THE UNIVERSITY OF ALBERTA

Colour Map Production and Desktop Publishing

by

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A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF
Master of Science

Department of Geography

EDMONTON, ALBERTA
Spring, 1989

ISBN 0-315-52986-5

THE UNIVERSITY OF ALBERTA

RELEASE FORM

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TITLE OF THESIS Colour Map Production and Desktop Publishing

DEGREE FOR WHICH THESIS WAS PRESENTED Master of Science

YEAR THIS DEGREE GRANTED 1989

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ABSTRACT

Digital techniques employed in the generation of cartographic colour separation negatives have been, for the most part, limited to large scale production facilities. Micro computers, coupled to laser printers using graphic languages called Page Description Languages (PDLs) offer a small scale production alternative. A complete map production demonstration was accomplished, in part, using the PostScript PDL. A 45-colour palette was developed for use with classed raster data and specific palette colours were selected to display a raster choropleth map of median household income (1981) for the city of Edmonton. Colour separations for the Edmonton map and the colour palette were produced at 300 dots per inch (dpi) and at 1270 dpi. The 300 dpi images were generated with a 60 line per inch (lpi) screen setting as black and white positives; the positives were photographed onto lithographic film to create negatives. The 1270 dpi images were generated directly on lithographic film on a Linotronic L300 laser printer at a screen frequency of 127 lpi. Composite colour proofs were generated for all four sets of negatives. Vector colour separations were generated as paper positives at 300 dpi but not used to create negatives or colour proofs. The1270 dpi images displayed a finer resolution and gave a better rendition of colour than the 300 dpi images, however, for proofing or research analysis a resolution of 300 dpi produces a useful map. The raster images were produced with a less complicated PostScript code but required more memory, printing time, and a more complex colour specification procedure than the vector images.

ACKNOWLEDGEMENTS

I wish to thank my supervisor, Ron Eyton, for his skillful guidance, support, and encouragement. Thanks also to my committee members, John Hodgson and Peter Bartl, for their interest and constructive criticism.

The technical assistance so patiently and professionally provided by Dan Hemenway and Randy Pakan's quality darkroom work were both most appreciated.

Particular thanks to Lauren Crooks for her interest and skillful editing; thanks to my friends in the Department of Geography who's interest and concern was always welcome.

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I. INTRODUCTION

The printing, graphic arts, and publishing industries are adopting digital processing techniques as a substitute for traditional photographic methods of production. These digital techniques are now being employed by small production shops through the use of powerful, inexpensive desktop publishing systems (available only within the last few years) that can electronically compose and print documents. (Dunn and Gantz, 1986; Goodstein, 1987). Desktop publishing not only offers a new set of computing tools but an alternative approach for map compilation and production. Examining both the limitations and capabilities of desktop publishing is necessary as this technology becomes more powerful, more widespread, and used more by practicing cartographers. The overall objective of this research is to evaluate the role of desktop publishing in cartographic production.

The first half of this research compared photomechanical and desktop publishing production techniques and addressed the following technical issues in colour production:

1. processes for creating photographic and digital halftones.
2. limitations of digital halftones.
3. the necessity of screen rotation in photographic and digital colour production.
4. production of both digital and photographic colour separations.

The second half of this research examined the positive and negative aspects of a digital map production demonstration which started with the development of the digital data bases and was carried through to the colour proofing of the printing separations. The specific objectives involved in this portion of the research were:

1. to examine two approaches (vector and raster) for the generation of a cartographic data base.
2. to compare the methods for generating digital colour separation images using the Page Description Language (PDL) called PostScript.
3. to examine the methods of producing colour maps on two different output devices, one at a resolution of 300 dots per inch (dpi) and the other at a resolution of 1270 dpi.
4. to evaluate the overall quality of these maps produced at the two different resolutions.

Desktop publishing technology will affect how digital geographical information is displayed and mass produced in hardcopy form. The growing availability and use of gridded geographical data bases (such as satellite data or digital elevation models) increases the need for systems with the means to process and output hard copy images from such data. Until very recently, the generation of hardcopy has been confined to output devices such as inkjet printers, film writers, and electrostatic plotters. Desktop publishing technology provides access to inexpensive but high quality output devices in the form of laser printers. Desktop publishing will impact on the printing of maps and diagrams for text and journal publication in both the academic and the nonacademic environment. The use of sophisticated drawing programs and desktop scanners (part of the desktop publishing technology) will also significantly alter the methods of map compilation, however this thesis only examined how this technology will effect the cartographic production process.

II. PHOTOGRAPHIC PRODUCTION CARTOGRAPHY

PHOTOGRAPHIC HALFTONING

A halftone on a printed map is a level of grey created by a pattern of black ink dots of varying size. Virtually all commercial printing processes are only able to set down a solid dot of ink and must employ halftones to reproduce continuous tone images. No actual grey exists in a halftone image but because the pattern of dots is very fine and closely spaced, the eye blends the dots together to create the illusion of a continuous tone. A conventional photographic halftone negative is created by photographically copying an original continuous tone image through a halftone screen onto high contrast lithographic film. The halftone screen consists of a fine mesh which acts like a series of very small pinhole camera lenses to break up the original image. Each opening in the halftone screen focuses a portion of the image onto the film as a very small dot; the size of the dot is proportional to the density of the image at a particular point. An infinite number of dot sizes are possible and because the screen consists of a very fine grid of openings, the resultant film negative is a crisp high quality halftoned copy of the original image (Colgi, 1980; Keates, 1980). The number of dots per linear measure (dots/in, dots/cm) of a halftone screen is the screen ruling or frequency and determines the coarseness or resolution of an image; typical applications for different screen rulings are shown in Table 1. Cartographers rarely make halftoned copies from continuous tone originals but usually create halftone images directly using tint screens.

COLOUR SYNTHESIS

The subtractive and additive colours (Table 2) form the basis for all colour reproduction. Additive primary colours (as emitted light) can be combined in varying amounts to create a desired hue (colour television) while the subtractive primaries (in the form of inks, pigments, and dyes) can be overlayed on top of one and other to create a desired hue (four colour printing, oil painting, colour photography). Four related concepts in colour production are discussed in this section: 1. the use of halftones in colour production, 2. the colour separation process, 3. the black printer, and 4. screen rotation.

Halftone dots are used to print colour tints. The four process colours: cyan, magenta, yellow, and black (the addition of black is explained later) are overlayed on top of each other in various amounts to achieve a desired hue. The amount or density of each process colour (ink) used to print an image is expressed as a percentage of the

TABLE 1.
Typical Printing Applications for Selected Halftone Screen Rulings

Screen Rulings (lpi)	Applications
65, 85	daily newspapers
100, 120	high quality newspapers, poor quality books and magazines
133, 150	high quality books and magazines, map production
200+	very high quality art reproductions

The screen ruling used (in the printing process) depends on the type of paper used and the kind of printing process employed (offset lithography, letterpress etc.) .
SOURCE: Adapted from: Bruno,1983; Keates,1980; Wesner,1974.

TABLE 2.
Additive and Subtractive Colour Mixing

Additive Mixing (light)	Subtractive Mixing (inks)
B+G=C (-R)	M+Y=R (-G,-B)
R+B=M (-G)	C+Y=G (-R,-B)
G+R=Y (-B)	C+M=B (-R,-G)
B+G+R=white	C+M+Y=black (-R,-G,-B)

R=red
G=green
B=blue

C=cyan
M=magenta
Y=yellow

The letter(s) in parentheses show the colour(s) missing from the combination of two colours in either mixing system.
SOURCE: Modified from Eyton, 1984.

amount of white area covered by the dots of ink. Differences in percentage are created by increasing or decreasing the size of the halftone dots for each of the process colours such that a density of 100% (large overlapping dots) is a solid colour and a density of 10% is composed of small evenly spaced halftone dots with 90% of the white space showing. For example, a high percentage of magenta and yellow (large overlapping dots) results in a more red looking image while a high percentage of cyan and magenta (large overlapping dots) creates a more blue looking image.

Colour separation involves decomposing an original colour image into the three additive colour primaries. The additive colour components of the image are derived by photographing (or electronically scanning) the original image using additive band-pass filters; this process is illustrated in Figure 1 (Shapiro, 1973). Instead of starting with a full colour image, cartographers usually create colour separation negatives directly from black and white copy.

The use of black as a fourth colour in the printing process is to compensate for the impurity of the cyan, magenta and yellow inks. These process inks do not perfectly absorb or transmitt the additive primaries. For example, magenta ink should transmit blue and red light while absorbing green light; however, magenta ink will actually transmit some green light and absorb some blue and red light. In a similar manner, cyan and yellow inks are not perfect absorbers and transmitters. Due to this imperfection of the inks, the shadows tend to be a "muddy brown" rather than a neutral grey. The use of a black printer insures good reproduction of the neutrals and is cost effective because of savings on the more expensive coloured inks (Bruno, 1980; Rocarp, 1980).

The halftone screens for each process colour are rotated (cyan 105°, magenta 75°, yellow 90°, black 45°) to avoid producing an unwanted moire pattern on the separation negatives. The moire (named after a fabric with a wavy appearance) is caused when the rows of parallel, equally spaced halftone dots intersect at small angles. The orientation of the screen for each colour separation insures that the moire pattern is avoided (Wesner, 1974).

CARTOGRAPHIC PRODUCTION METHODS

Manual methods of colour map production are well understood (Brannon, 1986; Keates, 1973) and a variety of mechanical and photomechanical techniques are employed to create a set of four colour separation negatives as previously described. Each colour separation is a composite of all of the map components that contain varying amounts of

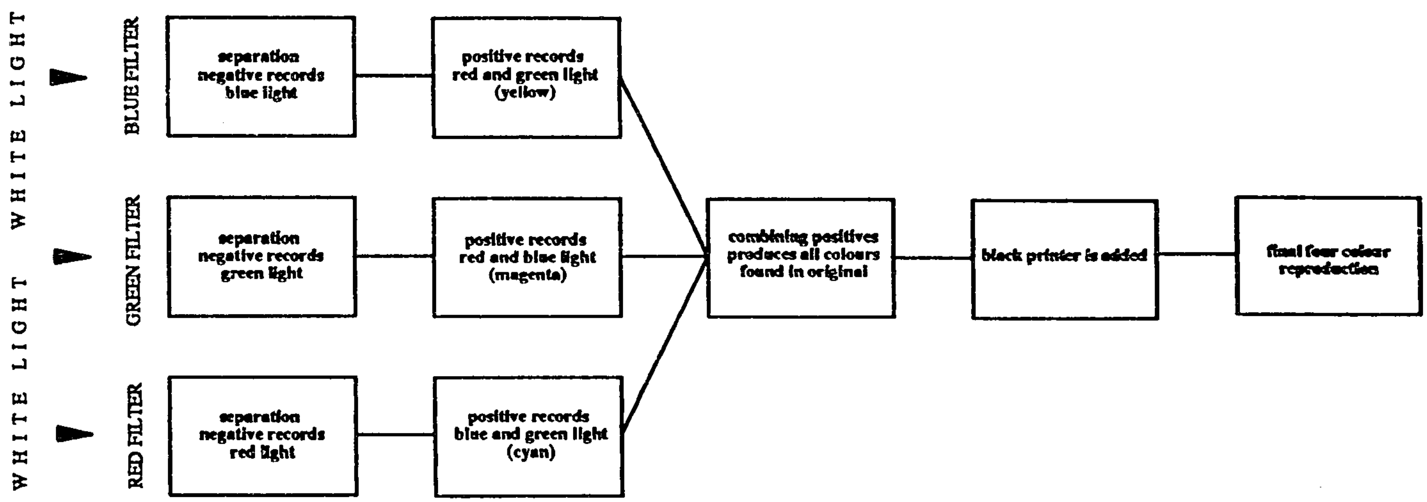


FIGURE 1. The principle of colour separation (modified from Brannon, 1986).

the associated primary colour. The four separation negatives are used to make printing plates which in turn are used to print the final map (Figure 2).

A map consists of three graphic components: 1. areas, 2. lines, and 3. type and symbols. These graphic components are created through the use of specific cartographic production techniques each using a different set of tools, materials, and procedures. Masks and open windows are created for screened or solid areas on the map and often several overlays are needed for the same area to achieve a desired hue. Used in conjunction with tint screens, the overlays (which can easily number thirty or more for a colour map) are combined to create tinted areas on the final map. Masks can be created by: 1. cutting out an area by hand using a knife and material designed for masking or, 2. using sensitized masking material which records an image by exposure to ultraviolet light. Lines such as boundaries, railways, or roads are usually created in negative form by scribing. Selected areas are physically removed from a scribable material to form a negative in which everything but the scribed line work is opaque. Certain symbols may be scribed or, as is the case with type, "pasted up" in a positive form and reproduced as a negative. The line work, as well as the type and symbols can be used in conjunction with tint screens to produce colour tints or grey tones on the final map (Brannon, 1986; Keates, 1973). Manual map production methods, while yielding high quality results, are labour intensive, utilize expensive materials, and require access to well equipped laboratory and darkroom facilities.

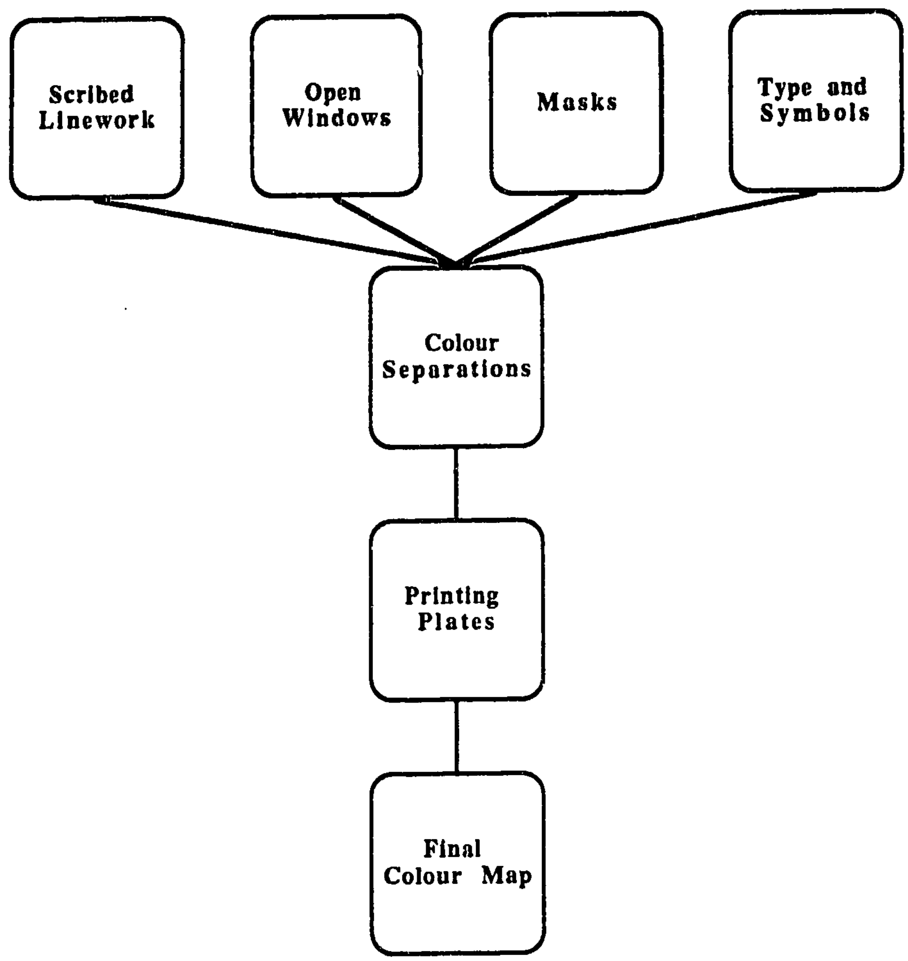


Figure 2. Schematic representation of the production of a colour map.

III. DIGITAL PRODUCTION CARTOGRAPHY

DESKTOP PUBLISHING

The processes involved in conventional printing can be accomplished with the use of new and sophisticated desktop publishing hardware and software. Desktop publishing technology enables a user to electronically accomplish the tasks associated with publishing such as set and edit text, create illustrations, paste up photographic images, and lay out and print a document. Desktop publishing systems are designed for the small scale print shop run by a single operator involved in the production of small manuscripts (typically under fifty pages) at minimum publishing quality.

The term "desktop" implies a physically small system which literally fits on the top of a desk and although this definition is readily accepted the expression actually originates from the concept of the "computer desktop" popularized by Apple Computers Incorporated (Apple). The Apple computer display was designed to simulate the top of a desk and allow the user to position "icons" (images of familiar objects such as file folders) in any convenient arrangement like an actual desktop (Seybold, 1987). It is the desktop analogy that in part distinguishes an Apple Macintosh system from an International Business Machines (IBM) personal computer (PC).

Desktop publishing is a new technology with origins that can be traced back only a few years; a combination of specific hardware and software developments initiated the "desktop publishing revolution" of the mid- 1980's. The marketing of inexpensive laser printers coupled with the expanding availability of microcomputers provided the required hardware while the development of high level programing languages, called page description languages, provided the necessary software. The result of this merger was a system which allowed the user to electronically compose text and graphics in a timely and cost effective operation. The personal computer acts as a platform or driver, for a desktop publishing system but it is the page description language and its capability to describe images for the laser printer that determines the type of graphic, and in part, the quality of the graphic produced (Seybold, 1987; Ayers, 1987).

Laser printers have been in use for several years but only recently have smaller, inexpensive table-top models been available. The basic operating principle of a laser printer is based on the design of electrographic copying machines (photocopiers). A laser printer creates an image on a page by transferring toner (dry ink) to selected areas on the page. A concentrated beam of laser light selectively removes an electrical charge from a specially treated drum; this drum attracts toner to the charged areas and the drum then comes into contact with the paper to transfer the toner onto the page (Stockford, 1987).

A PDL describes the entire make-up of any page from a set of instructions (parameters and procedures); these instructions are translated into addresses indicating where ink is to be placed on the page. A description of the graphic make-up of an entire page is sent to the laser printer resulting in fewer storage and communication requirements compared to other electronic printing methods that are used to accomplish the same task (scanned images are one exception). There are a number of PDLs offered by various companies; these include: Interpress (Xerox Corp.), Impress (Imagen Corp.), PostScript (Adobe Systems Inc.), and ACE (Chelgraph Ltd.) . The page description language referred to as PostScript and developed by Adobe Systems Incorporated was used exclusively for this research.

The development of the PostScript PDL (simply referred to as PostScript) dates back to the mid 1970s, however, the first full scale implementation of the language began with the production of the Apple LaserWriter in 1985. PostScript code can describe text, lines, and halftones. The necessary code can be generated from commercial drawing software packages (e.g. Illustator, Cricket Draw, Freehand) or written directly by a programmer (Rosenthal, 1987). The composition of a page is described in a two-dimensional plane using an X,Y Cartesian coordinate system and the language " has been designed specifically to communicate a description of a presentable document from a computer based composition system to a raster-output printing system" (Holzgang, 1987).

Several aspects of PostScript make it attractive for cartographic production. PostScript can easily output images which are in a grid form making it an ideal language for raster cartographic production and for the output of maps derived from other gridded geographic data bases such as digital elevation models or satellite images. PostScript is a device independent language which means it can be employed with a variety of laser printers. For example, the code sent to a 300 dpi laser printer can, without alteration, be sent to a 600 dpi laser printer and produce the same image but at twice the resolution. Postscript is supported by both Apple and IBM and is a *de facto* industry standard in desktop publishing (Burns and Venit, 1987).

The key to PostScript use, and its device independence, is the PostScript interpreter; only laser printers which have a resident PostScript interpreter can print the graphics described by PostScript code. PostScript code is delivered to the laser printer through a driver such as a personal computer. The code is sent to the interpreter which deciphers the instructions for creating a printed page. This deciphered information is turned into a bit-map which is reproduced by the laser printer engine . The bit-map describes which dots on the page are to be "turned on" or printed. Whether the dots which are printed become a line, a character, or a halftone image, is not distinguished by the laser printer. The creation of any image is reduced to decisions for either printing a dot or not printing a dot.

DIGITAL PRODUCTION

The production of computer (digital) halftones involves concepts and procedures considerably different from the procedures for generating photographic halftones. The smallest addressable point on a laser printer is fixed, unlike a photographic halftone dot. The variability in size of a photographic halftone dot can be simulated by clusters of dots that are grouped together and treated as a single point. This cluster of dots is called a plotting cell. Figure 3 shows a matrix of four dots grouped together to form a 2x2 plotting cell. A solid black is created (Figure 3a) when all four individual dots are printed; a grey is created (Figure 3b) when two of the dots are printed; when no dots are printed, white is created (Figure 3c). This group of dots (plotting cell) emulates a photographic halftone in which black, white, and three grey levels are possible. Digital halftoning using PostScript has three major controls: 1. the size of the plotting cell, 2. the resolution of the laser printer and, 3. the rotation of the halftone screen. A photographic halftone dot is produced in an infinite number of sizes and can therefore represent an infinite number of grey levels; conversely, a digital plotting cell has a finite size and can only represent a finite number of grey levels . The number of available grey levels, including white and black, is equal to the number of dots in the plotting cell plus one:

number of grey levels = number of dots in the plotting cell + 1

For example, the 2x2 plotting cell shown in Figure 1 can reproduce five levels of grey: (2 X 2) + 1 = 5, as illustrated in Table 3. The more pixels in a plotting cell, the greater

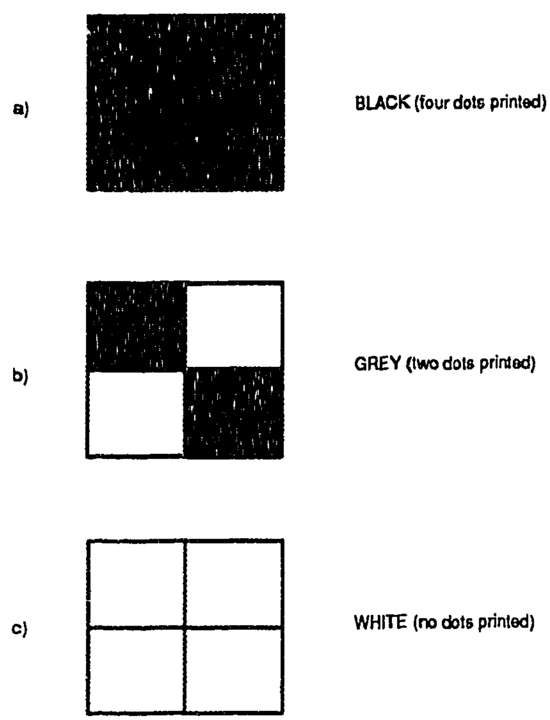


FIGURE 3. A 2x2 plotting cell.

TABLE 3.
Grey Levels for a 2x2 Plotting Cell

Number of Dots	Percent Grey
4	100% (black)
3	75% (grey)
2	50% (grey)
1	25% (grey)
0	0% (white)

number of available grey levels (Adobe,1986a).

The resolution of the laser printer, defined as the number of dots which can be printed for a given linear measure (usually dots per inch), restricts the capabilities of PostScript by placing a limit on the size of a usable plotting cell. The screen frequency or resolution , measured in lines per inch (lpi), of a grey-scale image can be determined by dividing the resolution of the laser printer by the number of dots along one row of the plotting cell (width of the plotting cell):

screen resolution = laser printer resolution / plotting cell width

The larger the plotting cell, the lower the screen resolution. A 2x2 plotting cell printed on a 300 dpi laser printer yields a screen resolution of 150 lpi and can only display five levels of grey; obviously the five levels of grey are not adequate for quality graphic production. The trade-off between plotting cell size and the screen resolution is shown in Table 4 (Schreiber, 1986; Bortman, 1986).

Digital colour production techniques follow the same principles as conventional photographic colour production. The colour separation negatives for a colour map produced with PostScript consist of four halftone images, each in perfect registration with one another. The total number of plotting cells available is the same for each separation (assuming the same screen frequency and screen angle). Each separation has the same number of plotting cells and each prints at the exact same location (X,Y coordinate) on a page so that each plotting cell will be perfectly registered when overlaying the separations.

In conventional photographic colour production, the rotation of photographic screens creates a rosette pattern of halftone dots composed of the four process colours; some of the dots fall on top of each other, some do not. This imperfect registration of photographic halftone dots results in a combination of both additive and subtractive mixing of the printing inks which degrades the sharpness and saturation of the image. The exact registration of digital halftones ensures a sharper image with pure colour (Williamson and Cummins, 1983); no screen rotation is necessary for raster colour separation images and, in fact, rotation of the screen will degrade the quality of the digital colour composite (Hou, 1983).

Screen rotation is accomplished easily with PostScript but changing the screen

TABLE 4.
Selected Plotting Cells and Corresponding Screen Frequencies for a 300 dpi Laser Printer

Plotting Cell Size*	Cell Width	Screen Frequency†	Number of Grey Levels
2x2	2	300/2=150 lpi	5
3x3	3	300/3=100 lpi	10
4x4	4	300/4=75 lpi	17
5x5	5	300/5=60 lpi	26
6x6	6	300/6=50 lpi	37

* Assumes Square Plotting Cell.
† Screen Frequency=Laser Printer Frequency/Plotting Cell Width.

angle will effect both the size of the plotting cell and the screen frequency. A frequency setting of 60 and an angle setting of 0° yields a 5x5 plotting cell (25 pixels) on a 300 dpi laser printer, whereas, a frequency setting of 60 with an angle setting of 45° will result in an actual frequency of 53 with 32 pixels in the plotting cell. Screen rotation alters the size of the plotting cell because the cell is rotated and is no longer square; this change in cell size, in turn, alters the screen frequency (Bortman, 1986). It is not possible to set every screen angle with PostScript because small changes in rotation cannot be accommodated by the plotting cell; when a plotting cell is rotated it must contain a certain proportion of a dot in order for that dot to be included in the plotting cell. For example, a screen rotation setting of 2° will default to 0°. Table 5 demonstrates the changes in screen frequency and screen angle for conventional halftone screen rotations used in colour printing.

TABLE 5.
Changes in PostScript Screen Angle and Screen Frequency for Conventional Halftone Screen Rotations (assuming a 60 lpi frequency setting)

Conventional Halftone Screen Rotation*	Plotting Cell size	Actual Screen Frequency	Approximate Screen Angle*
45 (45)	32	53	45 (45)
75 (15)	26	59	79 (11)
90 (0)	25	60	90 (0)
105 (165)	26	59	101 (169)

* The equivalent PostScript angle is shown in parentheses. The PostScript coordinate system assumes 0 degrees is at the conventional 90 degree compass position. PostScript angles of rotation are measured as positive or negative increments from 0 degrees such that -180 and +180 are the same rotation.
SOURCE: Modified from Bortman, 1986.

IV. DESKTOP MAPPING

THEMATIC DATA

Median incomes for private households obtained for the city of Edmonton from the 1981 census (part of the 20% census sample) were classed into five categories for display as a choropleth map. The median household income data ranged from $11,021 to $54,526 with a mean of $25,796 and a standard deviation of $7,302.9. The city is comprised of 125 census tracts but median income data was reported for only 112 tracts. Of the 13 tracts not reporting median household income, 11 were located in industrial or light industrial areas and/or areas on the edge of the urban built-up land and contained too few people to construct a valid statistic.

Two census tracts (numbers 009 and 005.1) had no published **median** values yet the **mean** values were listed. Statistics Canada provided no explanation for this deficiency. The two missing values were estimated using regression analysis in order to map the two unreported census tracts. Mean private household income is a good predictor of median private household income and the results of the regression analysis are summarized in Table 6. The use of regression analysis to predict the two unreported median income values resulted in 114 census tracts with data values and 11 census tracts classified as "Primarily Nonresidential".

RASTER PROCESSING

Raster data, while requiring more storage and download time than vector data, utilizes a simpler algorithm to generate a printed image. Halftones are implicit data structures in raster processing and the algorithm used for outputting raster colour separations can be easily modified to accommodate any gridded data base. A full raster production demonstration including the creation of the colour separations and subsequent colour proofs was completed as part of this research.

Raster Data Base

The 1981 Census Tract map for the city of Edmonton (Statistics Canada, 1982) was digitized on an Intergraph Interact Colour Workstation and the census tract polygons were generated using Intergraph's Graphic Polygon Processing Utilities (GPPU) software. A vector to raster conversion program (Eyton, 1987) was used to create a 650 column by 750 row raster data set on a DEC VAX 11/730 . All of the grid cells that made up a census tract polygon were assigned a census tract number. Grid cells falling

TABLE 6.
Regression Analysis †

Census Tract	Median Income	Mean Income
OO5.01	54 523	60 373
OO9	50 897	56 366

$r = .96228$ $a = -151.22$
$r^2 = .92599$ $b = .90565$

Dependent Variable (y) = Median Income
Independent Variable (x) = Mean Income

† Analysis done on the MIDAS statistical package.

between two census tracts (boundary cells) were assigned a value of zero and grid cells outside the city census tracts were assigned a value of 255. The legend boxes, digitized with the original map, were treated as census tract polygons and included as part of the raster data set.

The digitizing and the subsequent vector to raster conversion produced a gridded data set of 487,500 grid cells, each assigned one of 133 possible labels which included: one of 125 census tract numbers, one of six legend box numbers, a boundary cell number, or a non-census tract number. The raster data set was processed one grid cell at a time and the grid cell label was replaced with one of the six class numbers shown in Table 7. Grid cells labelled as census tracts were placed into one of the five income classes or the "Primarily Nonresidential " class. This classification was accomplished by comparing a grid cells' census tract number to the median income value for that census tract. The income value was then compared to the classification table (Table 7). The boundary and non-census tract grid cells remained unchanged. The original raster data set comprised of grid cells with one of 133 possible labels was used to create a classed raster data set of identical dimensions with each grid cell equal to one of eight possible numerical labels.

Raster images

Sampled image data consists of a two-dimensional array of grey level values which represents a scene such as a photograph (Adobe, 1986b) The PostScript language has the ability to print sampled images which contain up to 256 levels of grey. PostScript can interpret image data from two sources: 1. the data can be synthesized or 2. the image data originates from an external device such as an image scanner. The sampled image can be printed utilizing the PostScript halftoning capabilities and can be scaled, rotated, and positioned anywhere on the page.

PostScript is based on a language structure that uses **operators** which carry out a set of instructions when invoked by the interpreter. The **image** operator prints sampled images and uses five arguments: 1. sample width, 2. sample height, 3. bits per sample, 4. image matrix, and 5. data acquisition procedure. The first three arguments are critical to map production. The fourth argument (image matrix) controls the location of the sampled image origin on the printed page based on whether the image data is scanned from the top or bottom of the page. The fifth argument (data acquisition procedure) controls the specific structure of the image data.

The three arguments (height, width, and bits per sample) read by the **image**

TABLE 7.
Classification Table

Class Number	Median Income Range
1	10,000-19,999
2	20,000-24,999
3	25,000-29,999
4	30,000-34,999
5	35,000-55,000
6	Primarily Nonresidential

operator define the size and number of grey levels represented by the sample data. The height argument indicates the number of rows of sampled data values, the width argument indicates the number of columns, and the "bits per sample" argument is the maximum number of grey levels which can be displayed for any individual sampled data point. PostScript code can read grey level values stored as 1, 2, 4, or 8 bit integers which correspond to a maximum of 2, 4, 16, or 256 levels of grey, respectively. The number of grey levels is equal to 2^n , where n = the number of bits of storage (1, 2, 4, or 8). An 8 bit integer is required to display a full 256 grey levels (2^8=256), whereas to display 2 grey levels (black or white) a 1 bit integer (2^1=2) is required (Adobe, 1988a). The concept of grey level values originates from image processing in which reflectance values (normally expressed as 8 bit integers between 0 and 255) indicate a relative amount of reflected light. A grey level value of 0 normally indicates no reflectance and a grey level value of 255 normally indicates maximum reflectance. The PostScript **image** operator employs this same reflectance convention and explains why a value of 0 is black.

Raster Colour Palette

A colour palette containing 45 different colours (Plate 1 and 3) was developed for use with the classed raster data set. All colours were ordered 1 through 45 and assigned a colour label (Table 8). The limit of 45 colours (easily expanded) provided a reasonable selection of colours for this research. The palette colours are comprised of 45 sets of instructions (colour definitions) which describe the percentage of cyan, magenta, yellow, and black making up any particular colour in the palette. The 45-colour palette was modified and expanded from a simple colour palette involving three levels of grey for each of the subtractive primaries resulting in 3^3=27 colours. The colour palette increases in complexity beginning with simple colours (1-18) that are defined using only three levels of grey (15,7,and 0), while numbers 19-25 include the values 10 and 13 (as well as 15,7,and 0); the colour numbers 26-45 include the greatest variety of grey level values and were designed as progressions of light to dark colours.

The 45-colour palette uses 4-bit integers (represented in hexidecimal notation) to represent the percentage of each process colour. A 4-bit representation allows 16 grey levels ranging from 0 (100% black) to 15 (0% black) with the intermediate values 1 to 14 as percentages of grey. For example, colour #22 (brown) is described as 15 cyan, 7 magenta, 0 yellow, and 10 black. For any colour in the palette, a value from 0 to 15 is stored for each process colour; this value indicates a percentage of grey which

TABLE 8.
Description of the Colour Palette

Colour Number*	Colour Name	4-bit Colour Definition† Cyan	Magenta	Yellow	Black
1	Green	0	15	0	15
2	Red	15	0	0	15
3	Cyan	0	15	15	15
4	Magenta	15	0	15	15
5	Yellow	15	15	0	15
6	White	15	15	15	15
7	Light Blue	7	7	15	15
8	Dark Blue	7	7	15	7
9	Light Green	7	15	7	15
10	Dark Green	7	15	7	7
11	Light Red	15	7	7	15
12	Dark Red	15	7	7	7
13	Light Cyan	7	15	15	15
14	Dark Cyan	7	15	15	7
15	Light Magenta	15	7	15	15
16	Dark Magenta	15	7	15	7
17	Light Yellow	15	15	7	15
18	Dark Yellow	15	15	7	7
19	Brown	15	7	0	10
20	Light Brown	15	10	0	13
21	Turquoise	0	15	7	15
22	Lime	7	13	0	15
23	Orange	15	7	0	15
24	Pink	15	0	7	15
25	Purple	7	0	15	15
26	Light Grey	15	15	15	13
27	Grey	15	15	15	11
28	Medium Grey	15	15	15	6
29	Dark Grey	15	15	15	3
30	Black	15	15	15	0
31	Blue1	12	15	15	15
32	Blue2	7	15	15	15
33	Blue3	0	12	15	15
34	Blue4	0	7	15	15
35	Blue5	0	0	13	13
36	Tan1	15	13	3	15
37	Tan2	15	11	0	15
38	Tan3	13	10	0	15
39	Tan4	11	7	0	15
40	Tan5	10	6	0	13
41	Green1	13	15	3	15
42	Green2	10	15	0	15
43	Green3	7	15	0	15
44	Green4	3	13	0	15
45	Green5	0	12	0	13

* Colour Numbers: 31-35, 36-40, and 41-45 represent a progression from light to dark.

† 0=Black (100%), 1-14=Grey, 15=White (0%).

TABLE 9.
Colour Assignments for the Edmonton Median Income Map.

Map Class	Colour Numbers
Boundary Pixels	30 (black)
Non-Census Tract Pixels	6 (white)
Primarily Nonresidential	27 (grey)
10,000 -19,999	36 (tan1)
20,000 - 24,999	37 (tan2)
25,000 - 29,999	42 (green2)
30,000 - 34,999	43 (green3)
35,000 - 55,000	45 (green5)

corresponds to a specific number of dots in the plotting cell. Using 16 grey levels allows a potentially large selection of colours (16^3=4096).

Colours are assigned to the classed raster data set by comparing each grid cell to the eight pairs of values comprising the colour assignments (Table 9). A colour number is assigned to every grid cell; this operation generates four hexidecimal values, one value in each of four colour separation output files. The colour separation files are interpreted as a sampled image by PostScript and for each hexidecimal value (which corresponds to a grid cell), a grey level value is produced as a digital halftone.

VECTOR PROCESSING

An algorithm for creating a halftone images from vector data was obtained at a later stage of this research (Integrated Graphics,1988). An Edmonton census data set in vector format was used to produce paper positive colour separations at 300 dpi. No vector negatives or colour proofs were generated because the raster demonstration illustrates the concepts involved in colour production. Vector data does not display staircasing , requires less storage, and downloads to a laser printer faster than raster data. The vector data structure dictates the use of a different colour palette than that used with the raster data and the code for generating the map is slightly more complicated than the code used to generate the map from raster data (see Table 10 and the discussion that follows).

Vector Data Base

The polygon file generated by the GPPU software was reformatted to create an Edmonton vector data set consisting of 125 sets of points and polygon labels. The vector data was classified in a similar manner to the raster data; each polygon label was examined and reassigned a value corresponding to one of six categories (Table 7). The vector data set did not contain non-census tract or boundary areas. The boundary between the polygons in the vector data set is controlled by the PostScript code and is not a consequence of the image data structure as is the case with the boundary cells generated in the raster data set.

Vector Images

The outlines of the census tract polygons were defined by the PostScript **lineto** operator which plots a path from one X,Y location to another. A series of paths define a polygon that can be "shaded in" with a percentage of grey by means of the PostScript **fill** operator. The grey level used by the **fill** operator is specified by the **setgray**

PostScript Code:

```
300 250 moveto
300 275 lineto
375 300 lineto
400 275 lineto
360 250 lineto
340 260 lineto
closepath
.5 setgray
fill
```

Result:

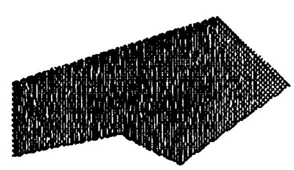


FIGURE 4. Sample PostScript code describing and filling a simple polygon.

operator ; a percentage of grey is specified as a value between zero and one: 0.0=100% (black), 0.5=50% (grey), 1.0=0% (white). Figure 4 illustrates the filling of a simple polygon.

Table 10 shows part of the PostScript code used to generate the cyan vector separations; the coordinates for two complete polygons are included. The "/DP" procedure effects the drawing and filling of a polygon; a complete polygon description has a **setgray** value, the **mark** operator, a series of X,Y coordinates defining the polygon, and the "DP" procedure. Polygon #1 has a **setgray** values of 0 followed by "mark" which indicates the start of the list of X,Y coordinates (in this case seven sets) and "DP" invokes the procedure to draw and fill the polygon. The code also allows for screen frequency and angle to be set with the "/freq" and "/angle" procedures respectively. The "/OF" procedure locates and scales the image on the output page.

Vector Colour Palette

Each colour in the vector colour palette is represented by four values (ranging from 0.0 to 1.0) interpreted by the **setgray** operator; these values define the percentage of any one process colour for a specific polygon. Assigning colours to the classed vector data results in the generation of four colour separation files; each of these files has identical sets of coordinates defining the outlines of the polygons but has different **setgray** values assigned to the polygons. The vector representation of the colour palette allows a simpler and more direct method of describing colours than the raster approach but an understanding of digital halftones is still necessary for using either the raster or vector colour palettes.

TEXT, LINE, AND SYMBOL PLACEMENT

The shape of any PostScript font is stored as a set of mathematical curve fitting equations. Storing fonts as a set of equations allows for text to be sized, scaled, rotated, filled with grey, and avoids the constraints of conventional font representation whereas a separate set of bit-maps must be stored for different type sizes and type styles (Cavuoto, 1985). The Times Roman typeface was used for the Edmonton income map; the type size ranged from 5 point to 20 point (1 inch=72 points, 12 cm=28.4 points). Table 11a shows how text was placed for the map title. The first line of code defines the type style (Times Roman); the second line establishes the type size (20 points) and the third line

TABLE 10.
Partial Listing of the Cyan Vector Separation PostScript File

```
% 1981 Edmonton data set        ---- Cyan separation ----
%
% PostScript polygon drawing and coordinate setup code modified from
% University of Alberta MTS Integrated Graphics program.
%
/OF {save 40 100 translate 6.5 6.5 scale 0 setlinejoin} bind def
%
/DP { counttomark /npts exch def newpath npts -2 roll moveto
 npts 2 gt {npts 2 div 1 sub /count exch def 1 1 count
 {pop npts 2 sub /npts exch def npts -2 roll lineto} for
 closepath pop /color exch def gsave color setgray fill grestore
 stroke 1 setgray} if } def
 %
 .1 setlinewidth  OF
 %
/freq 60 def
/angle 0 def /newspot {dup mul exch dup mul add 1 exch sub } def
/SetUpScreen
 {freq angle /newspot load setscreen} def
 SetUpScreen
%
0
mark
  32.771  20.347                                         % -- 1 --
  32.757  22.831
  34.954  22.640
  36.583  22.575
  36.599  19.809
  33.862  20.354
  32.771  20.347
DP
.67
mark
  32.757  22.831                                         % -- 2 --
  32.754  23.418
  32.450  23.937
  32.428  24.746
  36.570  24.753
  36.583  22.575
  34.954  22.640
  32.757  22.831
DP
```

SOURCE: Adapted from Integrated Graphics, 1988.

TABLE 11.
PostScript Listings for Text, Line, and Circle Placement

a.
```
/Times-Roman
20 scalefont setfont
347 496 moveto
(EDMONTON INCOME,1981) show
```

b.
```
1 setlinewidth
36 36 moveto
593.5 36 lineto
593.5 560 lineto
36 560 lineto
closepath
```

c.
```
182.5 245 3 0 360 arc
1 setgray
fill
```

indicates the location for placing the text. All locations are given as Cartesian coordinates measured in points from the bottom left corner of the page. The fourth line is the text string (in parentheses) that is to be placed on the page; similar PostScript code was used to place all text appearing on the map.

Rendering of the map neatline, north arrow, and scale was accomplished with the PostScript line drawing facility illustrated by the code used to create the neatline (Table 11b). The first instruction (line 1) sets a one point line width, the second instruction establishes the starting point of the neatline at the position 36 points in the X direction and 36 points in the Y direction from the bottom left corner of the page. The X,Y coordinates (lines 3, 4, and 5) define the locus of the line and the sixth line of code closes the polygon; the last instruction causes the neatline to be printed.

The white circles surrounding the asterisks were created by the code given in Table 11c. Line 1 of the code indicates the diameter and location of the circle. The centre of the circle is given by the first two values (X,Y coordinates in points), the third value defines a circle radius of three points, and the values 0 and 360 define the extent to which the curved line is drawn, in this case, a complete circle from 0° to 360°. The **arc** operator renders the circle on the page. The second and third lines of code fill the circle with white. The circles are printed on each colour separation to produce black asterisks on a white background. No line width was supplied so the circle is simply white with no outline.

The text, lines, and circles are printed in black, therefore, the code describing these features was added to the black separation file. The sampled image data is described first, and then the text, lines, and circles are placed on the page; this ensures the elements will appear on the final printed page because the last feature at a given location described by Postscript will show up completely, blocking out any other graphics laid down at that same position.

V. DESKTOP MAP PRODUCTION

COLOUR SEPARATIONS AND PROOFING

The colour separations for the raster colour palette and the Edmonton Income map were generated at 300 dpi and at 1270 dpi. The 300 dpi separation files were downloaded from a Mac Plus to a NEC LC-890 Silentwriter LED printer (the NEC LC-890 uses light emitting diodes instead of a laser to effect the printing process but the results are the same); four black and white positives were generated for both the map (Figure 5) and colour palette (Figure 6). The paper positives were photographed (1X) onto high contrast lithographic film to create negatives which were then used to make colour proofs with 3M Color Key. Colour photocopies were made from the completed proofs and appear as Plates 1 and 3. Vector separation positives were also produced on the NEC LC-890 (Figure 7) but were not used to generate colour proofs. The file used to generate the raster cyan separation (Figure 8) was approximately 490 K in size and took four minutes to download and print on the NEC LC-890 Silentwriter. The cyan vector separation file (Figure 9) was 53 K in size and took about 45 seconds to download and print.

The two sets of files used in generating the 1270 dpi map and 1270 dpi colour palette are identical to the files used to create the 300 dpi images except for a change in the screen frequency setting. The 300 dpi separations have a 60 lpi screen and 1270 dpi separations have a 127 lpi screen. The 1270 dpi images were printed directly on lithographic film by a Linotronic L300 laser printer (which can operate at 640 dpi , 1270 dpi, and 2540 dpi) and can accommodate the increase (from 60 lpi to 1270 lpi) in screen frequency. The negatives generated by the Linotronic were used to create colour proofs; Plate 2 and Plate 4 are colour photocopies of the original colour key composite proofs.

MAP EVALUATION

The raster and vector separation positives (Figure 8 and 9) are nearly identical except for the staircasing in the raster separation caused by the structure of the data in the raster file. The increase in printing resolution results in a less coarse looking map and colour palette (Plate 3 and 4). The quality of the 300 dpi map is effected by the halftone dots which when printed on paper tend to spread and are much less crisp than the dots printed directly on film. The quality of the image at 300 dpi is further degraded by the use of an intermediate photographic step to produce negatives. The deposition of toner on a page tends to be inconsistent; there are light and dark streaks across the page, and

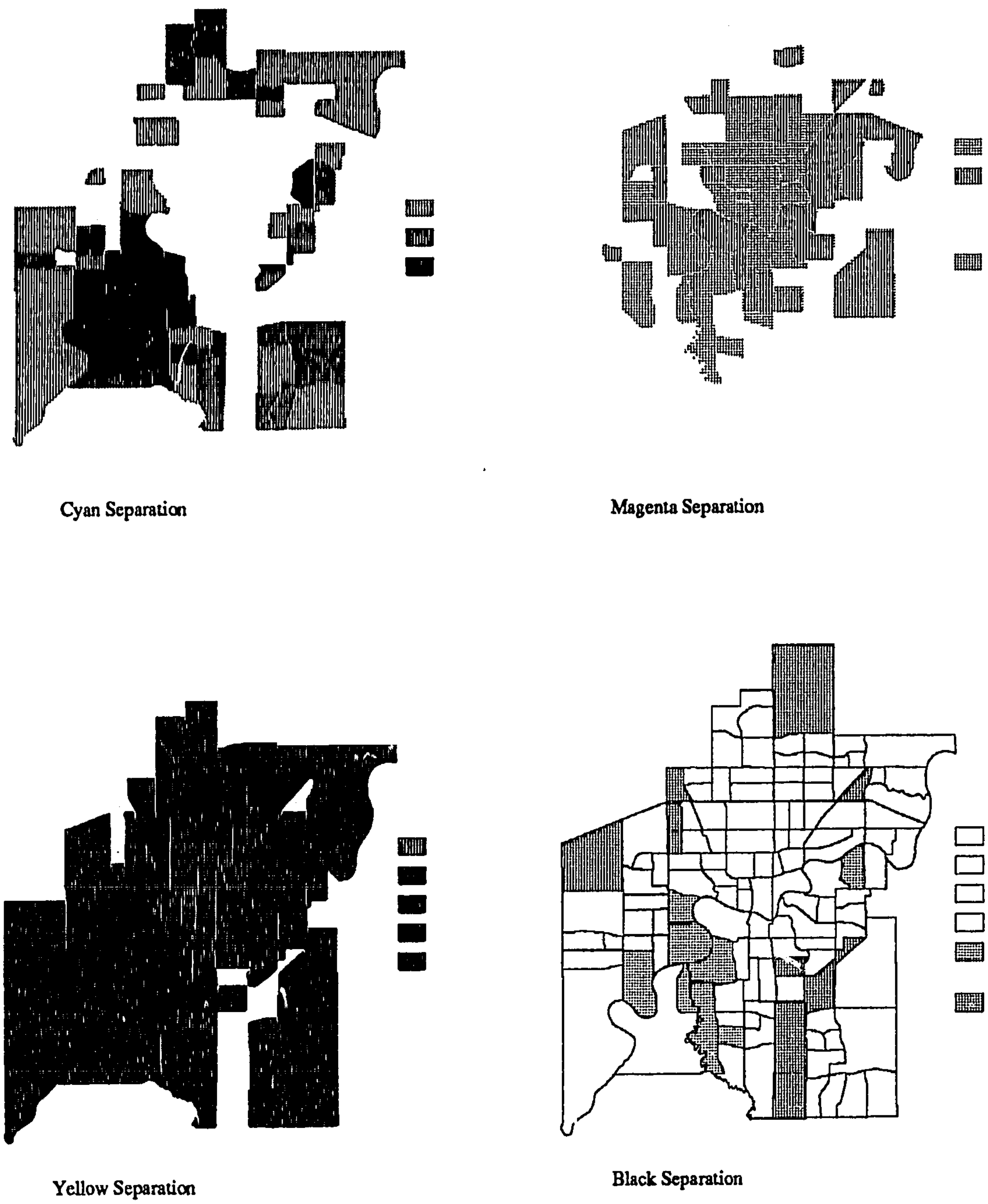


FIGURE 5. Raster colour separation positives (60 lpi).

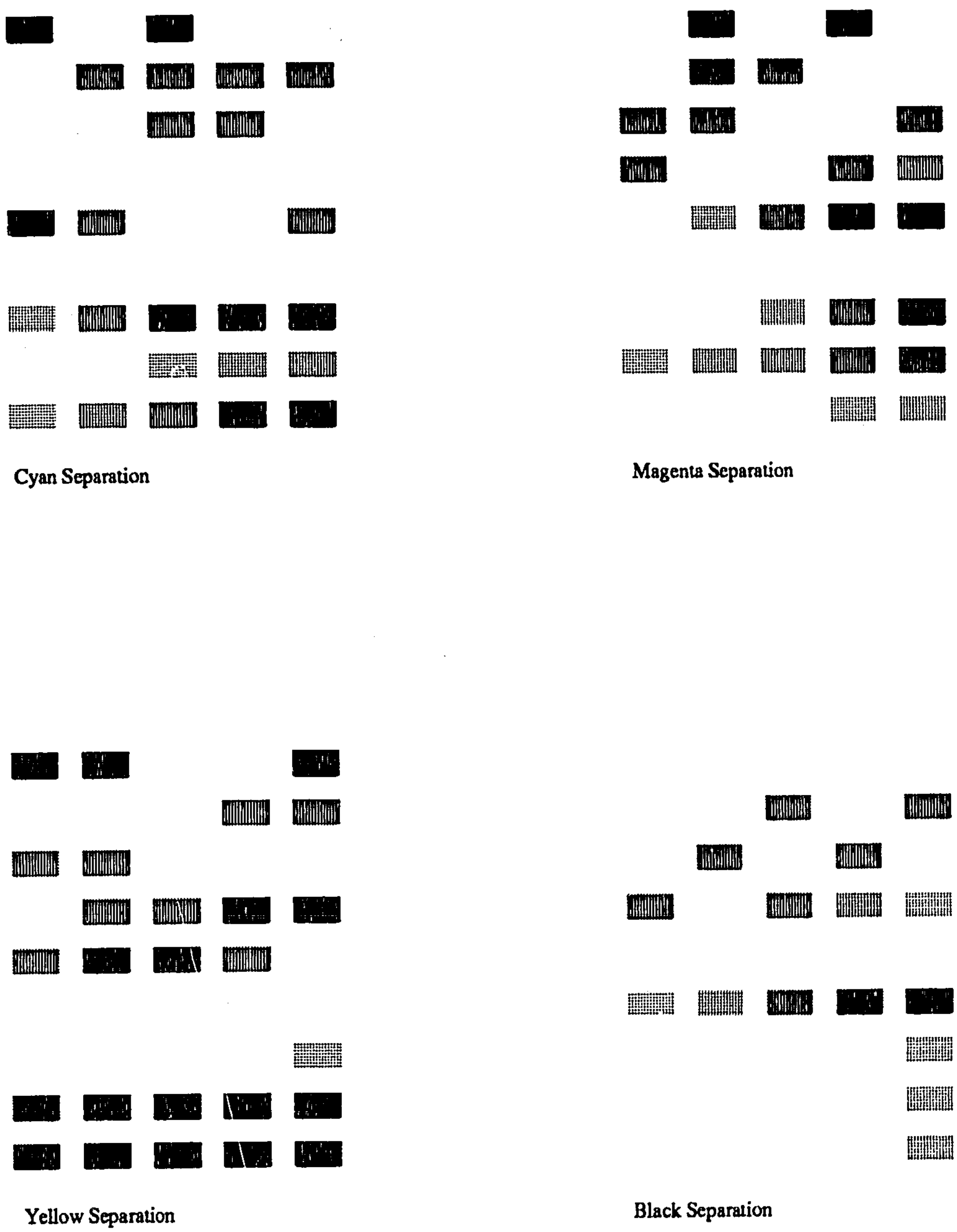


FIGURE 6. Raster colour palette colour separations (60 lpi).

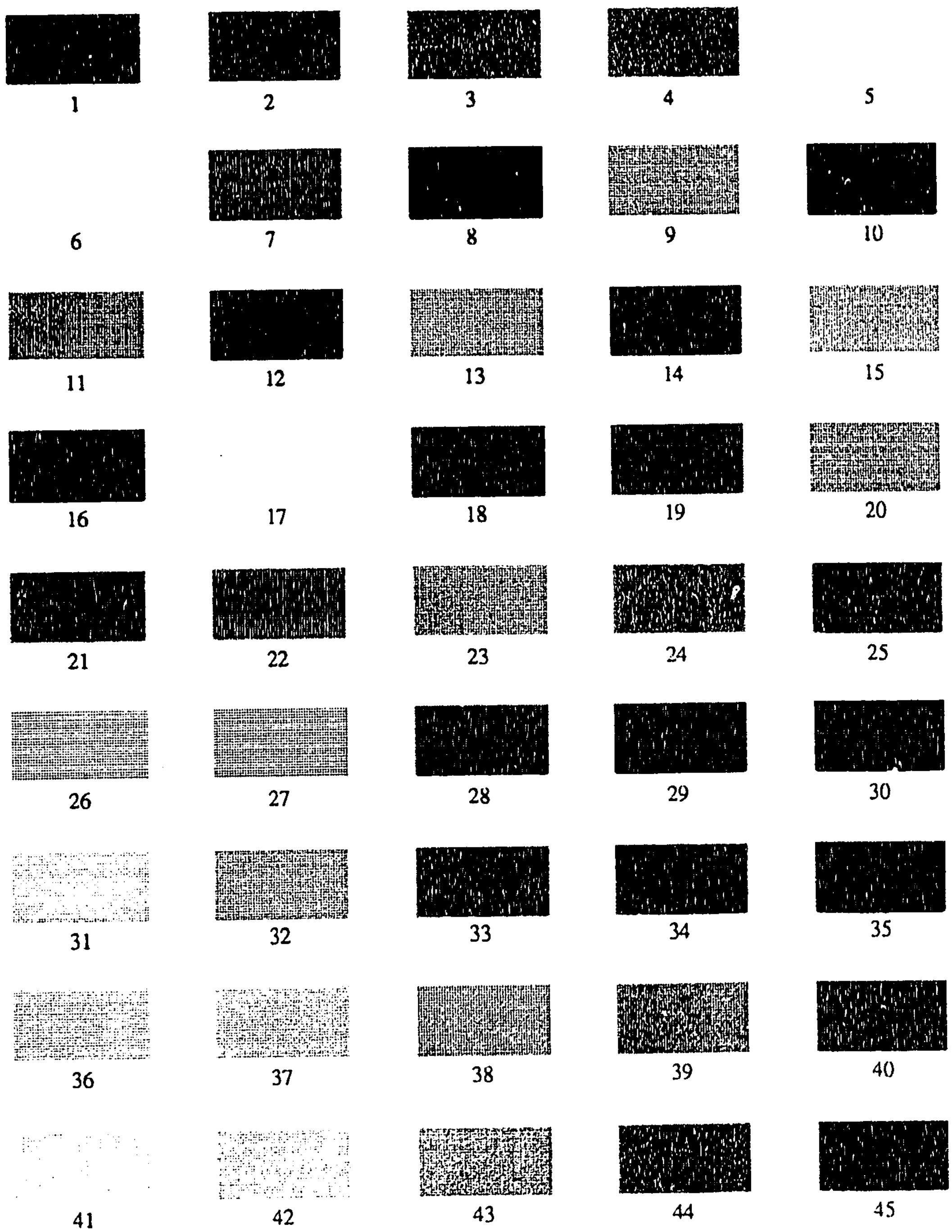


PLATE 1. Colour photocopy reduction of a 3M color key composite of the 300 dpi raster colour palette (60 lpi). The resolution of the photocopier, in conjunction with the four transparent overlays, produces a colour copy considerably degraded compared to the original colour proof.

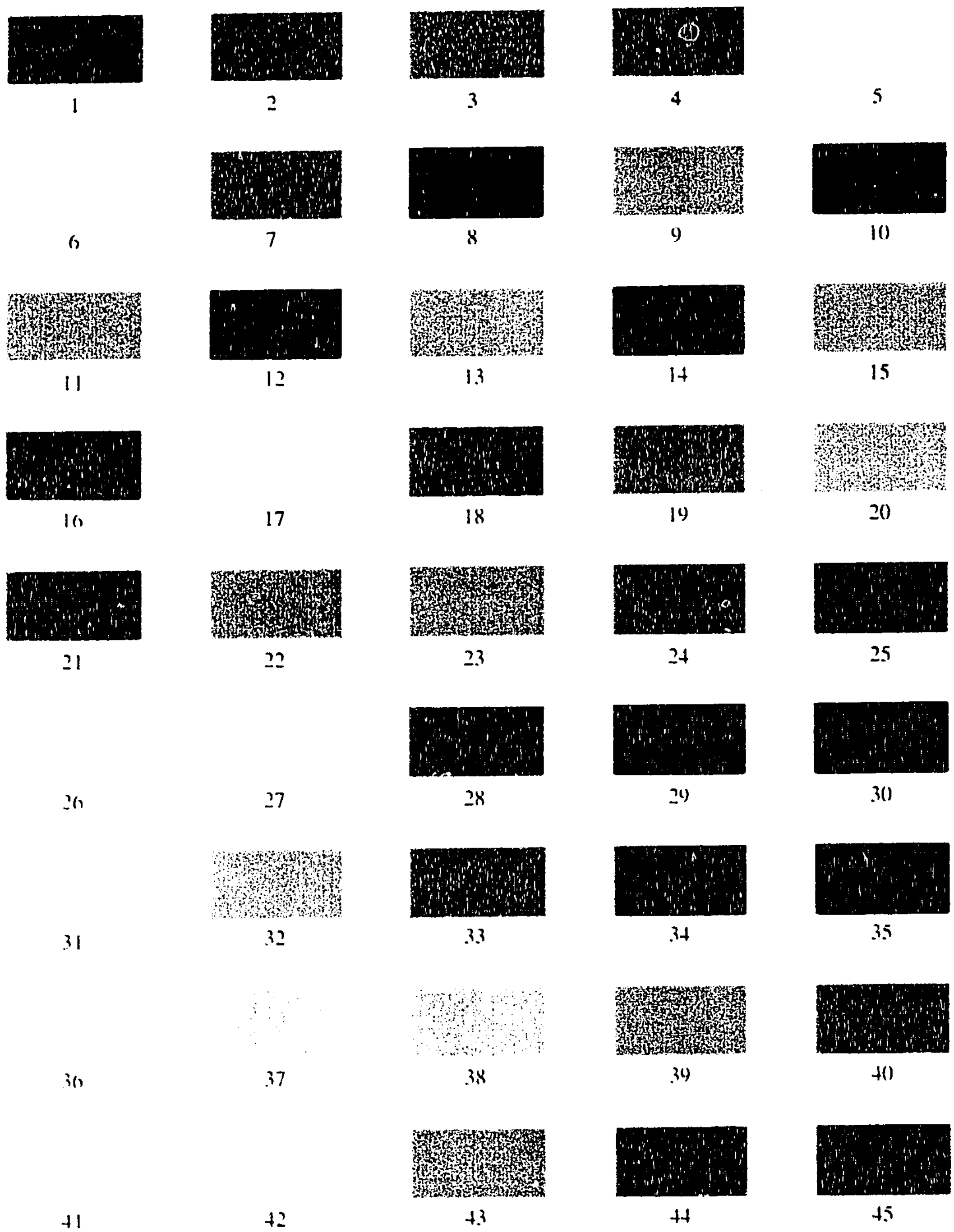
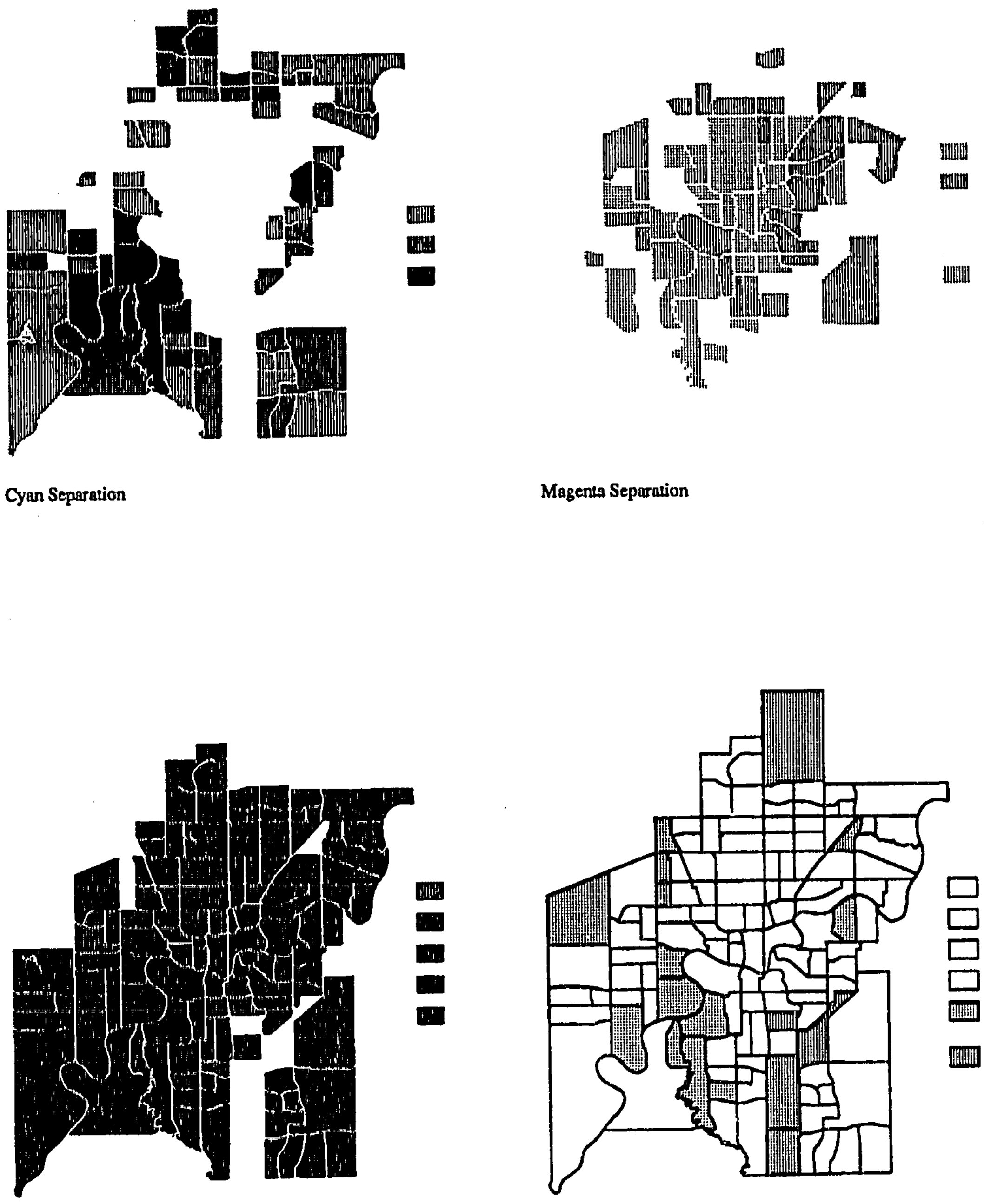


PLATE 2. Colour photocopy reduction of a 3M color key composite of the 1270 dpi raster colour palette (127 lpi). The resolution of the photocopier, in conjunction with the four transparent overlays, produces a colour copy considerably degraded compared to the original colour proof.



Cyan Separation

Magenta Separation

Yellow Separation

Black Separation

FIGURE 7. Vector colour separation positives (60 lpi).

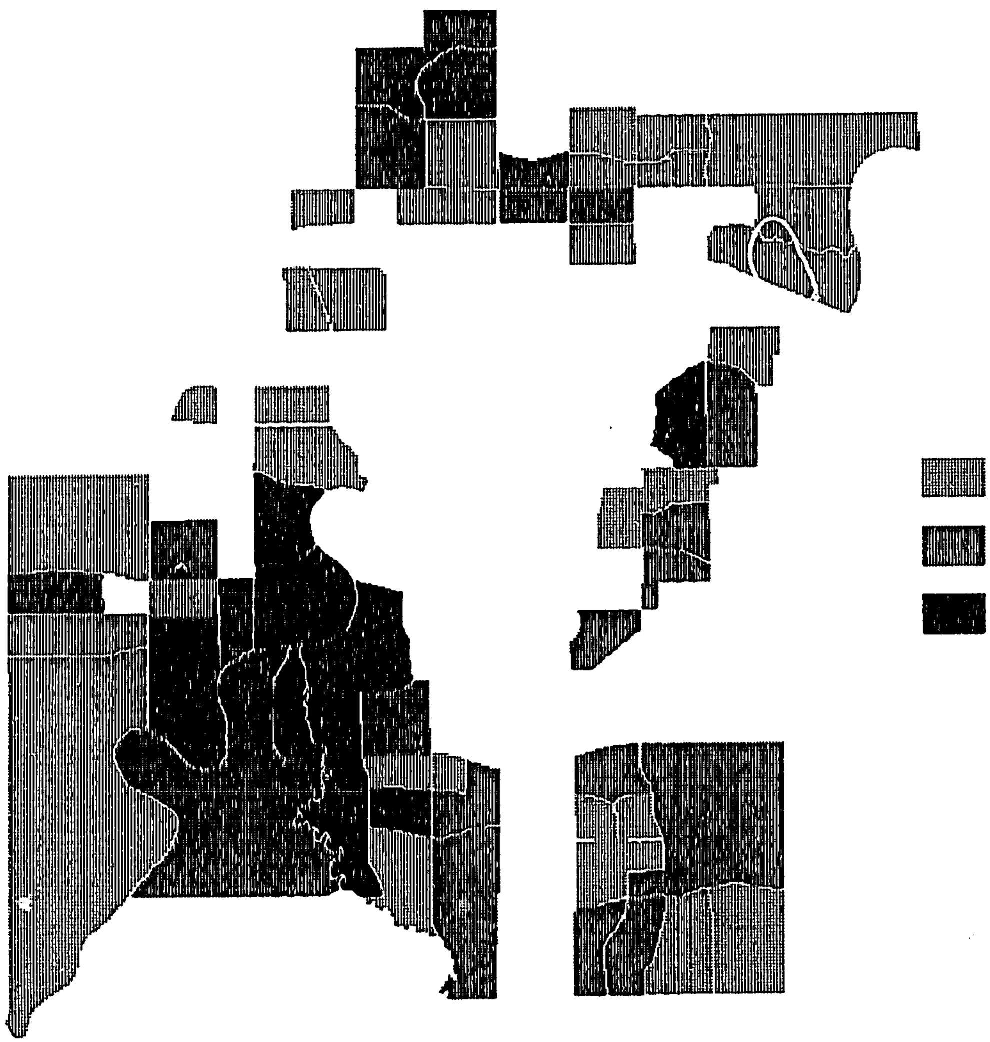


FIGURE 8. Raster cyan colour separation positive (60 lpi).

FIGURE 9. Vector cyan colour separation positive (60 lpi).

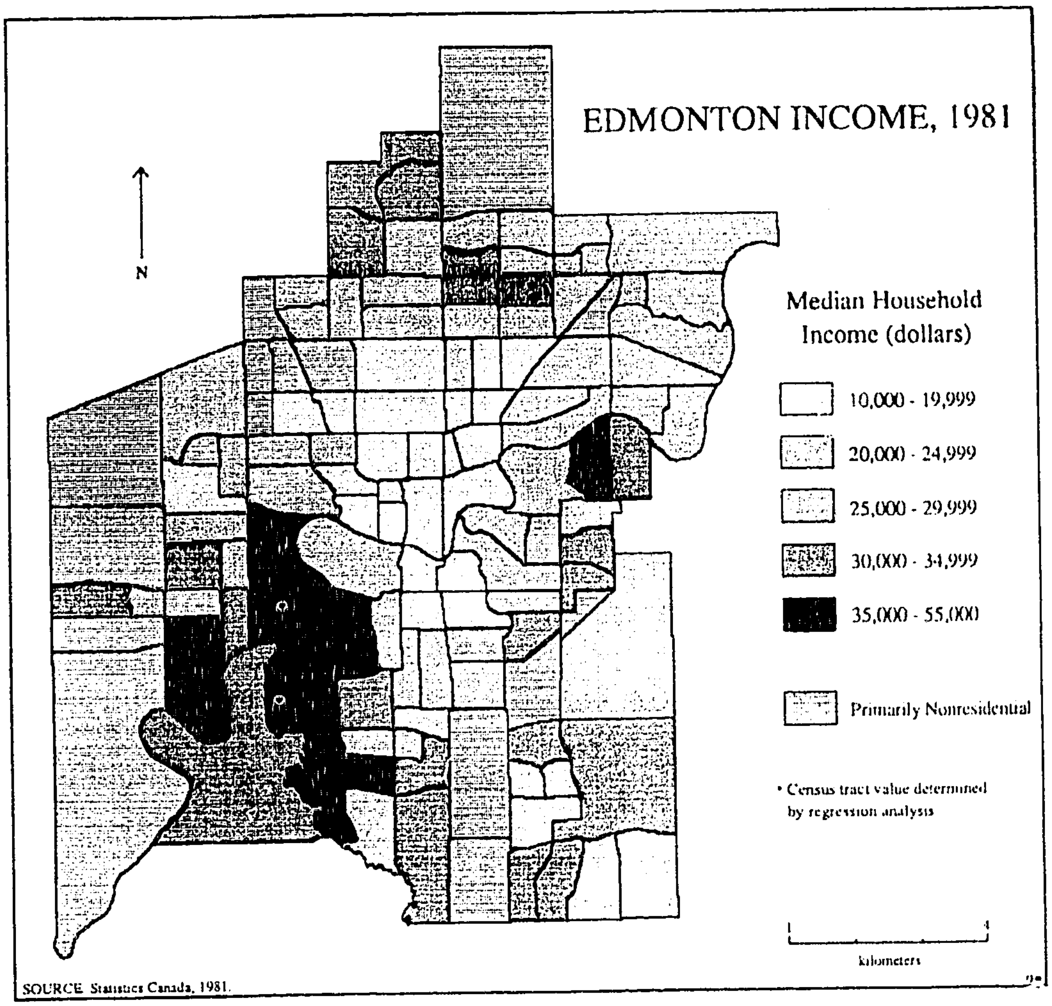


PLATE 3. Colour photocopy reduction of a 3M color key composite of the 300 dpi Edmonton income map (60 lpi). The resolution of the photocopier, in conjunction with the four transparent overlays, produces a colour copy considerably degraded compared to the original colour proof.

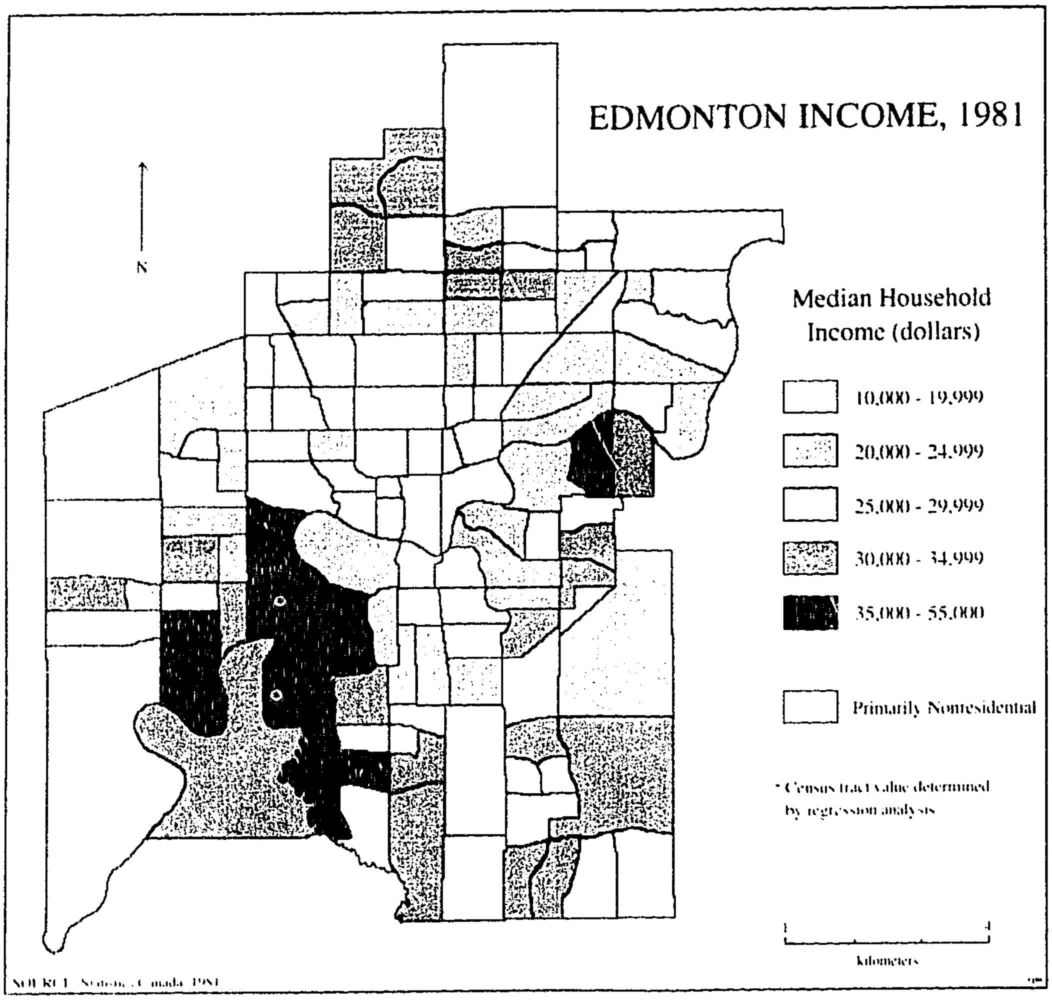


PLATE 4. Colour photocopy reduction of a 3M color key composite of the 1270 dpi Edmonton income map (127 lpi). The resolution of the photocopier, in conjunction with the four transparent overlays, produces a colour copy considerably degraded compared to the original colour proof.

solid black areas are not totally opaque. The high resolution film output from the Linotronic exhibits some streaking but is superior to the 300 dpi paper output. Printing at 1270 dpi yields better halftone images but requires access to a high resolution PostScript compatible printer and is more costly than photographing black and white paper positives. The 300 dpi resolution is acceptable quality for research analysis or teaching where the image quality is not paramount.

There is a change in the appearance of the colours from the 300 dpi images to the 1270 dpi images. The 300 dpi map employs 5x5 plotting cells while the 1270 dpi map uses10x10 plotting cells; each dot printed at 1270 dpi (in a particular plotting cell) represents 1% grey (100/100=1%) whereas in the 300 dpi plotting cell, one dot represents 4% grey (25/100=4%). This difference in plotting cell size allows for a more accurate rendition of subtle colours and explains why the colour takes on a lighter and softer appearance at high resolution.This change in the appearance of the colours (from low resolution to the high resolution) indicates that using the 300 dpi output as a proof for the 1270 dpi output is not practical; proofing must be done at the same resolution as the final map product.

COMMENTS ON THE METHODOLOGY

The 45-colour palette, while providing a reasonable selection of colours, would need to be expanded if used on a continuing basis for colour production. The addition of more gradations of colour from light to dark and more pastels would increase the utility of the palette. The vector colour palette could potentially contain PANTONE colours (or some other colour specification system) because of the way in which grey levels are expressed as percentages. The drawing program Illustrator '88 (Adobe Systems Inc.) is based on PostScript and has the option of selecting PANTONE colours for the production of colour separations (Adobe, 1988b).

The maximum output size of any image is governed by the capability of the laser printer. The actual printing area on the NEC LC-890 is Approximately 20 x 27 cm. (8 x10.5 in.). The Linotronic can accommodate film which is 46 x 20 cm. (18 x12 in.); the actual printing area would be slightly less than this size. The Linotronic can also print on resin coated (RC) paper that is 46 cm. (18 in.) wide.

Processing of the raster and vector data employs different procedures due to the difference in the structure of the two data types. Raster data is derived from vector data (using a vector to raster conversion) or is already in a gridded form such as satellite data or digital elevation models. The vector data requires about the same amount of processing when the PostScript colour separations are being generated and does not, of course, need to be run through a conversion program. The kind of data employed in colour production (raster or vector) is dictated by the task to be accomplished; obviously, creating a classed Landsat map requires raster data whereas creating a choropleth map could involve either data type.

VI. SUMMARY AND CONCLUSION

A methodology for producing map colour separations using desktop publishing has been presented. Manual methods of colour map production yield high quality results yet are labour intensive and require the utilization of expensive materials. Digital techniques employed in the generation of halftone colour separation negatives have been, for the most part, limited to large scale production facilities. Micro computers, coupled to laser printers using graphic languages called Page Description Languages offer a small scale production alternative. The Page Description Language called PostScript has the ability to create line, text, and halftone images and is ideal for cartographic production.

A full production demonstration using a raster data set was accomplished, in part, using PostScript. A raster data set of the Edmonton 1981 census tracts was used to produce a classed map depicting Median household income. A 45-colour palette was developed for use with the classed raster data and specific palette colours were selected to display the Edmonton raster data.

Colour separations for the Edmonton Income map and colour palette were produced at 300 dpi and at 1270 dpi. The 300 dpi images were generated on a NEC LC-890 Silentwriter with a 60 lpi screen setting as black and white positives; the positives were photographed onto lithographic film to create negatives. The 1270 dpi images were generated directly on lithographic film with a Linotronic L300 laser printer with a 127 lpi screen setting. Composite colour proofs were generated for all four sets of negatives. The images produced at 1270 dpi were much finer and gave a better rendition of colour than the 300 dpi images. The quality of 300 dpi output however is more than adequate for research analysis or teaching but for publication, the 1270 dpi resolution is necessary.Vector colour separations were generated as paper positives at 300 dpi but not used to create negatives or colour proofs.

Vector data has several advantages over using raster data; the vector data takes less storage and less time to download than the raster data. The vector data lacks the characteristic staircasing present in raster data and the vector colour palette allows for more precise colour definitions because they are expressed as percentages of grey and not as the 4-bit grey level values. The only disadvantage to using vector data is that the PostScript code required for generating the vector colour separations is slightly more complex than the code required for generating the separations from the raster data.The use of the **image** operator should be restricted to data which is originally generated or aquired in gridded form such as digital elevation models or satellite imagery. Creating the Edmonton income map in raster mode made the map production process unnecessarily

Edmonton income map in raster mode made the map production process unnecessarily complex. Vector data, because of its considerable advantages, is clearly the best choice for the Edmonton income map and applications of a similar nature.

Desktop publishing will alter the traditional cartographic production process. Making a colour map through conventional means involves the creation of many open window negatives, scribes, and peal coates; these components are used in the darkroom to build-up the map image with the result being four colour separation negatives. The colour map production process is simplified using desktop publishing technology because colour separation negatives can be generated directly without the use of any intermediate photomechanical techniques. Altering the production process will mean the skills and knowledge of cartographers must change and expand to encompass an understanding of desktop publishing.

The academic cartographic production shops of the future will look considerably different from contemporary facilities. Technological change will mandate a greater emphasis on digital techniques. A typical lab would include a micro computer with a laser printer, desktop scanner, and digitizing tablet as peripherals. Software would include sophisticated drawing and publishing packages. There would still be a need for a process camera to create negatives from paper output, and a plate maker for creating colour proofs but the majority of the map production process would be accomplished digitally.

The compilation and design process will also undergo reform because the production stage is being changed through the use of desktop publishing technology. Base maps will increasingly become more readily available in a digital form; alternatively, maps can be digitized point by point or scanned by a desktop scanner and then edited directly on a graphics screen. Maps will be designed using graphics terminals and decisions such as placement of a title or legend can be easily accommodated and implemented electronically. The electronic compilation and computer-assisted design of maps was not considered in this research but it is clearly the next issue which must be addressed in order to determine how the map making process will be accomplished in the near future.

REFERENCES CITED

Adobe Systems Incorporated, 1986a. PostScript Language Reference Manual. Don Mills, Ont.: Addison-Wesely.

Adobe Systems Incorporated, 1986b. PostScript LanguageTutorial and Cookbook. Don Mills, Ont.: Addison-Wesely.

Adobe Systems Incorporated, 1988a. PostScript LanguageProgram Design. Don Mills, Ont.: Addison-Wesely.

Adobe Systems Incorporated, 1988b. Color Guide. Adobe Illustrator 88.

Ayars, A. S., 1987. "How Desktop Publishing Can Help In-Plants Soar". In-Plant Reproductions and Electronic Publishing, October: 49-52.

Brannon, G. R., 1986. An Introduction to Photomechanical Techniques in Cartography. Kitchner: Glass Igloo Press.

Bruno, M. H., 1980. "Color Reproduction" in Graphics Arts Manual. New York: Arno Press, 346-350.

Bruno, M. H. (ed.), 1983. Pocket Pal. New York: International Paper Company.

Bortman, H., 1986. "PostScript" (part 2 of 3), The MACazine, December: 41-43.

Bortman, H., 1987. "Laser Wars". MACUSER, 3 no.10: 84-94.

Burns, D., and Venit, S., 1987. "PostScript: Putting Text and Graphics in Their Place". Computer Graphic Magazine, 1, no.3: 66.

Cavuoto, J., 1985. "Digitized Fonts in PostScript". Computer Graphics World, September: 27-30.

Colgi, J. E., 1980. Photo-Offset Fundamentals. Bloomington, Ill.: Mcknight Publishing.

Dunn, R. M., and Gantz, J.. 1986. "Electronic Publishing Market Mirage" Computer Graphics World, September: 26-34.

Eyton, J. R., 1987. MASK : a vector to raster conversion program. Unpublished Program. Department of Geography, University of Alberta, Edmonton, Alberta.

Gilbert, G. and Rooke, D., 1987. "Computerized screening and stippling using the Royal Australian Survey Corps Automap 2 system". Cartography, 16 no.2: 133-140.

Goodstein, D., 1987. "Desktop Publishing: Dawn of a New Era for Publishers". Printing Impressions, 30 no.9: 22-30

Holzang, D. A., 1987. Understanding PostScript Programming. San Fransisco: Sybex Incorporated.

Hou, H. S., 1983. Digital Document Processing. New York: John Wiley and Sons.

Integrated Graphics, 1988. Computing Systems, Univesity of Alberta, Edmonton, Alberta.

Keates, J. S., 1980. Cartographic Design and Production. New York: Longman Incorporated.

Morris, R. A., 1985. "Page Description Languages". An Introduction to Text Processing Systems: Current Problems and Solution (Lecture notes of a Workshop held in association with PROTEXT II conference). Dublin, Ireland: Boole Press, 67-85.

Rocap, W. A., 1980. "Effects of Undercolor Removal on Printing Quality" in Graphics Arts Manual. New York: Arno Press, 346-350.

Schreiber, W. F., 1986. Fundamentals of electronic imaging systems. New York: Springer-Verlag.

Seybold, J. W., 1987."The Desktop-Publishing Phenomenon". BYTE, May: 149-154.

Shapiro, C. (ed.), 1973."The Lithographers Manual. Pittsburgh: The Graphic Arts Technical Foundations Inc.

Sijmons, K., 1982. "Cartographic applications of digital techniques". ITC Journal, 2: 131-138.

Statistics Canada., 1982. " Final Population Counts, 1976 and 1981". 1981 Census of Canada. Ottawa: Minister of Supply and Services.

Stefanovic, P., 1982. "Digital Screening Techniques". ITC Journal, 2: 139-144.

Stiefel, M. L., 1981. "Color Hard Copy In Computer Graphics". Harvard Library of Computer Graphics/1981 Mapping Collection: Computer Graphics Hardware, 14: 52-54.

Wesner, J. W., 1974. "Screen Patterns Used in Reproduction of Continuous-Tone Graphics". Applied Optics, 13 no.7: 1703-1710.

Williamson, S. J. and Cummins, H. Z., 1983. Light and Color in Nature and Art. Toronto: John Wiley and Sons.