I paraphrase and reference you in my thesis? _____

4) Please alter my interview arrangements (listed below) if they are inconvenient:

____

<u>Day, Date, Time, Phone Number</u>

Back