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Scanning ratios for desktop imaging

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Scanning Ratios for Desktop Imaging

by

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requirements for the degree of Master of Science in the
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Rochester, New York

Certificate of Approval

Master's Thesis

This is to certify that the Master's Thesis of

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With a major in *Graphic Arts Publishing*
has been approved by the thesis Committee as satisfactory
for the thesis requirement for the Master of Science degree
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Abstract

Users of desktop scanning technology are conscious about the quality the image detail reproduction. Repeatability and accuracy are based on certain standards. Established scanning procedures for charged couple device (CCD) desktop scanners are primarily influenced by the Nyquist Criterion which states that an image must be sampled at twice the frequency of the line screen ruling that will be used to print the final image. These "rules of thumb" appear in many technical and trade publications that are consulted by the printing industry in order to insure the quality of printed products. Quality is not the only factor influenced by scanning ratios. File size, processing time, and cost are also affected.

The purpose of this study was to discover if it is possible to reduce sampling ratios below 2:1 while still preserving the desired level of image detail. The *paired comparisons* method of testing was employed to determine the threshold where a population could no longer discern the difference between images scanned at a 2:1 scanning ratio and images scanned at lower frequencies. The tests involved a high and low detail image scanned at ratios between 1:1 and 2:1. These were output by an image-setter to films at 85 lpi and 133 lpi. The results of the statistical analysis show that it is possible to reduce the scanning frequency below the limit established by the Nyquist Criterion while still maintaining a consistent level of perceived detail in an image. Also, it was shown that as the level of detail in an image decreases and as the line screen frequency used increases the scanning ratio can be allowed to decrease. Therefore, it is possible to reduce the size of a file before it is created and consequentially to reduce the time required to perform image processing functions.

Chapter One: Introduction

1.1 Statement of the Problem

Popular trade publications throughout the industry recommend that reflection copy and transparencies to be scanned into electronic publishing systems should be scanned anywhere between 1.25 and 2.5 times the frequency of the screen ruling in order to capture enough information to faithfully represent the image. This rule of thumb is based upon the Nyquist Criterion. In none of the publications I consulted were there any reference as to how these scanning ratios would be influenced by the *characteristics of image* that is being scanned and there was also no reference showing how the *frequency of the screen ruling* relates to the scanning resolution. Under existing guidelines, it is possible to assume that *any* image, regardless of detail, to be printed at 60 lpi would be scanned at the same ratio as an image to be printed at 250 lpi. It is proposed that these variables (image detail, line screen ruling, and scanning ratio) would most likely affect the perceived quality of an image. The assumption that these variables are consistent also needs to be investigated.

Another issue is file size. For example: a 24 bit, 5x7 image to be printed at 133 lines per inch could be scanned anywhere between 166 pixels per inch and 266 pixels per inch and still fall within the recommended scanning range. However the storage required to store the image at the different scanning resolutions is 2.7 MB and 7.1 MB respectively (Linotype-Hell). If we then decide to publish a catalogue with many images in it, the difference in storage space, the time used to pass the file over a network, the time needed to work with the file, and the money needed to cover those expenses increases even more. Ultimately the qual-

ity that the customer sees takes precedence over storage space and working time required for production. If storage space and money can be saved by applying more critical methods and guide lines for scanning images, then attempts must be made to establish a stricter standard.

The use of manual stripping and graphic arts cameras is decreasing. Instead of developing standards for the storage, exposure, and development of films, we have moved into the era of managing the quality of scanned images. It is not enough to follow a standard that has yet to rise above the status of being a "rule of thumb." For example, a company that was to publish a catalog that displays power tools would typically use a scanning ratio that is higher than a publication that displays photos of underwater photography because the images of power tools would contain more detail than the other. Simply adopting a scanning ratio standard of "...between 1.25 and 2.5 times the frequency of the screen ruling" (Publish, p.42) would not be adequate for either publication. Arbitrarily assigning a scanning ratio for all images assumes that there is a consistency in detail between them. There is not.

1.2 Background and Significance:

This thesis/project was an investigation into the applications of scanning ratios for desktop publishing. Specifically, color reflection copy was analyzed. Various articles and journals have cited that to produce a quality continuous tone image using CCD flatbed scanners, the image must be scanned at a frequency in pixels per inch that ranges from 1.25 to 2.5 times the frequency of the line screen ruling

that will be used in printing the final image. The following are some examples of some of those recommendations that appeared in various publications.

> "As a general rule, to produce a high quality image, the image resolution should be twice the screen resolution of the halftone screen that you will use to print. For example, to print a high quality image using a 133 line-per-inch screen, you will need an image resolution of approximately 266 pixels per inch." (Adobe, p.52)

> "After some testing, it has been determined that you get the best results if you have two times as many ppi in the scan as there are lpi in the output. This relationship guarantees that there is enough color information available to make a reasonably accurate halftone dot." (Agfa, p.14)

> "As a rule of thumb, halftones and color separations should be scanned at input resolutions that are approximately 2.5 times the highest screen ruling required." (GCA, p.32)

> "Typically you'll need 1.5 to 2 times as many pixels per inch in the sized image as the line-screen frequency you used to print it with" (MacUser, p.47)

> "For example, an image to be screened at 150-line screen ruling should have a resolution of at least 300 dpi." (Seybold, p.21)

> "The general rule is that for same size output as the original, the scan should be performed such that the number of pixels (measured in the X-direction will be at least twice what is needed for the halftone dot cells to be formed." (Seybold, p.15)

> "A good rule of thumb is to use a ratio from 1.25:1 to 2:1 (the relationship between the input resolution, measured in dpi and the output resolution measured in halftone lpi) for same size images." (Publish, p.41)

> "Sampling theory says that the sampling resolution must be at least twice as fine as the size of the smallest feature to be detected" (Digital Typography , p.42)

I believe that other factors need to be included in setting guidelines for effective scanning ratios. These variables are the degree of detail in the image being scanned and the line screen ruling that is used to print it. These scanning ratios directly affect image quality, image processing times, file storage space and the cost of maintaining that storage. In the future, however, the cost of digital storage for images will become less of an issue for many publishing firms because of the advances being made in the area of file compression technology. Also, there will soon exist the software to compress files immediately after scanning so that the files that are being moved around a network will also be compressed (Romano). Scanning ratios address the issue of quality and size of an image *before* it enters the system. Is not likely that in an industry where profit margins are low by comparison that a manager will be willing to incur unneeded expenses for data storage or the extra time that is required to work with large image files on the desktop. Therefore, more precise guidelines of determining scanning resolutions need to be established in order to supply people that operate and manage electronic publishing technology a guideline showing how to maintain a desired image quality, save time, money, and storage space.

1.3 Reasons for Interest

The interest for this study was sparked by my observation that the Nyquist Criterion can not be used as an absolute rule to standardize the scanning of a wide variety of images that are largely evaluated by subjective means. It then follows that there would be some measurable impact on processing time and file sizes as these scanning ratios are adjusted.

There are certain invalid assumptions embedded in this "rule of thumb" that seem to be quite prevalent in the printing industry. It is assumed that all of the images scanned by this method contain the same level of detail. It is also assumed that the line screen ruling used to print these images has no bearing on the corresponding acceptable scanning ratio. Furthermore, the Nyquist Criterion was never tested on the sight perception of observers. Only the detectability of sound was tested. (Mr. Harry Nyquist developed this theory in 1928. The technology that is being examined was not developed until some time after that.) The mathematics of the theory are correct. However, since the process of evaluating many images is a subjective one, I believed that further testing was required.

Although it may be impossible to set an absolute standard for desktop scanning, several trends can be identified. This is exactly what this study was meant to do. The trends that were identified would be helpful to a business that was trying to find a starting point for establishing its own range of ideal scanning ratios.

One of the motives for this study was to successfully address the issue from the "front-end". Until now, tools such as file compression have been used to

manage files after they have been created. Some would reason that because of this, the study of scanning methods is not needed. However, if the potential size of a file can be reduced to 39% before it is even scanned into the system, the compression software is made that much more effective. This study shows that the quality and size of a file can be managed with a little planning before scanning the image.

The final motive for this study was to help the readers realize that for many printing processes, many variables must be addressed before an absolute rule can be established. In many cases, it is not possible. A comparable example would be a standard that established that a certain number of turns of the ink keys on a press would insure good quality. It can't be done because there are too many variables. The same principle applies to scanning ratios. Businesses would benefit from a close evaluation of the variability between their primary type of image, and printing processes used for different jobs to see if an in-house standard would be possible.

Chapter Two: Technical Overview

2.1 Technical Information

The purpose of this section is to discuss the technology used by the scanner, the software and the imagesetter. This brief overview will assist in understanding the testing methods and findings of this thesis/project.

Raster file: The bitmap format of a scanned image. It is resolution dependent and creates large files. (TIFF, RIFF, PICT, PICT2, and EPS in the case of color separations where there is a main view file and files for CMYK) These files tend to be much larger than vector files because more information is stored. These files are images that are created in paint programs, images that are bitmapped, and images that are captured by a scanner. Any kind of resizing affects the resolution of that file.

Vector files: Object oriented file. It is resolution independent and is defined by mathematical functions. These are files that are comprised of line art. All of these files must be converted to a raster file before it is output to a printing device.

File size: The total resolution of a scanned file is the *spatial resolution x the tonal resolution*. The tonal resolution can represent a grayscale image (8-bit, 256 colors), or an RGB image (24-bit,16.7 million colors). These files tend to be quite large. Because of this, it is important to give some consideration as to the scanning ratio that will be used to capture an image.

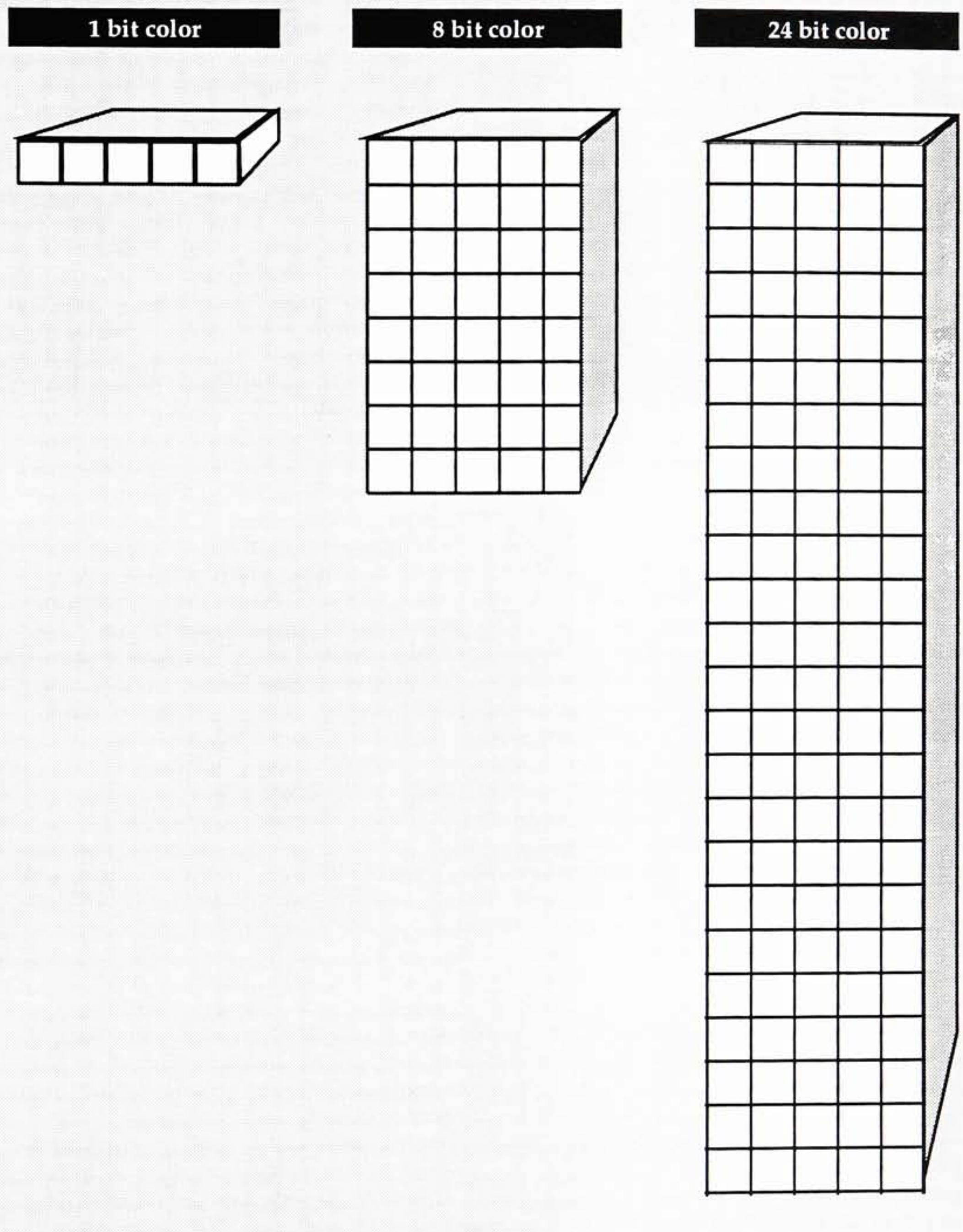


Figure 1: A representation of file sizes

These files can be defined by the following equation:

$$[\text{tonal resolution}/8]\,[\text{spatial resolution}]^2\,[\text{dimensions}] = \text{file size}$$

tonal resolution : bits per sample
spatial resolution : pixels per inch
dimensions : $inch^2$
file size : bytes
KB : bytes / 1024
MB : bytes / 1,048,576

RESOLUTION	1 BIT	8 BIT	24 BIT
75 ppi	703.0 bytes	5.5 KB	16.5 KB
100 ppi	1.2 KB	9.8 KB	29.3 KB
150 ppi	2.8 KB	22.0 KB	65.9 KB
200 ppi	4.9 KB	39.1 KB	117.2 KB
300 ppi	11.0 KB	87.9 KB	263.7 KB
400 ppi	19.5 KB	156.3 KB	468.8 KB
600 ppi	44.0 KB	351.6 KB	1.0 MB

Figure 2: File sizes for 1,8, and 24 bits in a 1 $inch^2$ image.

The scanner: The flatbed CCD scanner works in the following way. The CCD scanning head is fixed in place. It could be said that this linear array of up to 2600 photosensitive elements mimics the eye of an insect. This array is the CCD or Charged Couple Device. The reflected light from the image is recorded by the scanning head. Each cell in the scanning head produces an electrical signal proportional to the strength of the light that it receives. The darker the portion of the

image being recorded, the weaker the signal. That signal represents one pixel of the original image. If that signal does not reach a certain predetermined threshold, then that signal will be ignored by the computer. This is very important to remember because it plays a vital role in the construction of halftone dots. The signal is then digitized and sent to the computer. Most scanners use separate passes to record the individual files for Red, Blue, and Green. An array of 2590 cells across the one inch CCD scanning an 8.5 x 11 sheet gives the effective resolution of about 300 ppi.[10] (2590 cells / 8.5 inches = 300 ppi). Three passes will yield a complete RGB file with eight bits of gray for each color to give 24 bits per pixel and 16.7 million possible colors.

When a two dimensional image is scanned a slice one pixel wide is scanned and processed until the entire image is scanned. This scan line can be defined by a certain wave form and this is when the Nyquist Criterion is applicable. When this wave form is received it is processed similarly to an audio wave (this will be discussed in the following section). The waves for the RGB files are then multiplexed together to form a single wave.

Sampling process and the Nyquist Criterion: Sampling devices are typically analog devices. In this case it is a CCD flatbed scanner. The output is in the form of electrical signals that ultimately drive the output device. The intensity of the light received from the copy dictates the power of the signals. These signals are then digitized and converted into a set of numbers. This numbered data is finally reconverted into smooth signals to be drive the output device. The smoothness, and therefore, the true representation of the signal will increase as the sampling ratio of the image increases.

In 1928 AT&T mathematician Harry Nyquist proposed that under ideal conditions that *sound* must be sampled at twice the frequency as the highest frequency that is present in the signal in order to faithfully reproduce that sound (Seybold, p.21). It has been stated since then that any amount of sampling above a two to one ratio does not yield any additional information that benefits the end use (Linotype-Hell). It will be assumed that these statements are correct. It is not the purpose of this project/thesis to disprove the theory proposed by Harry Nyquist. Instead, this is a practical approach to investigate the significance of this principle in desktop imaging.

One has to recognize that reflected light can be digitized and graphed, and in theory these results can be compared and found to conform to the theory. In the case of this thesis the testing is not done to test the validity of the mathematics, but rather, the impact of sampling ratios for practical uses in desktop scanning. The variables that must be acknowledged as being different from the testing environment that was used by Nyquist are the fact that reflected light from a two dimensional image is being sampled, not one dimensional sound waves. Also, the stimulus from these samples are being received by the eyes, not the ears, and that the quality of the end result is largely determined by subjective means.

The sampling rate is determined by the frequency of the signal received from the copy. In the case of images, this frequency is called "spatial frequency" and is present in the form of changes in gray values per inch. The higher the amount of detail, the higher the spatial frequency, and the higher the sampling rate must be to capture the needed information in order to reproduce it.

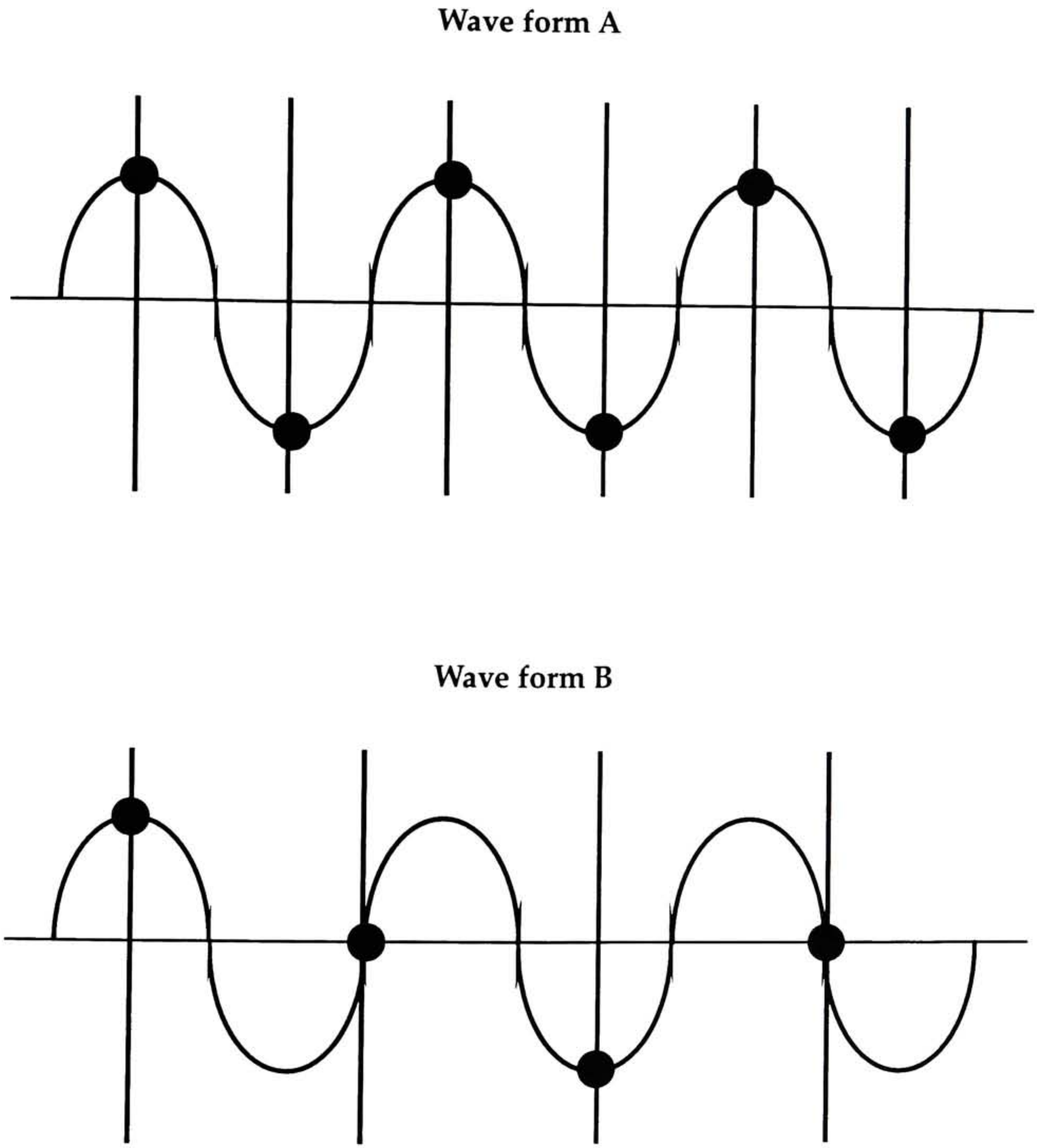


Figure 3: The sampling process.

The two waves represent images scanned at different frequencies and each has a discreet number of values that are sampled. Wave form "A" could be said to represent an image where a higher frequency is used. Wave form "B" could represent a lower scanning frequency. The resulting values of those samples are denoted by the small dots. This is how analog data looks after it has been digitized. When these dots are connected they define the wave form of the output and this data is used to drive the output device. Because wave form "A" was sampled at an appropriate rate, the wave form will be recreated in a way that very closely resembles the original. The recreation of wave form "B" is a different story. The wave was sampled at too low of a rate. The amount data received will only drive the output device to recreate a lower frequency image. For example, if a very high detail image were to be sampled at a low rate, then the output would be an image with much less detail than the original and the changes in gray value per inch would much lower.

The pixel grid (Resolution): The grid of information captured by the CCD scanner captures the input image in the form of the pixel grid. The resolution is usually referred to as *samples per inch, dots per inch,* or *pixels per inch.* The term *pixels per inch* (ppi) will be used for the remainder of this thesis/project.

When a scanner samples a picture element the result is called a pixel. A one bit pixel has only one memory location that can assume two values. They are two shades of gray (black and white). A byte has eight memory locations. When this byte is used to describe the value of a pixel, the number of gray values possible for that pixel is 256. The resolution of a scanner can be compared to the resolution of an image setter in the following way. To avoid confusion later in future

discussions, the resolution of the image setter will be referred to in terms of *dots per inch* (dpi). The resolution of an imagesetter is measured in two dimensions: length and width. The resolution of a scanner is also measured in these dimensions and is called the *spatial resolution*. There is also a dimension of depth that corresponds to the gray value of each pixel on the length/width plane. This is called the *tonal resolution*.

Effective Spatial Resolution: A function of the initial spatial resolution and the resizing factor of an image. Since raster images are resolution dependent, any change in the physical dimensions of an image will change its effective spatial resolution. For a scanned image that has not had its size altered, the initial spatial resolution and the effective spatial resolution are equal. This principle can be defined by the following equation:

effective spatial resolution = [initial spatial resolution/sizing factor]

For example, if an image were to be scanned at 150 ppi and reduced by 50%, the effective spatial resolution would be 300 ppi.

Interpolation: This is an "intelligent guess" algorithm to determine probable pixel values based on the values of surrounding pixels that were actually scanned. Through the use of this algorithm, a 400 ppi image can be used to yield an image of up to 1600 ppi. The advantages to interpolation are that jagged lines can be smoothed in scanned images. Suppose an image were to be scanned at 300 ppi. The image in digital form might have two neighboring pixels A and B of gray values of 48 and 76 respectively. If the image were to be interpolated up to 600

ppi then a pixel of an unknown value would lie between the pixels A and B. The value of the new pixel "X" would be derived by averaging the values of pixels A and B.

The laser spot grid of the image setter: The grid established by the image setter's array of potential laser spots. In other words, it is a measure of how many marks an image setter can make in a linear inch.

Postscript halftoning: The three variables present in PostScript halftoning are gray level, addressability of the image setter and halftone screen ruling. The number of gray values is dependent on the resolution of the imagesetter and the screen ruling frequency. This is the electronic method of creating halftone dots. Each halftone dot grid has a certain number of laser spots within its boundaries that correspond to the addressability of the imagesetter. The number of cells corresponds to the number of potential gray values for that dot and subsequently the entire image.

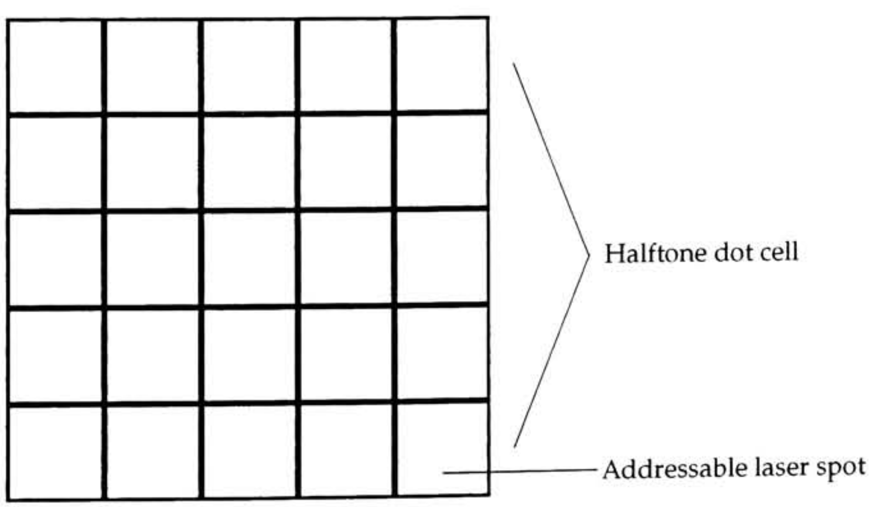


Figure 4: The halftone dot cell is five x five. This means that there are twenty-six possible shades of gray (including white)for the cell and the entire picture.

Therefore, as the halftone frequency rises with all other variables being held constant, the number of gray values falls. That is why a high addressability image setter is desirable because both of these factors (gray level and screen ruling) are allowed to increase.

The screen frequency selected is gray level related. Choices must be dependent on the resolution of the imagesetter. The following equation demonstrates this:

$[\text{Addressability of the imagesetter/halftone screen}]^2 + 1 = \text{Gray Levels}$

The tools of electronic halftoning are the screen angles, screen frequencies, the laser spot functions, and the halftone cells. A gradual blackening of the cell is handled by the postscript interpreter with pixels of the highest priority being blackened first. The spot function calculates these priorities for each location in each halftone cell. This is how printed shades of gray are accomplished. It has been stated that 100 to 256 levels of gray are acceptable for halftones (Linotype-Hell) The following chart displays this.

RESOLUTION	256 GRAY SHADES	100 GRAY SHADES
300 dpi	19 lpi	30 lpi
600 dpi	38 lpi	60 lpi
635 dpi	40 lpi	64 lpi
846 dpi	53 lpi	85 lpi
1016 dpi	64 lpi	102 lpi
1693 dpi	106 lpi	169 lpi
2540 dpi	159 lpi	254 lpi
3386 dpi	212 lpi	339 lpi

Figure 5: Gray levels produced by various resolutions and line screen rulings.

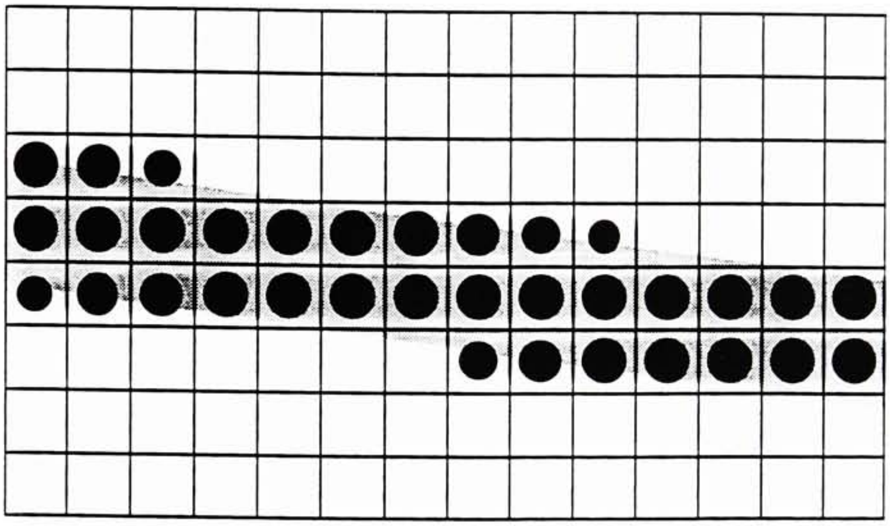
The Spot Function: In graphic arts photography, there is only one grid to consider; this is the halftone dot grid. With PostScript halftoning there are three. These are the laser spot grid of the imagesetter which ranges from 300 ppi on a laser writer to 3300 ppi on a high resolution image setter, the halftone dot grid, and the pixel grid which is the resolution of the scanned image. The pixel grid exists independently of the halftone grid (Seybold, p.16). The halftone dot values output by the imagesetter are an interpretation of the gray values of the pixels of the scanned image. This spot function is completed by screening algorithms in the raster image processor (RIP).

The amount of data available to create halftone dots is dependent on the resolution that was used to scan the image. In other words, as more pixels are recorded from an image, the amount of information used to create accurate halftone dots is increased. It is the focus of this thesis to determine the threshold where additional pixel information recorded from an image fails to improve the quality of that image in the eyes of an observer.

As the scanning resolution rises, so does the number of gray values. This leads to gradual shade transitions and truer reproduction of image detail. As the halftone screen frequency rises, the dots get smaller so that more fine points of detail are imaged. The higher the resolution of the output, the higher the gray shades of the fine detail and the better the quality. The resolution of the pixel grid should not be more than two times the frequency of the halftone grid because the halftone grid will tend to mask it and interference will result at that point (Seybold, p.15).

Gray values are the electronic equivalent of tones. The intensity of the light reflected off of the copy when it is being scanned is read by the scanner. This is then translated into a pixel that is twenty-four bits deep for RGB color. This is then translated into C,M,Y,K information. Inside the RIP the pixel value is compared with the spot function which is a pre-calculated lookup table. A threshold exists to determine the gray level of the halftone dot that will correspond to the gray values of Cyan, Magenta, Yellow and Black of the pixel. This is the setting that sets the lowest value sets that can be used to generate a halftone dot. The RIP determines exact halftone dot values for the colors in the pixel group. If a sampled pixel has a value higher than the threshold then a halftone dot is formed. The imagesetter laser spot grid is divided into halftone cells so each can be assigned a threshold matrix.

The method used to create halftones dots for a 2:1 ratio is completed in the following way. Each halftone cell corresponds to a portion of detail in the original image and each cell contains four pixels. The four pixels are individually compared to the spot function in the RIP. If the value for a pixel exceeds the predetermined threshold value in the spot function look-up table, then that value is used to derive the average of the values for the four pixels. This single value is then used to form the halftone dot to represent the detail in the four pixels. The question is whether less than four pixels per halftone cell are enough in some cases to form accurate halftone dots.



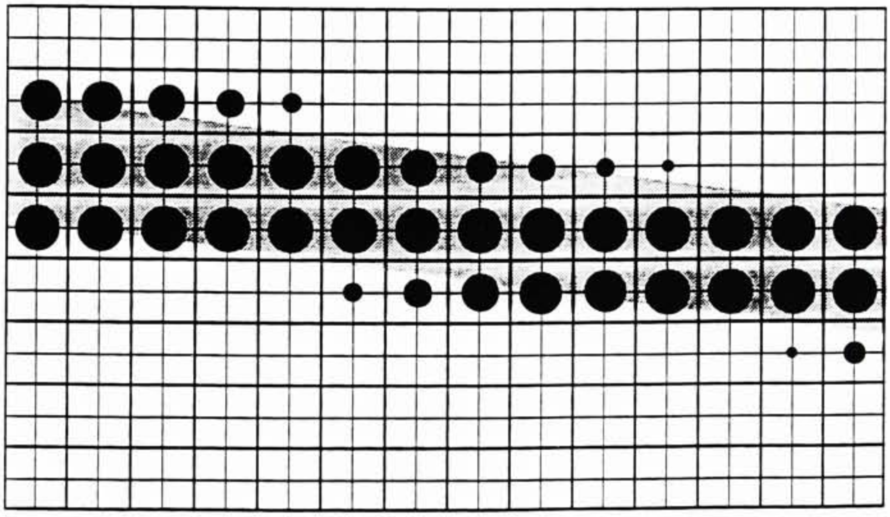


Figure 6: This shows how the threshold function in postscript halftoning works. In the first instance where a portion of the image is sampled at 1 : 1, no value will be assigned to certain halftone dot cells if the scanned pixel does not meet or exceed the threshold value. In the second instance, more pixels are assigned to a halftone cell at a 2 : 1 ratio. Each individual pixel within the cell has a threshold value. Even if just one of the four pixels records a value, the halftone cell that contains that pixel will produce a halftone dot after that value is averaged with the other three cells. This is why aliasing is more prominent at lower scanning resolutions. The halftone cells in the second example has more "chances" to have a dot assigned to the halftone cell.

The image operator is the PostScript language mechanism accommodates sampled images of any size up to 256 shades of gray. There are five parts in the image operator. The first three parts represent the length, width and the tonal values of the pixels. The fourth is the image matrix which is a transformation matrix that maps user space onto the coordinate system created by the data acquired from the scanning process. The fifth part is the data acquisition procedure. First, the operator determines the number of bits needed to represent an image by multiplying length, width and depth. The data acquisition procedure is executed as many times as necessary to image each string into a device space. The mapping provided by the image matrix is applied as the data is being imaged. It takes data represented by many small samples and renders it on the current page at a specific location, size and rotation. Each pixel can equal 1, 2, 4, or 8 bits of gray value. In the case of a photograph it will be eight bits per RGB channel.

The data acquisition procedure is used by the image operator. It obtains sampled data, converts it into a string and leaves it on the operand stack. The procedure is called as many times as necessary. Each time it uses the strings remaining on the operand stack until all the data is read. This data is the *length x height x tonal value* as provided by the image operator. Suppose there were an image that measured ten pixels in length, eight pixels in width and four bits of grayscale information in depth. The length and width values would be handed directly to the image operator on the operand stack. The data string must be the correct length to match the dimensions of the image. Strings contain eight bit bytes. To represent 10 x 8 x 4 bits of image data, 320 bits of information are needed, which requires a 40 byte string to contain the 320 bits. The pixels are interpreted one at

a time to represent the gray value of successive samples as specified by the bits per pixel value passed on to the image operator.

Aliasing: In the attempt to describe a curve using a grid, a stair step effect occurs. This is the result of introducing low frequencies into the image that misrepresent high frequencies in the original. The degree of aliasing is directly related to the sampling frequency used to capture an image. As the sampling frequency increases, the amount of pixels to describe the image increases. When this number in pixels per inch increases, the individual pixels become increasingly difficult for the eye to decipher and this results in a decrease in aliasing (Linotype-Hell).

2.2 Statistically Valid Methods of Evaluation

This section is discussion of the subjective tests conducted on proofed images and is accompanied with their respective results. The purpose of these tests was to analyze the sharpness of detail which is used as a tool to indicate the quality of the scanned images with respect to the detail of image being scanned, the sampling frequency, and the screen ruling used to print the image. The presentation, evaluation, and comparison of these results is presented as a form of statistical analysis.

There were two test images. One had very fine detail and the other had average detail. Each of these were sampled at different frequencies relative to 85 lpi and 133 lpi. These are the screen rulings used most commonly for newspapers and magazines respectively. The number of gray levels was above 326 which is

well out the range an average observer can detect (Russell, p.70). My observer audience consisted of students and faculty in the printing department mainly because of ease of accessibility. The observers chosen may have had a better idea of what attributes to look for compared to the average person and this variable will be noted in the test results. All testing was conducted in standard viewing conditions of 5000°K and a viewing distance of twelve inches. All of the images were proofed using the Cromalin proofing system. These are also the images that were examined during the testing. There was no need to print the images on different substrates because paper dictates the halftone screen ruling and the sampling frequency is referenced to that.

Average Detail Image (Hand)		High Detail Image (Web)	
85 lpi	133 lpi	85 lpi	133 lpi
1.00 : 1	1.00 : 1	1.00 : 1	1.00 : 1
1.25 : 1	1.25 : 1	1.25 : 1	1.25 : 1
1.50 : 1	1.50 : 1	1.5 0: 1	1.50 : 1
1.75 : 1	1.75 : 1	1.75 : 1	1.75 : 1
2.00 : 1	2.00 : 1	2.00 : 1	2.00 : 1

Figure 7: The testing was structured in the following way.

The tool used to evaluate the images is called the *paired comparisons* method (Bartelson, p.84) This established method of comparison is designed to show the relationship between two images of similar but not exact characteristics. Observers are forced to make a choice between the two images and the results are recorded on a matrix that is evaluated after the testing is completed. When

an observer is uncertain about which image to choose, a best guess is made. They are asked to indicate which member of the pair has more of the attribute in question. In this case the attribute was clarity of detail (or degree of aliasing). The test works best when the stimuli are similar enough to be often confused. It demonstrates the relationship relating the proportionate number of times any stimulus i is judged according to some attribute to be greater than the stimulus j in terms of the perceptible differences of the two stimuli on a judgement continuum. This model determines the proportion of times one stimulus is preferred over another and calculates the normal standard deviation corresponding to that proportion to determine the interval scale of a stimulus. This method is used to determine which stimulus shows more of the attribute by comparing all of the samples with each other.

When all samples are compared with each other a condition of i vs. j and j vs. i is created. In other words two samples are compared to each other twice during the course of the evaluation. The number of comparisons needed is defined by $N = n(n - 1)$ (Bartelson, p.82) where N equals the total number of comparisons and n equals the number of samples to be compared. In order to keep N as small as possible the equation $N = (n/2)(n-1)$ will be used to eliminate redundant pairs, thus decreasing the time required to perform testing without losing pertinent information (Bartelson, p.82) In this case it is not desirable to simply decrease the number of n because as n decreases, it becomes more difficult to determine the point where additional scanned information makes no significant contribution to the quality of an image. Another way to eliminate pairs is for the experimenter to decide which images will unanimously be judged one way or the other so that the proportion is 1 or 0. These pairs would then be eliminated. The

danger of this is that the inclusion or exclusion of data that is not the same as the observers could occur. The purpose of this experiment is to map proportions of decisions that are 0 > x <1. I decided not to eliminate any pairs according to these particular parameters. In the case of this experiment each column had five samples that were compared to each other to examine the impact that the sampling frequency had on an image. The number of comparisons was *(5/2)(5-1) = 10.* Multiplying this by four columns resulted in 40 paired comparisons. This is an ideal number of comparisons to both accurately complete the study and avoid any significant degree of fatigue imposed on the subjects making the comparisons.

The testing was completed by thirty observers. If the function between degree of detail and observer detectability is a smooth curve then the more observers that are used, the smoother the curve will be. This is not infallible but it is true often enough so that it can be taken as a useful approximation. (Bartelson, p.45)

When the data was collected there was four tables. the data in each table was converted to a proportion matrix by using the equation p = f/N where N is the number of observations and f is the frequency. Results from tables A, B, C, and D were then analyzed individually to make conclusions concerning the scanning ratio. Statistical analysis was carried out to one standard deviation. For a complex system, especially in the area of subjective testing, this is all that is required. Data from tables A and B were compared with each other to see how the scanning ratio is affected by screen ruling. The same was done for tables C and D. Finally the data from the average detail image and the data from the high detail image were compared to see how the degree of detail in the image being scanned.

Chapter Three: Hypothesis

This study was founded on the hypothesis that there are exceptions to the Nyquist Criterion as it relates to the scanning of images into pre-press systems.

It was hypothesized that the Nyquist Criterion failed to take into account that different images have a varying amount of detail. Therefore, scanning resolutions that fell below the established 2:1 ratio could possibly capture enough sampling information to faithfully reproduce the image. It was also hypothesized that scanning resolutions could decrease as the frequency of the screen ruling increased. As the screen ruling for a printed image increases, it becomes more difficult to see the dots. Therefore, it was thought possible that it becomes increasingly difficult to detect a decrease in information that comprises those dots. The trends that needed to be proved were:

1. As the amount of detail present in an image decreases, the scanning resolution used should also be allowed to decrease.

2. As the screen frequency of the final printed image increases, the scanning resolution should be allowed to decrease.

3. The average observer cannot tell the difference between an image scanned at a 2:1 ratio and the same image scanned at a lower ratio.

Chapter Four: Methodology

4.1 Choice of Sampling Frequencies

The sampling frequencies that I chose for these tests were designed to both reveal a threshold in viewer detectability while at the same time minimizing the amount of data collected so that viewer fatigue during the testing could be minimized. For example, instead of choosing five scanning ratios on the continuum between 1:1 and 2:1, I could have chosen as many as twenty increments to obtain more exact results. For the purposes of this study, a result of that accuracy was not needed because it was only being determined *if* the Nyquist Criterion could be violated and which trends could be derived from that. Also, viewer fatigue would have all but nullified the results. A test of that size would have ballooned the size of the test per individual from 40 observations from to 760 observations.

4.2 Choice of Images

The two images chosen for the testing were specially chosen for their degree of detail. The image of the hands were chosen because it represented subtle changes in detail that would be indicative images of this type. The image of the web was chosen to represent images of high detail. It was reasoned that if this image could be scanned at a resolution lower than the Nyquist Criterion, then almost any image can. It was also chosen to reveal if images of different levels of detail can be scanned at frequencies differing from each other. These results would reveal a trend in scanning ratios between images of varying detail. Color images were chosen to represent the trend toward four-color work and to focus the study.

4.3 Choice of Screen Ruling Frequencies

The screen rulings were chosen to represent the the more common rulings used. The two chosen images were output at the two line screen rulings. The line screen rulings of 85 lpi and 133 lpi were chosen to represent newspaper quality and magazine quality. Also, these publications use many images per publication and would be representative of a printed piece where a decrease in scanning frequency would cause a noticeable change in production costs associated with image storage, manipulation and output. These two different screen rulings also vary enough in resolution that if there were any trends in scanning resolutions associated with output at different line screen rulings, they could be detected.

4.4 Preparation of Images

An Agfa Horizon scanner, Photoshop 2.0, a Macintosh Quadra 700, and an Agfa Selectset 5000 were used to scan and output the film for all test images. The pages were built using Quark XPress.

Using the Fotolook Software and Photoshop I set the highlight and shadow for each individual scanning resolution. Ideally I would have liked to set these values only once for each image but the software would not allow it. Therefore each scan had to have these values set each time. Every effort was made to take the readings from same location. However it is possible that small variations in the readings occurred. As a result there could have been some experimental noise introduced in the form of a small shift in contrast between the final film images. This would not affect the scanning resolutions but might affect the observers

perception of the paired comparisons. To counter this, I did not just tell them to identify which image they preferred as instructed in the testing outline. Instead, they were told exactly what to look for. This will be discussed in more detail in a proceeding section.

4.5 Output

The final output of the 133 lpi images were set to SWOP specifications and the 85 lpi images were output at standard newspaper specifications. All output was in the form of positive films because the Cromalin positive proofing system was used. The image setter recorded at an addressability of 2400 dpi. The two line screen rulings used were 85 lpi and 133 lpi. This means that the minimum number of gray levels was 326 ($[2400/133]^2 + 1$).

4.6 Proofing

The final proofs evaluated by the observers were created on the Cromalin positive proofing system. One of the reasons this system was chosen was its accessibility. The exposure times on this system were also much shorter than the Matchprint proofing system. Thus the production of the test images was significantly reduced.

Positive films were used in the proofing process because I found that registration was easier to achieve. Because of this, the experimental noise that could have entered the process at this stage and affected the perception of image detail was reduced.

It had been suggested that printed specimens of the images be supplied to the observers for evaluation. However, the purpose of this study was to test the Nyquist Criterion and in order to do this, experimental noise had to be kept to a minimum. Therefore, only films were created. This is the first point where all of the digital information that had been collected by the scanner is translated into halftone dots. The registration of these were carefully controlled by making proofs instead of press sheets. There are slight color differences between proofs and the printed sheets but slight color shifts do not affect aliasing - the tool used to evaluate image detail reproduction.

4.7 Visual Evaluation Process

4.7.1 The Observers

The observers that were chosen for the testing were either students or faculty in the School of Printing. The test results recorded from these apparent groups were treated as one sum of data. In prior cases where the paired comparisons method was used to evaluate an aspect of printing technology that noted differences between these two groups, no noticeable difference was discovered (Susstrunk) Therefore, I concluded that the test results of the entire population would not be skewed because of one group or the other. Because all of the observers used for the testing have had exposure to printing technology, and as a result, might be more inclined to discover anomalies that the average observer may not, it is also concluded that the test results that reveal an acceptable scanning ratio are equal to or a bit stricter than the requirements needed for a population of average

observers. In other words, if an observer with a printing technology background cannot distinguish between two images scanned at different resolutions, then the average observer will not either.

4.7.2 Testing Environment

The observations of the various samples were performed in a controlled environment. All of the test images were placed on a neutral colored background. The image pairs had their identifying labels covered and were presented for evaluation in a random order. Even if the label for an image were to be uncovered, it was in a code that a person could not attempt to decipher without seriously delaying the completion of the testing. The listing for the order remained hidden to the observer. Although the attribute in question had very little to do with color, the variable of color had to be controlled never the less. All observations took place in a viewing booth illuminated with 5000°K light. The rational for this is the same as the above. The conditions of the tests had to conform to standard viewing conditions in order for the test results to receive the desired level of credibility.

The observers were provided with a specific set of oral instructions prior to testing. They were told to identify the image that had a better clarity of detail. If the choice was not readily apparent, they were told to make a best guess after 30 seconds. If they weren't quite sure what was meant by "clarity of detail", aliasing was explained and its role in detail reproduction was defined. Any other questions were answered before testing began. The observers were also told to

make their best attempt to ignore slight color shifts between the images if any perceived difference occurred. These differences most likely arose from the fact that images were scanned, and had their highlights and shadows recorded individually. There could have been a minor difference in readings which would result in shifts in image reproduction.

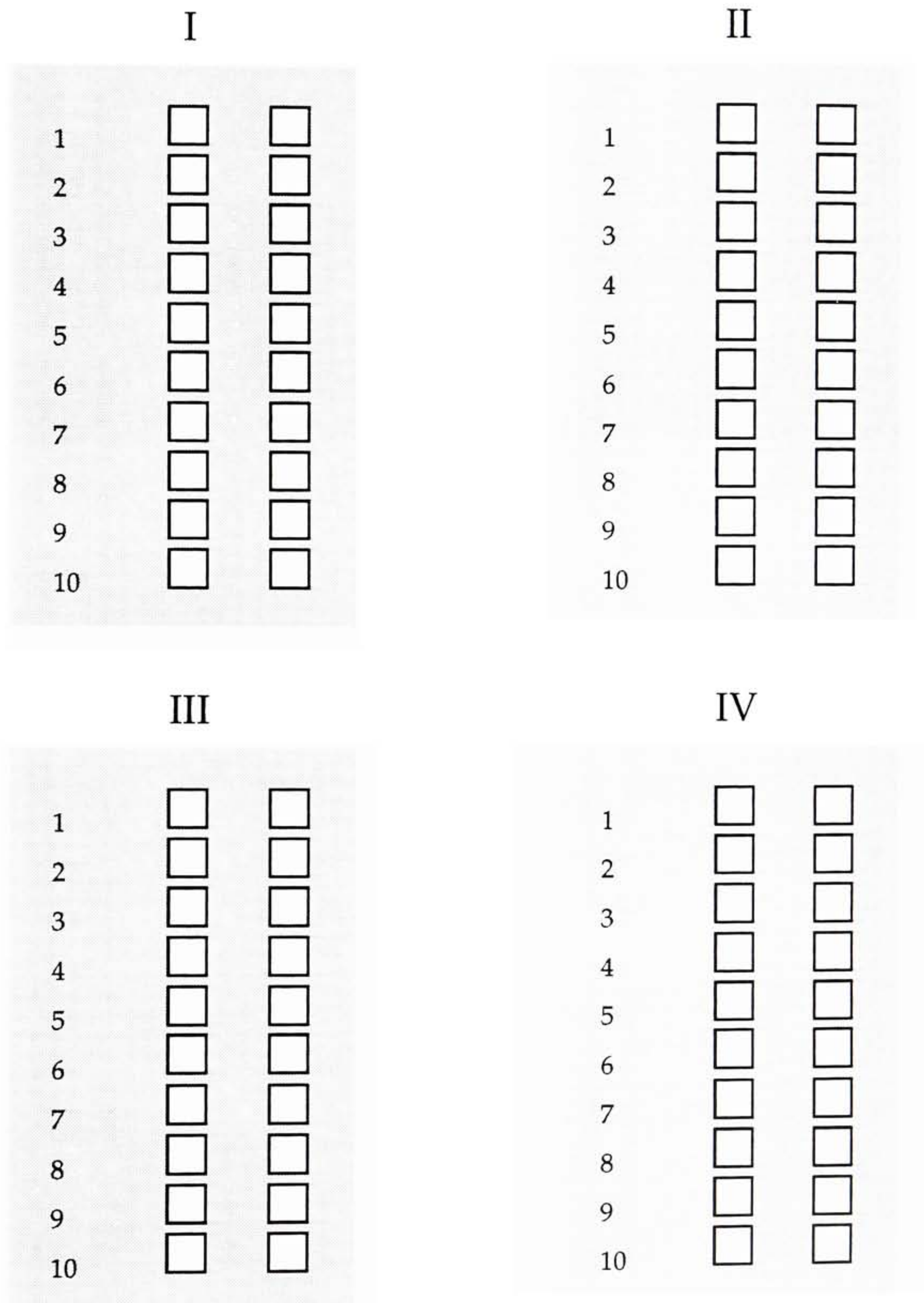


Figure 8: The observers marked their choices on a sheet like this one.

KEY:

N: Image of the hands
S: Image of the Web
A: 85 lpi line screen ruling
B: 133 lpi line screen ruling
1: 1 to 1.00 scanning ratio
2: 1 to 1.25 scanning ratio
3: 1 to 1.50 scanning ratio
4: 1 to 1.75 scanning ratio
5: 1 to 2.00 scanning ratio

1	NA2 NA5	SA2 SA3	NB5 NB4	SB4 SB5
2	NA3 NA5	SA2 SA1	NB2 NB3	SB4 SB1
3	NA5 NA1	SA4 SA5	NB1 NB5	SB1 SB5
4	NA4 NA1	SA4 SA1	NB4 NB1	SB2 SB1
5	NA2 NA4	SA5 SA1	NB3 NB4	SB2 SB4
6	NA3 NA4	SA2 SA4	NB1 NB3	SB3 SB5
7	NA3 NA2	SA4 SA3	NB5 NB3	SB2 SB3
8	NA1 NA2	SA1 SA3	NB2 NB5	SB5 SB2
9	NA3 NA1	SA5 SA3	NB2 NB4	SB1 SB3
10	NA4 NA5	SA2 SA5	NB1 NB2	SB3 SB4

Figure 9: The answers were coded in such a way that it would be nearly impossible for an observer to alter the test questions even if the answer key were to be seen. Images were presented to the observers in the order shown. Identification labels on the images were concealed.

Chapter Five: Results

5.1 Results of Observer Analysis

Evaluations of the images by the observers were complied into four tables of raw data. There are tables representing the low detail image output at 85 lpi, the high detail image output at 85 lpi, the low detail image output at 133 lpi, and the high detail image output at 133 lpi. Proportion matrixes and frequency matrixes were created from this pool of data. The frequency matrixes merely identify how many times one image was preferred over another in the effort to identify detectable differences in scanning resolution. The proportion matrix assigns a percentage to the values found in the frequency matrix. One can start to identify trends that apply to the relationship existing between scanning ratio, the level of detail in the image scanned, and the line screen ruling used to print the image.

In the frequency matrix and the proportion matrix, any value that equals 15 or .50 respectively or has a value "close" to that, identifies a pair of images where the population of observers were split as to which image had a better clarity of detail. This means that there is essentially no perceivable difference between the images even though they were scanned at different scanning ratios. The tables work in the following way:

A = a scanning ratio equal to 1 : 1.00

B = a scanning ratio equal to 1 : 1.25

C = a scanning ratio equal to 1 : 1.5

D = a scanning ratio equal to 1 : 1.75

E = a scanning ratio equal to 1 : 2.00

	A	B	C	D	E
A	15	27	27	25	28
B	3	15	18	23	26
C	3	12	15	19	16
D	5	7	11	15	17
E	2	4	14	13	15

The row of letters along the top of the table and the column of letters to the left side of the table equals one of these scanning ratios. If one wanted to find out how many observers preferred a 1.75 ratio to a 1.5 ratio then they would locate "D" on the top row and move down the chart to where it intersects with "C" from the column on the left side. Suppose this is a frequency matrix and the value located at this intersection is 18. This means D was preferred to C by 18 of the 30 observers. Or in other words, A little over half of the observers preferred a scanning ratio of 1.75 over a ratio of 1.5. The proportion matrix works in exactly the same way. The statistical analysis will show the degree significance of values that deviate away from an even split between observers.

Data from the entire table in all four instances was acknowledged to perform statistical calculations for the entire population. The primary concern of this study is to investigate the significance of the Nyquist Criterion and the information for that is contained in the column of data located on the far right column of the tables where E is compared to A, B, C, and D. This will show how scanning ratios of less than 1 : 2 compare to the scanning ratio established by the Nyquist Criterion. Without consulting the statistical analysis, one can identify a threshold in each table where the number of observers that detect a difference between scanning ratios suddenly increases. This is most likely the point at which a lower scanning ratio could be substituted for the 2 : 1 scanning ratio.

OBS	B,E	C,E	A,E	A,D	B,D	C,D	B,C	A,B	A,C	D,E
1	E	C	E	D	D	D	C	A	C	D
2	E	C	E	D	D	D	C	B	C	E
3	E	E	E	D	D	D	B	B	C	D
4	E	E	E	D	D	D	C	B	C	D
5	E	E	A	A	D	C	C	A	A	E
6	E	E	E	D	D	D	C	B	C	E
7	E	E	E	D	D	D	B	B	C	D
8	E	E	E	D	D	D	B	B	C	D
9	E	C	E	D	D	C	C	B	C	D
10	B	E	E	A	B	D	B	B	C	E
11	E	E	E	D	B	D	C	B	C	E
12	E	E	E	D	D	C	C	B	C	E
13	E	E	E	D	D	D	C	B	C	E
14	E	C	E	D	D	C	B	A	A	E
15	E	C	E	D	D	C	C	B	C	E
16	E	C	E	D	D	C	C	B	C	E
17	E	C	E	A	D	D	B	B	C	E
18	B	C	E	D	B	D	C	B	C	E
19	E	E	E	D	D	D	B	B	C	D
20	B	C	E	A	B	D	C	B	C	D
21	B	E	E	D	D	D	C	B	C	E
22	E	E	E	D	D	C	C	B	C	D
23	E	C	E	D	B	C	B	B	C	E
24	E	E	E	D	D	D	C	B	C	E
25	E	C	E	D	D	C	B	B	C	E
26	B	E	A	A	B	C	B	B	A	E
27	E	E	E	D	B	D	C	B	C	D
28	E	C	E	D	D	D	B	B	C	D
29	E	C	E	D	D	D	B	B	C	E
30	E	C	E	D	D	C	C	B	C	E

Figure 10: The raw observer data for the low detail hands image at 85 lpi.

OBS	B,C	A,B	D,E	A,D	A,E	B,D	C,D	A,C	C,E	B,E
1	C	A	D	A	E	D	C	C	E	E
2	C	B	E	D	E	D	C	C	C	E
3	C	B	E	D	E	D	D	C	E	E
4	C	B	E	D	E	D	D	C	E	E
5	C	A	D	D	E	D	D	C	C	E
6	C	B	E	D	E	B	C	C	E	E
7	C	A	D	D	E	D	C	C	E	E
8	C	A	E	A	E	D	C	C	C	E
9	C	B	E	D	E	B	D	C	C	E
10	B	A	D	D	A	D	D	C	E	E
11	C	B	D	D	E	D	D	C	E	E
12	C	A	D	D	E	D	C	C	E	E
13	C	B	D	D	E	D	D	C	E	E
14	C	B	D	D	E	D	D	C	C	E
15	C	A	E	D	E	B	C	C	E	E
16	C	B	D	D	E	B	C	C	C	E
17	C	B	D	D	E	D	D	C	C	B
18	C	B	D	D	E	D	D	C	C	E
19	B	B	D	D	A	D	C	C	C	E
20	C	A	E	A	E	B	D	C	E	E
21	C	B	E	D	E	D	C	C	E	B
22	C	B	E	D	E	D	D	C	E	E
23	C	B	E	D	E	B	C	C	C	E
24	C	B	D	D	E	D	C	A	C	E
25	C	A	D	D	E	D	D	C	C	B
26	B	B	E	A	A	B	C	C	C	B
27	C	A	E	D	E	D	C	C	E	B
28	C	A	D	A	E	D	C	C	E	E
29	B	B	D	D	E	D	D	C	E	E
30	C	B	E	A	A	D	C	C	E	E

Figure 11: The raw observer data for the high detail web image at 85 lpi.

OBS	D,E	B,C	A,E	A,D	C,D	A,C	C,E	B,E	B,D	A,B
1	D	C	E	D	C	C	C	B	D	B
2	D	C	A	D	D	C	E	B	D	B
3	E	C	E	D	C	A	E	E	D	B
4	D	B	E	D	C	A	C	E	B	B
5	D	C	E	D	D	C	E	B	D	B
6	E	C	E	A	C	A	E	E	B	A
7	E	B	E	D	D	C	C	E	B	B
8	D	C	A	D	D	A	C	E	D	A
9	E	B	E	D	D	C	E	B	B	B
10	E	C	A	D	D	A	C	E	D	B
11	D	C	E	D	D	C	C	E	B	A
12	E	B	E	D	D	A	E	B	B	B
13	D	B	E	A	C	C	E	B	B	B
14	E	B	A	D	C	C	C	B	D	A
15	E	B	E	D	D	A	C	B	D	B
16	D	B	E	A	C	C	E	B	D	A
17	EE	C	A	D	D	C	E	B	D	A
18	D	C	E	D	D	C	E	B	D	A
19	D	C	E	A	D	C	C	E	D	B
20	E	B	E	D	C	C	E	E	B	B
21	E	C	E	D	D	C	E	E	D	B
22	E	C	A	D	D	C	C	E	D	A
23	D	C	E	D	C	C	E	E	D	B
24	E	C	A	D	D	C	E	E	D	B
25	E	C	E	D	D	C	E	E	D	B
26	D	C	E	D	D	A	E	B	D	B
27	E	C	E	A	D	C	C	E	D	B
28	D	C	E	D	C	C	E	E	D	B
29	E	B	E	D	C	C	C	E	B	B
30		B	A	A	C	C	E	E	B	B

Figure 12: The raw observer data for the low detail hands image at 133 lpi.

OBS	D,E	A,D	A,E	A,B	B,D	C,E	B,C	B,E	A,C	C,D
1	E	D	E	A	D	E	BB	E	C	D
2	E	D	E	B	D	E	B	E	C	D
3	D	D	E	A	D	C	C	B	A	C
4	E	D	E	B	D	E	C	E	C	D
5	E	D	E	A	D	E	C	E	A	D
6	E	D	E	B	B	E	B	E	C	D
7	D	D	E	A	B	E	B	E	A	C
8	E	D	E	B	B	C	B	E	C	D
9	E	A	E	A	D	E	C	E	A	C
10	E	A	A	B	D	E	B	E	C	C
11	E	D	E	B	D	C	C	E	C	D
12	E	D	E	A	D	E	C	E	A	D
13	E	A	E	A	D	E	B	E	C	D
14	E	A	E	A	B	E	B	E	C	C
15	E	D	E	B	D	E	C	B	C	C
16	E	D	E	A	B	E	C	B	C	D
17	E	D	E	A	B	E	B	B	C	C
18	E	A	E	A	B	E	C	E	A	D
19	E	D	A	B	D	E	B	E	C	C
20	D	D	E	A	B	E	C	E	A	D
21	E	D	E	B	D	E	B	B	C	D
22	E	D	E	B	B	E	C	E	C	C
23	E	A	A	A	D	E	B	E	A	D
24	E	D	E	A	D	E	C	E	C	D
25	E	D	E	B	B	E	C	E	C	D
26	E	D	A	B	D	C	C	E	C	C
27	E	D	E	B	D	E	C	E	C	D
28	E	D	E	A	B	E	C	E	C	C
29	E	A	E	A	D	E	C	E	C	C
30	E	D	E	B	B	E		E	A	

Figure 13: The raw observer data for the high detail web image at 133 lpi.

Hands Image @ 133 lpi.

Y	/Y-M/	$(Y-M)^2$
15	0	0
8	5	49
7	13	64
6	10	81
8	11	49
22	5	49
15	0	0
11	11	2
10	8	25
12	11	9
23	14	64
19	11	16
15	0	0
12	0	9
13	0	4
24	10	81
20	8	25
18	0	9
15	0	0
13	1	4
22	11	49
18	11	9
17	0	4
17	1	4
15	0	0
375		**606**

375/25=15
m = 15

$$s^2 = \sum (y-m)^2 / 25$$

$$s^2 = 24.62$$

$$s = 4.96$$

Figure 14: The statistical data for the low detail hands image at 85 lpi.

Web Image @ 85 lpi.

Y	/Y-M/	$(Y-M)^2$
15	0	0
10	5	25
2	13	169
5	10	100
4	11	121
20	5	25
15	0	0
4	11	121
7	8	64
4	11	121
28	14	196
26	11	121
15	0	0
15	0	0
15	0	0
25	10	100
23	8	64
15	0	0
15	0	0
16	1	1
26	11	121
26	11	121
15	0	0
14	1	1
15	0	0
375		**1471**

375/25=15
m = 15

$$s^2 = \sum (y-m)^2 / 25$$

$$s^2 = 58.84$$

$$s = 7.67$$

Figure 15: The statistical data for the high detail web image at 85 lpi.

Hands Image @ 85 lpi.

Y	/Y-M/	$(Y-M)^2$
15	0	0
3	12	144
3	12	144
5	10	100
2	13	169
27	12	144
15	0	0
12	3	9
7	8	64
4	11	121
27	12	144
18	3	9
15	0	0
11	4	16
14	1	1
25	10	100
23	8	64
19	4	16
15	0	0
13	1	1
28	13	169
26	11	121
16	1	1
17	2	4
15	0	0
375		**1541**

375/25=15
m = 15

$$s^2 = \sum (y-m)^2 / 25$$

$$s^2 = 61.64$$

$$s = 7.85$$

Figure 16: The statistical data for the low detail hands image at 133 lpi.

Web Image @ 133 lpi.

Y	/Y-M/	$(Y-M)^2$
15	0	0
16	1	1
9	6	36
7	8	64
4	11	121
14	1	1
15	0	0
13	2	4
11	4	11
5	10	100
21	6	36
17	2	4
15	0	0
13	2	4
4	11	121
23	8	64
19	4	16
17	2	4
15	0	0
3	12	144
26	11	121
25	10	100
26	11	121
27	12	144
15	0	0
375		**1317**

375/25=15
m = 15

$$s^2 = \sum (y-m)^2 / 25$$

$$s^2 = 52.68$$

$$s = 7.25$$

Figure 17: The statistical data for the low detail hands image at 133 lpi.

Frequency Matrix: "Hands" image @ 85 lpi.

	A	B	C	D	**E**
A	15	27	27	25	**28**
B	3	15	18	23	**26**
C	3	12	15	19	**16**
D	5	7	11	15	**17**
E	2	4	14	13	**15**

Proportion Matrix:"Hands" image @ 85 lpi.

	A	B	C	D	E
A	.50	.90	.90	.83	.93
B	.10	.50	.60	.78	.87
C	.10	.40	.50	.63	.53
D	.16	.23	.37	.50	.57
E	.06	.13	.47	.43	.50

Frequency Matrix:"Web" image @ 85 lpi.

	A	B	C	D	**E**
A	15	20	28	25	**26**
B	10	15	26	23	**26**
C	2	4	15	15	**15**
D	5	7	15	15	**14**
E	4	4	15	16	**15**

Proportion Matrix:"Web" image @ 85 lpi.

	A	B	C	D	E
A	.50	.66	.93	.83	.87
B	.33	.50	.87	.77	.87
C	.06	.13	.50	.50	.50
D	.16	.23	.50	.50	.46
E	.13	.13	.50	.50	.50

Figure 18: The proportion and frequency matrices for images output at 85 lpi.

Frequency Matrix: "Hands" image @ 133 lpi.

	A	B	C	D	**E**
A	15	22	23	24	**22**
B	8	15	19	20	**18**
C	7	11	15	18	**17**
D	6	10	12	15	**17**
E	8	12	13	13	**15**

Proportion Matrix:"Hands" image @ 133 lpi.

	A	B	C	D	E
A	.50	.73	.78	.80	.73
B	.27	.50	.63	.67	.60
C	.23	.36	.50	.60	.57
D	.20	.33	.40	.50	.56
E	.26	.40	.43	.43	.50

Frequency Matrix:"Web" image @ 133 lpi.

	A	B	C	**D**	E
A	15	14	21	**23**	26
B	16	15	17	**19**	25
C	9	13	15	**17**	26
D	7	11	13	**15**	27
E	4	5	4	**3**	15

Proportion Matrix:"Web" image @ 133 lpi.

	A	B	C	D	E
A	.50	.47	.70	.78	.86
B	.53	.50	.56	.63	.83
C	.30	.43	.50	.56	.87
D	.23	.36	.43	.50	.90
E	.13	.17	.13	.10	.50

Figure 19: The proportion and frequency matrices for images output at 133 lpi.

5.2 Results of the Statistical Analysis

5.2.1 Trends Involved with Images of Different Levels of Detail

In order to identify a trend showing how the level of detail in an image can affect the scanning ratio, I compared the data from the low detail image output at 85 lpi with the data from the high detail image printed at 85 lpi. The same comparison was performed for the images output at 133 lpi.

The data from the images output at 85 lpi showed that there was not much of a difference between the viewers perception at the different scanning ratios. It was expected that the high detail image would have to be scanned at a higher scanning ratio than the low detail image in order to capture the information needed to produce an image where one could not discern between the image scanned at 2 : 1 and a lower frequency. According to figures 18 and 19 the column where a 2 : 1 ratio is compared to all of the others, the threshold occurres at the same position for both the low detail image output and the high detail image output. Therefore it can be concluded that for many images printed at 85 lpi, the same scanning resolution can be used regardless of image detail. In this case 1 : 1.5 was found to be satisfactory.

The statistical evaluation for the low detail image output at 85 lpi revealed that a standard deviation of 7.85 existed (refer to figure 14). Therefore, any values on the chart that fall between the values of 7.15 and 22.85 are significant. The actual test results actually fell in a range much closer than that. They only differed from 15 (the point where *no* difference is perceived) by 2 which falls well inside the bounds of one standard deviation. This was true for the scanning ratios of 1 : 1.75

and 1 : 1.5. The threshold occurres at the scanning ratios of 1 : 1.25 and 1 : 1 where the values of 26 and 28 occur. This is a significant increase in the number of people that detected a difference between two scanning ratios. In these instances the observers preferred the image scanned at a 2 : 1 ratio 26 out of 30 times and 28 out of 30 times respectively. These values also fall well outside the range of significant values established by the standard deviation. The difference from 15 is 11 and 13 respectively. The analysis for the high detail image output at 85 lpi was nearly identical (refer to figure 19). A possible explanation for this is that the resolution of an 85 lpi screen may not reveal differences in image detail when comparing scanning resolutions. These differences would become even less apparent when the images are actually printed and other sources of noise occur.

The analysis for two very different images output at 85 lpi showed that regardless of the image content, in this case, no difference in the acceptable scanning resolution occurred. The same trend occurred when the two images were output at 133 lpi (figure 18). The standard deviation for the low detail image matrix was 5.00. Therefore any values between 20 and 10 were significant. According to figure 18 this remains true until the threshold that occurs at a 1 : 1.25 scanning ratio. Unlike the 85 lpi output the values in the 133 lpi matrix do not cluster as tightly around the value of 15. In this instance the difference is 3 but it still falls well inside the bounds of one standard deviation. The threshold occurs at a value of 18 before the next value on the matrix jumps to 22.

The statistical analysis for the high detail image output at 133 lpi was conducted differently than the low detail image. If figure 18 is examined, the column to

the far right shows data that is irregular when compared to the other data. In a complex test such as this one, the reason for such a discrepancy most likely lies with testing variables rather than valid experimental data. To remedy this, I chose to ignore this column of data and attributed it to probable observer fatigue. This was after all, the last set of images to be observed in a tedious experiment. If the test could be given again, I would have randomly presented each of the four sections to each observer instead of presenting them in the same sequence to all of them. Prior to testing it was decided that 40 evaluations would most likely avoid the variable of fatigue. This was not entirely correct.

Further examination of figure 18 shows that the column where a scanning ratio of 1 : 1.75 is compared to the others follows the expected trend in values. This, in light of the above information, was used instead to draw my conclusions. The standard deviation derived for this table was 7.25. Therefore, any values falling between 7.75 and 22.25 are significant. The threshold for this table occurred at a value of 19. This corresponds to a scanning ratio of 1 : 1.25. The scanning ratio of 1 : 1 corresponds to a value of 23 and this falls outside of the bounds of one standard deviation. In this instance, it appears that the type of image scanned does not significantly affect the scanning ratio used. It was noted earlier that the increments between the scanning ratios were a variable that had to be acknowledged. It is likely that if a test were given where these increments were reduced even further, the thresholds between a high detail image and a lower detail image would be different.

5.2.2 Trends Involved with Different Line Screen Rulings

There were trends identified in regards to how different line screen rulings would relate to different scanning ratios. For this analysis, the two different line screen rulings for the same image were compared. At this point, enough statistical background has already been given and can be applied to this section if more information is desired. Only the trends will be addressed at this point.

The first comparison deals with the low detail image output at 85 lpi and 133 lpi. As can be seen in figures 18 and 19 there exists a difference between the thresholds of detectability. For the 85 lpi output it occurres at a scanning ratio of 1 :1.5 and for the 133 lpi output it occurres at a scanning ratio of 1 : 1.25. The reason for this is that aliasing that occurres at 85 lpi exists in the form of larger dots and is more easily detected than aliasing at 133 lpi. This trend is congruent with the hypothesis of this study. The same trend also existed for the high detail image. The thresholds occurred at the same scanning ratios as well. In this set of comparisons it was firmly established that the scanning ratio for a given image can be allowed to decrease as the lpi frequency increases.

5.2.3 Trends for Scanning Ratios of Lesser Value than the Nyquist Criterion

The third part of the hypothesis that needed to be proved was that it was possible to scan an image below the 2 : 1 ratio established by the Nyquist Criterion. Of the three parts to the hypothesis, this one is the best supported. For both the low detail image and the high detail image acceptable scanning ratios for these images output at 85 lpi and 133 lpi was 1 : 1.5 and 1 : 1.25 respectively. If the

acceptable scanning ratios had fallen only slightly below the 2 : 1 ratio it could be argued that experimental noise was the cause. However, experimental noise such as press misregistration and dot doubling were eliminated. Even at the proofing stage it was possible for a significant number of the viewing population to mistake an image scanned at a 1 : 1.25 ratio for one scanned at 2 : 1. was 1 : 1.5 and 1 : 1.25 respectively. This means it is possible to reduce a file to between 39.2% (1 : 1.25 ratio) and 56.4% (1 : 1.5 ratio) of the size of the file scanned at a 2 : 1 ratio *before* it even enters the system.

Chapter Six: Conclusions

By using statistically valid methods and extensive testing two of the three points proposed in the hypothesis were able to be proven. It was proposed that the type of image scanned would significantly affect the scanning ratio. This was not proven. It is possible that the increments chosen to represent the scanning ratio continuum were too large to isolate this variable. It must also be noted that aliasing in images evaluated on the monitor will be much more apparent than those same images after they are translated into halftone dots.

It was also proposed that as the line screen ruling used to print the image increases, the scanning ratio would be allowed to decrease. This was proven. For both the low detail and high detail images, a definite threshold in the perceptibility of the audience occurred. The threshold for the 85 lpi images occurred at a higher scanning ratio than the 133 lpi images in both instances (1 : 1:5 and 1 : 1.25 respectively). Given this, it is possible that scanning ratios used for the hi-fi color printing using 300 lpi to 400 lpi screens could approach a 1 : 1 scanning ratio.

The final proposal in the hypothesis stated that it would be possible to reduce scanning ratios below the 2 : 1 standard without being detected by a general viewing audience. This was also proved. In all cases of different image type and different line screen ruling, the scanning ratio was successfully reduced to at least a 1 : 1.5 scanning ratio without being detected by a significant proportion of the population.

The results of this study must be kept in light of the fact that they are on the

conservative side. Variables involved with printing were eliminated. Therefore the acceptable scanning ratios established for the particular images used here would either be equal to or greater than those required for a printed product. A variable such as slight misregistration could push the acceptable ratios down even further. Also, it must be noted that black and white images would most likely require higher scanning ratios than their color counter parts. Variables such as misregistration do not exist and a difference in scanning ratios would be more difficult to disguise. Since the trend is toward color and this study had to be kept to a reasonable size, only color images were addressed.

From the reading material that is circulating throughout the printing industry, it is evident that quite a few people using desktop scanning technology are relying on the Nyquist Criterion to guide their scanning techniques. The problem is that this rule of thumb assumes a certain consistency that does not exist. Image detail can affect the scanning ratio to a small degree, the line screen ruling affects it to a significant degree, and the fact that the average observer simply can not tell the difference when an image is scanned at a lower scanning ratio is also a factor. Under these circumstances, a general standard does not work. This is further supported by the findings in an attached supplemental report concerned with scanning frequencies for geologic basemaps. These maps are *all* identical in terms of image detail and line screen frequencies used for printing. In this instance a single scanning frequency can be derived. Commercial publishing is not fortunate enough to have that kind of consistency, and therefore is not able to adopt a single absolute standard. Instead, those who extensively use desktop scanning technology must establish their own custom standards based on the screen rulings they use for printing and the kinds of images they use. The results

found in this study are a good starting point and reference but are not absolutes. This work would otherwise only be a contribution to the general standard that already exists. It was one of the goals of this study to expose the flaws in present in this standard.

If scanning ratios did not have a notable impact on the size of the files created by the scanning process, then scanning ratios would not be much of an issue. However the size of the file affects the cost of storing that file, moving it over a network, and manipulating it on the desktop. Some would argue that new technology such as J-PEG compression, and technology that will most likely develop that compresses a file immediately after scanning makes the investigation of scanning ratios an issue if diminishing importance. However, if a file can be created, with a little planning, to 39% of the size of a file created with a 2 : 1 scanning ratio, the new technology being developed will be that much more effective.

Supplemental Report:

Applications for the Oregon State Department of Geology and Mineral Industries

Introduction

The Oregon State Department of Geology and Mineral Industries is a group that can benefit from the results of this study even though there is no direct connection to the electronic publishing industry. They, along with the other state agencies around the country are under a deadline imposed by the National Map Act of 1992. Essentially, mapping of the United States needs to be completed within the next six to ten years at an estimated cost of fifty million dollars. The state of Oregon has decided to investigate the possibility of using electronic publishing equipment to help complete this task by the deadline. They require a high quality digital base map in a file format that can be used as a *template* in which to draw other maps. Since cost was an issue, the file had to be created as small as possible while still conforming to their quality standards. The results of this thesis/project will be passed on to the other state agencies if it can be successfully implemented. If it is not successful, the data I have collected will also be helpful because they now know to what extent desktop publishing technology can satisfy their needs. I decided to add this project on to my thesis as a supplement. It was done in this way so that I could apply the principles from the thesis to this project.

Essentially, the problem was to maximize the current graphic arts technology in order to create a "good enough quality" digital base map using the desktop

scanning equipment, image setting equipment and software that was available to me in the IEP Lab. The map was created by scanning a printed paper map. An ideal scanning resolution had to be established in order to capture needed information. Experimentation was also completed to define an ideal file format but this is a secondary issue and will be treated as such.

Ideally, the state mapping agency would be able to have a high quality digital base map supplied to them on a disk from the United States Geologic Survey (USGS). Unfortunately, only a small portion of the country is mapped in digital form and USGS cannot meet the demands of the state agencies that need these maps. In response to this situation, the State of Oregon has decided to adopt an alternative in order to meet their deadlines. This alternative would be to scan a hardcopy map and use the digital file as the base map. There are numerous variables affecting quality, including scanning resolutions that could affect the quality of that base map. The investigation of those variables is what this portion of the project was about.

This alternative construction of digital basemaps that is being investigated is the beginning of two standards of base maps. The proposed model is a digital base map that is used as a reference base upon which to plot geological elements for the sole purpose of *visual representation*. The established model is a topographic base which other topographic bases are referenced to for the *conducting of extremely high quality GIS analysis*. Ideally, one model would serve both applications but time, cost, and the immediate need for digital base maps is forcing a split approach. USGS prepares high quality digital maps for the demands of the second application but nobody has a quicker, more inexpensive technique that

lends itself to the first application. Since digital base maps are not readily available from USGS, the question is whether cities, states, towns and counties can conveniently get accurate, readable and inexpensive, digital base maps from paper copy or mylar or negatives. The geologists at the state agencies want to be able to digitize the maps themselves and are willing to sacrifice some quality because they would suit the applications needed by the Oregon Department of Geology.

Background Information

Geologic Information

The basemap is one of several planimetric maps used by geologists. The basemap is used to plan or compile data for specialized maps. For example, a cadastral map uses a basemap as the template in which to draw boundaries and subdivisions of land. Line route maps show pipelines, circuits used by utility companies.

The 7.5 minute quadrangle map is the one selected nation wide as the standard to be used for geologic maps. Because of this standard, a certain predictable level of detail is represented. It is this attribute that will set the scanning frequency for geological maps apart for scanning images for desktop publishing. Images vary in detail that are used for desktop publishing but the level of detail is consistent for maps. Ideally, a single scanning frequency can be established for scanning these maps.

The 7.5 quadrangle map is suited for densely settled areas and other areas where detailed map information is needed.

1 : 3,168,000	50 miles/inch	1 : 125,000	2 miles/inch
1 : 2,500,000	40 miles/inch	1 : 63,360	1 miles/inch
1 : 1,000,000	16 miles/inch	1 : 31,680	.5 miles/inch
1 : 500,000	8 miles/inch	1 : 30,000	2,500 feet/inch
1 : 250,000	4 miles/inch	1 : 24,000	2,000 feet/inch

Figure 20: The following chart is a guide to various publication scales.

The scale determines the size of the map for a given ground area, the accuracy needed for surveys, and the amount of detail being represented on the map.

The quadrangle is actually a trapezoid. This is due to the curvature of the earth. The north boundary will always be shorter in length than the south (in the northern hemisphere) because of this. Also, the area of the quadrangle will vary from north to south. The Layout of the quadrangles are the same now as the standard set up in 1882. Each map is a quadrangle and each sheet is called a quadrangle map.

The standard for horizontal accuracy is as follows. If the map is greater than 1 : 20,000 scale then not more than 10% of the control points should be misplaced by more than 1/30 inch. If the map is less than 1 : 20,000 then not more than 10% of the points should be off by more than 1/15 of an inch. The points that are used as reference points are always well defined. These would include monuments, markers, property lines, intersections of roads, and large buildings. Points that are not identifiable on the ground are not valid test points. Examples would be timber and soil lines. For vertical accuracy no more than 10% of the elevations tested should be off by more than on half of a contour interval. Maps that meet these standards shall note that " This map complies with the National Map

Accuracy Standards ". Any maps in error will omit this. When a map is enlarged from an existing map it should be noted. All federal maps conform to the 15/7.5 minute latitude and longitude boundaries. The accuracy of a base map refers to the relationship between the reproduced map and the original with respect to the distance between control points. Any distortion that occurs can be categorized as random distortion or uniform distortion.

The base map that will be created fits into a specific process containing four elements:

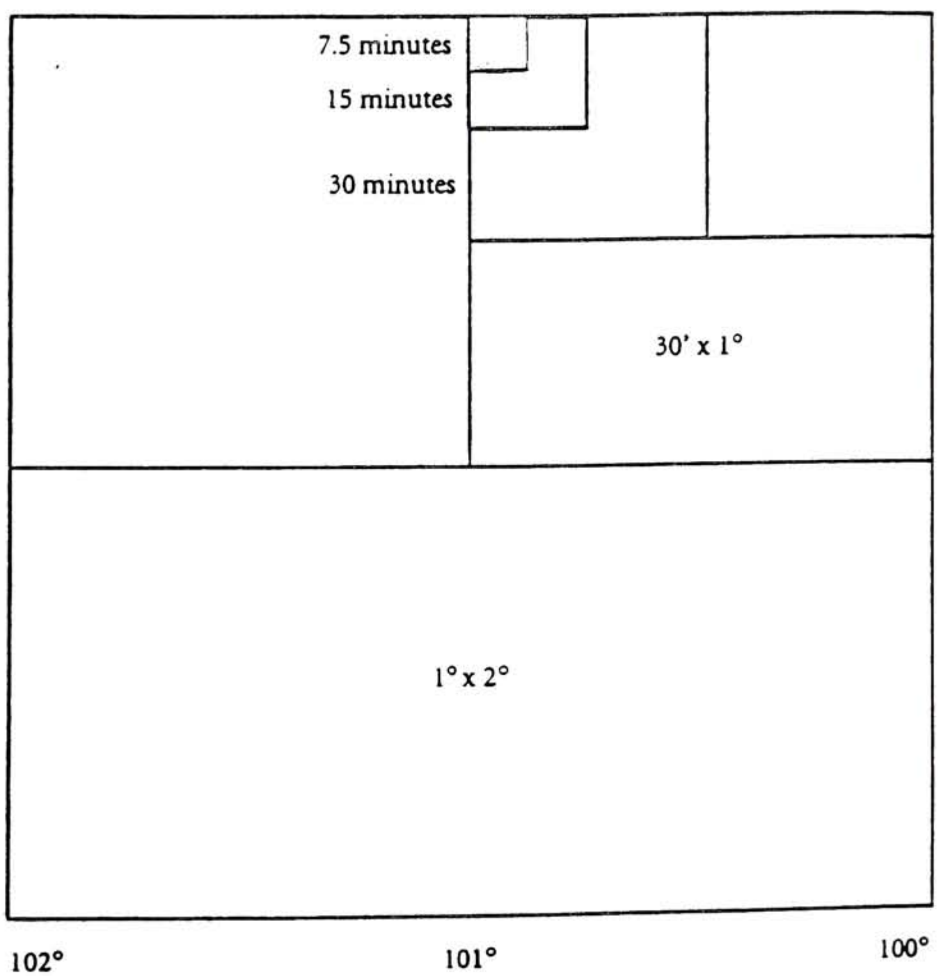


Figure 21: Measurements of a 7.5 minute quadrangle map.

1. *Satellite Negative:* This is a negative of the base map on high contrast lith film using data gathered from geologic satellites. This is also the same negative that will be sent to the printer to print the black printer.

2. *Paper Copy:* This is a printed copy of the base map using the satellite negative and at times other negatives representing various geologic features placed on the base map.

3. *Digital File:* This is the scanned base map. In almost all of the cases a paper copy will be scanned. This introduces variables in accuracy that will be discussed later.

4. *Theme Map:* This is the file containing the element placed on the base map in the computer. For example, a cartographer opens the base map file (K). He then uses this as a reference to place an area of green (C,Y) representing forests on the map. The cyan, magenta, and yellow information would be the theme map.

The base map that was created addressed specific needs. Readability was the primary concern. The maps that were digitized had a high enough resolution so

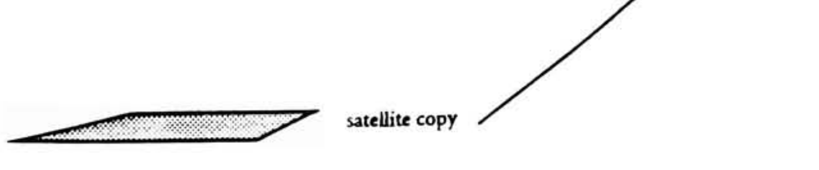


Figure 22: The production process.

that the contour lines are separate, readable and discernable. Some of these lines are separated by 1/2 millimeter in some instances. The lettering was readable. Typical point sizes ranged from seven to eight points. File size and format was important because the number of maps that need to be digitized is significant so the cost of storage space needs to be kept to a minimum. If these files are compressed, they must be lossless. Another factor that was researched is accuracy. Ideally, the theme map negative can be placed on top of the original satellite negative and align perfectly. The reason for this is that these are the materials that will be supplied to the printer for final printing. If the negatives do not align correctly then the type of distortion has to be defined as either *uniform distortion* or *random distortion*. Uniform distortion defines a distortion that is a shift in size only. Random distortion refers to distortions that vary in amount along the horizontal and vertical axis of the map.

The entire process has variables that influenced the quality of the map. The variable I worked with and derived a solution for is the scanning resolution and file format. The other variables were addressed but my only instructions in this area were to record observations and to make recommendations based on simple tests to deal with those variables.

The first phase of the process that affected the accuracy of the relationship between the digital base map occurred between the negative and the paper copy. As soon as the paper is printed the environment that the paper is in influences its size because the dimensional stability of paper is not very high. Even before the paper map was scanned it could have incurred some changes in size and therefore, accuracy. Many of the variables that this project dealt with occurred

during the phase of scanning the paper base map to digital form. The main concern was to establish a frequency to scan the base maps. What was different about the requirements for this project as opposed to the graphic arts is that the resolution of the image on the screen had to be taken into consideration as well as the resolution of the printed image. To accomplish this a base map was scanned at various resolutions and the ideal resolution was determined by a member of the Oregon State Department of Geology and Mineral Industries. A "snapshot©" was also taken of the screen to determine whether the image that appears on the screen is readable enough for a cartographer to use it as a template to draw the needed elements of the map. When *both* of these conditions have been fulfilled, the correct scanning resolution will have been established. Also, the format of the file established maximized file space and was reusable while still maintaining a desirable level of detail. A test was conducted to establish whether the base map should be scanned in the mode of grayscale or color. It was found that gray scale is the more useful mode. It was also determined that eight-bit gray is to be established as the standard. It was possible to open a grayscale map in a color environment so that other colors could be layered on top of it and still remain separate. All tests were accompanied by results and explanations. Another consideration was that the paper may undergo additional changes in size as the light on the scanner warms it. Differences in accuracy between output from the imagesetter and the scanned copy might also come from the scanner itself. A test image will be scanned that is dimensionally stable to determine whether the variation occurs because of the paper size change or whether it is a combination of both the scanner and the change in paper size. It is going to be assumed that the registration between the base map file (K) and the

theme files (C, M, Y) are accurate. From past experience, I have witnessed the capabilities of the equipment in the lab for four color work and it falls within the parameters set by the geologists' needs.

Variables in the Map Creation Process

When the images were scanned into Photoshop to be manipulated There existed the choice of doing it under the mode of gray scale, RGB, and CMYK modes. When making the decision to do this I had to take into consideration file space and the ease of manipulating the image during different sessions. The experiment done was done purely for the purpose of investigating how a person, the cartographer for example, would be able to call up a base map image, manipulate, add color or delete images to fit their needs. This file eventually ends up as a CMYK film separation in final film output. One also has to realize that the map created was not stored as layers of data like a GIS map. It is in fact a two dimensional raster graphic. Type, lines and color spaces are not independent of each other. If these elements were able to be scanned and converted to vector based graphics, then type, line art, and color spaces could be moved and manipulated independently of each other. The reason being that each "object" would be defined as a mathematical formula instead of a flat bitmap. There is software in the works to convert raster based graphics to vector objects but for the purpose of a *visual reference only* map, it is not needed. Raster based graphics were best suited for the current needs because only they allowed for the ability to manipulate images and output separations. The following definitions will help the reader understand how the final scanning procedure was derived and the issue of file structure will be treated as a secondary issue.

Grayscale Mode: This mode samples in 8-bit color and occupies a little less than one third the disk space occupied by an RGB file and one fourth the space of a CMYK file.This appears on the monitor as a black and white image with varying levels of gray. This mode of file format was investigated as an option for these reasons: The resolution of this file is no less than that of a color file. The only difference is that there is no color information present. the absence of color information makes it possible to work with the file at a much faster pace; it occupies up less RAM and as a result, functions executed out by the computer at a much faster rate. Any modifications made to the file are done in varying levels of gray since no color information is present.

RGB Color: This is the mode that the scanner records base map. It makes three separate passes over the copy and collects color information for red, blue and green. It appears on the monitor as a full color image. Each of these is an eight bit color file and they are combined to form 24-bit color. In this mode, color modifications can be made to the base map.

CMYK Color: This file format is necessary for the output of film negatives for printing. The conversion of RGB to CMYK is a simple function of the software. However the file size is larger (about 25%). This conversion will also result in some color shift. It is unavoidable because it is inherent in the design of the software. The difference in file size can also affect the speed of the computer to some degree.

File Conversion: This conversion involves nothing more than taking the collective information of the RGB file and reorganizing the data to CMYK specifications. Files must be output in this format because those are the colors used by the printer. Since the scanner only scans in RGB (or grayscale) and film output must

be in the form of CMYK negatives, translation from RGB to CMYK is inevitable. One has the option of determining *when* this occurs however and this will be discussed.

Bit Map: This should not even be considered as a scanning option. The files created are extremely small and save storage space. However there is only one bit of color information. These colors are black and white; there are no gray values. The software does not allow for any manipulations in this mode and color separations for the printer cannot be created except for one color: black. This mode of scanning and manipulating the base map image is essentially useless.

File Size: This is a factor in the way that the size of a file will contribute to digital storage costs and the time it takes to manipulate images on the computer.

Figure 23: Representations of different file sizes.

1 in.^{2} Scanned at 300 dpi		23x16 Base Map Size at 300dpi	
Grayscale scan:	87.75 Kb	Grayscale scan:	3.23 Mb
RGB:	257.5 Kb	RGB:	94.760 Mb
CMYK:	342.5 Kb	CMYK:	126.1 Mb

Image Manipulation

The base map can be altered in the modes of grayscale, RGB, and CMYK. In the grayscale mode there is no color information; only varying levels of gray. This also the smallest usable file so operations in this mode would be much quicker. Even a conversion to RGB or CMYK will still appear as gray because only grayscale information was captured by the scanner. The file will still increase in size. This is because the gray is now represented by equal amounts of RGB or

CMYK. These colors are all present, but in certain combinations they all appear as gray.

An RGB file is created by the scanner and is roughly three times the size of a grayscale file. The advantages are that all manipulations can be made in color and this file is slightly faster to work with than a CMYK file. The disadvantage is that the conversion to CMYK will result in a color shift. A CMYK color file is made from the conversion of an RGB color file. When manipulations are made in this mode, those same colors will be preserved on the film output. The disadvantage is that this file takes slightly more time to work with as an RGB file. In sum, if speed is paramount, work with the file in RGB and convert it to CMYK prior to output. If color is paramount then immediately convert the file to CMYK after scanning and perform the work in that mode. If color doesn't matter at all then the grayscale mode should be used in order to achieve the quickest speed.

Working with Files

In order to preserve the original base map image, the following can be done. First call up the image: "base-map" through the selected software. Make some adjustments and then save the image under a different name such as "color overlay". The original file called "base map" is preserved. If one wishes to manipulate the image during multiple sessions then the file called "color overlay" would be used.

Descreening

This is normally done to printed images when they are scanned in order eliminate the halftone dots created during printing. This is done to avoid moire patterns when the image is reprinted. If an image were to not have this done then the halftone screen applied to the image which already has a screen would cause a disturbing pattern called moire. The drawback to descreening is that by default the image blurs a bit and this decreases the readability. Therefore, when scanning the base map with the descreen function there is no moire when it is output to film but detail is lost and the map will have to be scanned at a higher resolution in order to capture more detail information to counteract the effects of the descreening. However, a possible moire pattern will result.

Testing

Agfa Horizon Scanner with Fotolook Scanning software.

Quadra 700 comes with 4 Mb RAM upgradable to 68 Mb

(Quadra 950 comes with 8 Mb RAM upgradable to 256 Mb)

Agfa Selectset 5000 Imagesetter

Adobe Photoshop

Figure 24: Hardware/Software Used.

Accuracy Test

This test was designed to measure the accuracy of the final electronic base map in comparison to a paper original copy and a film original copy. The test results indicated how much of a significance that paper stability and scanning reproduction had in producing this base map.

As indicated by Figure 25 The dimensional stability of paper only had a small effect on the final basemap. There was approximately a 1/32 inch variance in each direction. Since this difference was a uniform variation it is acceptable quality. This test did not reveal how much of an effect the scanner, software and image setter played. Therefore, a second test was performed to isolate this variable. A map was scanned off of a piece of mylar, very stable in comparison to paper. These results indicated that the scanner was very accurate across the scanning bed, but there was a 1/32 variation in the long direction. This sort of uniform variation is also acceptable.

Resolution Test

The purpose of this test was to take the results obtained from the earlier thesis section and see how they compare with the results from the geology section. This test also designed to establish the samples/inch ratio that is best suited for mapping needs. This result will be an absolute for all basemaps since all of these maps conform to a very strict single standard. There are some considerations. Printed quality is defined by readability and distortion degree. This means that if an image has aliasing , yet is still readable, it is a quality image according to the definitions that have been provided to me by the Oregon State Department of

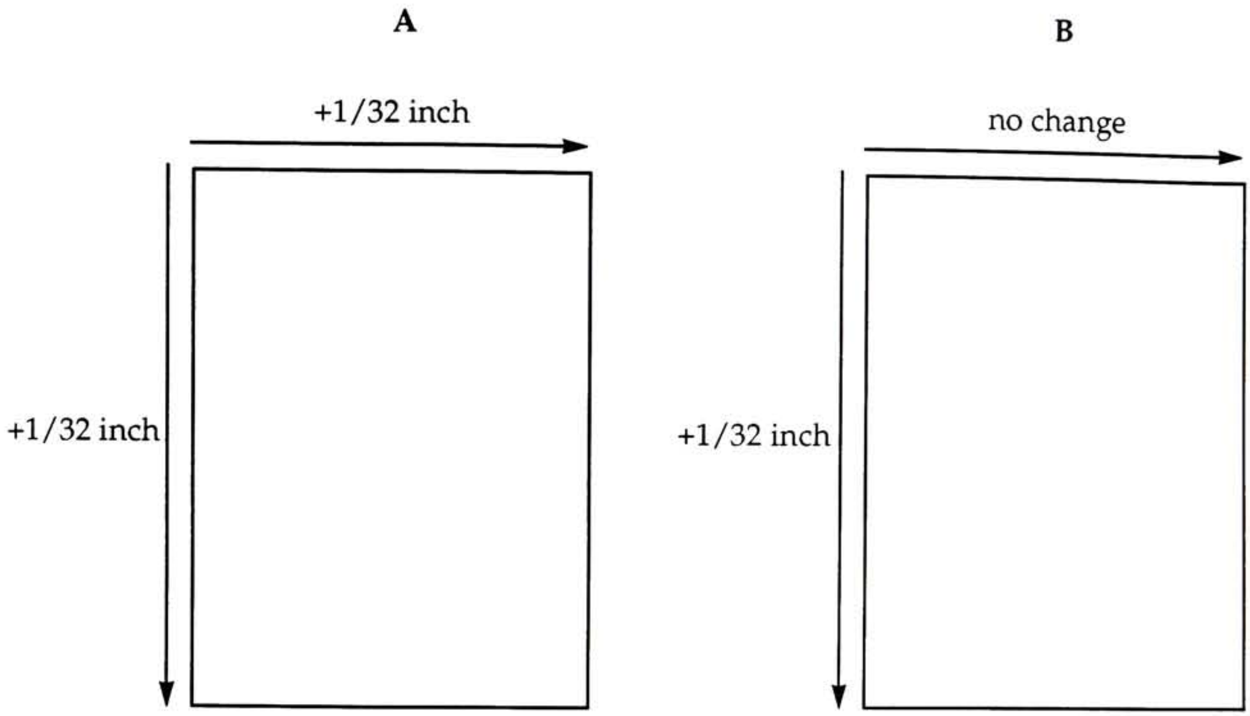


Figure 25: The distortion between the original and scanned maps.

Geology. Also, if the distortion is proportional and not random, the image is a quality image because it can be altered to conform to standards. Another criteria that must be addressed is the resolution of the image on the screen. A cartographer must be able to enlarge the image enough to draw on contour lines that are about on the average 1/2 ml apart on a printed image. Therefore it is possible that a printed piece will appear to be of acceptable quality but the image on the monitor will not. It was proposed that the scanning ratio needed to achieve a quality image for the screen will be a higher ratio than that needed to produce a quality printed image. This is because in the publishing industry, most image corrections involve a much larger area and don't require the additional resolution for the screen. The following data shows several scanning ratios used to scan a basemap. They are followed by my subjective comments and the size of the file that would be created by scanning at the corresponding resolution.

	50 samples/inch	Illegible on screen, unacceptable output.
	75 samples/inch	Illegible on screen, unacceptable output.
3.61 MB	100 samples/inch	Illegible on screen, unacceptable output.
5.64 MB	125 samples/inch	Screen output became legible.
8.10 MB	150 samples/inch	Type on output just started to become legible, detail became recognizable.
11.09 MB	175 samples/inch	Type continued to look better.
14.39 MB	200 sample/inch	Type outside the contour were clear, inside the contour the type was legible, one could start to draw on the smallest lines with some effort.
22.66 MB	250 samples/inch	Type inside of the contour lines are legible, still not at point to edit the minor contour lines.
32.35 MB	300 samples/inch	Starting to look very good.
43.24 MB	350 samples/inch	very good.
57.41 MB	400 samples/inch	very good.

Figure 26: Evaluation of the monitor images.

When a representative at the Oregon State department of mineral industries evaluated the printed image and a sample of the images as they would appear on the screen, they concluded that the printed image was acceptable at 250 samples per inch. At this scanning resolution enough of the information on the topographic map was captured to produce a satisfactory *for visual reference only* map. It was also noted that the image produced by the monitor was not satisfactory until the image was scanned at 300 lpi. Therefore the acceptable scanning frequency for *all* basemaps is 300 lpi. This is because the geologists require an image of acceptable quality for both the printed output and the monitor.

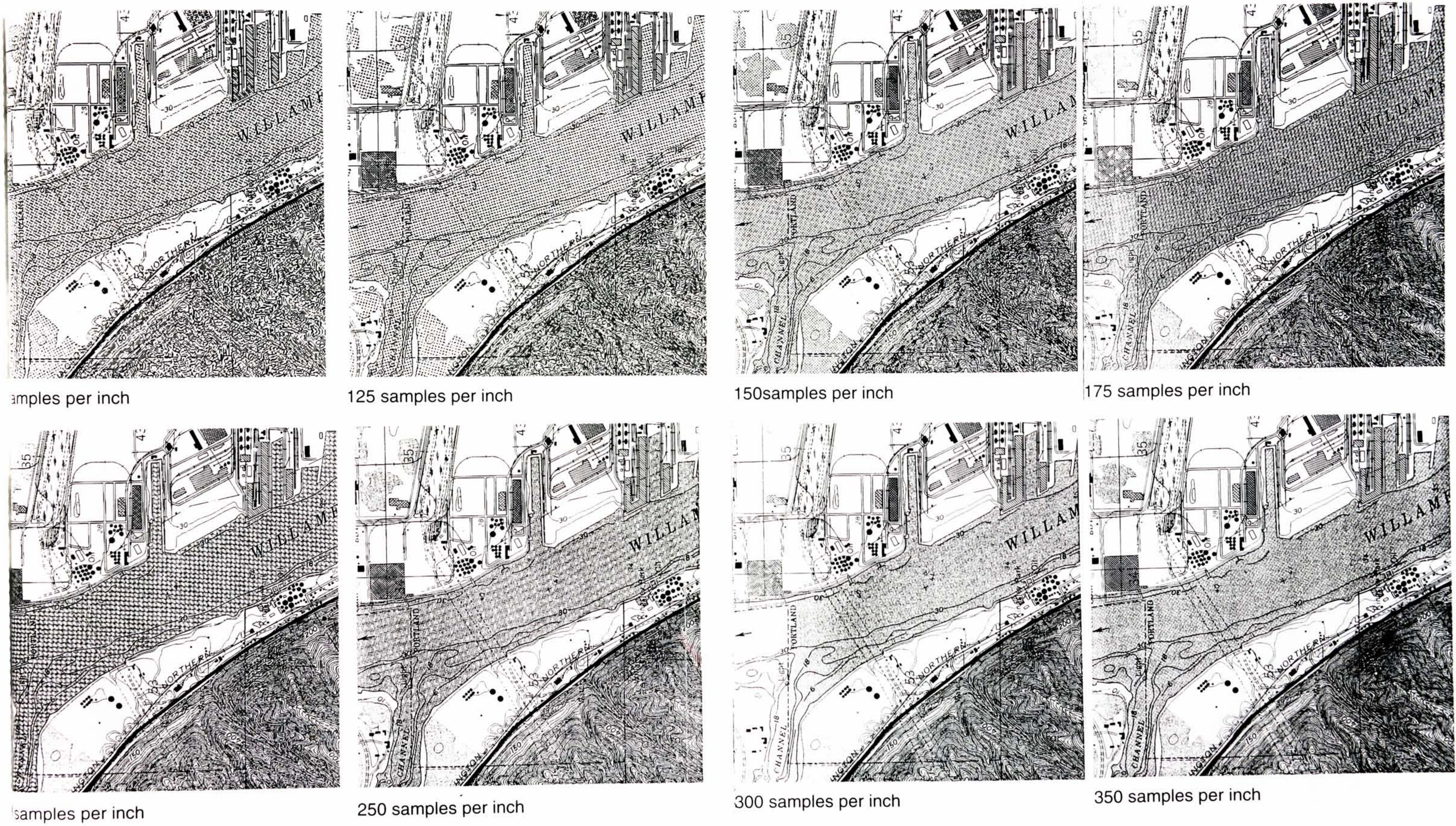
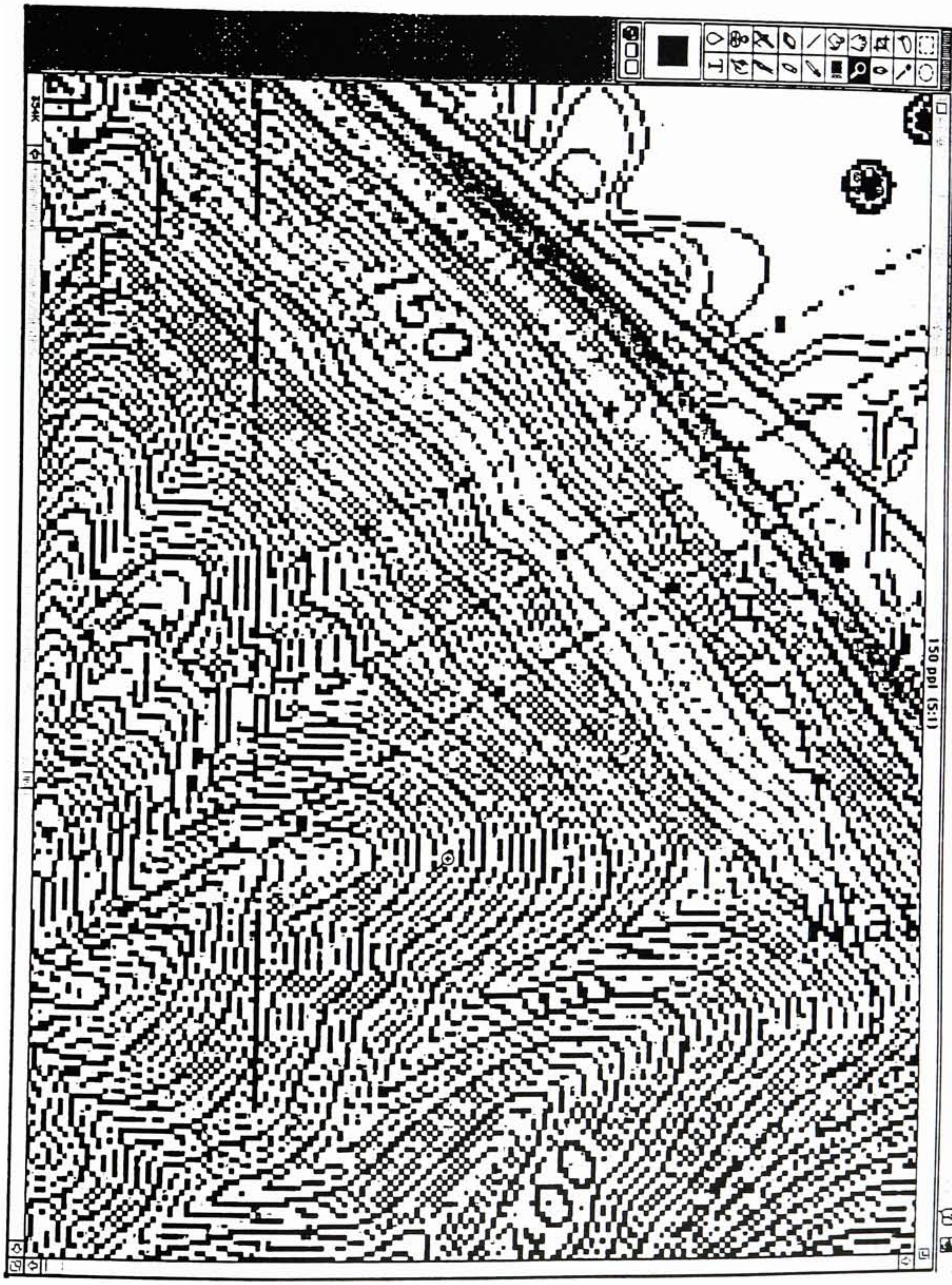
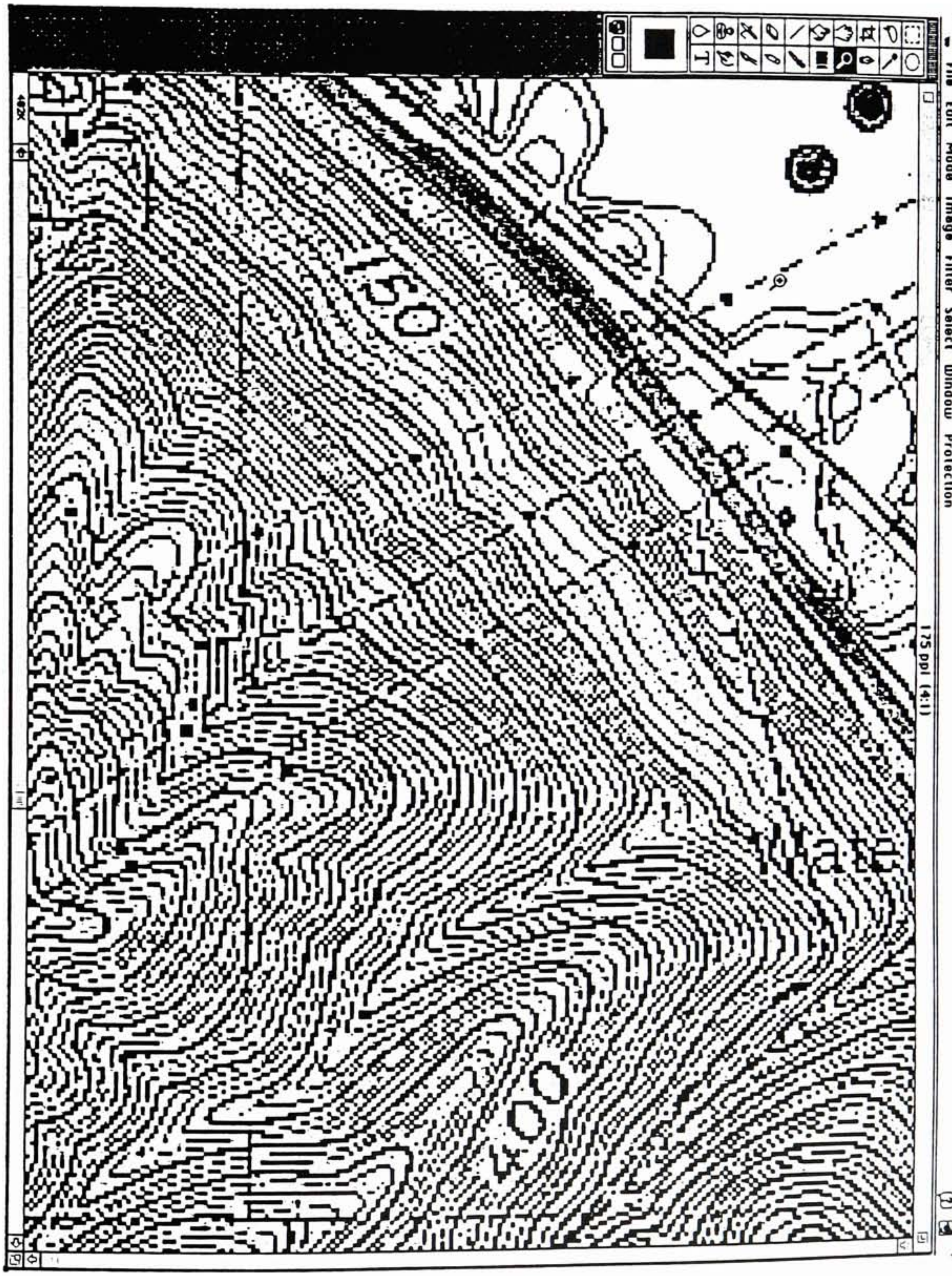
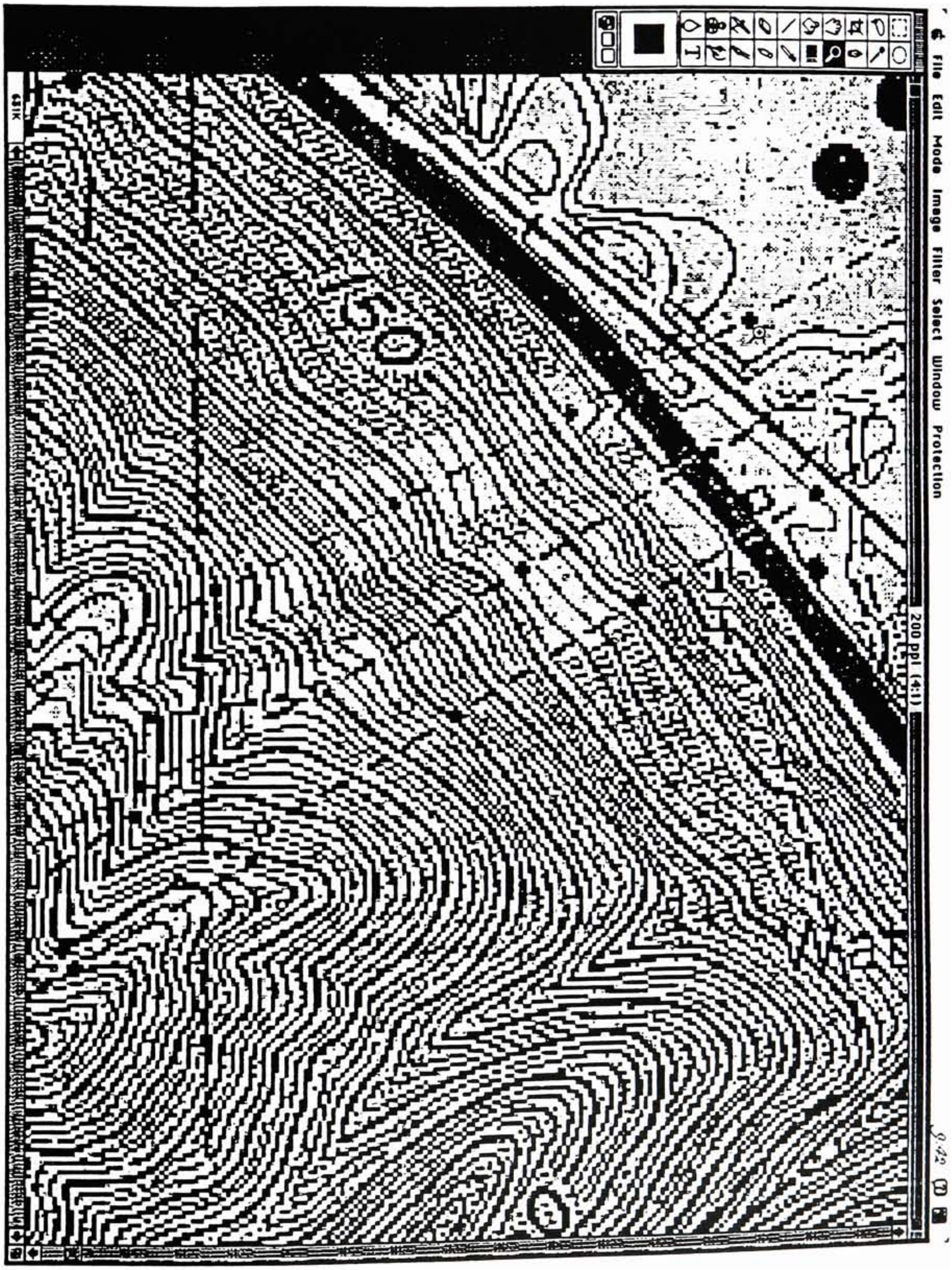


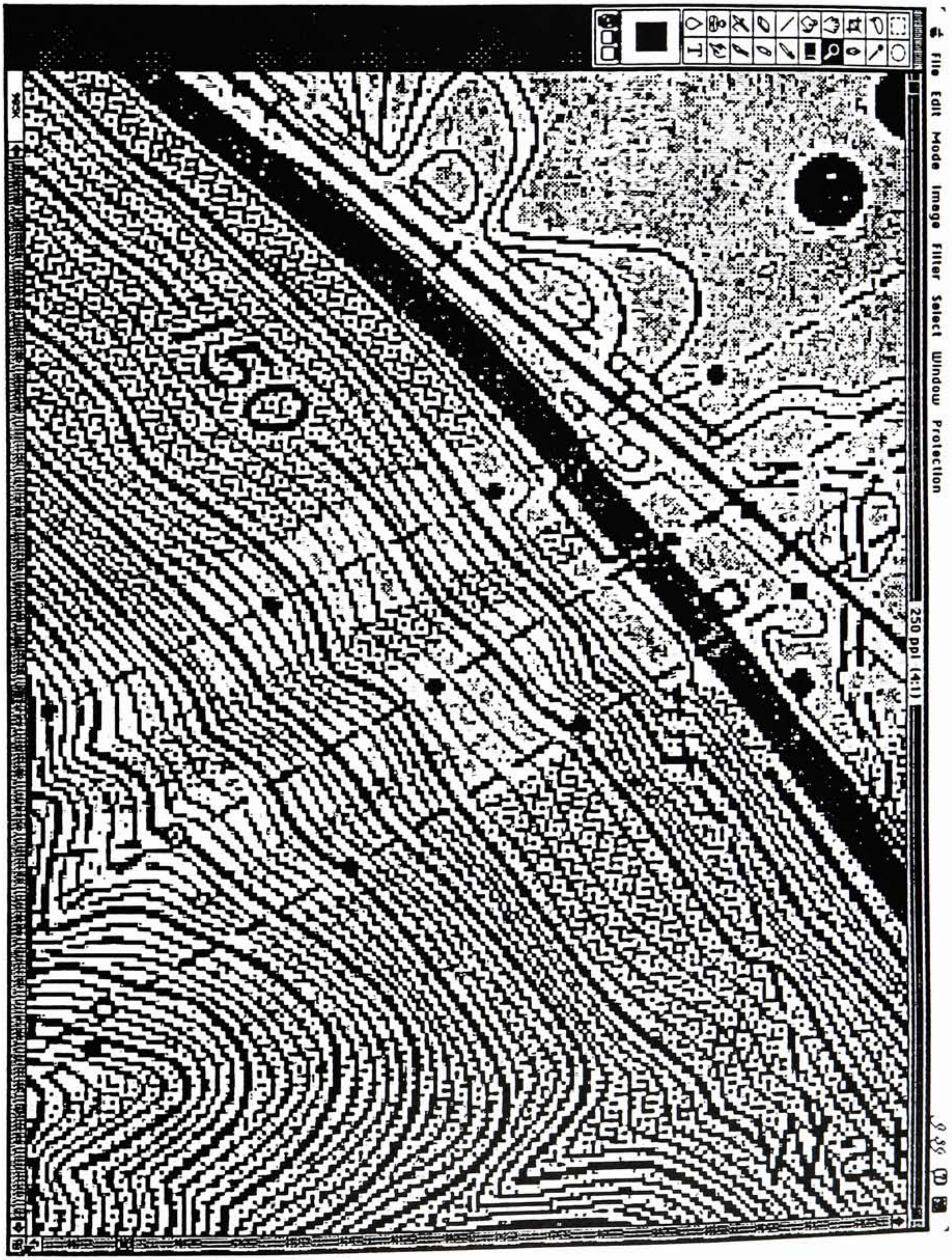
Figure 27: The printed output at the various scanning frequencies.

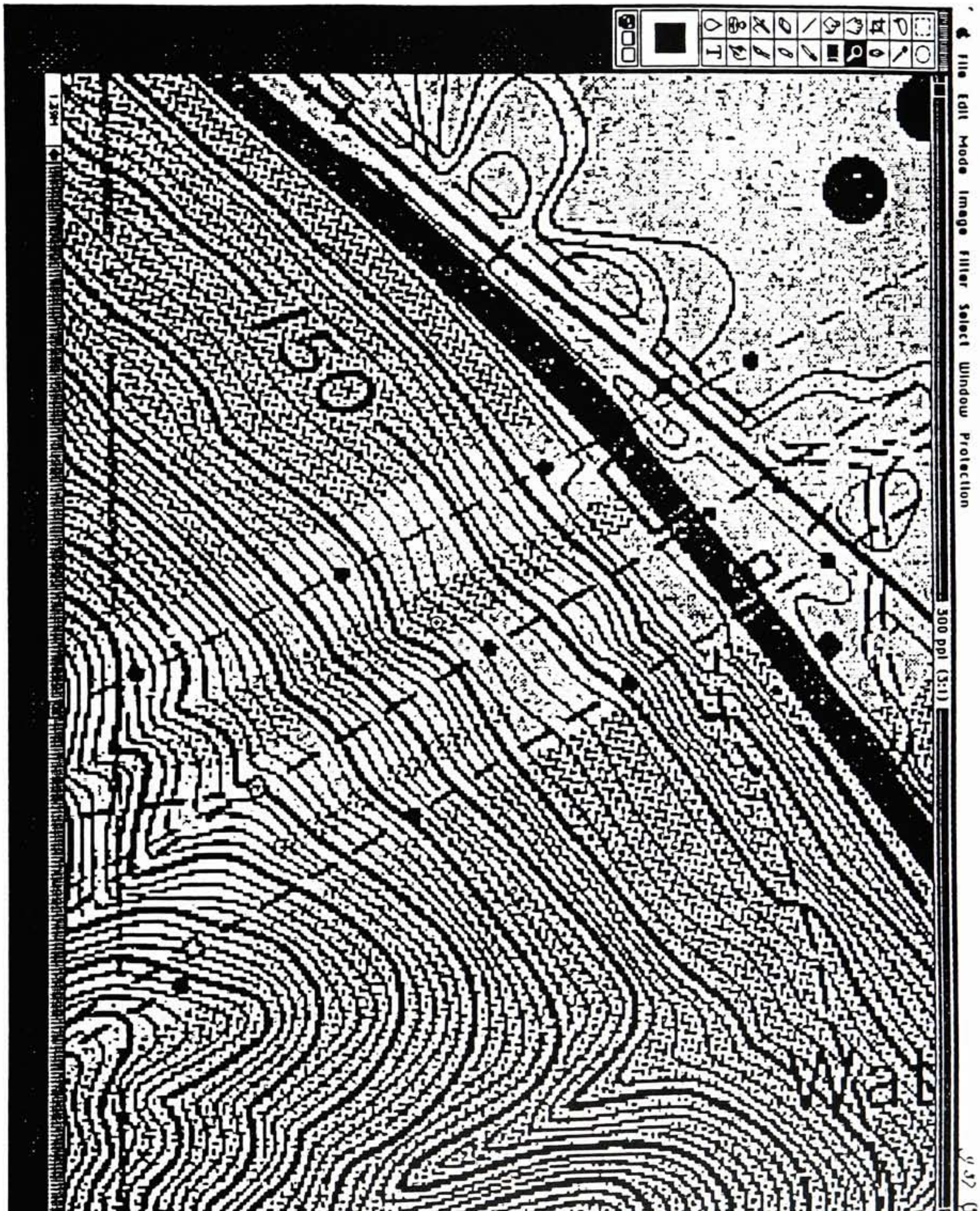

File Edit Mode Image Filter Select Window Protection
125 ppi (7:1)
244K

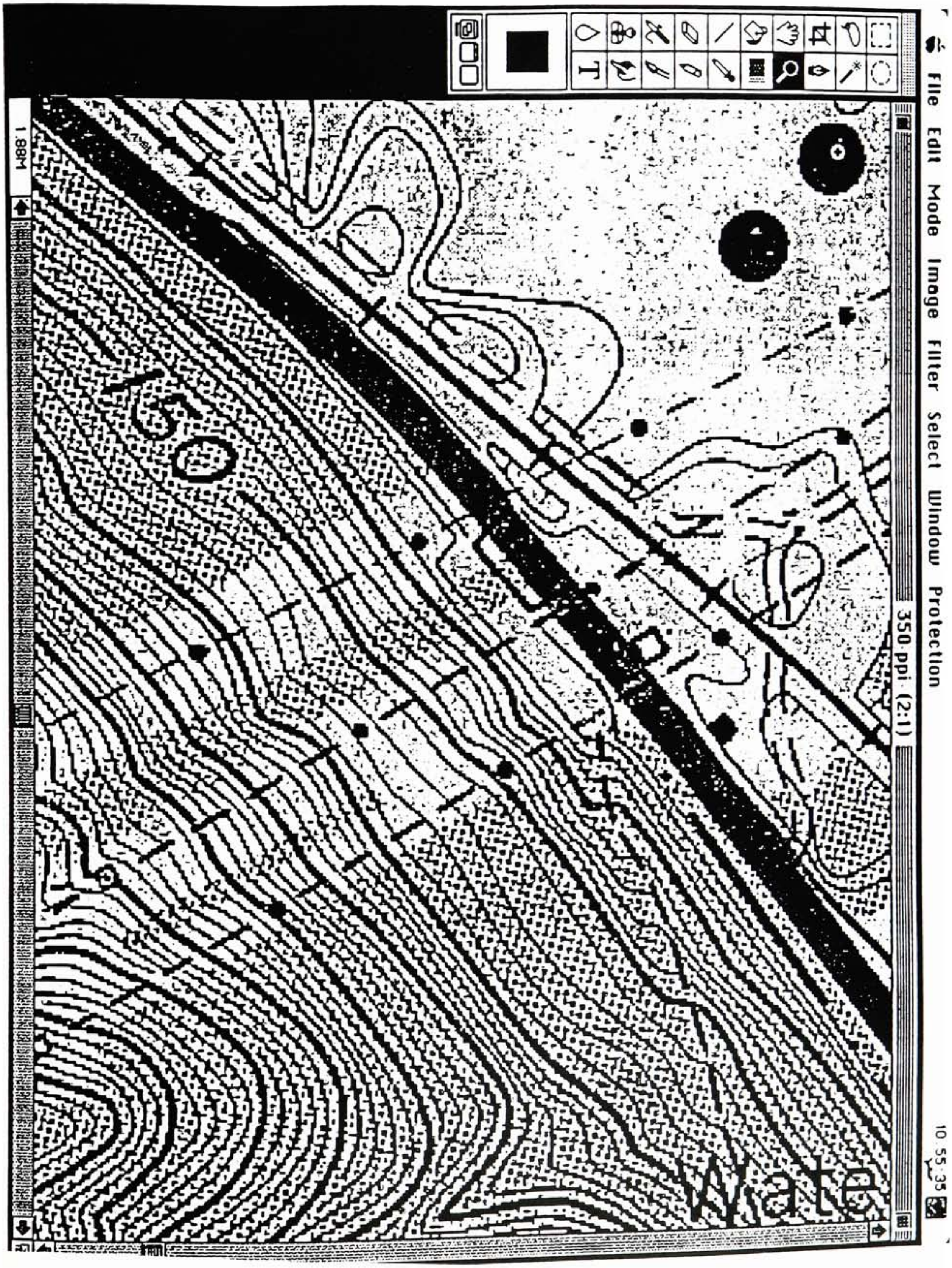

File Edit Mode Image Filter Select Window Protection
150 ppi (5:1)


File Edit Mode Image Filter Select Window Protection
175 ppi (4:1)
150


File Edit Mode Image Filter Select Window Protection
200 ppi (4:1)
631K


File Edit Mode Image Filter Select Window Protection
250 ppi (4:1)


File Edit Mode Image Filter Select Window Protection
300 ppi (3:1)


File Edit Mode Image Filter Select Window Protection
350 ppi (2:1)
1.88M
160
Wate
10:55:35

Data Input Test

Scan RGB at 400 dpi (10.2) MB. 4 in ^{2} : In one instance I scanned the image in the RGB mode and immediately converted it to CMYK before output. I found that because I did not descreen the image, a moire pattern developed where ever the original had some kind of screen tint. This was to be expected. This image as output had remarkable detail. Even the contour lines that were about .5 millimeters apart were distinguishable. When the positive was placed on top of the original copy the accuracy was perfect. In sum, this method of input preserves the accuracy and detail, but moire develops. This can be solved by using a basemap with only line art and no tints.

The next test was performed to observe the effects of descreening the image then sharpening it. This would eliminate any moire patterns and it did. The image was descreened at 120 lpi. and sharpened in Photoshop. however, accuracy was off by -3/32in (3.44 %). per four inch area. Apparently this can be corrected by scaling when the basemap is put to use. The thing that cannot be accounted for or corrected is the detail that was lost in the process. This was either due to Photoshop or descreening or a combination of both.

They have a few choices: They can scan a basemap with tints and have perfect accuracy and detail but will also have a moire pattern. They can scan a basemap with tints and descreen it and sharpen it to eliminate moires. Later they can rescale it to get the accuracy they need but never will recover the detail. Last they can chose to obtain basemaps with no tints and do a straight scan. This method will take the shortest amount of time and will produce the best results.

Previous to the testing the weather had been cold and dry. so any dimensional shift that might have happened on the scanner wouldn't have been much.

Bitmap File Size Test

4 inches ^{2}

400 ppi

B/W 313 K.

RGB 7.34 Mb.

CMYK 9.79 Mb.

This scan was an attempt to scan the map at the smallest file size possible. This portion of the experiment was successful in the way that the file size was only 313 kilobytes. Supposing this format would only be used to store the image once then this would be the format to use. However, in trying to accommodate the other needs, this format will not be sufficient. This format cannot be manipulated because it only supports black and white color. It can be converted to a color or grayscale mode but the file sizes are the same and image quality is much worse. This scan introduced quite a bit of noise that were not present in the other scans. The only good thing about this scan was the small file size, otherwise it was useless, even image quality is not acceptable despite the fact that it was scanned off of a color map.

Grayscale and Color File Size Test

4 inches ^{2} 400 ppi

grayscale 2.45 Mb.

RGB 7.34 Mb.

CMYK 9.79 Mb.

During this test I did a test to scan the map as a gray scale and reopen it as color so that the image could be manipulated. The three things that need to be discussed is storage, image manipulation and the fact that the map is color. Storage would be small if the map were kept in a grayscale format. This can always be reopened to a color mode (RGB) in order to perform various functions. However, if this is to be used for multiple sessions, then all of the color information put on the map from a previous session will be lost. At this point I recommend that the map be scanned in a RGB format so all color information can be preserved from multiple sessions. Also RGB is a smaller file size than CMYK and manipulation functions will go much quicker. However, if one just wants to capture the image of a basemap, color, or black and white, use the grayscale function as opposed to CMYK, RGB, or bitmap.

In the grayscale mode it is possible to do manipulations on the image after it has been converted to RGB, CMYK. This is because the image exists in 8-bit color and this is allowed.

Conclusions and Recommendations

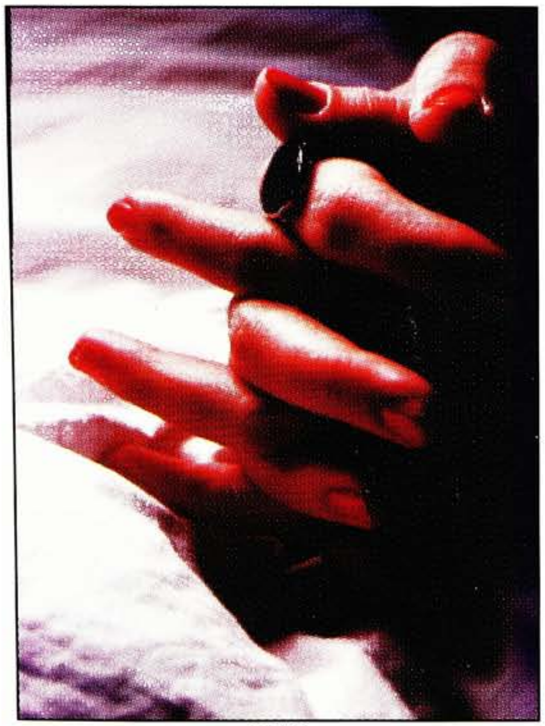
It is possible to construct accurate for visual reference only maps using conventional desktop publishing equipment. As explained before, these maps are not GIS and color separations produced are for printing only. There is no color recognition involved.

Since the size of the maps that would be produced are quite large, it is recommended that they be stored on a Syquest removable hard disk or CD-ROM. The digital maps contained on these disks are used as templates and shouldn't be manipulated until that particular quadrangle is updated.

To insure accuracy of the scanned map it is recommended that a map on some kind of mylar be scanned as opposed to paper. Paper is not as dimensionally stable. Because all basemaps that would be used for scanning contain the same level of detail, a single scanning frequency can be established.

Appendix

This is the set of images used for the visual evaluation testing.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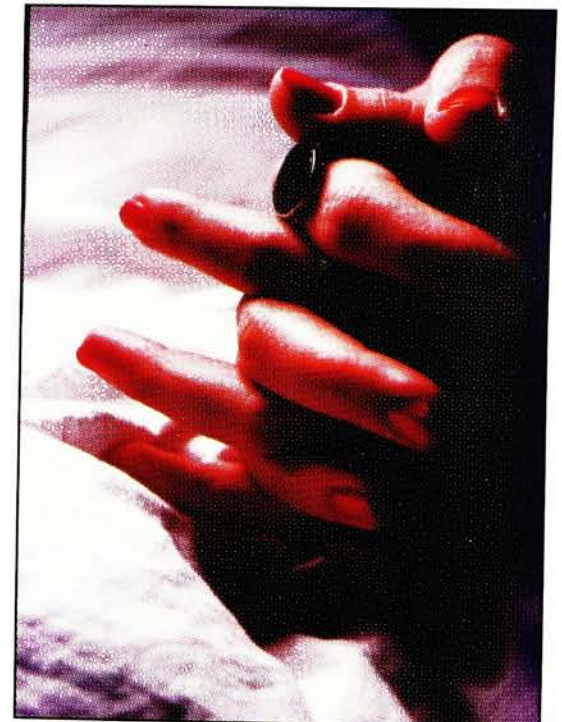
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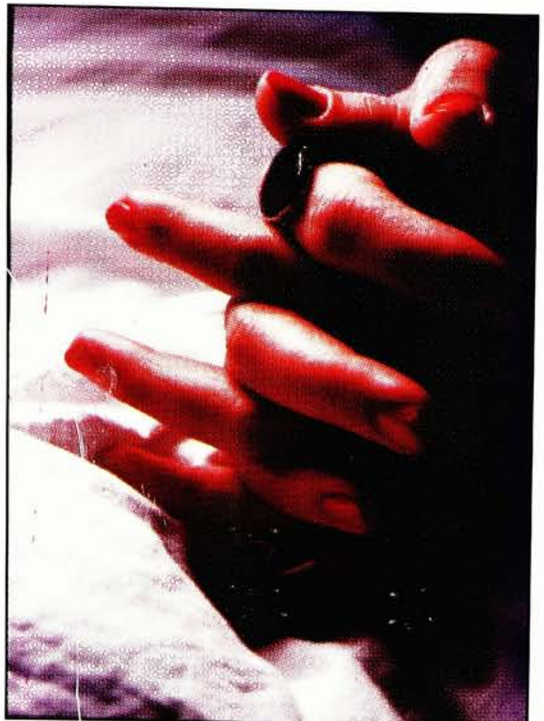

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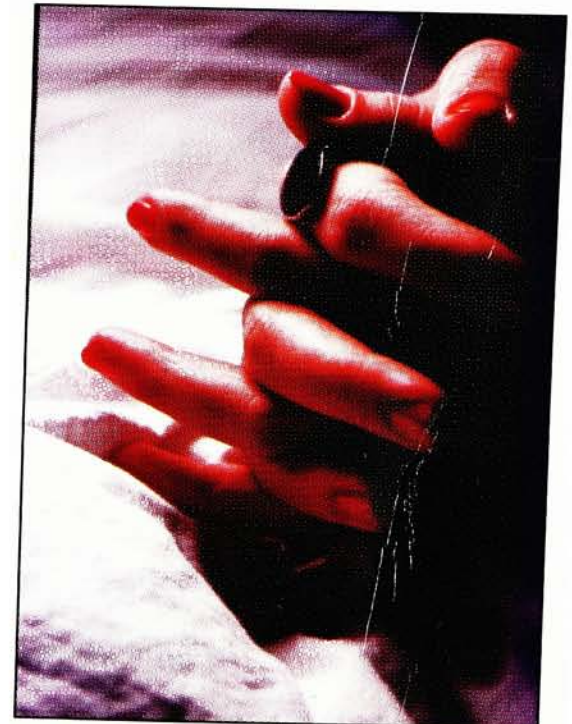
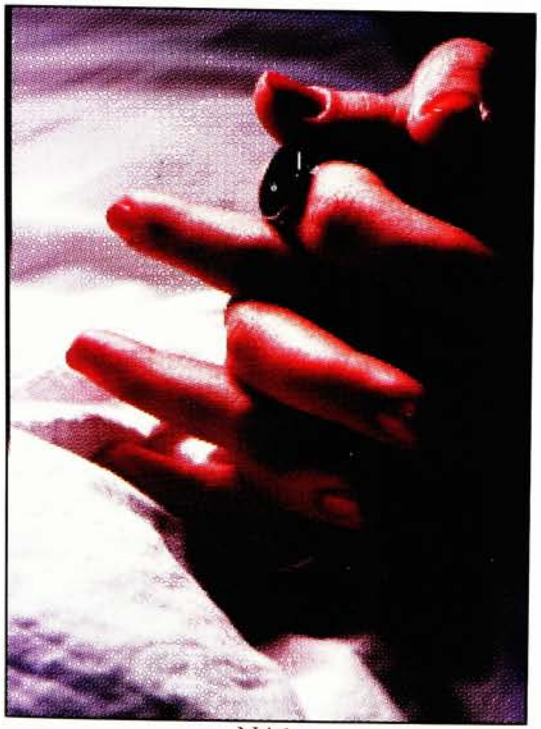
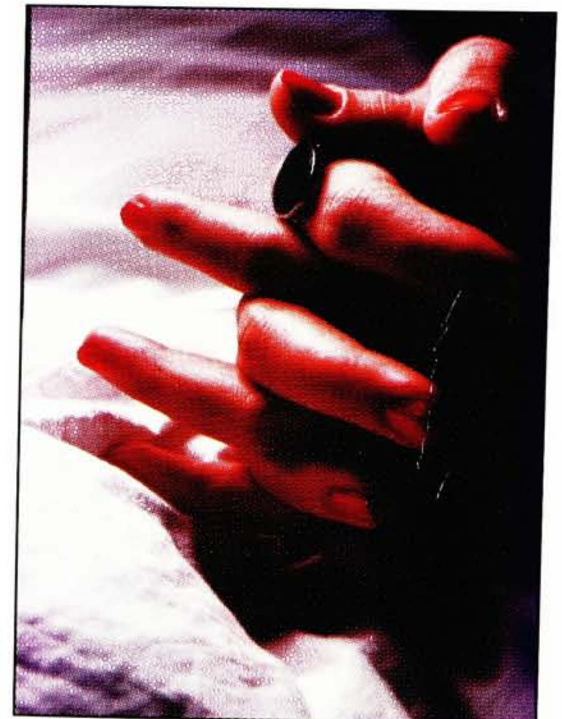


NA5


NA1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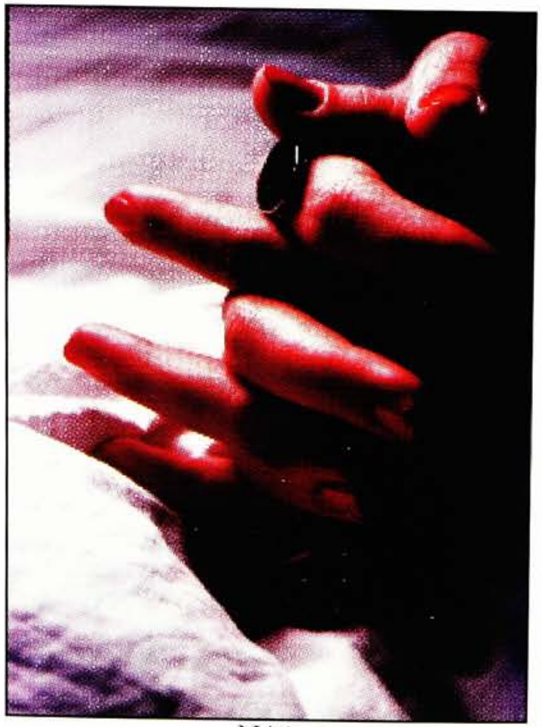
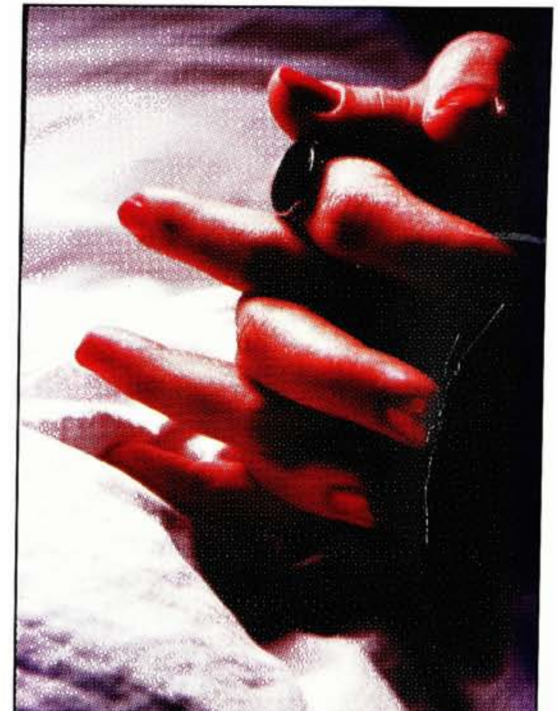

NA1


NA4


NA2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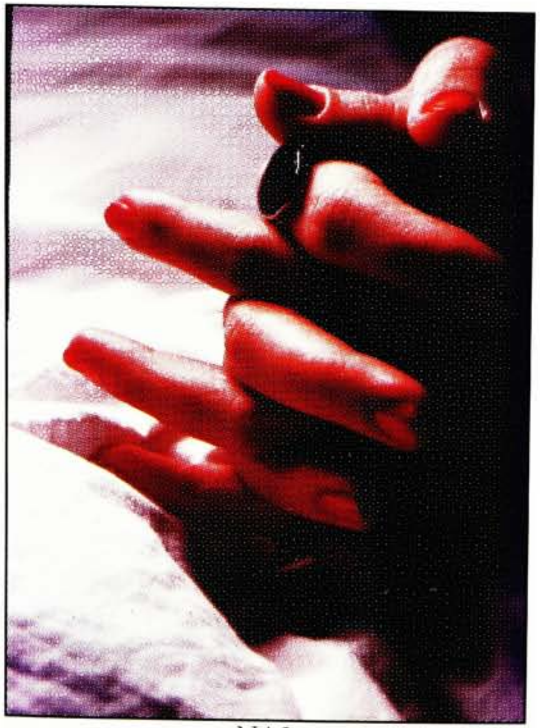

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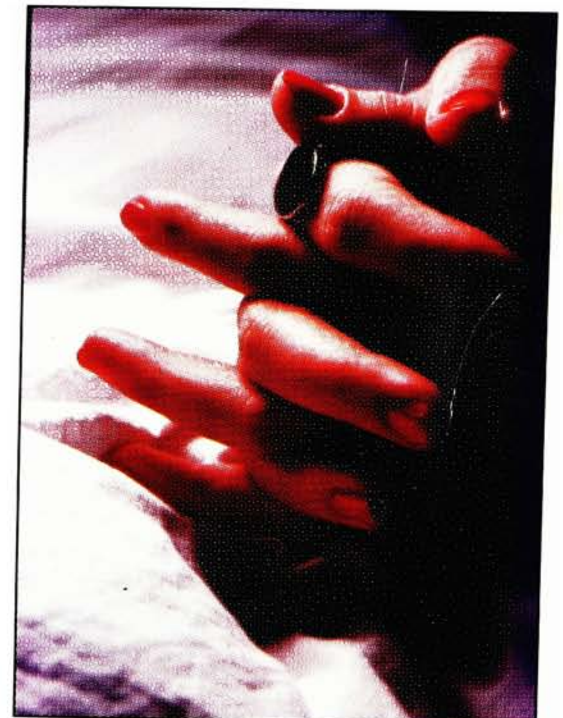
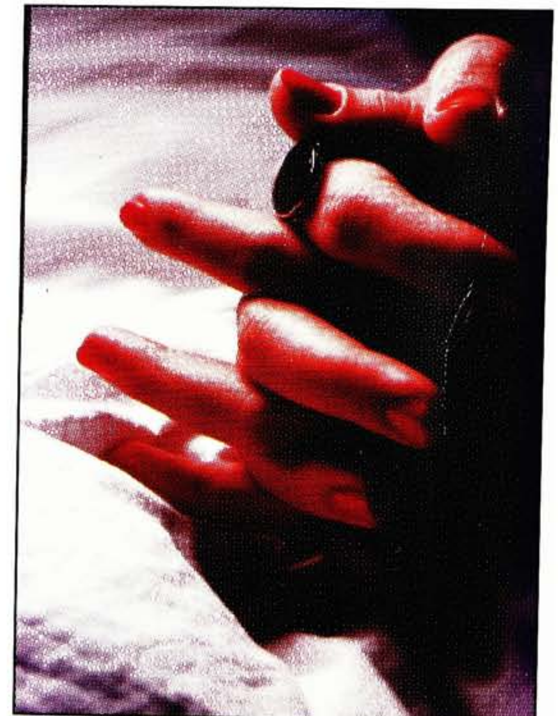


NA4

NA2



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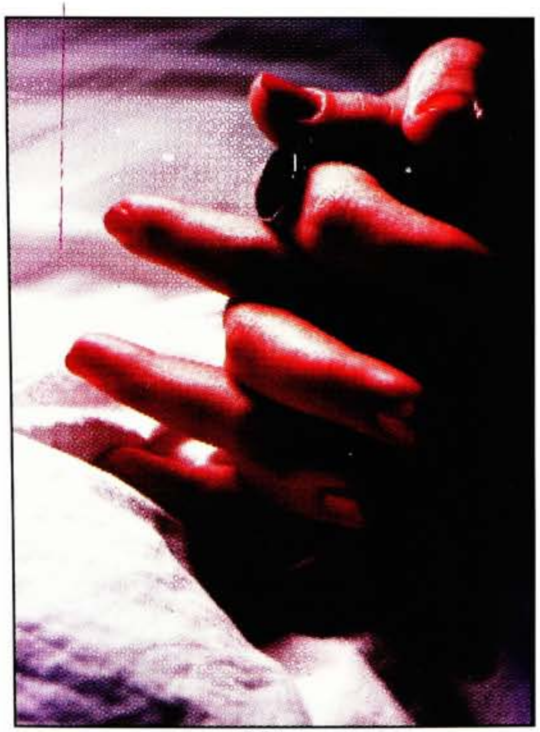
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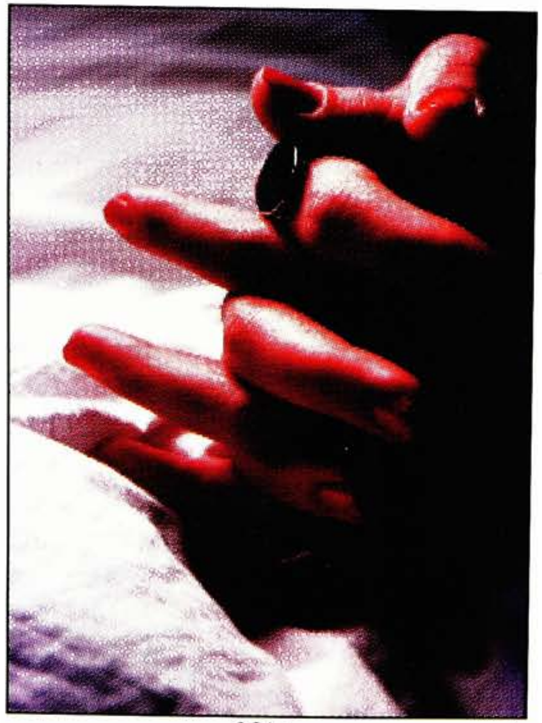
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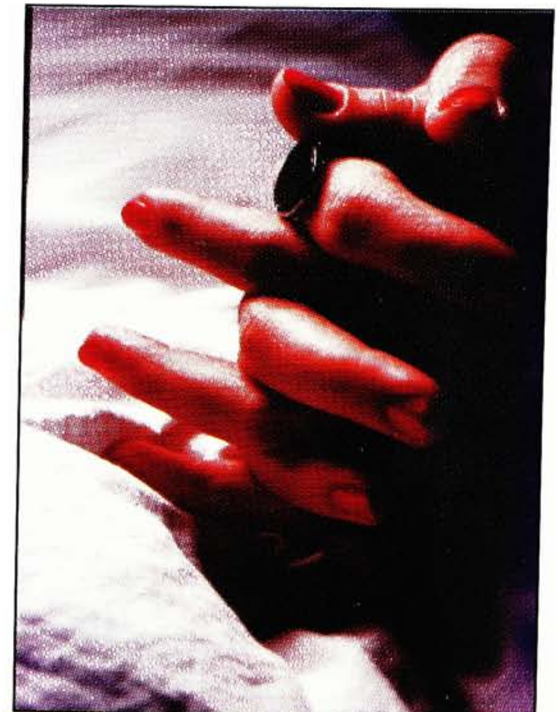
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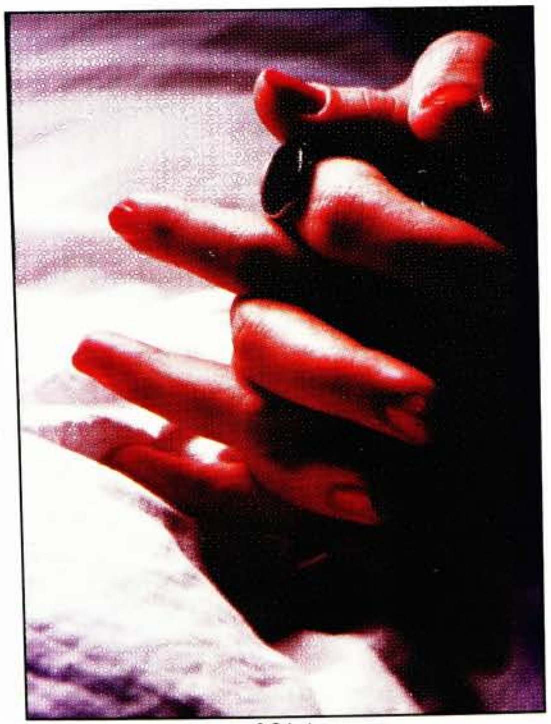

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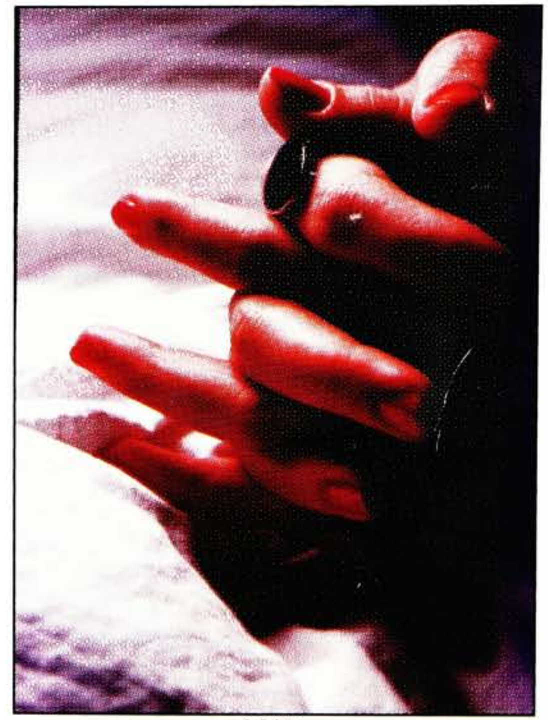
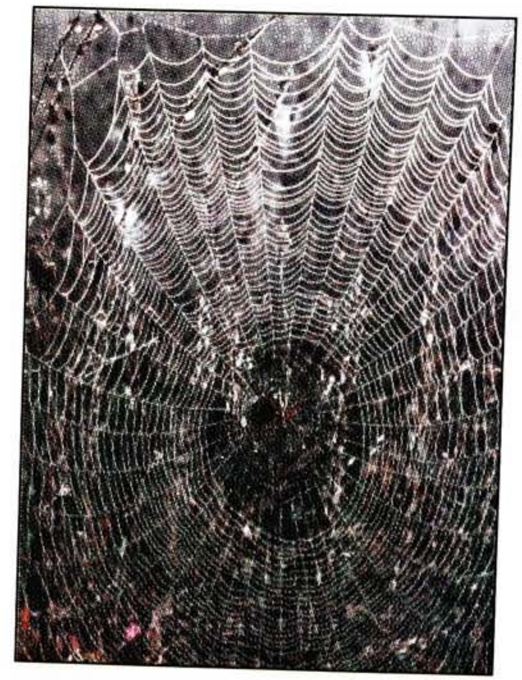


NA5


SA2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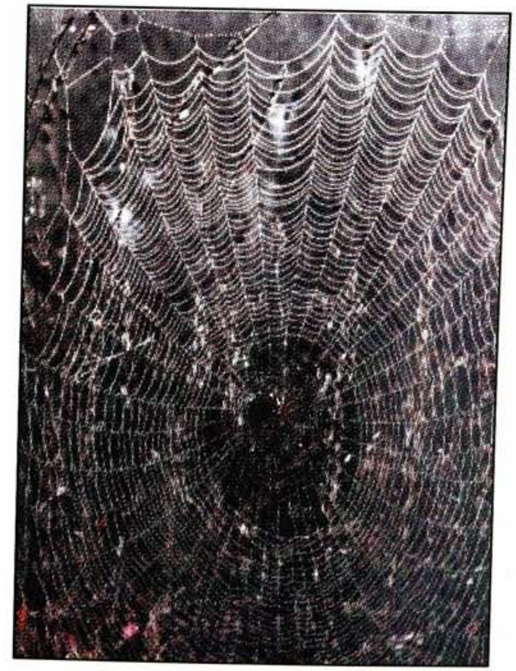
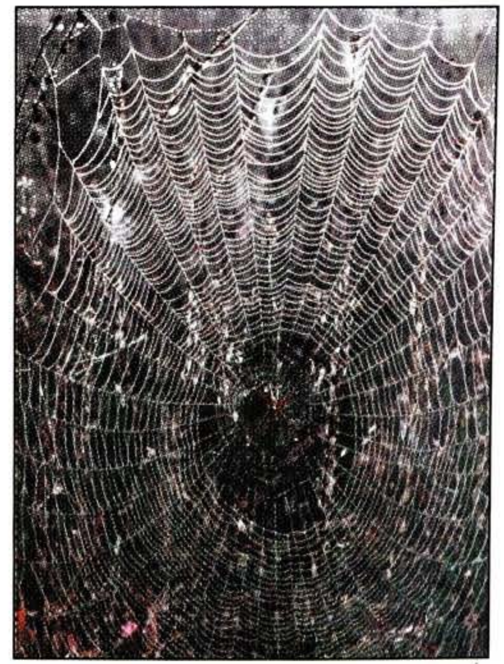
SA1



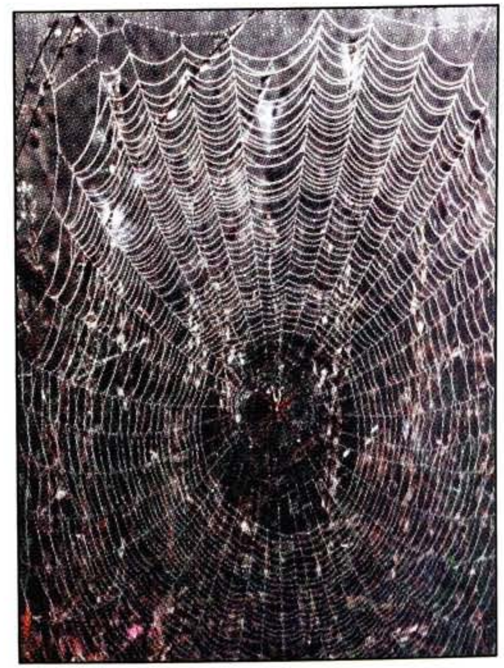
SA2

SA4



SA5

SA1



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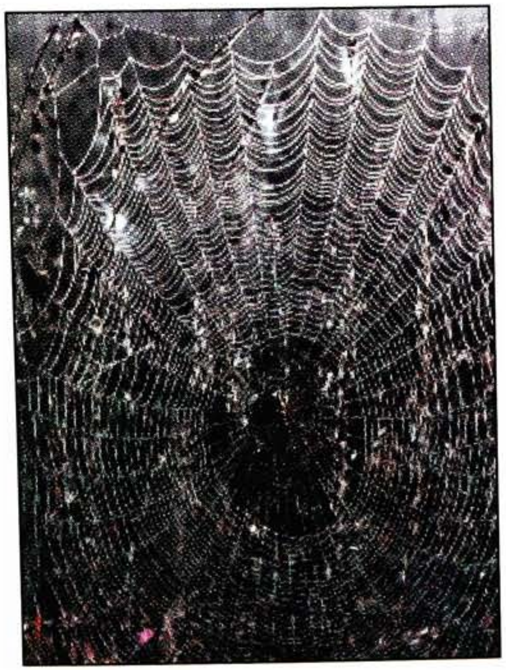

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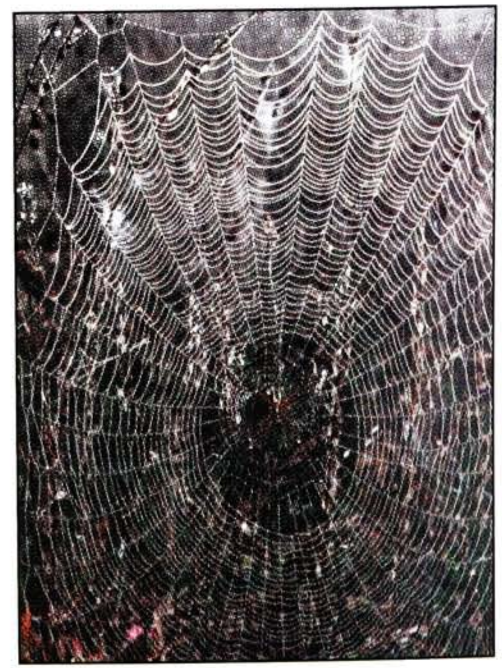

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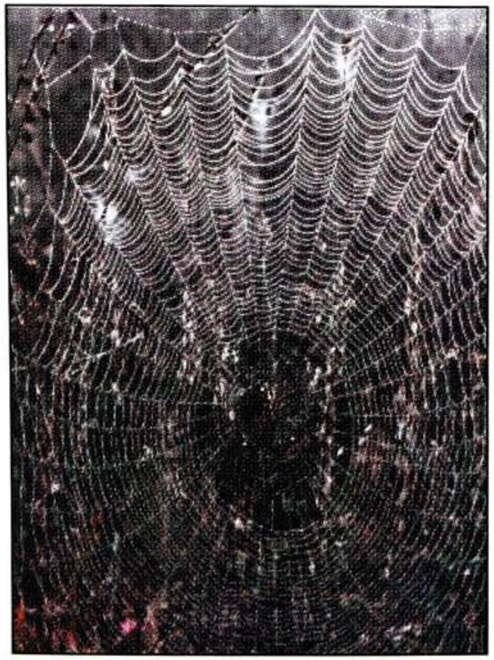


SA2

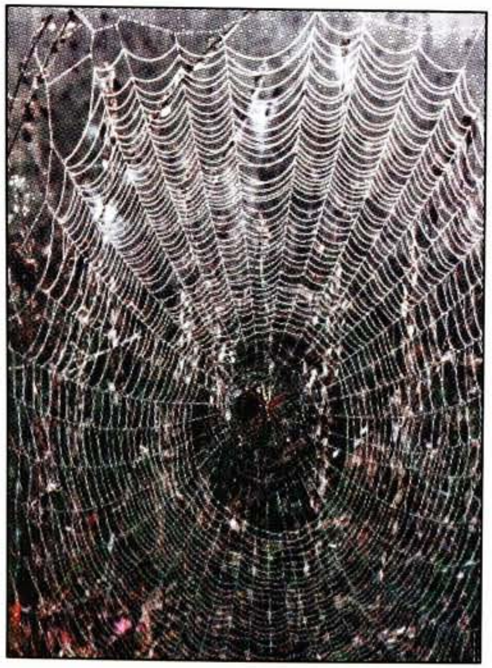
SA4

SA3

SA4

SA1

SA3



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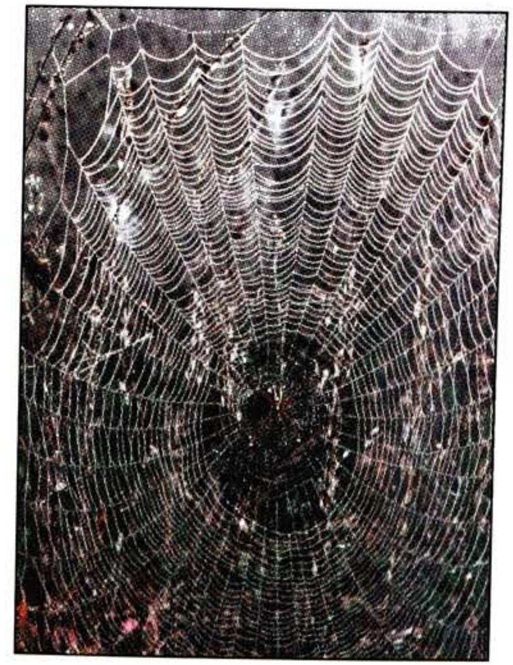
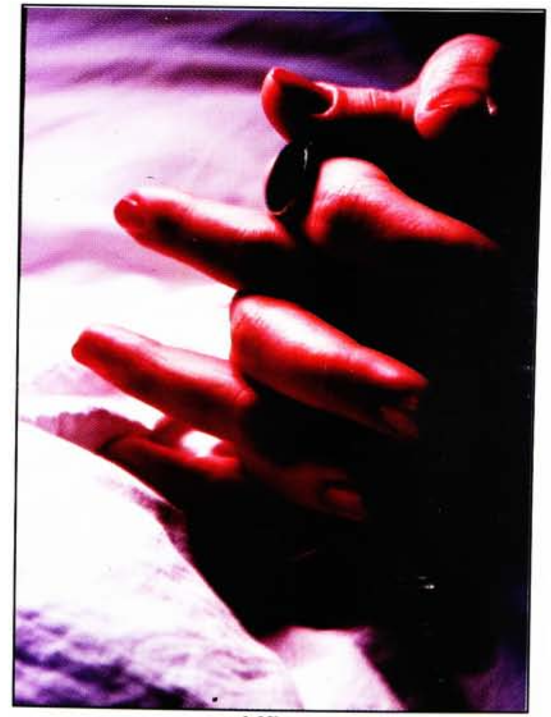


SA5

SA2

SA5

NB4



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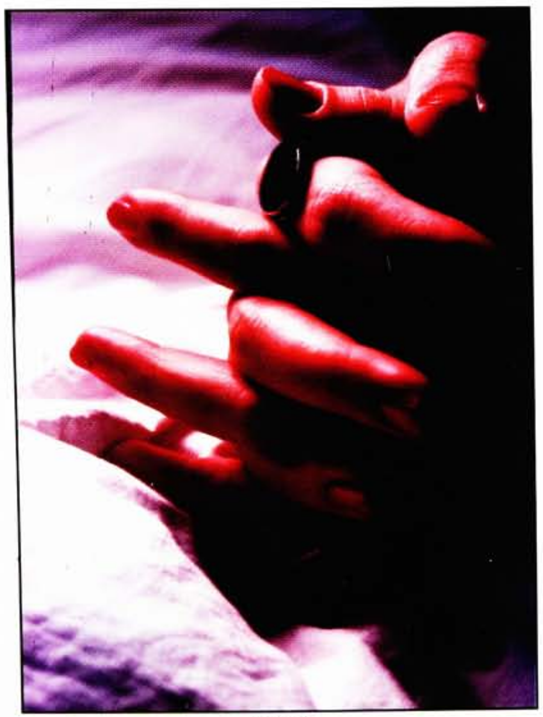
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NB3

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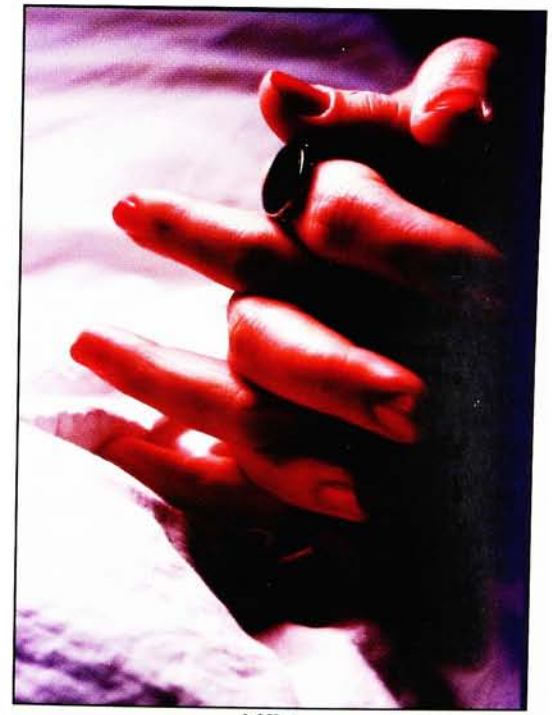
NB5


NB1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NB3

NB4

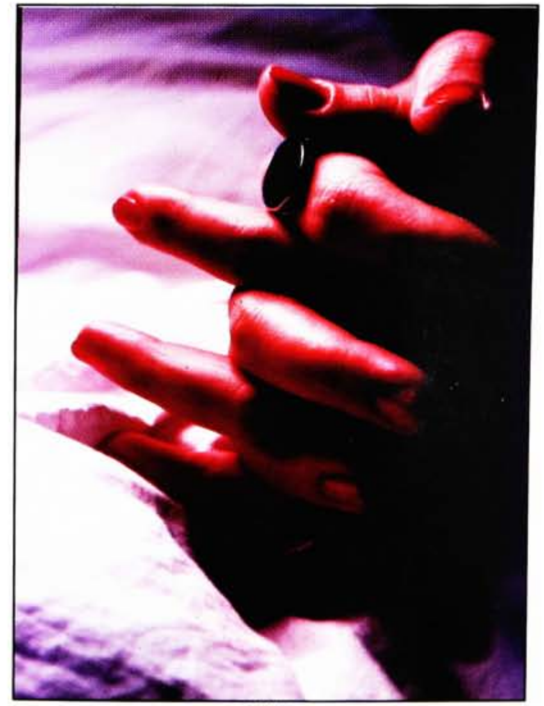
NB1

NB3


NB3


NB5

NB2



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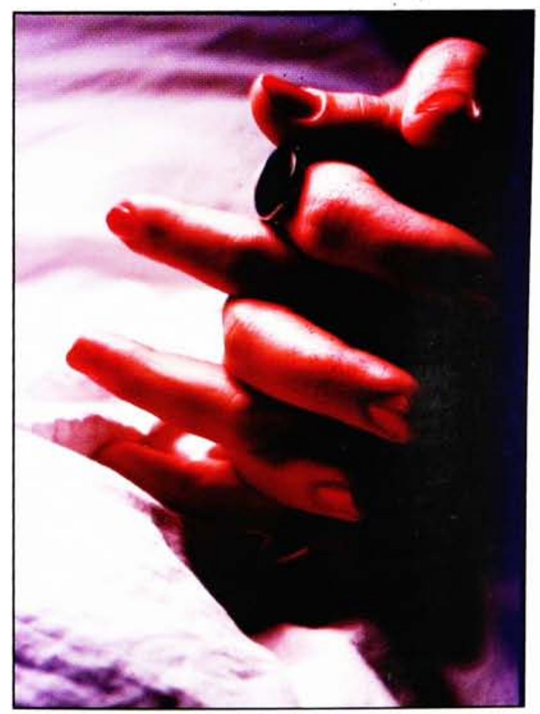
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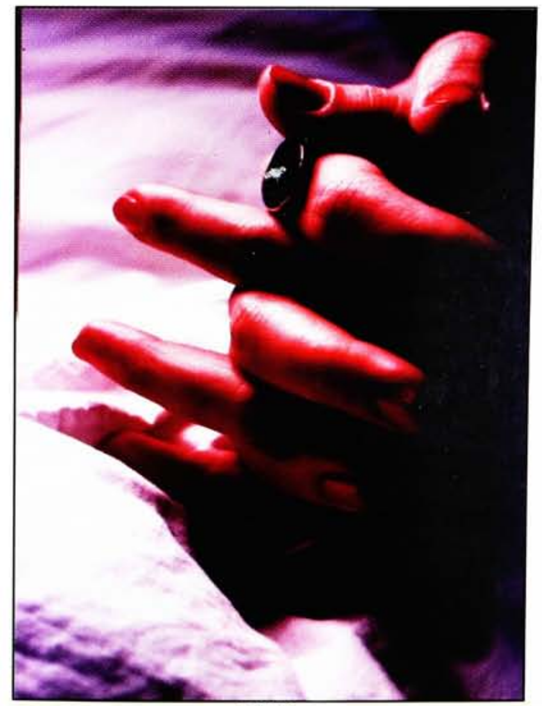


NB2

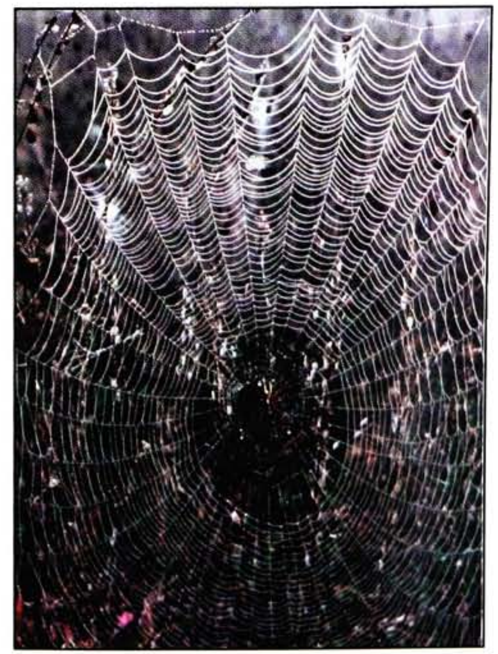
SB4

SB5

SB1

SB4

SB1



SB5

SB1

SB2

SB2

SB4

SB3

SB5


SB2


SB3

SB2

SB5

SB1

SB3

SB3

SB4

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