Digital Imaging for Preservation and Access of Paper Based Colour Maps: Results of a Survey

by

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Abstract

The object of this study is to devise a simple technique to provide digital access to fragile paper-based colour maps and images that might otherwise be damaged by misuse and abusive handling. On the basis of certain physical attributes, five different map and image types are defined. Using low cost equipment and software, seventeen representative maps and images were digitized. The digital files were then compressed, indexed and re-formatted, and a selection of these images were used in a survey of undergraduate students testing the legibility and colour reproduction of the various combinations of digital attributes.

The study suggests that there is a positive relationship between increased scanning resolution and both increased legibility and better colour reproduction. Furthermore, the study concludes that, for certain image types, there is a negative relationship between bit depth and image sharpness. Finally, the study arrives at the determination that every image must be treated individually, and standards for digitization must be customized for every image type.

Keywords: maps, digital preservation, digital access, digital colour reproduction, digital image legibility, digital image sharpness, compression, colour indexing.

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Table of Contents

List of Tables

List of Figures

List of Appendices

Note: Several sources used in this thesis were downloaded from the Commission on Preservation and Access Homepage on the Internet. Since the pagination of the downloaded versions depended upon the font size, line spacing and margins of my word processor, I have omitted the page numbers from direct quotations of these sources. These articles can be obtained from the Commission on Preservation and Access - the address is listed in the bibliography, on page 159.

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Chapter 1.

Introduction

1.1 Rationale: Problems of Digital Preservation and Access Presented by Paper-Based Colour Materials

The Commission on Preservation and Access (CPA) paper, "Scholarly Resources in Art History" (1989), and the report of its Joint Task Force on Text and Image, Preserving the Illustrated Text (1992), have documented the woeful inadequacy of preservation microfilming techniques to preserve colour graphical materials. Furthermore, the CPA, in its report "Phase II of the Cornell/Xerox/CPA Joint Study in Digital Preservation" (1992), recommended that a study addressing the problem of scanning and storing faithful reproductions of colour images be undertaken.

Colour maps present a particularly difficult challenge to digital preservationists. Researchers need to be able to see every fine detail and all the colours on the map with extreme accuracy. Therefore, any reproduction must faithfully recreate every nuance of the original. While high quality microfilm may be an ideal preservation medium for text and black and white images, it is unsatisfactory for capturing colour. The digital medium offers scholars high quality colour reproduction capabilities as well as remote access capabilities. A colour image can be digitized at a high resolution in 24 bit colour and saved as an archival record. Compressed versions, which require less disk space, can then be made as access copies for general use. However, within the archive community, there is heated debate concerning long-term access to digital archives due to both data migration and the rapid obsolescence associated with digital technology. Many have taken the hybrid-systems approach, using a film copy for archival purposes and a digital copy for access purposes.

1.2 Goals

The goal of this research is to devise a simple methodology for providing digital access to paper-based colour graphical materials using low cost equipment and software typically found in most universities. Utilizing subjective analysis techniques, this study will compare images possessing different combinations of scanning resolution, colour bit depth, and compression algorithms to identify the desirability and feasibility of the use of this technology by novice map users. The questions addressed in this thesis are:

1) What is the resolution required by novice map users to fully capture all the text and fine details of a map or image?

2) What bit depth is required to fully capture all the colours?

3) Can digital images be compressed and yet remain useful to the novice map user?

To answer these questions, the researcher presented a questionnaire to 56 undergraduate students, who were assumed to represent a typical cross-section of inexperienced and experienced map users. The students were asked questions designed to test the legibility of text and fine details and the colour reproduction capabilities of a variety of methodologies to produce digital onscreen versions of paper-based colour maps and air photos. However, this thesis does not go into great detail in its study of legibility or colour perception. The limitations of this study are expanded upon further in Chapter Six: Conclusion.

1.3 The Need for Preservation: The Problem of Acidic Paper

Damage to collections in libraries and archives can result from inadequate storage, war conditions, greater frequency of use and vandalism (Federal State Task Group [FSTG], 1994). However, the insidious deterioration of an item begins during its creation. Since the invention of paper in China around 300 B.C., production techniques remained largely unchanged until the middle of the 19th century; bamboo, hemp, flax, linen and cotton provided the fibres for traditionally made paper. Paper was hand made, labour- and cost-intensive, and was used primarily for administrative purposes, official correspondence, archival documents, and later in the printing of books. Such low demand delayed the development of new production methods and alternative fibre sources until late in the Renaissance (Schwerdt, 1989).

In 1799, the invention of the chlorine bleaching process to lighten coloured plant fibres considerably increased the availability of suitable fibres for paper production. Later, the application of alum resin for gluing paper en masse furnished the basis for mechanized paper production (FSTG, 1994; Cloonan, 1993). However, the acceleration of scientific, technical and cultural progress in the 19th century resulted in such an increased demand for paper that the available procedures and raw materials were no longer sufficient. In 1844, F.C. Keller succeeded in using wood as a cost effective, widely available source of plant fibre for paper production (Schwerdt, 1989). His invention was followed in 1854 by the development of chemical wood pulp production using the soda, sulphite and sulphate process (Schwerdt, 1989).

The use of acids in the production process, as well as the use of alum (aluminum sulphate) for gluing, are the fundamental causes of the poor durability of industrially produced paper. The hydrolytic decomposition of the alum due to humidity results in the release of sulphate ions that combine with water vapour to form hydrosulphuric acid (H_2SO_4). Indeed, the acidity in paper can potentially be in the range of pH 4 (or less) to pH 6 (pH 7 is neutral), depending on composition and age. The formation of acids and the simultaneous aging of the paper stock are accelerated by unfavourable storage conditions, such as high temperatures and humidity, fluctuations in room climate, and air pollution, which exposes the paper to sulphur dioxide and nitrogen oxide (FSTG, 1994). In combination with water, these oxides form acids that build up in the paper.

The aging and decomposition of paper is determined by numerous complex chemical and physical processes, in which hydrolytic and oxidative reactions overlap. The decisive factor is the decomposition of the cellulose fibre structure when the fibre length of the cellulose molecules diminishes.

The causes for the loss of fibre durability include hydrolysis under the influence of acids, oxidation with formation of carboxyl and carbonyl groups, formation of netting between cellulose molecules, microbiological damage, and mechanical wear and tear (Schwerdt, 1989).

Oxidation and hydrolysis are mutually complementary processes (FSTG, 1994). That is, auto-oxidation takes place and the acidic by-products of this process accelerate hydrolysis. The hydrolysis of the cellulose in turn increases the sensitivity to oxidation. Industrially mass-produced paper is especially sensitive, because cellulose obtained from wood is less resistant to decomposition than the previously used cellulose obtained from cotton, linen, flax, or hemp (Schwerdt, 1989). Furthermore, so-called "healthy paper" suffers as a result of direct contact with unhealthy paper through a process known as acid migration (FSTG, 1994).

In 1992, Hogarth and Martin conducted a research project based on a postal questionnaire as part of the requirements for the degree of MSc in Information Science at University College, London, England. Among other things, the survey was designed to determine what factors jeopardized the preservation of non-textual archive materials. Over 80% of the respondents claimed they had the following preservation problems: lack of storage space, lack of appropriate storage media, lack of regulated storage conditions, excessive handling of fragile originals, the sheer volume of material, and inherent degradation problems, such as those previously discussed (Hogarth and Martin, 1994).

1.4 Extent of the Damage

It is estimated that between 70% and 80% of all paper-based documentation of our knowledge, our literature, and our history held in libraries and archives around the world originates from the period following the introduction of sensitive acidic and/or woodpulp paper (FSTG, 1994). Approximately 97% of the holdings at the Library of Congress has a pH below 7, and is therefore in imminent danger (Schwerdt, 1989). Furthermore, in 1986 the Library of Congress declared that 25% of its collection, or about 3.5 million volumes, was unusable due to paper deterioration (FSTG, 1994; Brown, 1991; Lesk, 1990; Schwerdt, 1989) and this number is increasing by 77,000 volumes each year (Schwerdt, 1989). In U.S. research collections, the pages in approximately 80 million volumes are brittle because of alum sizing introduced into the paper-making process around 1850 (Commission on Preservation and Access [CPA], 1989). Furthermore, studies conducted in Germany revealed that 12% of all academic collections, or 60.5 million volumes, were unusable (FSTG, 1994). Large portions of collections around the world are soiled, yellowed, damaged and infested with mold as a result of inadequate storage conditions, excessive handling and poor manufacturing methods (FSTG, 1994); there are literally billions of pages at risk held in libraries around the world.

While these numbers refer almost exclusively to paper in book form, one could reasonably assume that the situation regarding paper-based cartographic resources is similar, if not worse. That is, paper in book form is reasonably well protected. A book on a shelf usually exposes only the edges of the paper to light sources, air pollutants and other potential sources of damage. However, a paper-based map is much more vulnerable, for its exposed surface area is far greater than that of a typical book. Folded maps are especially susceptible, for as paper ages, it becomes brittle; the map may tear along the creases when a user attempts to unfold it. Furthermore, as a result of their large surface areas, maps are especially vulnerable to other types of mechanical damage, intentional and otherwise, such as tears, stains and annotations left by thoughtless users.

1.5 Effects Upon the Political, Cultural and Academic Communities

Libraries and archives store a significant portion of a nation's cultural heritage. In a society wherein access to information is seen as a fundamental right, libraries exist in part to provide access to that information whereas archival facilities exist primarily to preserve information. Because of the fragile nature of most archival documents, making information available for extensive scholarly use, while certainly important, has always been a secondary purpose of archival centres. While it may often be thought desirable to hold and read original documents, the use of damaged or endangered materials must be subject to restrictions. That is, in the interest of preservation, access and use must be limited or prohibited, measures which users in today's information society may find objectionable or difficult to understand. Researchers and other academicians expect the freest possible access to collections, including those containing endangered or archival material. In gaining access to these materials, they contribute to the process of deterioration and destruction.

Archival and library materials, to the extent that they are to be permanently preserved, are not consumer goods intended for the use of one or two generations and then discarded. They must be preserved for future use, for future generations also have the right of access to the cultural legacy preserved in libraries and archives. Thus, librarians and archivists have a fiduciary duty to preserve the cultural legacy entrusted to them.

The duties of preserving cultural documents and of making them available for use are in direct opposition to one another, and this can only be resolved if libraries and archives have access to sufficient funds and resources for the protection, conservation and restoration of damaged and endangered materials. The preservation of library and archival materials is a task of key importance for states and societies, for if nothing is done to stop the relentless deterioration of archival sources, knowledge, thought and the time-bound experiences of whole epochs, as they are found in paper-based form, will disappear. This would have an astonishing impact on the political, cultural and academic communities. For example, the quality of research and teaching would suffer; there would be negative impacts on science and the development of new technologies; the continuity of legislation, administration and jurisprudence could no longer be assured; legal and property relationships would no longer be documented; the memories of entire nations would develop irreparable gaps; historical questions would never again be answered using primary material. The paradox inherent in this situation is that the more recent materials of the 19th and 20th centuries would disappear. These documents provide insight into the complicated process of the development of the modern state under the rule of law, while older materials printed on more durable paper or parchment would remain accessible. In other words, over time the amount of knowledge that civilization has produced that must be preserved for future generations has increased, while the durability of the record of that information has decreased. For instance,

> in the era of manuscripts and printed books, access to knowledge depended upon the health of the artifact. And the longer the life cycle of the artifact, the lower the access to the knowledge it contained. For example, stone, clay and papyrus were relatively stable media, but the labour-intensive quality of their creation plus their cumbersome nature militated against widespread access to the knowledge contained within the artifacts (CPA, 1993).

The scarcity of materials to make high quality paper inhibited access to knowledge as literacy grew, so the advent of cheap mass-produced acid paper increased the access to the intellectual content of the artifact while decreasing the stability of the medium (CPA, 1993). The development of digital technology has hastened the process so that today's society can produce enormous volumes of information, and the time to access that information is measured in fractions of a second.

> The success rate of each succeeding generation's effort to immortalize itself through communication is dropping off virtually in inverse proportion to the rise in our propensity to communicate and record our thoughts and actions (Brown, 1991:11).

Libraries and archives collect information contained on a wide variety of media, including paper, film, analogue and digital tape and disks, all of which have a finite lifespan. When the original media deteriorate sufficiently to threaten the loss of information, the archivist must make a major decision about which preservation technology to use.

> The decision can be difficult because no preservation technology is perfect; some information is lost in order to save other information....Libraries and archives are filled with examples of compromises made to preserve some information at the expense of [other] information....(Ogden, 1989).

There are two types of information held in a document: 1) the intellectual content, and; 2) the item's provenance, or the record of the item's ultimate derivation and passage through its various owners. That is, there is a distinction to be made between the item itself (the format of the information) and the actual information that it contains; most users seek only the intellectual content and are relatively unconcerned with the format of the information. According to Clements (1991), the preservation objectives of a library/archive are twofold: 1) to preserve the intellectual content of an item through restoration, and; 2) to preserve its original physical form. However, these goals can be contraposed to one another. The restoration process - washing, deacidification, cleaning and stain removal, mending of physical damage, and resewing and rebinding (when appropriate) - affects the evidence that is useful in reconstructing the printing process of that item, which is of interest to bibliographers (Lundberg and Estick, 1989). This distinct contrariety can be summed up by the fact that "either the [item] is restored so that it can continue to be used for research, or it is 'put on ice' indefinitely so that, in the future, it might be useful for researchers" (Lundberg and Estick, 1989:78). The question to be addressed is, how might an archivist protect both the intellectual content and provenance of an item while still providing access to that item?

1.6 Preservation Alternatives

Although the low quality of industrial paper has been known for over a century, and the problem of acidic decomposition has been recognized for almost as long, the endeavours of many researchers have so far produced few solutions. Two principal approaches are used in libraries and archives in order to preserve the printed cultural heritage, namely reformatting of items to other media, such as microfilm or digital media, and the preservation of the items in their original form.

In his report to the Commission on Preservation and Access, Lesk

(1990) stated that the two most expensive parts of any preservation activities are selecting the materials to be preserved, and turning the pages for item-by-item chemical treatment, microfilming or digitization. Thus, each book should be handled only once to reduce the expense. Bulk deacidification, which does not require page turning, offers low-cost preservation (Schwerdt, 1989; Sparks, 1990), but does not increase the number of copies of the item. Furthermore, this process leaves the original item in its fragile condition (Lesk, 1990; Sparks, 1990; Schwerdt, 1989). On the other hand, microfilming and digitization, while also leaving the item in its fragile state, make surrogates of the item for general use, thereby relieving the pressure of excessive handling of the original.

1.6.1 Mass Chemical Deacidification

Manual aqueous deacidification, in a single leaf process which is routine for conservation specialists, is not feasible for bound materials in large quantities because of various side effects and the necessary time- and cost-intensive freeze-drying process (Sparks, 1990; Schwerdt, 1989). In Canada, France and the United States, experience has been gathered in several pilot projects using various nonaqueous procedures. By using a gaseous substance, either diethyl zinc (DEZ) or magnesium methyl carbonate (MMC), many of the side-effects damaging to paper, printing inks and bindings, which could occur in processes employing aqueous or other liquid solutions, are generally avoided (Schwerdt, 1989). Thus, the time consuming and costly preselection of materials to be treated is, in some cases, unnecessary.

In principle, the DEZ method, being tested by the Library of Congress, consists of three steps: 1) vacuum drying of materials to the desired residual humidity content of 0.5% of their weight; 2) treatment with gaseous DEZ, and; 3) rehumidification with water vapour; the entire time of treatment is approximately 50 hours (Schwerdt, 1989). This procedure neutralizes the acids in the paper while forming zinc sulphate, which reacts with the humidity of the paper to form zinc oxide as a buffer against further acid formation (Schwerdt, 1989). Despite its apparent advantages, the handling of DEZ is problematic because of its high instability and extreme volatility. It ignites spontaneously with air, reacts with extreme violence in water, and decomposes at temperatures above 120 degrees Celsius (Schwerdt, 1989). Obviously, a high degree of technical knowledge is required to use this product safely. Furthermore, this process is economically feasible only for large capacities; the Library of Congress has set a goal of treating 1 million books per year (Schwerdt, 1989).

The MMC process, entitled the Wei T'o process after an ancient Chinese god who protects paper from fire, worms and thieves, is being tested by both the National Library of Canada and the Bibliotheque Nationale in France. While the two procedures being tested are slightly different, the principal steps are the same. The items are dried in warm air and vacuum dryers to remove excess humidity; the items are then soaked in the MMC solution; after drainage of the solution, the items are dried in a climate-controlled chamber where they are returned to normal environmental conditions; the entire process takes less than 30 hours (Schwerdt, 1989). The acids in the paper are neutralized when magnesium sulphates are formed and the excess reagent remains in the paper to act as a buffer in the form of magnesium carbonate and hydroxide. The alkalinity of the treated paper ranges from pH 8.5 to pH 9.5 (Schwerdt, 1989). The Wei T'o process can be implemented at a relatively low cost; the test plant built by the National Library of Canada in Ottawa in 1985 cost $500,000 (US) and treats about 20,000 items per year (Schwerdt, 1989). Furthermore, the process requires less technical knowledge than the DEZ method, and is less hazardous. However, since the MMC solution is incompatible with some bindings, printing inks and colours, items to be treated must be sorted, a costly step that is one of the prime disadvantages of the Wei T'o process (Schwerdt, 1989).

There are three reasons to consider mass deacidification as an option for preserving original materials. First, the chemical effect of removing the acids in the paper, coupled with the inclusion of an alkaline buffer, markedly stabilizes the cellulose fibres and prevents the paper from becoming weaker and more brittle (Sparks, 1990; Schwerdt, 1989). Second, as there are currently a number of concerted efforts grappling with the task of transferring information to secondary preservation media, such as microfilm and the digital format, the time gained by deacidification can be used in the future to implement new preservation approaches that are still under development (Joint Task Force on Text and Image [JTFTI], 1992; Sparks, 1990). That is, deacidification cannot help to preserve paper that is already brittle, as its primary utility is to preserve paper that still has some strength. However, it can play a major role in keeping the balance of collections that are on stronger paper from becoming brittle for long periods of time. "This is an important contribution to the overall preservation effort because the amount of embrittled paper that must be reformatted is large and will require many years of work and continuing large-scale funding to complete" (Sparks, 1990). The third reason is that mass deacidification has the potential to stabilize large quantities of paper-based records at a reasonable unit cost. The high production capacity of the process means that an entire research collection can be treated in a matter of several years (JTFTI, 1992; Sparks, 1990).

Schwerdt (1989) offers another, perhaps more compelling, reason to consider mass deacidification. Original items not only contain intellectual content, but often represent art objects or documents of high cultural value, which simply cannot be replaced by a reformatted version. From the archivist's point of view, the preservation of the artifact in its original form is highly desirable.

1.6.2 Preservation Microfilming

Preservation microfilm is a black and white photographic material of extremely fine grain and high resolution for copying documents on a greatly reduced scale. Film resolution is a measure of image sharpness and is defined as "the ability to render visible fine detail of an object" (Willis, 1992). Film resolution is expressed as the number of line pairs per millimetre (lppm) that can be resolved; a line pair is one black line and one white line juxtaposed. Theoretically, microfilm is capable of resolving 1,000 lppm, but this is never actually achieved (Willis, 1992). Vagaries in studio lighting, exposure control, lens quality, focal length, development chemistry and the presence of minute vibrations limit the effective resolution to 120 - 150 lppm (Willis, 1992). The Research Libraries Group standard for preservation microfilm identifies any resolution above 120 lppm as excellent.

Microfilming has been acknowledged as the primary preservation reformatting medium (for example, see Conway, 1994; Lynn, 1994; Cory and Hessler, 1993; Willis, 1992; Lesk, 1990, and many others). Microfilm has a well established archival life measured in centuries when maintained under the proper conditions, and improvements in film, optics technology and processing software are continually taking place. Yale, Columbia, Harvard, and the New York Public Library, which pioneered the development of preservation microfilm standards, have produced over half a million titles in the medium (Conway, 1994). Furthermore, the Library of Congress has more than 258,000 volumes on microfilm and spent $2 million on microfilm in 1994, while the US National Archives has a program of filming high-use government files and currently has over 260,000 reels of film (Conway, 1994).

Closer to home, the Canadian National Archives, which must ensure the security of 1.5 million maps, many of which are rare and priceless, implemented a program whereby the maps would gradually be reformatted to microfiche in order to alleviate concerns of fire and water damage, and excessive handling of these fragile documents (Rogers, 1990). Also, many local libraries have made investments in newspaper microfilm.

In his article, Willis (1992) outlines the advantages of preservation microfilming. Primarily, microfilm is durable, inexpensive to produce and use, and the equipment is unlikely to become obsolete - all that is required is a light source and a magnifying lens. Furthermore, the standards for creating, processing, storing and reading preservation microfilm are well established. Indeed, since photographic materials make faithful replicas of the originals, including foxing (blotchy discolouration), waterstaining, yellowing and faded inks, microfilm is a recognized archival medium (see American National Standards Institute [ANSI] IT9.5-1988, and ANSI PH1.67-1985). Finally, microfilm copies have been recognized as legally acceptable substitutes for original documents.

Willis (1992) also outlines the disadvantages of microfilm. Since the preservation masters can suffer mechanical damage if handled improperly, archival film is stored in a vault, and copies are distributed for general use. However, each generational copy loses 10% to 20% of its original fidelity (Skupsky, 1989). Furthermore, printouts are of poor quality. And finally,

> ...because microfilm is difficult to use, the challenge of locating and using preservation microfilm may offset its advantages for patrons. The relentless linear march of microfilm frames across the reader's field of vision distorts the natural structure of most information sources, further reducing the usability of the medium. It now appears that digital technology...is a significant improvement over microfilm for purposes of access (Conway, 1994: 42-43).

Chapter 2

Digital Imaging: Summary of Current Practice and Implications for Research

Digital conversion is the transforming of analogue signals into a coded number or sequence of numbers. This usually means capturing the light either reflected from a portion of the document, or transmitted through a piece of microfilm, and storing this information as a binary number. These numbers can be used by the computer to reconstruct a digital representation of the document or microfilm. However, simply assigning numbers for light reflectance values does not constitute digital conversion. The spatial location of each region on the document must also be encoded. For raster-based images (vector-based images will not be discussed in this study; see Guy, 1990, or Aronoff, 1989, for the differences between raster- and vector-based images), this code describes position in a column/row format. As a result, each region of the digital document is characterized by two values: 1) a number indicating the light reflectance value, and; 2) a sequence of numbers that maps its spatial location.

While there are numerous specialized manuals that explain digital image capture, Murray and vanRyper (1994), Williams (1994), Willis (1992), and Pazner *et al.* (1992) each outline the fundamentals of digitization in a technically sound manner while remaining easily accessible to the layperson; the following sections are derived from these sources.

2.1 Methods of Data Capture

In the column/row grid pattern in which digital images are organized, each square of the grid is assigned a number proportional to the average amount of light that comes from the corresponding portion of the original document. This process of detecting and recording the amount of light at a given location is called "sampling"; each grid element or sample is commonly referred to as a "picture element", or "pixel" ; the process of sequentially collecting samples is called "scanning" (Pazner *et al.*, 1992). The way that scanning is accomplished differentiates one digital conversion method from another. Four different scanning methods are discussed here.

2.1.1 Point Scanning

This is the fundamental method upon which the other scanning methods are based (see Figure 2.1). A portion of the document is illuminated; light from a small region of the document is focused through a lens onto a detector; once the light is detected, the measurement of its reflectance is converted to a number by the electronics and stored, thus creating a single pixel (Williams, 1994). Once the data conversion is complete, either the document or the scanner steps to the next region; the process is repeated for each pixel location on the document. Although it is considered slow and primitive, this approach provides very good positional and radiometric accuracy.

2.1.2 Line Scanning

The natural one-dimensional extension of point scanning, this is by far the most popular digital conversion method in use (see Figure 2.2). A linear

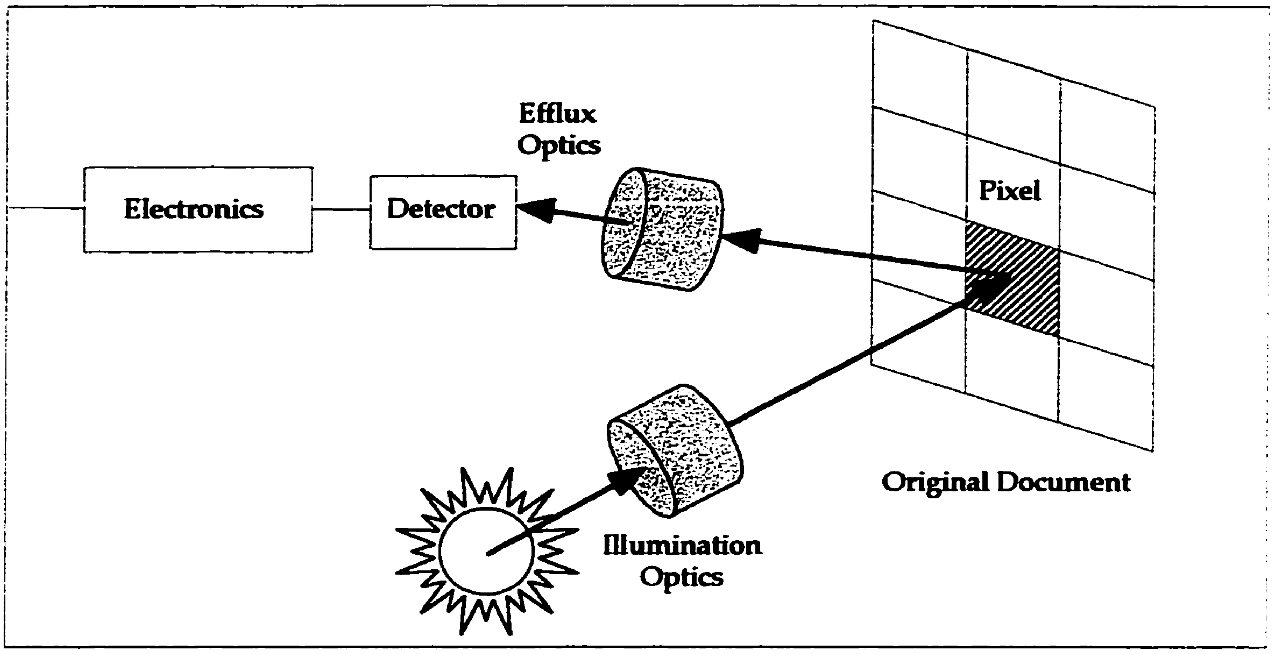


Figure 2.1 Point Scanning

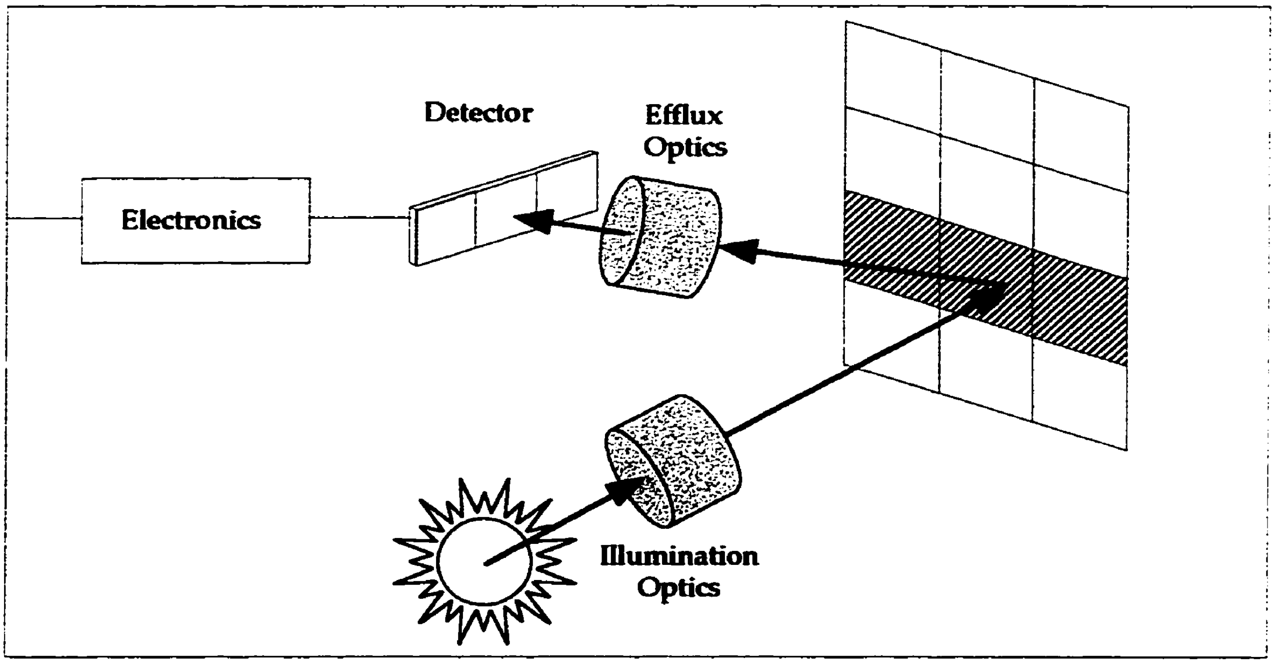


Figure 2.2 Line Scanning

array of individual detectors and supporting electronics is fabricated onto a single rigid substrate of silicon (Williams, 1994). This detector array collects information for an entire row of pixels simultaneously. The supporting electronics on these detectors link or couple the electronic charge created by the incident light, and thus are called "charge coupled devices" or CCDs (Williams, 1994). Devices which use this method of data conversion, such as document scanners, film scanners and facsimile machines, while providing greater speed than point scanning, are often less radiometrically accurate.

2.1.3 Array Scanning

Derived from line scanning, this method expands simultaneous pixel detection in two dimensions (see Figure 2.3) (Williams, 1994). Camcorders and digital cameras are example applications of this technology. This method is used in instances when capture speed is paramount to the application. However, array scanners are plagued by higher image noise and less radiometric accuracy than either point or line scanning.

2.1.4 Colour Scanning

Colour scanning may use any of the previous three methods for collecting spatial information, but must do so once for each of the three primary colours, almost always red (R), green (G) and blue (B). Colour scanning is accomplished most simply through three separate and sequential scans using the same detector array and filtering the illumination with R, G, or B colour filters (Williams, 1994). However, this is the most time-

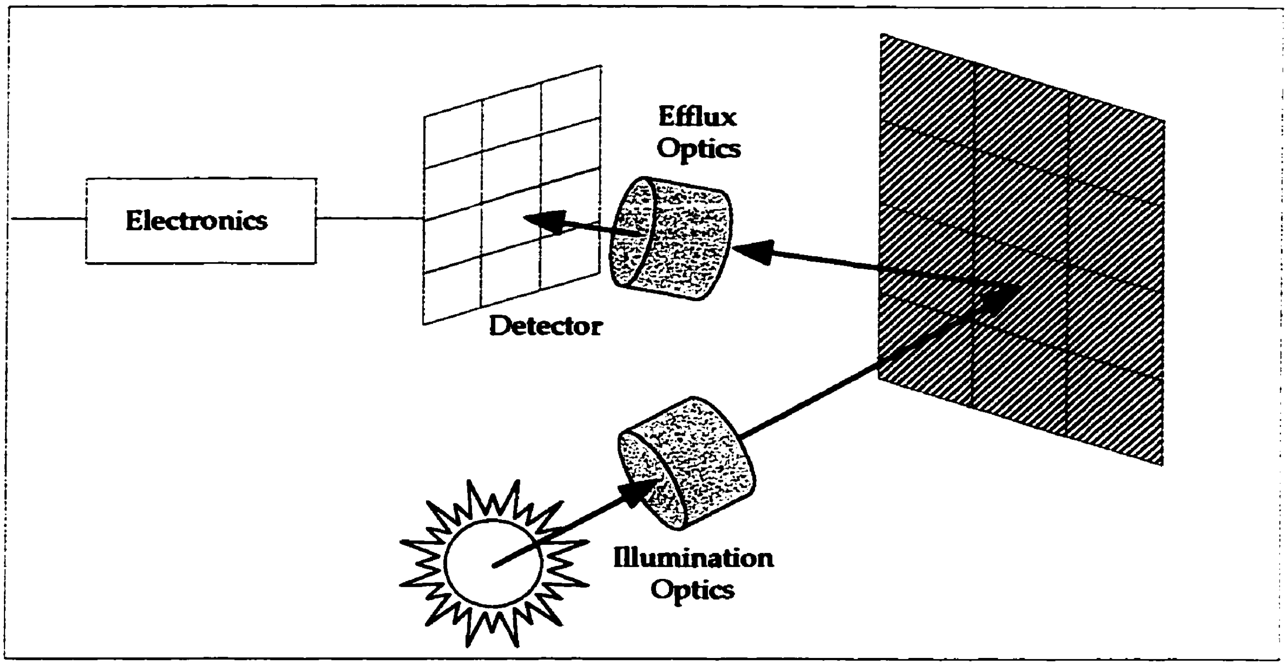


Figure 2.3 Array Scanning

consuming method because the detector array must return to the beginning of the document for each colour. To overcome this inefficient waste of time, so-called "one pass" colour scanners have been developed which contain three sets of CCDs, one set for each of the three colour channels.

2.2 Transforming the Document

2.2.1 Analogue and Sampled Images

A digital image could be described as a light intensity map of the original document. To represent a document in this way, one must have a method of recording both the light intensity and the position of each intensity measurement. More simply put, digital imaging is the recording of light intensity as a function of spatial location. The fineness to which these two descriptors can be quantified defines the quality of the converted image.

Plotting light intensity along a profile of an analogue image would produce a plot similar to Figure 2.4a. Note that the light intensity varies continuously from one location to another along the profile - this is typical of a continuous tone image, such as a photograph. However, rather than varying continuously from point to point, a sampled image varies in intensity to the same extent, but is only actually measured at a limited number of spatial locations (see Figure 2.4b). The continuous line is now represented by sample averages taken at each interval.

2.2.2 Sampling and Resolution

By placing line data sequentially one after the other, a two-dimensional

Figure 2.4a Continuous Image - light intensity varies continuously from one location to another.

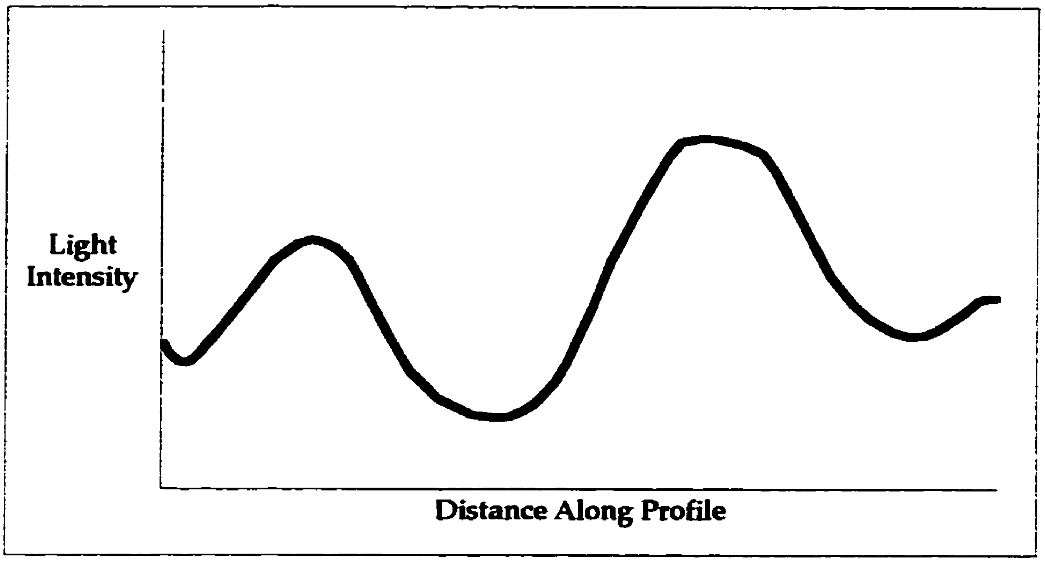
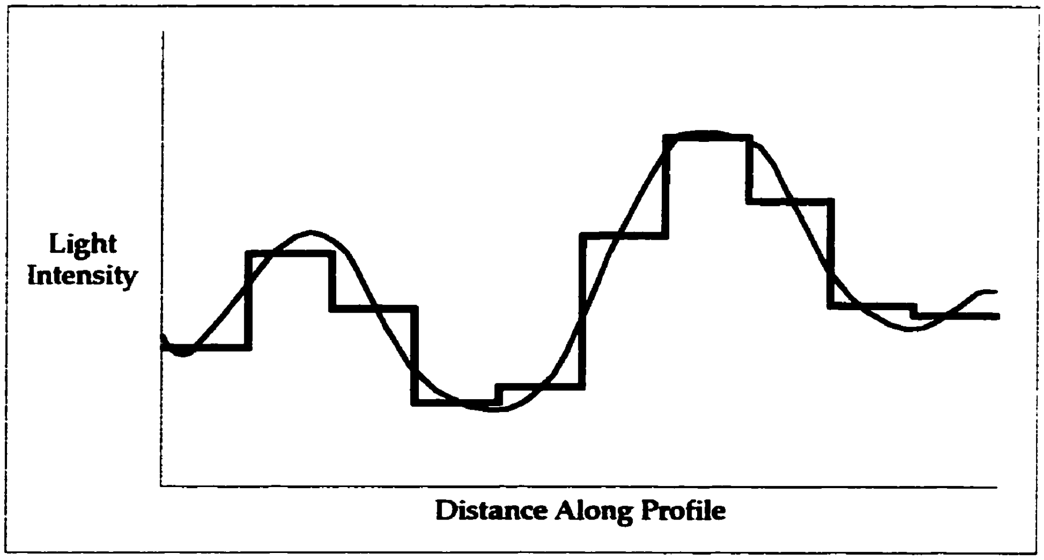


Figure 2.4b Sampled Image - light intensity varies at a limited number of locations.



array or matrix of pixels is formed that represents the width (row length) and height (column length) of the scanned document. The distance between the centres of neighbouring pixels is called the "sampling pitch" (Pazner *et al.*, 1992); it is more commonly referred to as "samples per inch" or "dots per inch", abbreviated as dpi. Thus, an 8.5" x 11" document scanned at 300 dpi would yield an image size of 2,550 samples x 3,300 lines.

Generally speaking, the greater the dpi, the better the image quality. However, since there is an infinite number of points on a document, and only a small subset of these points can be chosen for sampling, knowledge of the basic theory behind sampling is important for understanding data conversion. Perhaps the most fundamental question asked by amateur digital preservationists is, how many dpi are required to capture all the information on a given document? At a minimum, the distance between samples should be no greater than the width of the smallest sized feature that is to be captured. For example, the letter "e" is used as an industry benchmark for sampling quality because of its small size and confined stroke proximity (see Figure 2.5) (Kenney and Chapman, 1995; Williams, 1994). The character height can be visualized as divided into five roughly equal intervals, three dark bars interleaved with two white spaces. It is the size of this interval that defines the sampling pitch for minimum legibility under ideal conditions. Notice in Figure 2.5 that as the sampling pitch, represented by the grid pattern in the background, decreases, the legibility of the character increases.

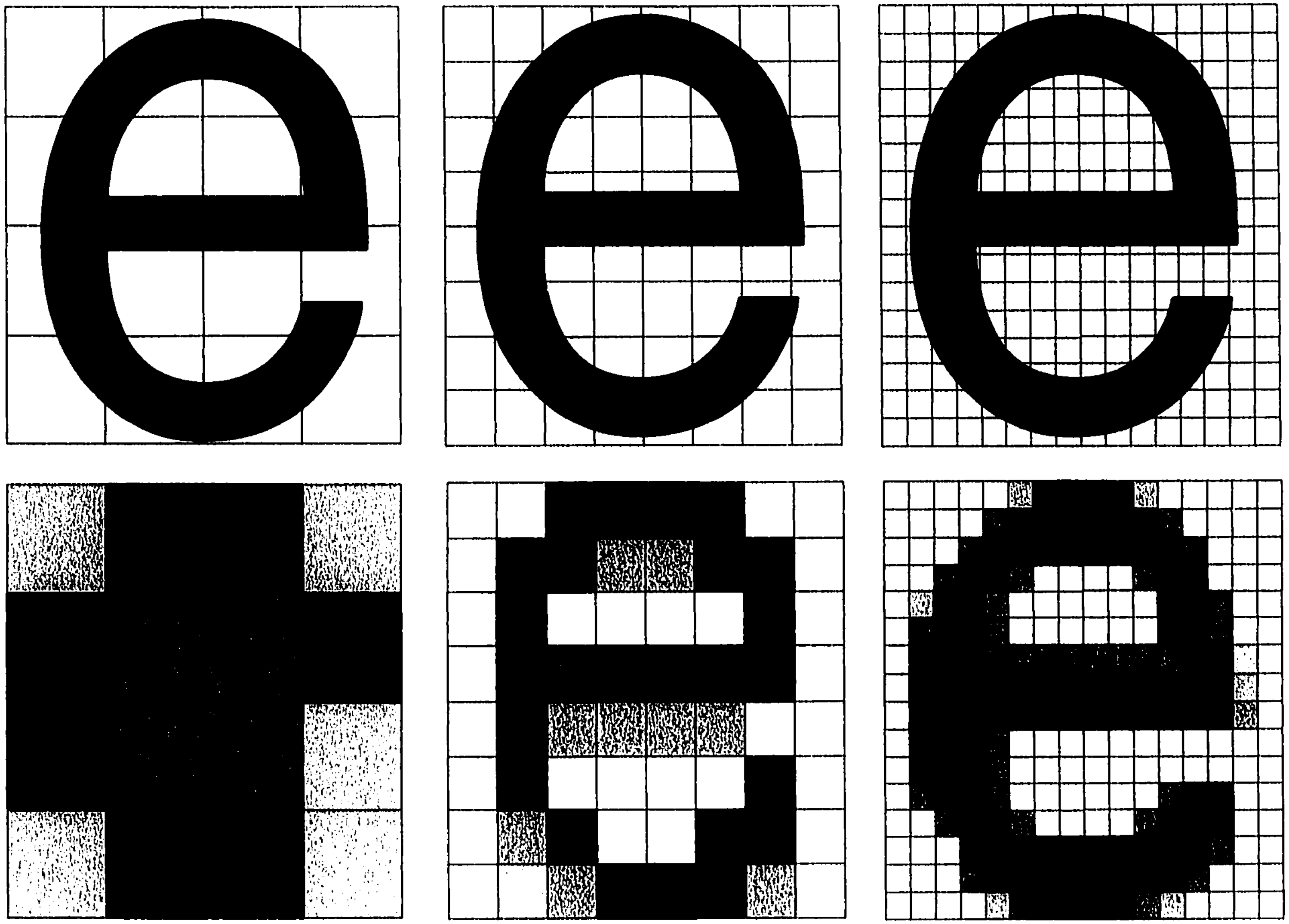


Figure 2.5 Resolution and Image Quality - doubling the resolution increases the legibility of the letter, but the file size is quadrupled.

Doubling the resolution improves the image quality, but requires four times as many pixels. Thus, the third example in Figure 2.5 contains 16 times as many pixels as the first example.

This example is based largely on a simple theoretical model and should be tempered for actual conditions. For example, halftones, used for reproducing images in newspapers and magazines, utilize a pattern of repeating black and white cells to simulate the appearance of grey shades. The spacing of these cells is determined by the screen frequency and the desired level of image quality; the higher the screen frequency, the better the quality. However, the pattern of the screen frequency is rarely matched with the pixel pitch of the scanner, which leads to moiré, an interference pattern in the digital image. Moiré is characterized by a wavy appearance that is an artifact of the digitizing process; scanning at higher resolutions tends to mitigate the problem.

Willis (1992) defines three different qualities of image resolution. "Archival resolution" is the resolution necessary to capture a faithful replica of the original document, regardless of cost. At this point, it appears to be 600 dpi, but could be higher. "Optimal archival resolution" is the highest resolution the technology will economically support at any given time. It attempts to balance system cost and image quality. "Adequate access resolution" is the resolution sufficient to capture 99.9% of the information content of an image, approximately 300 dpi. While this may be acceptable for access requirements, it is unacceptable for preservation requirements.

2.2.3 Grey Scale and Colour Images

While analogue images may have any value over the light intensity range, a digital image can record and store only a limited number of intensity levels for any given spatial location (see Figure 2.6). Generally, the greater the number of grey levels, the better the image quality. The link between grey levels and image quality is dependent upon image type. For instance, most office documents consist solely of dark tones and light tones; storing scanned data with more than just two grey levels - black and white - would not necessarily increase the quality of the image. However, digital replicas of black-and-white photographs, which in fact have a great number of grey shades, require a greater "bit depth" to accurately render the grey-shade information. Quantizing with insufficient bit depth often introduces "contouring" into the digital image, an artifact that often appears in areas of smoothly varying intensity such as shorelines in an air photo. The colour of the water becomes continuously darker as the depth increases; contouring gives the impression of a series of stepped plateaus rather than a continuous change.

The number of grey levels in a digital image is specified in "bits". These are fundamental computer units that, for a digital image, are used to encode the grey shade information. A bit (Binary digIT) can have a value of either 0 or 1. A 1 bit image has only 2 levels of brightness - 0 typically

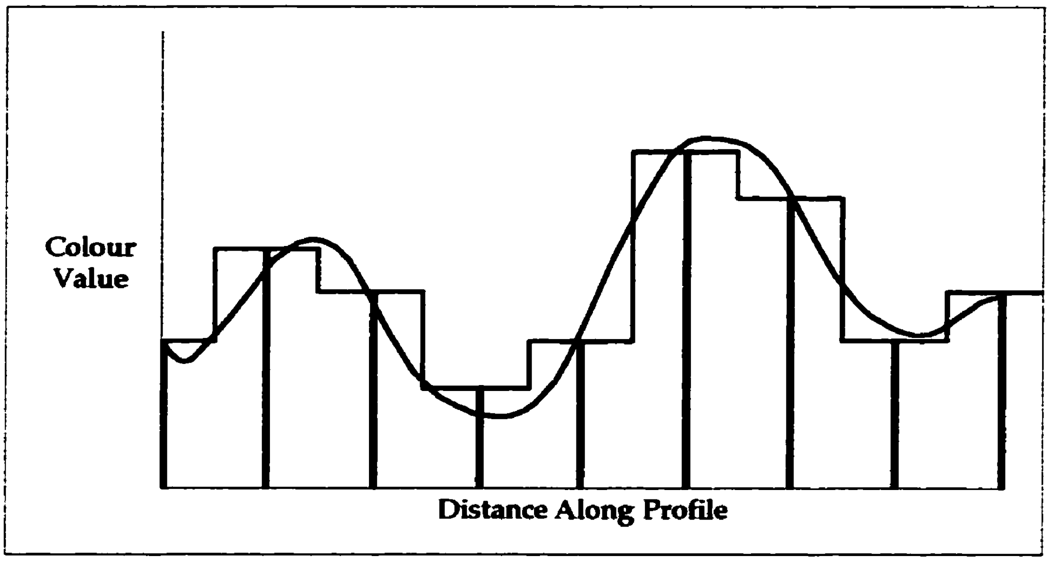


Figure 2.6 3 Bit Sampled Image - while the analogue image could have any colour in the spectrum, sampled images are limited by the number of bits per pixel. Since sampled colours can only vary incrementally, not continuously, the colour reproduction will not be exact. In this case, the continuous tone image is reproduced in 3 bpp, or 8 colours.

represents black and 1 represents white; thus, in a 1 bit image, pixels with a bit value of 0 will be black, and those with a bit value of 1 will be white. By combining groups of bits, more grey shades can be encoded. For instance, a 2 bit image has four possible permutations of 0's and 1's (00, 01, 10, 11), and can therefore save four levels of grey. For n bits per pixel, the maximum number of grey levels is 2^n. For instance, if $n = 8$, there are 256 different combinations of 0's and 1's; that is, $2^8 = 256$. A digitized image containing 8 bits per pixel (bpp) can generally produce high quality reproductions of black and white photographs.

Colour images can also be quantized using 8 bpp, but again, there are only 256 possible colours. In order to capture colour images more satisfactorily, a bit depth of 24 bpp is required; the computer assigns 8 bpp for each of the RGB components. For example, a bright red colour might have an R value of 246, a G value of 30 and a B value of 25. When the values of all three components are equal, the result is a shade of grey. When the values are all 255, the result is white; when all three are 0, black is the result. The various brightness values of red, green and blue light are thus combined to form the colours on the screen. The individual colours in the visible spectrum are produced by varying the intensities of the individual RGB components. In this manner, almost 16.8 million discrete colours are possible, that is 2^{24}, or 256^3.

2.3 Digital Image File Size

Increased scanning resolution and increased bit depth, while raising the level of image quality, also serve to dramatically increase the digital file size. For example, an image scanned at 75 dpi may appear blurry, at 300 dpi it is very legible and at 600 dpi it is almost indistinguishable from a photo. However, every time the scanning resolution is doubled, the digital file size quadruples. For example, in an image scanned at 300 dpi, one square inch contains 90,000 individual pixels. However, in an image scanned at 600 dpi, one square inch contains 360,000 pixels, four times as many as the 300 dpi version. Furthermore, an 8 bit image is eight times larger than a 1 bit image, and a 24 bit image is three times larger than its 8 bit counterpart. Therefore, the file size of an image scanned at 600 dpi with 24 bpp will be 48 times larger than the same image scanned at 150 dpi with 8 bpp.

To determine the actual file size of any given image, this basic formula can be used: BS = BPP(LxRxWxR),

where:
BS = binary storage requirements, in bits,
BPP = the number of bits per pixel,
L = the length of the original, in inches,
W = the width of the original, in inches,
R = the scanning resolution, in dpi
(Willis, 1992).

For example, the storage requirements for a document 4" x 6", scanned at 600 dpi with 24 bpp would be,
BS = 24(6 x 600 x 4 x 600)
= 207,360,000 bits, or
= 25,920,000 bytes (eight bits = 1 byte), or
= 25.92 megabytes (Mbytes)
(1,000,000 bytes = 1 Mbyte).

That same image captured at 150 dpi with 8 bit colour would require 4,320,000 bits, or 0.540 Mbytes, only $^1/_{48}$th the size of the previous example. However, along with the reduction in storage requirements is the concomitant reduction in image quality.

2.4 Data Compression

An enormous amount of information is produced when a document is sampled and quantized to create a digital image. The amount generated could be so great that it results in impractical storage, processing and transmission requirements. Compression addresses the problem of reducing the data required to represent a digital image. The underlying basis of the reduction process is the removal of redundant data. This transformation is applied prior to the storage or transmission of the image. Later, the compressed image is decompressed to reconstruct the original image or an approximation to it.

A clear distinction must be made between "data" and "information". Data are the means by which information is conveyed; various quantities of data may be used to represent the same amount of information. For example,

> a long-winded individual and someone who is short and to the point...relate the same story. Here, the information of interest is the story; words are the data to relate the information. If the two individuals use a different number of words to tell the same basic story, two different versions of the story are created, and at least one includes non-essential data. That is, it contains data (words) that either provide no relevant information or simply restate that which is already known. It is thus said

> to contain *data redundancy* (Gonzalez and Woods, 1992: 309) (original italics).

Data redundancy is the central issue in digital image compression. Three basic data redundancies can be identified and exploited: coding redundancy, interpixel redundancy, and psychovisual redundancy (Gonzalez and Woods, 1992).

2.4.1 Coding Redundancy

If the grey levels of an image are coded in a way that uses more code symbols than absolutely necessary, the resulting image is said to contain coding redundancy. In general, coding redundancy is present when the binary codes assigned to a set of grey level values have not been selected to take full advantage of the probability of a given grey level being present in the image (Gonzalez and Woods, 1992). That is, the basis for coding redundancy is that certain grey levels are more likely to occur within a given image than other grey levels. Typical binary coding of grey levels assigns the same number of bits to both the least and most probable grey level values, thus resulting in coding redundancy. To achieve data compression, fewer bits are assigned to the more probable grey levels than to the less probable grey levels (Gonzalez and Woods, 1992).

2.4.2 Interpixel Redundancy

Because the value of any given pixel can be reasonably predicted from the values of its neighbours, much of the visual data of a single pixel is redundant (Gonzalez and Woods, 1992). In order to reduce the interpixel redundancies in an image, the data must be transformed into a more efficient format. For example, differences between adjacent pixels can be used to represent an image (Murray and vanRyper, 1994). Transformations of this type, those that remove interpixel redundancies, are referred to as "mappings" (Murray and vanRyper, 1994; Gonzalez and Woods, 1992)..

2.4.3 Psychovisual Redundancy

The human eye does not respond with equal sensitivity to all types of visual information; certain information has less relative importance than other information in normal visual processing. For example, the human eye is limited in the number of colours it can distinguish simultaneously, particularly if those colours are not immediately adjacent to one another or are not sharply contrasting (Murray and vanRyper, 1994; Gonzalez and Woods, 1992). This colour information is said to be psychovisually redundant. Some of it can be eliminated without significantly impairing the quality of image perception (Murray and vanRyper, 1994; Gonzalez and Woods, 1992).

Psychovisual redundancies exist because human perception of an image normally does not involve quantitative analysis of every pixel or luminance value in the image. Usually, an observer searches for distinguishing features such as edges or textural regions and mentally combines them into recognizable groups (Gonzalez and Woods, 1992). The brain then correlates these groups with prior knowledge to complete the image interpretation process. The elimination of psychovisually redundant information is possible only because the information itself is not essential for normal human visual processing. Furthermore, the exploitation of psychovisual redundancies results in a loss of quantitative information and is an irreversible process (Murray and vanRyper, 1994; Gonzalez and Woods, 1992).

2.5 Compression Algorithms

Almost every file format incorporates some kind of compression method, no matter how rudimentary. Also, only a few different compression schemes are in common use throughout the computer graphics industry. The most common are Run Length Encoding (RLE), Lempel-Ziv-Welch (LZW), and Discrete Cosine Transform (DCT) (Murray and vanRyper, 1994; Gonzalez and Woods, 1992). Compression algorithms fall into one of two very broad categories: 1) lossless, wherein the information contained within the original digital image is preserved - no data has been lost or discarded, or changed in any way, and; 2) lossy, wherein some information is discarded (Murray and vanRyper, 1994). Some lossy methods contain elaborate heuristic algorithms that are self-adjusting to give the maximum compression while changing as little of the visual information as possible. An advanced algorithm can take advantage of psychovisual redundancies, analyze an image on that basis, and achieve significant data reductions based on the removal of colour information not easily seen by most people (Murray and vanRyper, 1994; Wallace, 1991).

Data can be made more compressible by reducing the amount of extraneous information using a method called "differencing" (Murray and vanRyper, 1994). This is similar to interpixel redundancy; adjacent pixels in many continuous tone images vary only slightly in value. If the value of a given pixel is replaced with the difference between it and its neighbour, the amount of data will be reduced without losing any information (Murray and vanRyper, 1994).

2.5.1 Run Length Encoding (RLE)

RLE works by reducing the physical size of a repeating string of characters. This repeating string, called a "run", is encoded in two bytes, the first of which encodes the number of characters, the second encodes the character value itself (Murray and vanRyper, 1994). For example, uncompressed, a character run of "AAAAAAAAAAAAAAA" would require 15 bytes, one for each "A". However, using RLE, it would require just two bytes, "15A", a significant reduction in size without any loss of information. A group of characters such as "AAAAABBBBBBBCCCDDD", which would require 18 bytes, would be encoded in 8 bytes as "5A7B3C3D". However, RLE is not as effective if the characters do not repeat. For example, a group of characters such as "ABCDABCDABCD", currently encoded in 12 bytes, would actually require 24 bytes in RLE - "1A1B1C1D1A1B1C1D1A1B1C1D". RLE schemes are very simple and fast, and while this scheme is suitable for compressing any type of data, compression efficiency depends on the data content. For example, a black and white image, such as a sheet of text which consists mostly of white background, would encode very well whereas a continuous tone photograph would not.

2.5.2 Lempel-Ziv-Welch (LZW) Compression

One of the most commonly used algorithms, LZW is capable of working on almost any type of data. LZW is referred to as a "dictionary-based" encoding algorithm (Murray and vanRyper, 1994) which builds a dictionary or translation table of data occurring in an uncompressed data stream. Patterns of data, called "substrings", are identified and a code phrase is created based on the content of the substring, which is stored in the dictionary (Murray and vanRyper, 1994). When a recurrence of the substring is identified, the phrase of the previously-stored substring is written into the output. Because the phrase value has a smaller physical size than the substring it represents, data compression is achieved (Murray and vanRyper, 1994).

2.5.3 Joint Photographic Experts Group (JPEG)

The Joint Photographic Experts Group is a standards committee that originated within the International Standards Organization. It was this committee that invented the group of lossy compression algorithms that bear the name JPEG.

Most previously developed compression algorithms are relatively ineffective at compressing continuous tone image data; very few can support 24 bit raster images. For example, LZW compression does not work very well on typical scanned image data because the low-level noise usually found in such data defeats LZW's ability to recognize repeating substrings (Murray and vanRyper, 1994; Wallace, 1991). However, JPEG was designed to compress colour or grey scale continuous tone images; line art and black and white documents do not compress very well under JPEG. It is, however, excellent for storing 24 bpp photographic images.

JPEG is not a single algorithm. Instead, it is a group of lossy compression algorithms that can be adjusted to fit the needs of the user. That is, the end user can tune the quality of a JPEG encoder using a parameter called the "Q" factor (Murray and vanRyper, 1994; Wallace, 1991). The optimal Q factor depends on the image content and is therefore different for every image.

JPEG is not always the ideal compression solution. For instance, images containing large areas of a single colour do not compress very well. In fact, JPEG will often introduce artifacts into such images that are visible against a flat background, making them considerably worse in appearance than if a lossless method was used. Furthermore, JPEG is not supported by many file formats (Murray and vanRyper, 1994; Wallace, 1991). The formats that do support it are all relatively new and can be expected to be revised at frequent intervals. However, all JPEG-aware applications are required to support "Baseline JPEG" (Murray and vanRyper, 1994; Wallace, 1991), a minimum standard set down by the JPEG committee. Baseline JPEG uses Discrete Cosine Transform (DCT) to achieve compression. DCT is effective only for compressing continuous tone images; in fact, the baseline standard specifies that images to be compressed must have at least 24 bpp (Murray and vanRyper, 1994; Wallace, 1991).

The JPEG compression scheme is divided into the following steps:

> <u>Step 1</u>) down-size the colour components by averaging groups of pixels together: the simplest way to exploit the eye's lesser sensitivity to colour information is simply to use fewer pixels to represent the colours in the image (Murray and vanRyper, 1994; Wallace, 1991). For example, in an image sized 1,000 x 1,000 pixels, a full 1,000 x 1,000 pixels could be used to represent luminance while using only 500 x 500 pixels to represent each colour (chrominance) component. In this manner, each chrominance pixel covers the same area as a 2 x 2 block of luminance pixels. This reduction in data volume has almost no effect on the perceived quality of most images.
>
> <u>Step 2</u>) apply a DCT to blocks of pixels, thus removing redundant image data: the image data are subdivided into 8 x 8 blocks of pixels and a DCT is applied to each block. The DCT converts the spatial image representation into a frequency map, separating the high-frequency data, to which human eyes are less sensitive, from the low-frequency data (Murray and vanRyper, 1994; Wallace, 1991). At this point, the high-frequency data are discarded without losing the low-frequency data.
>
> <u>Step 3</u>) quantize each block of DCT coefficients using weighting functions optimized for the human eye: to discard an appropriate amount of information, the compressor divides each DCT output value by a "quantization coefficient" and rounds the result to an integer (Murray and vanRyper, 1994; Wallace, 1991). The larger the quantization coefficient, the more data is lost.

Furthermore, separate quantization coefficients are used for luminance and chrominance data, with the chrominance data being more heavily quantized (Murray and vanRyper, 1994; Wallace, 1991). This allows the compressor to further exploit the eye's differing sensitivity to luminance and chrominance. It is this step that can be controlled by the end user by tuning the Q-factor.

Step 4) encode the resulting coefficients using an algorithm to remove redundancies in the coefficients: the resulting coefficients contain a significant amount of redundant data. Another compression scheme, called "Huffman" compression, is used to losslessly remove the redundancies, resulting in still smaller JPEG data (Murray and vanRyper, 1994; Wallace, 1991).

2.6 Advantages and Disadvantages of the Digital Format

Digital imaging and optical recording technologies have been available for well over a decade. CD-ROMs are now a ubiquitous feature at library reference desks, due in part to widely accepted industry standards assuring that data on disks can be read by machines manufactured by different companies. Given the widely publicized claims about the cost-effectiveness of digital conversion (Cartolano *et al.*, 1995; Cloonan, 1993; CPA, 1992), it is not surprising that interest is growing in libraries and archives to transform information on paper and film to electronic media. However, the use of digital imaging as a preservation medium is a hotly contested issue within the library and archive communities (see Kenney and Conway, 1994; Gartner, 1994; Weber, 1994; Cory and Hessler, 1993; Willis, 1992, and others).

Perhaps the greatest advantage of digital imaging is its remote access capabilities (Gartner, 1994; Cory and Hessler, 1993; Willis, 1992). The number of electronic archives on the Internet is growing everyday; digital imaging has the potential to transform archive facilities into libraries, making previously unobtainable documents more accessible.

Once delivered to a machine, a digital image is much more tractable than its analogue counterpart. For example, a scholar can resize the image, zoom in to magnify a specific point, use false colours and heighten the contrast to highlight faded text or other details. Other enhancement capabilities include the removal of stains, underlining, and bleedthrough (Kenney and Conway, 1994; Gartner, 1994).

Digital imaging technology offers great flexibility in output options. It is possible to separate the medium for preservation from the medium for access and use (Kenney and Conway, 1994). These various output formats need not all be created at the same time. For example, microfilm may be created for archival purposes from the digital images at the time the object is scanned (Kenney, 1993). At another time, a print copy can be made, which is superior in quality to the print copies made from microfilm. This flexibility obviates the need to make final decisions about output format at the time of preservation.

Digital imaging allows duplication of the images without degradation (Kenney and Conway, 1994; Gartner, 1994; Cory and Hessler, 1993; Willis, 1992). Digital images can be reproduced repeatedly with absolute fidelity; light-lens copies suffer 10% to 20% image degradation with each succeeding generation (Skupsky, 1989). Furthermore, digital images do not decay with use.

Despite the apparent advantages digitization offers, there are several concerns that must be addressed; none are insurmountable. The most important disadvantage is the obsolescence of digital imaging hardware and software (Kenney and Conway, 1994; Cory and Hessler, 1993). System requirements used to produce and access digital images will likely change several times during the lifespan of digital media. Therefore, the data will have to be reformatted long before the medium itself degrades. For example, the U.S. National Archives holds the records of the 1960 census, the first to be automated in that country. In 1970, archivists discovered that there were only two computers *in the world* that could read the 1960 census data - one was in the Smithsonian, the other in Japan (Willis, 1992). This underlines the necessity either to provide human-readable back-ups for the digital images by maintaining the original or making a film copy (Kenney and Conway, 1994) or to reformat the data periodically onto a more modern medium (Kenney and Conway, 1994).

Digital imaging is not resolution-indifferent. That is, to obtain a higher quality image, more storage space is required. Digital files of a high enough quality to serve as suitable substitutes for primary materials can be very large. For instance, an $8^1/_2$" x 11" document captured at 600 dpi with 24 bpp uncompressed would require 105 Mbytes. Just six such images would fill a

CD-ROM. In other words, a document $25^{1}/_{2}$" x 22", six times the size of an $8^{1}/_{2}$" x 11", or about half the size of a typical NTS 1:50,000 mapsheet, would fill a CD-ROM if captured at the specifications mentioned. Obviously, to apply digital imaging technology to preserve a large collection could be very expensive. However, a CD-ROM or optical disk is no more valuable than the original map whose image it carries.

Because digital imaging is a new technology, standards for scanning, enhancing, saving, compressing, displaying and printing images are lacking (Willis, 1992). Furthermore, digital media are not yet sufficiently age-resistant. That is, digital technology is simply too new for any definitive testing to have been performed; accelerated aging tests may not provide accurate results (Willis, 1992). According to the preservation literature, the definition of "archival" is the preservation of a document for up to 500 years or more (Conway, 1994; Lynn, 1994; Cory and Hessler, 1993; Willis, 1992; Lesk, 1990; Sparks, 1990; Schwerdt, 1989). This definition works well for information that is non-machine readable, that is, it can be interpreted directly by humans. However, information stored in electronic format must be interpreted by computers or computer peripherals for it to be intelligible. Therefore, two factors influence our ability to gain access to the information: 1) the permanence of the medium, and; 2) the life of the technology needed to interpret the files (Willis, 1992). The fact that the recording medium may last for up to 500 years is irrelevant. For electronic formats, "archival" should be defined as the "ability to recreate an exact copy from the original medium before it degrades or the technology to read it becomes obsolete" (Willis, 1992).

While it is undeniably true that the digital format is not yet suitable as a long-term preservation medium, this is not the key issue.

> Archivists must not judge [digital] technology on its preservation merits, but on the consequences resulting from its ability to make archives accessible even while affording protection from careless or deceitful users. The major issue is not, in other words, long-term storage. Accessibility and security considerations should take precedence (Cory and Hessler, 1993:12).

2.7 Digital Imaging for Preservation and Access: State of the Art

As universities discovered the extent of deteriorating materials in their libraries and archives, the concept of a collaborative program to address preservation concerns gradually developed. One of the first collaborative efforts in the U.S. was undertaken in 1956 by the Council on Library Resources (CLR) (CPA, 1989). In 1961, the CLR helped establish the Barrow Research Laboratory in Richmond, Virginia, to investigate the effects of temperature and humidity on book paper (CPA, 1989). These results were an important step in informing archivists about optimum storage conditions. Furthermore, the Association of Research Libraries (ARL) also established an active program on the topic. In 1962, the ARL commissioned a study on the preservation problem in American libraries. The report, issued in 1966, acknowledged the importance of coordinated efforts in finding a solution (CPA, 1989).

In 1984, following two decades of preservation initiatives, the ARL passed a resolution urging the CLR to establish a national strategy for preservation due to the increasingly national and international implications of the preservation challenges and the need to coordinate activities (CPA, 1989). The CLR proposed that a Committee on Preservation be formed; in 1984, the Committee held its first meeting (CPA, 1989). On July 1, 1988, the Commission on Preservation and Access (CPA) was formed as a separate non-profit corporation (CPA, 1989).

From its beginnings, the CPA has supported many preservation initiatives, both at home and abroad, such as the Brittle Books Program, the International Project, scholarly advisory committees, and the Technology Assessment Advisory Committee (CPA, 1989).

> The ultimate goal is the existence of a collective knowledge base from which institutions and individuals can obtain information in their choice of format to serve their scholarly objectives and programs....For its own work, the Commission seeks...to support a range of research and demonstration projects, consultants, technical advice, and scholarly expertise to help develop a coordinated preservation effort (CPA, 1989).

The following passages will outline several projects, some sponsored by the CPA, which are evaluating the relative merits of digital technology as a preservation medium. The focus will be on the reasons underlying the need for preservation, the search for an appropriate preservation solution, and the evaluation of that solution.

In 1990, the CPA, Xerox Corporation and Cornell University began a collaborative project to investigate the use of digital technology to preserve library materials (Kenney and Personius, 1992; CPA, 1992). The primary emphasis of this joint study was on the capture of brittle books as digital images and the production of printed paper facsimiles (Kenney and Personius, 1992; CPA, 1992). The study was also equally interested in the role of digital technology in providing access to resources.

This study led to a number of conclusions regarding preservation, access and electronic technology. Perhaps the most important was the finding that digital image technology provides an alternative to microfilming for preserving deteriorating documents (Kenney and Personius, 1992; CPA, 1992). The primary benefits are image quality, duplication capabilities, quality of paper output and cost-effectiveness (Kenney and Personius, 1992; CPA, 1992). However, the study also found that while digital scanning technology offers a cost-effective adjunct or alternative to microfilm preservation, the obsolescence associated with rapidly changing technologies causes concern that scanned images may not remain accessible over time (Kenney and Personius, 1992; CPA, 1992). The study concluded that some problems remain to be solved before digital technology can compete with the preservation advantages of microfilm as an archival medium (Kenney and Personius, 1992; CPA, 1992).

The CPA, in its report on Phase II of this joint study, suggested that a study involving special materials, such as oversize materials, graphic material, and colour images is still needed (CPA, 1992). They recommend that a study focusing on the scanning of materials not normally available through inter-library loan, addressing the problem of scanning and storing faithful reproductions of oversized colour images, be undertaken (CPA, 1992). This thesis will, in part, fill this need.

In 1992, the Joint Task Force on Text and Image (JTFTI) issued a report to the CPA, wherein it was stated that present preservation practices are relatively insensitive to the majority of images found in books and fail to capture them with adequate fidelity to be useful. Among the principal conclusions of this report was that the preservation of halftone illustrations in text, increasingly common after 1880, requires further exploration (JTFTI, 1992). The report concludes that high contrast black and white microfilm does not reproduce halftones satisfactorily for scholarly purposes, and available alternatives, such as colour microfilming and digitization, require further study and experimental trials (JTFTI, 1992).

Yale University, also in collaboration with Xerox Corporation and the CPA, will convert 10,000 volumes into digital image format in "Project Open Book" (Conway and Weaver, 1994; Waters, 1991). However, rather than scanning directly from the originals, the researchers of Project Open Book will convert 35 mm microfilm to digital images and thus "explore the promise [sic] that once we have preserved materials on film we can eventually and satisfactorily convert those documents into digital form" (Conway and Weaver, 1994:109). The Project Open Book researchers hope that they will reach the specific conclusion that research libraries will choose to maintain information on microfilm for long-term preservation and in digital format for ease of access (Conway and Weaver, 1994; Waters, 1991).

In her article, Andrews (1994) outlines a project at the University of Wisconsin-Milwaukee to preserve native American maps by digital methods. While Amerindian maps remain understudied, unexplored and undiscovered to most researchers, these maps are among the most precious records of the native peoples of North America (Andrews, 1994). Surviving examples are scattered in a large number of museums, libraries, archives, and private collections. This project is designed to bring these widely scattered resources together, making them readily available for scholars to research, examine and study (Andrews, 1994). Given that the artifacts themselves are scattered over a wide geographical area, the most effective method for obtaining high resolution digital images for the archive was to create a digital scan from a colour slide or transparency of the original item. Scans could not be made directly from the originals, for the artifacts could not leave the facilities in which they are housed, the cost of on-site visits was prohibitive, and many of the artifacts are not suitable for scanning due to the fragile nature of the materials, such as bark, skin, and tusks (Andrews, 1994).

At the Geology Sciences Library, Lamont-Doherty Earth Observatory, Columbia University, a survey of the collection was undertaken in the early 1980s which found hundreds of books produced on acidic paper contained oversized maps stuffed into pockets in the back of the books (Klimley, 1993). Furthermore, 50% of the serials titles also contained oversized maps (Klimley, 1993). Over time, the maps have become brittle and prone to tear when researchers attempt to unfold them. When reformatted to microfilm, the colour maps were filmed in 6" x 4" sections in black and white, rendering them completely unusable (Klimley, 1993). This was due to the lack of an archivally recognized colour preservation medium.

A pilot project sponsored by the CPA and headed by Klimley, demonstrated at the Geological Society of America's meeting in Cincinnati in October, 1992, compared colour Cibachrome microfiche and digital technology as preservation media (Klimley, 1993). This project concluded that Cibachrome microfiche had colour reproduction satisfactory for the needs of preserving geology literature (Klimley, 1993). While the colours on the microfiche underwent a major palette shift, they were still well within the limits needed for colour coding. The digital images on CD-ROM, scanned at 300 dpi, produced high quality page sized grey scale and colour images, but the project researchers were unable to resolve the problems of handling oversized images (Klimley, 1993).

From this pilot project came the Oversized Colour Images Project at Columbia University, sponsored by the CPA (Cartolano, Gertz and Klimley, 1995). The goals of Phase I of this project were to identify acceptable preservation and digital access techniques for dealing with oversized colour images associated with text, and to provide an archival-quality photographic copy, a digital version, and a paper printout of all the images tested (Cartolano, Gertz and Klimley, 1995). Among the questions addressed in this project were:

> How do digital versions made from the film copy compare to digital versions obtained by scanning the original?
>
> What level of resolution is needed to capture at least as much information (and preferably more) as the traditional technologies?
>
> Will users accept the digital version and be able to use it to their own satisfaction? (Cartolano, Gertz & Klimley, 1995).

The project compared the results of scanning five oversize, colour brittle maps to produce both onscreen versions and hardcopy print outs (Cartolano, Gertz and Klimley, 1995). Geologists, geoscientists, other specialists and librarians then offered their reactions to the digital and paper versions.

This project was not seeking to achieve the best possible image quality, but rather the image quality that is good enough to fully serve the needs of researchers in lieu of the original paper maps (Cartolano, Gertz and Klimley, 1995). As such, the concept of "quality" was defined. The definition of "adequate quality" has two parts:

> <u>legibility</u>: all of the print can be read on the screen

> and on the print outs, including the 1mm contour elevations, although the print may be somewhat fuzzy;
> colour accuracy: all colour codes are distinct on the screen and in print outs, even if colours have shifted in comparison to the printed originals (Cartolano, Gertz and Klimley, 1995).

The definition of fully successful quality:

> legibility: all of the print, including the 1mm contour elevations, can be read on the screen and on the print outs with full clarity;
> colour accuracy: all colour codes are distinct on the screen and in print outs, and there is no colour shift in comparison to the printed originals (Cartolano, Gertz and Klimley, 1995).

In this project, the researchers were capturing the images with 24 bpp, and found that 200 dpi produced adequate quality (Cartolano, Gertz and Klimley, 1995). The project found that adequate quality can be achieved by starting either with the paper original, a microfiche version or a transparency (Cartolano, Gertz and Klimley, 1995). The authors concluded that archival quality microfiche should continue to serve as preservation replacements for brittle originals (Cartolano, Gertz and Klimley, 1995). Furthermore, the project researchers were confident that film intermediaries could later be scanned and still capture the full intellectual content of the originals (Cartolano, Gertz and Klimley, 1995).

The user evaluation was carried at several different levels:

> i) at Columbia, where the project team, librarians, computer experts and faculty in the Department of Geological Sciences evaluated both the on-line and printed versions;

> ii) the images were shown off-campus several times and audience reactions were recorded;
>
> iii) demonstrations were given at the Geological Society of America and Geoscience Information Society meetings;
>
> iv) demonstrated at the New York State Library, attended by library and geology specialists;
>
> v) presented to the Reformatting Committee of the Preservation and Reformatting Section of the American Library Association;
>
> vi) a demonstration is planned for the United States Geological Survey;
>
> vii) the images are available on the World Wide Web for interested parties to view and send comments (Cartolano, Gertz and Klimley, 1995).

All of the evaluators were asked to determine which images were acceptable/not acceptable for identification and research purposes. From this, several areas were identified as needing further research work; guidelines must be developed that specifically identify adequate and high quality resolution for various media and for various levels of use, and improving the accuracy of colour capture and display (Cartolano, Gertz and Klimley, 1995).

In Britain, the National Railway Museum's photographic archive contains 750,000 images, mostly negatives, of the U.K.'s railways from 1866 to the present. This constitutes one of the most comprehensive railway photo archives in the world (Booth and Hopkin, 1994). The photos cover a wide range of socio-economic and technical subjects and are of interest to a number of academic disciplines. The negatives are stored in an environmentally controlled facility with no public access (Booth and Hopkin, 1994). Only about 25,000 images, or 3% of the collection, are available to the public as reference prints mounted in ring binders; a rudimentary card index is available as a finding aid, but extensive cross-referencing is lacking (Booth and Hopkin, 1994).

The use of various imaging technologies were investigated as a result of this poor public access. At the outset of the project, it was determined that any system adopted must be able to produce high quality images which could be copied without degradation (Booth and Hopkin, 1994). After a review of existing technologies, high resolution digital imaging was chosen as the most appropriate for several reasons: the capture equipment could be operated by staff without extensive photographic skills; images could be readily transferred to other systems, either digital or analogue, and; the production of high quality prints was possible directly from the digital image (Booth and Hopkin, 1994).

Two projects are currently underway at Oxford University's Bodleian Library (Gartner, 1994). The first aims to create an image databank of 7,000 images from the John Johnson Collection of Printed Ephemera, the second venture will digitize 30,000 images of iconography from medieval manuscripts (Gartner, 1994). Both of these projects will use photographic transparencies as an intermediate step towards digitization. This was done because the Bodleian's archivists felt that film is the only true archival medium for high resolution images, citing the fact that it is non-machine readable and has a potential life expectancy of several hundred years, if stored properly (Gartner, 1994).

The digital images will be stored in two forms: a "deep" store for uncompressed files, and a "shallow" store for their compressed counterparts. The deep store will act as the long-term digital archive: a central file server capable of expanding up to 10,000 terabytes (10,000,000,000,000,000 bytes) will be installed (Gartner, 1994). The shallow store will form the day-to-day interface, holding both the main compressed image and a smaller thumbnail for browsing (Gartner, 1994). The digital files will be available for use both throughout the campus and on the Internet (Gartner, 1994).

Other projects using digital media for preservation and access include the Seville Project in Spain, where 45 million documents and 7,000 maps and blueprints, housed at the Archivo General de Indias, which record Spain's 400 years of influence in the Americas, are being digitized; the texts are being scanned directly while all colour materials are being captured on colour microfilm, then converted to digital (JTFTI, 1992). The Royal Library of Copenhagen is evaluating three filming techniques as well as high resolution digitization for setting up a national picture database from its collections (JTFTI, 1992).

There are a number of other substantial projects being carried out worldwide (see Conway, 1994, for a list of projects underway in the U.S.), and it is significant to note that opinion has by no means solidified on what approach to take. It appears that a hybrid systems approach, one that combines both film and digital imaging, could well offer the best overall design for current preservation needs. Microfilm provides a relatively inexpensive, high-quality archival storage medium while digital imaging contributes access, distribution and transmission strengths. A hybrid system could be implemented with today's technology either by filming first and then scanning the film, or by scanning then producing film copies. With a "scan-first" preservation system, each page to be preserved can be reduced to separate areas of text, line art, and halftone images. Each of these areas can then be electronically enhanced to maximize overall page quality; microfilm can then be produced from the digital image (Willis, 1992). By scanning and enhancing the digital data prior to filming, it will be possible to create higher quality film than can currently be created using light-lens techniques.

Chapter 3.

Methodology

The ultimate goal of this research is to devise a simple methodology for digitizing maps and images using equipment and software found in a typical university map library. In order to accomplish this, it must be determined which combination of digital attributes (scanning resolution, bit depth, and compression algorithm) produces the best compromise between image quality and file size. The research design consists of six steps, each of which will be discussed separately.

3.1 Step 1: Definition of Map Types

In most cases, maps are defined by their intellectual content, such as "road maps", which contain information about transportation networks, or "topographic maps", which depict the shape and elevation of the terrain. Other map types include planimetric base maps, cadastral surveys, bathymetric maps, flood control maps, choropleth maps, proportional area symbol maps, and cartograms (Campbell, 1991). While this list is by no means exhaustive, it illustrates the fact that maps are usually defined by the information contained within them. This thesis is not concerned with the intellectual content of maps, *per se*, but rather with certain physical attributes, such as the number of colours in the map, the size of the text, and the fineness of details. As a result, a new system of classifying map types is required.

In their article, Kenney and Chapman (1995) identify and define four document categories:

> Text/Line Art: can be produced by hand, typescript or machine. Usually in black and white. Includes books, manuscripts, newspapers, reports, typed or laser printed documents, blueprints, maps, line drawings, etchings, lithographs, and music scores.
>
> Halftone: Colour or black and white. Reproductions, usually created from a photograph, comprised of small dots or squares or hatchings, which are used to represent continuous tones. Most 'photographs' in publications are halftones.
>
> Continuous Tone: Colour or black and white. Includes graphics in which all values of grey and colour can be reproduced: photographs, crayon, chalk and some pencil drawings, acrylics, watercolours, and photographically reproduced facsimiles.
>
> Mixed: Colour or black and white. Refers to items containing both text and halftone or continuous tone images, such as newspapers, magazines, illustrated books, playbills, and sheet music covers. Does not include text and line drawings together (Kenney and Chapman, 1995:2).

While these definitions deal with both text and images, they are used in this thesis as the basis for a new classification system designed strictly for maps and images. The categories in this new system are differentiated by the following criteria: the number of different line widths present in the image; the number of different text sizes present; the presence or lack of colour, and; in the case of coloured maps and images, by the number of colours present in the map. The new classification system is as follows:

1) Monochrome Line Maps: the least complex category. Normally black and white, these maps and images possess few differences in line widths

and text size. This category can include line maps, base maps, outline maps, cadastral surveys and line route maps, among others.

2) Monochrome Continuous Tone: grey scale images. Includes black and white aerial photographs and other remotely sensed images, hand drawn black and white maps, and other images in which all values of grey can be reproduced.

3) Simple Polychrome: includes images which contain a background colour and the image outline, and normally one to three other colours. Included are flood risk maps and simple thematic maps, and other similar images.

4) Intermediate Polychrome: consists of maps and images which contain four to ten (can be more in certain cases) discrete colours. These maps are characterized by large areas of the same colour and a flat texture. Included in this category are modern topographic maps, nautical charts and more complex thematic maps.

5) Complex Polychrome: reserved for full colour, continuous tone images, such as old hand-painted maps, colour air photographs and satellite images, wherein there is a vast number of possible combinations of colours and textures. They may also contain myriad tiny details that may be difficult to discern, but that are essential to the integrity of the image. These maps and images present the toughest challenges to the digital preservationist, who must find a compromise that optimizes both file size and image quality.

The purpose of this classification scheme is to assist the digital preservationist in finding the proper combination of bit depth and scanning resolution when digitizing these images. That is, the maps of each class possess certain physical attributes which are different than those of the other classes. These attributes affect the decisions to be made concerning the digitization of the map or image. For example, as stated in the previous chapter, Section 2.3, a document 4" x 6", scanned at 600 dpi with 24 bpp would require 25.92 Mbytes of disk storage space. This combination of bit depth and scanning resolution may be required to adequately capture all the information in a Complex Polychrome image. However, this combination of bit depth and resolution is likely to be unnecessary if the preservationist is digitizing an image from one of the other classes. For example, using 24 bpp to digitize a Monochrome Line Map would result in a huge waste of disk storage space, for the map could be digitized adequately using a much smaller bit depth. If a bit depth of 1 bpp was used instead, then the resulting binary image would require $^1/_{24}$th the amount of disk storage space of its 24 bpp counterpart.

3.2 Step 2: Selection of Maps

The maps used in this project were selected from the collection in the Serge A. Sauer Map Library in the Department of Geography at The University of Western Ontario. The researcher selected maps which are representative of the categories in the new classification scheme. That is, maps and air photos were selected which are typical examples of the items one would expect to find in each of the five categories. On the following page is a list of the bibliographic citations for the maps, arranged by category (also, see Appendices 1 through 17).

Monochrome Line Maps

Image 1: "The Great Lakes", Cartographic Section, Dept. of Geography, UWO.

Monochrome Continuous Tone

Image 2: "Population Change by Census Divisions 1966-71", 1971 Census of Canada.
Image 3: "Flood Risk Map, Champlain, Fleuve St-Laurent", sheet no. 31/08-020-1506-0, Environment Canada.
Image 4: "Flood Risk Map", sheet no. 20 17 4900 51600, Nickel District, Environment Canada, Inland Waters Directorate, Ministry of Natural Resources.
Image 5: "Lac Superieur et autre lieux...", Fathers Claude Allouez and Claude Dablon, originally published in the Jesuit Relations, 1670-71, reproduction available in the Map Library, Dept. of Geog., UWO.

Simple Polychrome

Image 6: "Flood Risk Map", sheet no. 20 17 4900 51600, Nickel District, Environment Canada, Inland Waters Directorate, Ministry of Natural Resources.
Image 7: "Rideau Waterway Small Craft Chart, no. 1513 Smith Falls to Kingston, sheet 5", Canadian Hydrographic Service.
Image 8: "Net Internal Migration for Population 5 Years and Over, by Census Division, 1976", 1976 Census of Canada.

Intermediate Polychrome

Image 9: "Map no. 25e, South Part of Frontenac County, Eastern Ontario, to accompany report by M.B. Baker, in Part III, Volume 25, Report of the Ontario Bureau of Mines, 1916".
Image 10: National Topographic Series, 1:50,000, Bath, sheet no. 31 $^{C}/_{2}$, edition 5, 1979.
Image 11: National Topographic Series, 1:50,000, Bath, sheet no. 31 $^{C}/_{2}$, edition 7, 1991.

Image 12: National Topographic Series, 1:50,000, Lake Louise, sheet no. 82 N/8 West, edition 5, 1972.

Complex Polychrome

Image 13: Air photo, Lambton County, 1973, no. RSA 30719-127
Image 14: Air photo, Lambton County, 1973, no. RSA 30720-6

Image 15: World Map of Vesconte Maggiolo from his portolan atlas 1511, reproduced by Rand McNally, no date.
Images 16 & 17: "The Pacific Ocean in 1589", reproduced from an engraving in the collection of Historic Urban Plans, Ithaca, New York (two separate sections of this map were used).

3.3 Step 3: Digitization

After completing the selection process, sections of the maps were scanned using the equipment in the Air Photo room of the Serge A. Sauer Map Library. Because so many maps were selected, and disk space was limited, only small sections of each map were scanned. Each section was captured at 400 dpi, 300 dpi, 150 dpi and 75 dpi; the same map section was used for all four different scanning resolutions. The digital images were stored on a one gigabyte external hard drive in PICT format, PICT being the resource name for the images. PICT format supports colour images at varying resolutions. PICT files are widely supported in the Macintosh environment and thus can be easily transported from one software application to another. Furthermore, the PICT format supports raster graphics, vector graphics and text.

Below is a list of the hardware and software used:

Power Macintosh 7100/80 with 24 Mbytes of RAM
Power Macintosh 7100/66 with 16 Mbytes of RAM

17 inch Apple Multiscan monitor
15 inch Apple Multiscan monitor
Hewlett Packard ScanJet IIcx
Seagate 1 gigabyte external hard drive
Colour Stylewriter 2400 colour printer, 360 dpi
Adobe Photoshop 3.0
JPEGView 3.3.1, © Aaron Giles (postcard-ware)
GraphicConvertor 1.7.6, © Thorsten Lemke (shareware)

3.4 Step 4: File Formats

The digital images produced by Step 3 were converted to various file formats to determine whether or not the format impacts legibility, colour reproduction or file size. Step Four consists of several different procedures, each of which are discussed separately.

3.4.1 Step 4a) Convert to TIFF Format

Copies of every digital image were converted from PICT format to TIFF (Tagged Image File Format), a public standard for storing raster images. TIFF files are used in both the Macintosh and DOS/Windows environments and are ubiquitous enough to represent a *de facto* industry standard (Guy, 1990).

3.4.2 Step 4b) Compression

Copies of all the digital images in PICT format were subjected to Adobe Photoshop's version of JPEG compression. This program allows the end user to tune the Q factor to four different compression settings: JPEG Maximum, JPEG High, JPEG Medium, and JPEG Low. The terms "maximum", "high", "medium", and "low" directly refer to the quality of the compressed image and not to the compression ratio. That is, a negative relationship exists between the image quality and the amount of compression applied; as a rule, images subjected to lower compression ratios tend to be of higher quality than images subjected to higher compression. Furthermore, copies of the images in TIFF format were subjected to LZW compression, which has no similar "quality tuning" capabilities.

3.4.3 Step 4c) Indexing

As mentioned earlier, all of the images were captured at 24 bpp; this bit depth can reproduce over 16.7 million discrete colours. In a 24 bpp image, each of the three colour channels (RGB) are assigned 8 bits. In Step 4c), the 24 bpp images were reduced to 8 bpp - this is known as "indexing". This bit depth is capable of reproducing only 256 colours, but the digital image file size is reduced to one-third of its 24 bpp counterpart. By using the "adaptive palette" feature of Adobe Photoshop, the end user can mitigate the image degradation that may occur when an image is indexed. In basic terms, when indexing to 8 bpp, the software "looks" at the image and compiles a colour table made up of the 256 most dominant colours in the RGB image. Furthermore, Photoshop uses a technique called "dithering" wherein the colours of adjacent pixels of different colours are adjusted to give the illusion of a third colour (Adobe Systems, Inc., 1994). If a particular RGB colour is not present in the 8 bit colour table, the software matches the colour to the closest colour in the table or simulates the colour using the available colours.

3.5 Step 5: Subjective Analysis of Images

There are several approaches which allow the measurement and/or comparison of digitized images. The first of these determines the average colour distortion, positional distortion and signal-to-noise ratio of a compressed image (Gonzalez and Woods, 1992). Using root mean square error, this method mathematically defines the amount of distortion between an original digital image and its compressed counterpart. A second method, diagnostic accuracy, has been used mainly with compressed medical images (Cosman *et al.*, 1994). In the third method, Subjective Fidelity Ratings, a set of images is presented to a group of typical end users who rate them, usually on a numeric scale. Subsequent analysis of the ratings can highlight averages, variability and other trends. While such formalized subjective testing is common in speech and audio compression systems, and some effort has been made to develop a rating system for entertainment video, there is currently no standardized rating system for still images (Cosman *et al.*, 1994).

A useful attribute of an objective quality measure such as signal to noise ratio is its ability to anticipate subjective quality. However, most digital images ultimately are viewed by humans. Therefore, while objective fidelity criteria offer a simple and convenient mechanism for evaluating information loss, measuring image quality by the subjective evaluations of a human observer often is more appropriate; several different methods of subjective analysis are used in this research.

Step 5 offers an interesting parallel to the project undertaken at Columbia University, reported by Cartolano *et al.* in their article entitled

"Oversized Colour Images: Addressing Issues of Preservation and Access" (1995). In that particular study, digital images of five geological maps were presented to several groups of "expert" end users, including: map librarians, researchers in the geological sciences, computer experts, members of the Geological Society of America, and members of the Reformatting Committee of the Preservation and Reformatting Section of the American Library Association (Cartolano *et al.*, 1995). Reactions to the images were recorded and several important conclusions and recommendations were made (see Section 2.7 of this thesis).

By contrast, in this research study, a group of non-experts was presented with a series of digital images and asked to answer specific questions about each image. The students enrolled in Geography 142a, The History of Cartography, taught by Dr. P.J. Stooke in the fall semester, 1995, in the Department of Geography at The University of Western Ontario, were selected to perform this task. It should be emphasized that the questionnaire was designed to provide information for a proposed change to the lab projects in Geography 142a; the data were made available for this thesis as well. The researcher felt that this class provided a sufficiently wide-ranging sample of the "non-expert" population at large; these students were assumed to have had an average amount of experience dealing with high quality digital images and maps. Furthermore, the likely viewers of the digitized images of maps considered in this thesis would be a mixture of experienced and inexperienced users.

In general, surveys and questionnaires are used to obtain information that is unavailable from other sources or that would be more difficult and expensive to obtain otherwise. A survey/questionnaire may be conducted for one or more of three reasons:

> 1) [Sponsors] may want to influence or persuade some audience.
> 2) [Sponsors] may want to create or modify some product or service for a particular public.
> 3) [Sponsors] may focus directly on understanding or predicting human behaviour or conditions because this is the focus of their academic or professional work (Alreck and Settle, 1985: 3).

The questionnaire used in this research study was designed to fulfil both the second and third of these reasons. That is, the questionnaire was designed to discover the needs, wants and desires of a particular segment of the population regarding the use of digital images. There are many options and alternatives concerning the possible combinations of digital attributes that can be provided in a digital image; this questionnaire was designed to furnish practical information oriented toward making such decisions.

Images with various combinations of resolution and bit depth were presented to the students. Several of the images had also been subjected to JPEG compression. The questionnaire was designed to test the legibility of text and the colour reproduction capabilities of the different combinations (see Appendix 18). To test the legibility of text, the students were asked to identify specific words on the images. The image resolution varied from 75 dpi to 300 dpi, and the text was of various sizes, from 1mm-high contour labels to large, bold-faced text indicating latitude and longitude coordinates.

To test the colour reproduction capabilities, two separate methods were used. First, questions were designed to elicit answers indicating the respondent's "position" along a continuous spectrum. That is, respondents were asked to rate the images using a scale from 1 to 5. The response scale was merely a representation of the categories (such as "good", "fair", and "poor") along which the respondents arranged themselves. The scales were coded with numbers; numeric codes that represent answers to questions are more easily manipulated than words, and the positions of individuals can be readily compared. The "Comparative Scale" was used for these questions (Alreck and Settle, 1985: 144). With this type of scale, one image was used as the benchmark or standard by which others were judged. Two important advantages to the use of this scale are: 1) no absolute standard is required, and all evaluations are made on a comparative basis - ratings are all relative to the benchmark, and; 2) its flexibility - the same two images can be compared on several different dimensions or criteria, and several different images can be compared with the benchmark. The comparative scale is a very powerful tool, for it presents an easy, simple task to the respondent, insuring cooperation and accuracy and it permits several images that have been compared to the same benchmark to be compared to one another.

Second, colour reproduction capabilities were tested by asking the students to identify the colours in a given image. The legend and several small sections of a colourful geological map were scanned separately and presented on the same display screen. The colours in the legend were labelled alphabetically, and the students were required to list the letters of the colours in the legend that corresponded with the colours present in the display images. Furthermore, each of the display images possessed different digital attributes. That is, different combinations of scanning resolution, bit depth and compression were used in each image.

The questionnaire images were loaded into a Power Macintosh 7100/80, located in the Serge A. Sauer Map Library and viewed with JPEGView, which supports the following image file formats: JPEG, TIFF, PICT, GIF (Compuserve Graphics Image Format), as well as 24 bpp RGB images and 8 bpp indexed images. The questionnaire was presented to the students in late September, 1995. The questionnaire was designed to take 20 to 40 minutes to complete, but because of a lack of sufficient access to the computer due to the Map Library's hours of operation, the students were allotted six weeks to complete it and submit it to the professor. All 56 students submitted completed questionnaires. Several students were unfamiliar with the computer hardware and/or software; these students were given assistance in starting the computer and loading the image files into the software, but were given no help in completing the questionnaire.

Once the completed questionnaires were submitted, the results were compiled on a question-by-question basis and averages were calculated; as a result, several surprising trends appeared, which are discussed in detail in Chapter Five.

3.6 Step 6: Calculation of File Sizes and Compression Ratios

As stated earlier, in Steps 1 through 5, the 17 paper maps were digitized at four different scanning resolutions - 400 dpi, 300 dpi, 150 dpi, and 75 dpi - with 24 bpp bit depth, thus creating 68 individual digital images. After the images for the questionnaire were prepared and loaded into the computer., the 68 images were cropped to 2" x 2" (*i.e.*, in the case of the 400 dpi versions, 800 pixels x 800 pixels), and copies were made; some of the copies were converted to different file formats, others were compressed and others were indexed. In all, over 700 individual images were created, all originating with the first 68 files. In Step 6, tables which document the file size of each different combination of digital attributes for each individual image were made (see Tables 1 through 4, Chapter 4). Also, the ratios of the sizes of the original scanned images to both the compressed and indexed versions were calculated and documented (see Tables 5 through 8, Chapter 4). This was done to assist the researcher reach specific conclusions regarding the compromise between file size and perceived image quality, as described in Step 5.

Chapter 4.

The Data

4.1 Results of the Questionnaire

The questionnaire was designed to furnish practical information oriented toward making decisions about the combinations of digital attributes for each of the five image types, defined in Section 3.1. In this section, the questions and the concomitant images are presented, along with the results obtained from the students (see Appendix 18 for the complete questionnaire). It must be noted here that there may be some subtle differences between what the respondents saw on the computer screen and what is printed in this thesis. That is, a 24 bpp colour monitor was used for the questionnaire, but the printer used for the images in this thesis was only capable of reproducing 65,536 colours.

In some instances, the questions had definite, correct answers. For example, students were asked, "What is the word indicated at Point A?". In other cases, the answers were qualitative in nature. That is, the students were asked questions such as, "Assume that Figure i) is a good representation of the original. Rate the colour reproduction of the other figures". In this section, for those questions that have correct answers, the most common errors for each question/image combination are also presented; the researcher can gain as much information from the errors as from the correct responses. Furthermore, the students were told in the introduction to the questionnaire that "it is just as useful to say 'can't read it' as to give a 'correct' answer...."

In the subsequent subsections, the questions are presented along with a synopsis of the answers given. Where appropriate, the correct answer, in parentheses, is also given. Furthermore, following each question/answer, the digital attributes of the image are presented. The questionnaire images were enlarged as it was felt that typical users of images such as these would likely magnify them. The enlargement factors were selected to maintain a common pixel size on the displayed image. That is, an image of any given dimensions scanned at 150 dpi will be twice the size onscreen as an image of the same dimensions scanned at only 75 dpi. The display resolution for the images remains constant, therefore to keep the physical dimensions of the images equal, the enlargement factors had to be adjusted accordingly.

In the survey, questions testing legibility were interspersed with questions testing colour reproduction; in the following subsections, legibility and colour reproduction are dealt with separately, therefore the questions are not described in the same order in which they appeared in the questionnaires.

4.1.1 Test of Legibility.

Image 1.

1) The elevation indicated at "A" is: (6500 feet).
2) The name inside the box at "B" is : (Wapta Mountain).
Attributes: 24 bpp RGB, 75 dpi, 400% enlargement.

Most Common Errors:

1) 1,000 (3 times); 500 (2); 9 other incorrect answers.
2) Wafta (7); Wapia (5); Wamia Mountain (4); Wama, Wafia, Wamta, Maria (2 each).

Image 1.	Number Correct	Number Incorrect	Number Cannot Read	Number Spoiled
Question 1.	0	20 (35.71%)	33 (58.93%)	3 (5.36%)
Question 2.	25 (44.64%)	28 (50.0%)	2 (3.57%)	1 (1.79%)

Image 2.

3) The latitude and longitude at "A" are: (51° 30' N x 116° 30 ' W).
4) The name at "B" is: (Whiskey Jack).
5) The elevation at "C" is: (5,000 feet).
Attributes: 24 bpp RGB, 150 dpi, 200% enlargement.

Image 2.	Number Correct	Number Incorrect	Number Cannot Read	Number Spoiled
Question 3.	54 (96.43%)	1 (1.79%)	0	1 (1.79%)
Question 4.	54 (96.43%)	1 (1.79%)	0	1 (1.79%)
Question 5.	54 (96.43%)	1 (1.79%)	0	1 (1.79%)

Figure 4.1 Image 1.

Figure 4.2 Image 2.

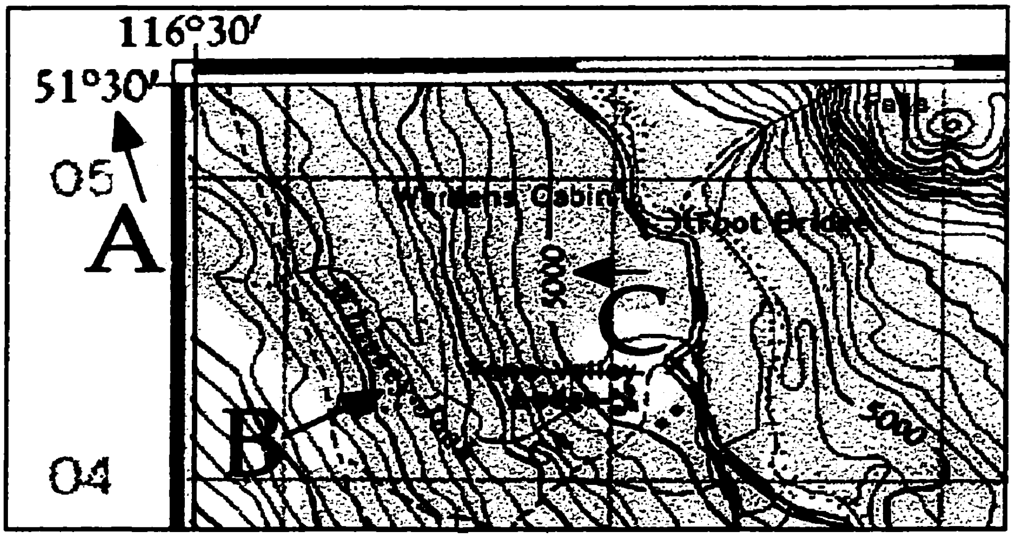


Image 3.

6) The contour interval is 100 feet. The elevation at "A" is: (8,500 feet).
7) The feature at "B" is: (fire lookout tower).
Attributes: 24 bpp RGB, 300 dpi, 200% enlargement.

Most Common Errors:

6) 7,900 (9); 5,500 (3); 4,500, 8,700, 2,200 (2 each).
7) 8,500 (7); 7,900 (6); Power Station (2).

Image 3.	Number Correct	Number Incorrect	Number Cannot Read	Number Spoiled
Question 6.	35 (62.50%)	20 (35.71%)	0	1 (1.79%)
Question 7.	36 (64.29%)	19 (33.93%)	0	1 (1.79%)

Image 5.

In Figure i), "A" is a church and "B" is a school.
9) In Figure ii), is "C" a church or a school? (school).
10) How many churches and how many schools are there in Figure iii)? (3 churches, 2 schools).
11) How many churches and how many schools are there in Figure iv)? (2 churches, 1 school).

Attributes: Figure i) 24 bpp RGB, 400 dpi, 400% enlargement.
Figure ii) 24 bpp RGB, 75 dpi, 200% enlargement.
Figure iii) 24 bpp RGB, 150 dpi, 200% enlargement.
Figure iv) 24 bpp RGB, 300 dpi, 200% enlargement.

Image 5.	Number Correct	Number Incorrect	Number Cannot Read	Number Spoiled
Question 9.	55 (98.21%)	0	1 (1.79%)	0
Question 10.	44 (78.57%)	11 (19.64%)	1 (1.79%)	0
Question 11.	49 (87.5%)	7 (12.5%)	0	0

Figure 4.3 Image 3.

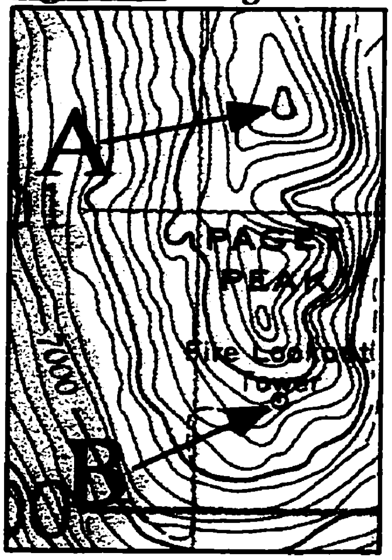


Figure 4.4 Image 5.

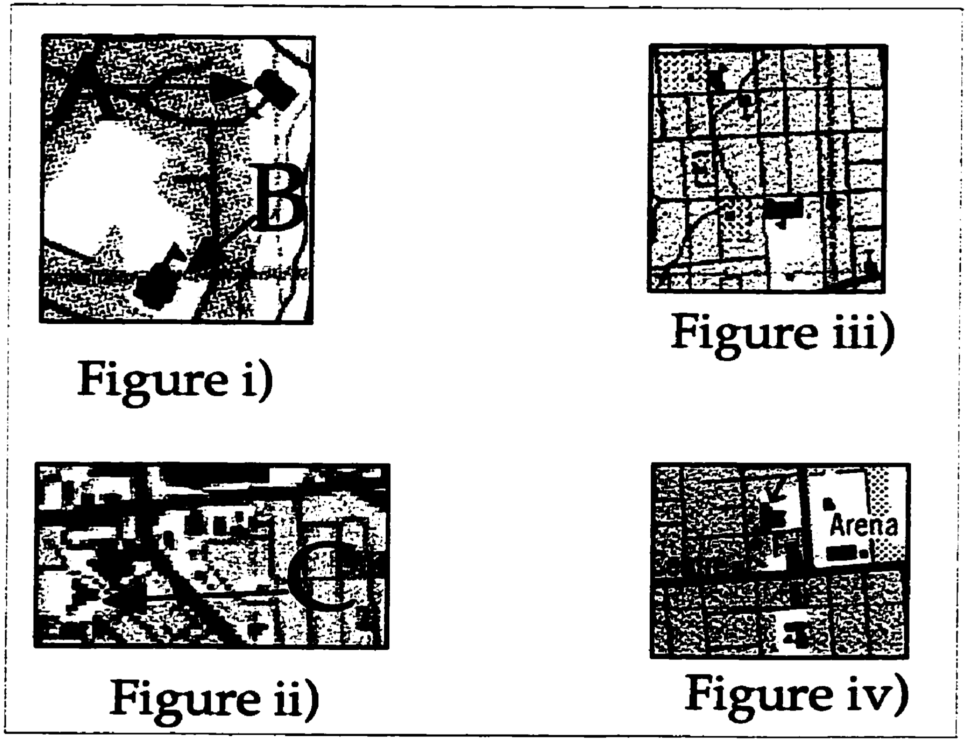


Figure i)

Figure iii)

Figure ii)

Figure iv)

<u>Image 6a.</u>

Give the placenames indicated at "A", "B", and "C".
12a) A (Gallecia).
12b) B (Mondego).
12c) C (Granada).
Attributes: 24 bpp RGB, 75 dpi, 400% enlargement.

Most Common Errors:

12a) Gallecur (3); 15 others.
12b) 22 different answers.
12c) 15 different answers.

<u>Image 6b.</u>

Give the placenames indicated at "A" and "B".
13a) A (Jenoa).
13b) B (Naplia).
Attributes: 24 bpp RGB, 150 dpi, 200% enlargement.

Most Common Errors:

13a) Feno (1).
13b) Noirin (3); Nofia (3); Noria (3); Naifia (2); Noefia (2); Norfia (2); Naufia (2); sp_fia (2); 15 others.

<u>Image 6c.</u>

Give the placenames indicated at "A" and "B".
14a) A (Cales).
14b) B (Noemadia).
Attributes: 24 bpp RGB, 300 dpi, 200% enlargement.

Most Common Errors:

14a) Caler (2); Calese (1).
14b) Noëmadu (12); Normadu (4); NozmandN (2); Moemadu (2); 4 others.

	Number Correct	Number Incorrect	Number Cannot Read	Number Spoiled
Image 6a.				
Question 12a.	17 (30.36%)	18 (32.14%)	20 (35.71%)	1 (1.79%)
Question 12b.	0	25 (44.64%)	31 (55.36%)	0
Question 12c.	22 (39.29%)	14 (25.0%)	20 (35.71%)	0
Image 6b.				
Question 13a.	50 (89.29%)	6 (10.71%)	0	0
Question 13b.	2 (3.57%)	33 (58.93%)	21 (37.5%)	0
Image 6c.				
Question 14a.	50 (89.29%)	4 (7.14%)	2 (3.57%)	0
Question 14b.	41 (73.21%)	15 (26.78%)	0	0

Figure 4.5 Image 6a.

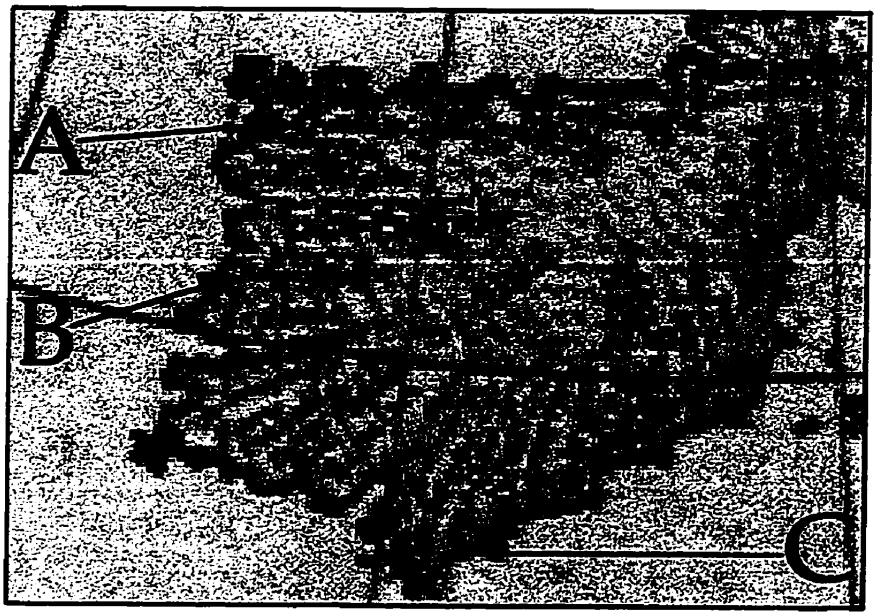


Image 6b.

Image 6c.

4.1.2 Test of Colour Reproduction

Image 4.

Using the large letters indicated beside the legend boxes, identify all the colours in the small maps (figures i, ii, and iii). Be warned, though - not all of the colours in the legend will be in every map and not all colours in a map will necessarily be in the legend. If you find a colour in a map which does not appear to be in the legend, simply write a name for the colour (e.g. blue, pink) at the end of the answer.

8i) Figure i) contains: (CDEG).
8ii) Figure ii) contains: (CDEGH).
8iii) Figure iii) contains: (DEGH).
Attributes: Legend - 24 bpp RGB, 150 dpi, no enlargement.
Figure i) 24 bpp, JPEG Low, 150 dpi, no enlargement.
Figure ii) 24 bpp, JPEG Max, 150 dpi, no enlargement.
Figure iii) 8 bpp indexed, 150 dpi, no enlargement.

	A	B	C	D	E	F	G	H
Figure i	27	3	**53**	**43**	**49**	6	**53**	0
Figure ii	16	1	**52**	**49**	**45**	13	**54**	**53**
Figure iii	29	1	0	**43**	**52**	1	**52**	**52**

Other colours listed in the answers:
Figure i) beige (4), cream, red, black, yellow.
Figure ii) beige (4), red (4), cream, black, yellow.
Figure iii) beige (3), cream, red, black.

Figure 4.6 Image 4.

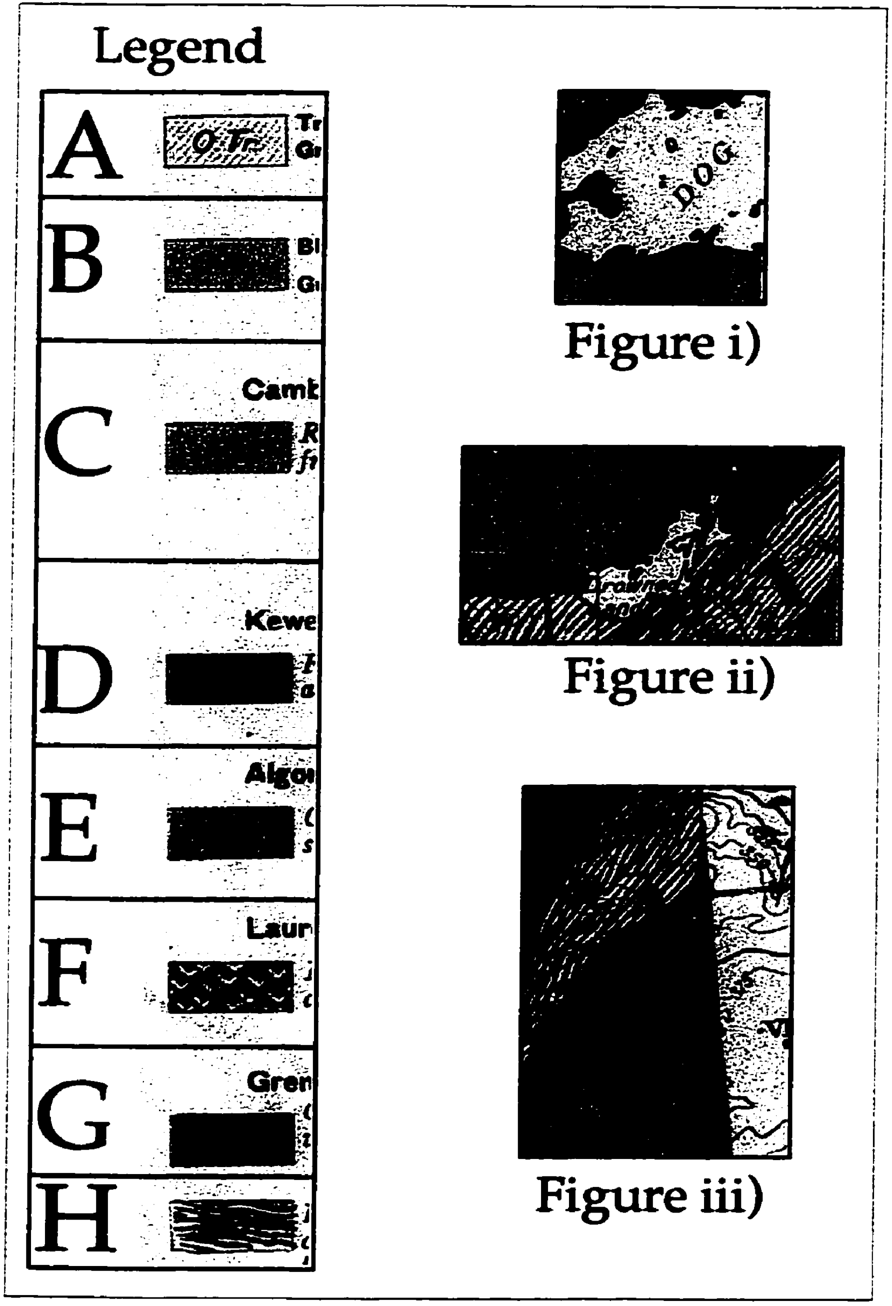


Figure i)

Figure ii)

Figure iii)

Image 7.

This is part of a colour air photo showing land and water. Assume that Figure i is a good representation of the original.

A) rate the colour reproduction of the other figures.
B) rate the sharpness of fine details in the other figures.
Attributes: Figure i) 24 bpp RGB, 150 dpi, 400% enlargement.
Figure ii) 8 bpp indexed, 150 dpi, 400% enlargement.
Figure iii) 24 bpp RGB, JPEG Low, 150 dpi, 400% enlargement.
Figure iv) 24 bpp RGB, JPEG High, 150 dpi, 400% enlargement.
Figure v) 24 bpp RGB, JPEG Max, 150 dpi, 400% enlargement.

	Rank	1 Good	2	3 Medium	4	5 Poor
A						
Figure ii	4	5	7	14	16	11
Figure iii	3	5	9	18	16	5
Figure iv	2	9	35	8	2	1
Figure v	1	24	21	7	0	1
B						
Figure ii	1	31	12	4	5	3
Figure iii	4	1	4	12	17	21
Figure iv	3	5	19	24	6	0
Figure v	2	14	26	12	1	1

Figure 4.7
Image 7.

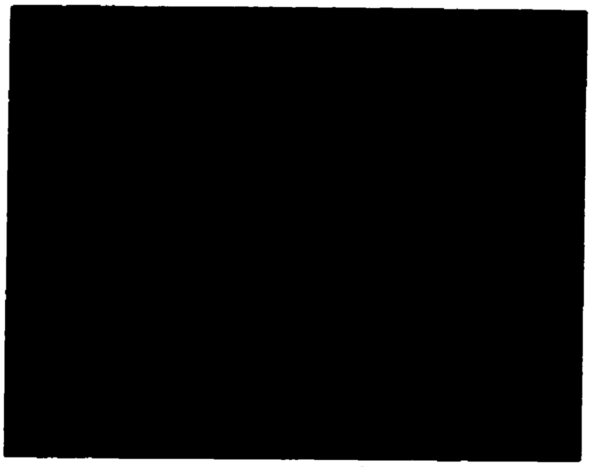


Figure i)

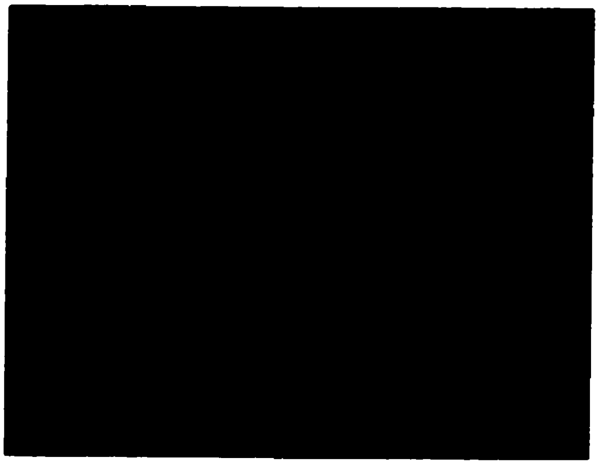


Figure ii)

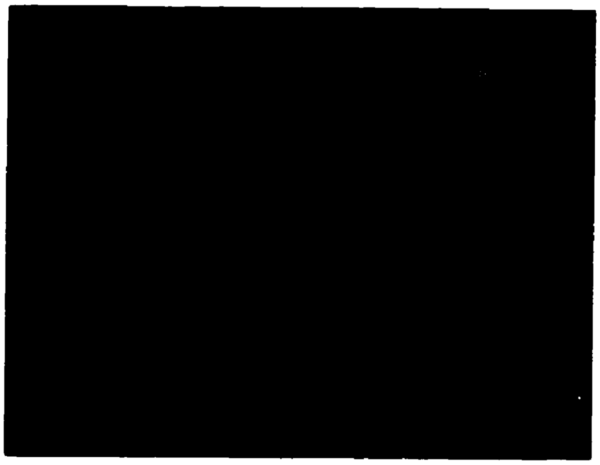


Figure iii)

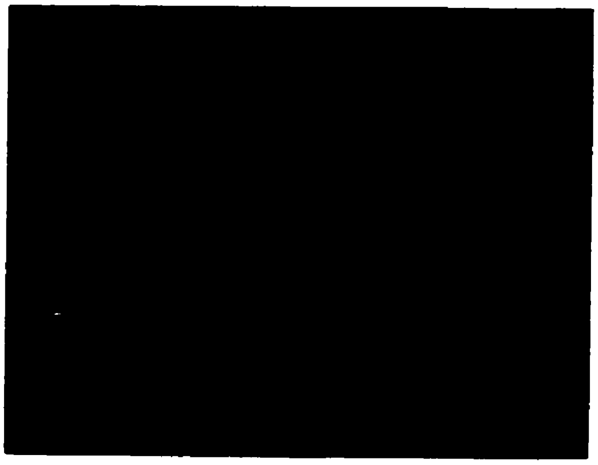


Figure iv)

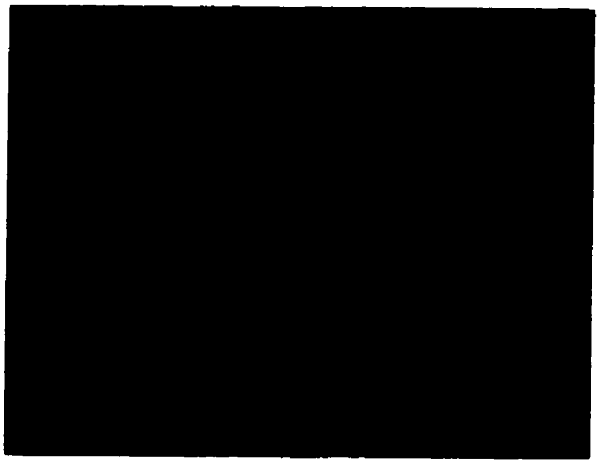


Figure v)

Image 8.

Compare the objects indicated at "A" and "B" in the various figures. Assume that Figure i) is a good representation of the original.

16a) Which figure (ii, iii, or iv) gives the best representation of the COLOUR of the object at "A":

16b) Which figure (ii, iii, or iv) gives the best representation of the COLOUR of the object at "B":

Attributes: Figure i) 24 bpp RGB, 150 dpi, 150% enlargement.
Figure ii) 8 bpp indexed, 150 dpi, 150% enlargement.
Figure iii) 24 bpp RGB, JPEG Max, 150 dpi, 150% enlargement.
Figure iv) 24 bpp RGB, JPEG Low, 150 dpi, 150% enlargement.

	Figure ii	Figure iii	Figure iv	Spoiled
16 a	1	39	11	5
16 b	1	27	17	11

Figure 4.8 Image 8.

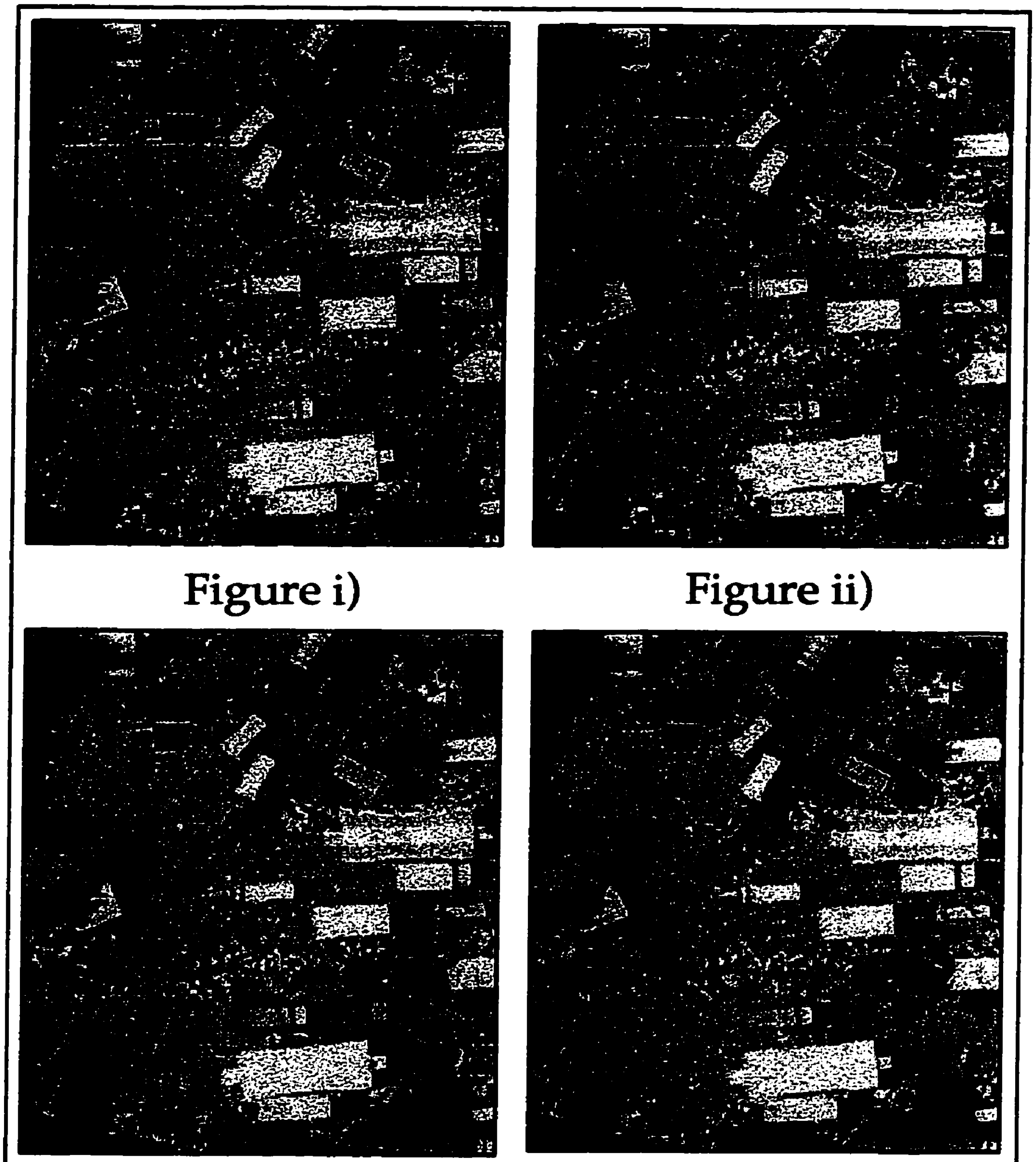


Figure i)

Figure ii)

Figure iii)

Figure iv)

Image 9.

Assuming Figure 9a is a good representation of the original photo, and concentrating on the areas outlined with black boxes,

Part A:
17a) compare colours - which other figure (9b, 9c, or 9d) is the closest to 9a?
Part B:
17b) compare sharpness of details - which other figure (9b, 9c, or 9d) is the closest to 9a?

Attributes: 9a) 24 bpp RGB, 150 dpi, 200% enlargement.
9b) 8 bpp indexed, 150 dpi, 200% enlargement.
9c) 24 bpp RGB, JPEG Max, 150 dpi, 200% enlargement.
9d) 24 bpp RGB, JPEG Low, 150 dpi, 200% enlargement.

	Figure 9b	Figure 9c	Figure 9d
Part A	2	46	8
Part B	17	28	11

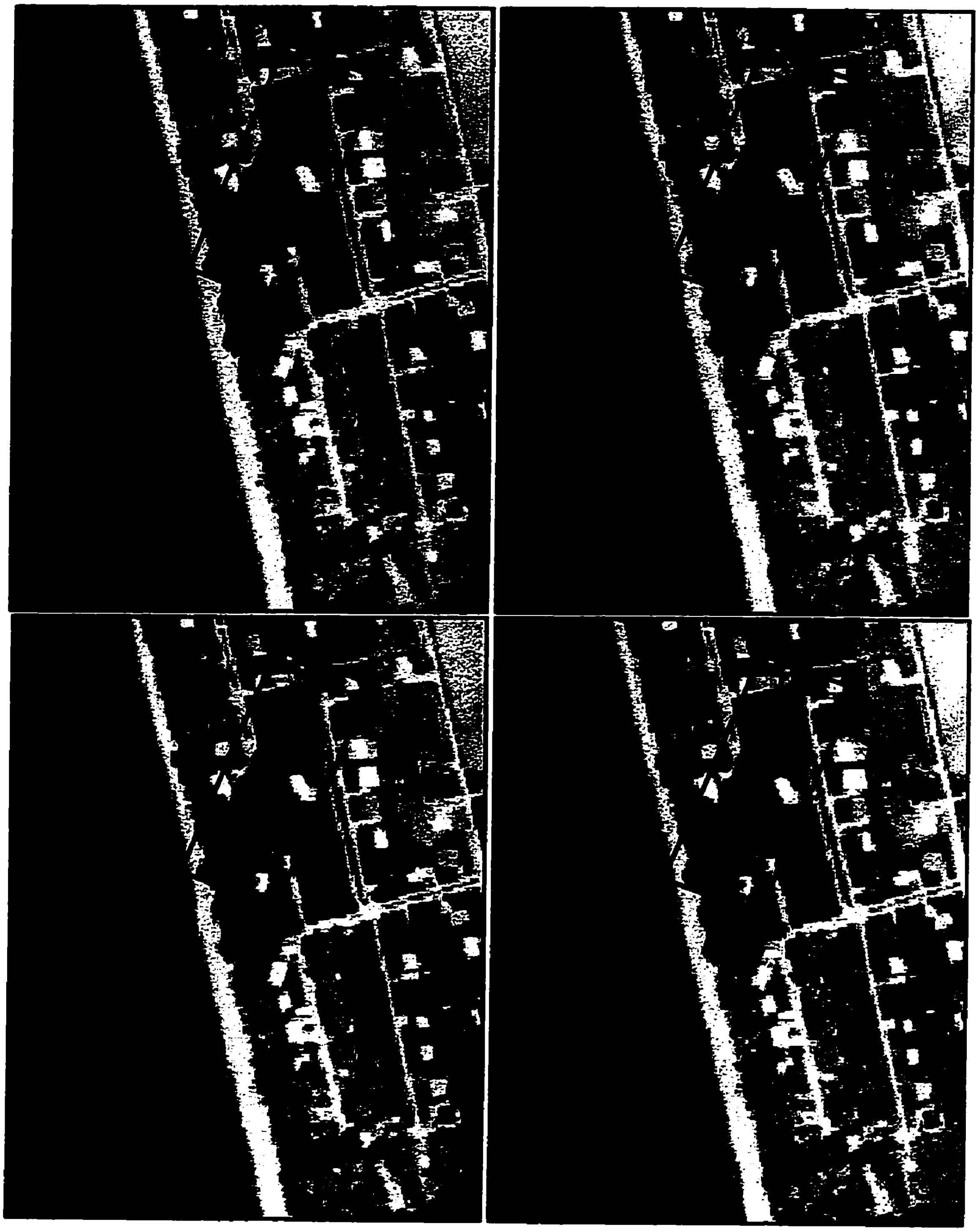


Figure 4.9 Image 9.

Image 10.

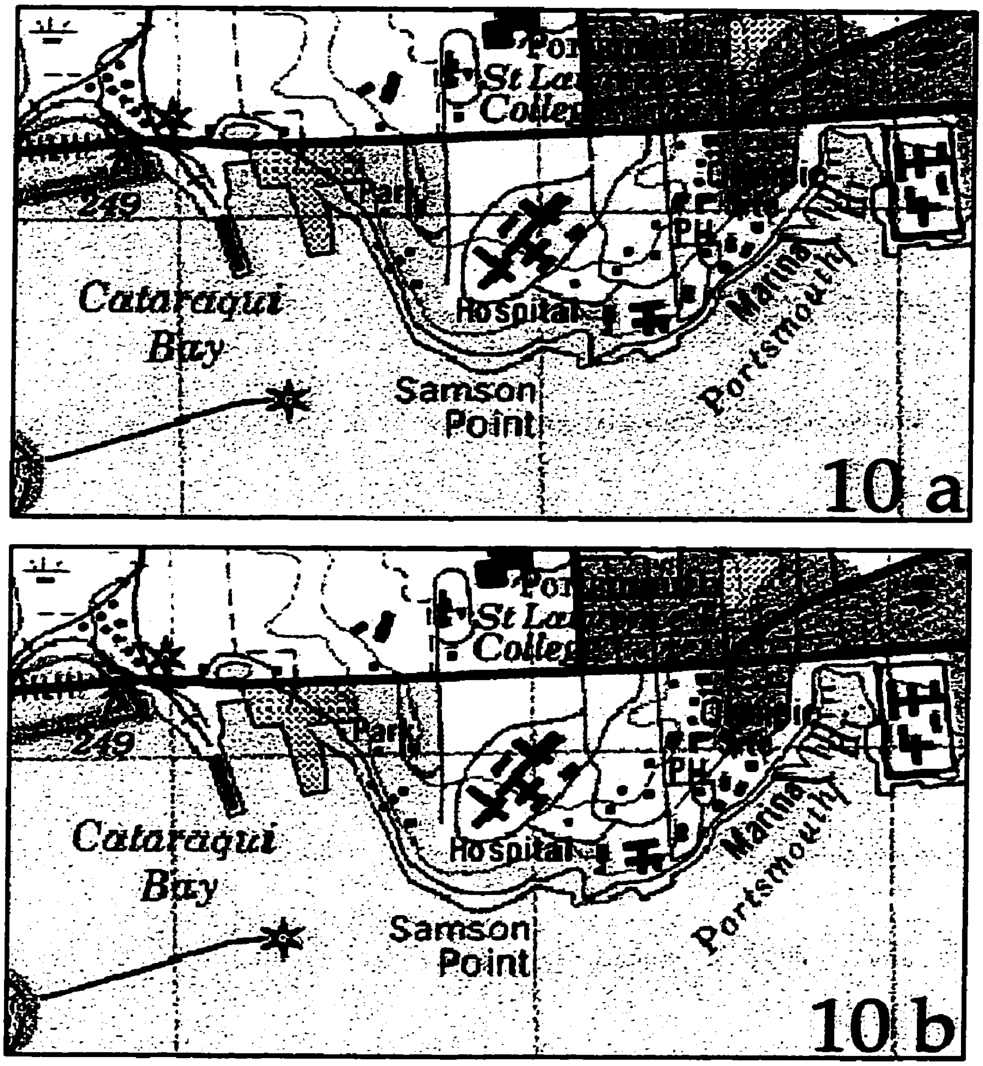
Compare Figure 10a to Figure 10b.

18a) Which figure (a or b) is easiest to read?
18b) Which figure (a or b) is clearest overall?
18c) Which figure (a or b) gives the best colour reproduction of the brown contour lines?

Attributes: 10a) 24 bpp RGB, 150 dpi, no enlargement.
10b) 8 bpp indexed, 150 dpi, no enlargement.

	Figure 10a	Figure 10b
18a	15	41
18b	8	48
18c	17	39

Figure 4.10 Image 10.



4.2 Calculation of File Sizes and Compression Ratios

In Step 6, sections of seventeen paper maps were digitized at four different scanning resolutions, thus creating 68 digital images. These images were then cropped to 2" x 2" and copies were made; some copies were compressed using JPEG or LZW, while other copies were subjected to palette indexing. In this section, the file size of each compressed and indexed copy is compared with the file size of each corresponding uncompressed 24 bpp RGB image; that is, the copies are compared to the original scanned images. The file size reduction factor (RF) for each copied image is then calculated. This is done by dividing the file size of the copied image into the file size of the original 24 bpp RGB image. The resulting number represents the reduction factor for the copied image. For example, if the original 24 bpp RGB image is 12 Mbytes in size, and the compressed version is 3 Mbytes, then the RF value is four; that is, $RF = \frac{12 \text{ Mbytes}}{3 \text{ Mbytes}}$

$$RF = 4.$$

The following tables are arranged by scanning resolution, and each table is internally sorted by image type.

Table 1. 75 dpi, File Sizes in Megabytes

File Name	PICT	JPGMax	JPGHigh	JPGMed	JPGLow	TIFF	LZW	IDX 8
Monochrome Line								
Image 1	0.007	0.023	0.020	0.019	0.018	0.033	0.012	N/A
Monochrome Continuous Tone								
Image 2	0.079	0.027	0.021	0.018	0.016	0.078	0.085	0.042
Image 3	0.072	0.020	0.016	0.014	0.013	0.077	0.057	0.038
Image 4	0.079	0.025	0.021	0.018	0.016	0.079	0.063	0.042
Image 5	0.034	0.017	0.014	0.012	0.011	0.031	0.027	N/A
Simple Polychrome								
Image 6	0.083	0.033	0.026	0.023	0.021	0.082	0.080	0.042
Image 7	0.083	0.035	0.027	0.023	0.021	0.082	0.078	0.040
Image 8	0.081	0.036	0.029	0.024	0.022	0.082	0.070	0.039
Intermediate Polychrome								
Image 9	0.085	0.043	0.033	0.027	0.025	0.084	0.094	0.042
Image 10	0.082	0.033	0.025	0.021	0.019	0.081	0.075	0.041
Image 11	0.082	0.034	0.026	0.022	0.020	0.081	0.079	0.041
Image 12	0.083	0.038	0.029	0.024	0.022	0.082	0.092	0.043
Complex Polychrome								
Image 13	0.081	0.028	0.021	0.018	0.016	0.080	0.075	0.042
Image 14	0.082	0.032	0.025	0.021	0.019	0.081	0.077	0.042
Image 15	0.083	0.033	0.025	0.021	0.019	0.082	0.082	0.042
Image 16	0.086	0.044	0.034	0.029	0.026	0.084	0.098	0.043
Image 17	0.085	0.043	0.032	0.027	0.024	0.084	0.100	0.043

Table 2. 150 dpi, File Sizes in Megabytes

File Name	PICT	JPGMax	JPGHigh	JPGMed	JPGLow	TIFF	LZW	Idx 8
Monochrome Line								
Image 1	0.011	0.043	0.035	0.032	0.029	0.100	0.016	N/A
Monochrome Continuous Tone								
Image 2	0.269	0.094	0.061	0.047	0.040	0.282	0.285	0.106
Image 3	0.263	0.050	0.033	0.024	0.021	0.279	0.193	0.093
Image 4	0.282	0.063	0.042	0.032	0.028	0.282	0.198	0.093
Image 5	0.103	0.039	0.027	0.021	0.017	0.099	0.078	N/A
Simple Polychrome								
Image 6	0.287	0.081	0.055	0.041	0.034	0.284	0.254	0.107
Image 7	0.287	0.091	0.061	0.044	0.037	0.285	0.243	0.100
Image 8	0.278	0.084	0.058	0.042	0.036	0.285	0.214	0.086
Intermediate Polychrome								
Image 9	0.289	0.110	0.074	0.052	0.043	0.287	0.307	0.108
Image 10	0.286	0.089	0.059	0.039	0.032	0.284	0.246	0.104
Image 11	0.286	0.095	0.063	0.043	0.036	0.284	0.258	0.104
Image 12	0.288	0.109	0.074	0.051	0.043	0.285	0.294	0.108
Complex Polychrome								
Image 13	0.285	0.072	0.046	0.033	0.026	0.282	0.260	0.109
Image 14	0.285	0.076	0.050	0.036	0.030	0.284	0.255	0.105
Image 15	0.288	0.076	0.049	0.035	0.029	0.284	0.264	0.110
Image 16	0.290	0.125	0.082	0.055	0.045	0.287	0.329	0.110
Image 17	0.290	0.133	0.087	0.057	0.047	0.287	0.350	0.111

Table 3. 300 dpi, File Sizes in Megabytes

File Name	PICT	JPGMax	JPGHigh	JPGMed	JPGLow	TIFF	LZW	IDX 8
Monochrome Line								
Image 1	0.022	0.090	0.072	0.064	0.055	0.370	0.027	N/A
Monochrome Continuous Tone								
Image 2	1.030	0.338	0.201	0.137	0.106	1.090	1.010	0.330
Image 3	1.030	0.208	0.131	0.069	0.054	1.090	0.879	0.315
Image 4	1.090	0.177	0.106	0.068	0.053	1.090	0.718	0.364
Image 5	0.373	0.098	0.062	0.044	0.033	0.369	0.237	N/A
Simple Polychrome								
Image 6	1.100	0.301	0.188	0.107	0.083	1.100	1.110	0.357
Image 7	1.100	0.264	0.160	0.102	0.078	1.090	0.905	0.330
Image 8	1.050	0.235	0.143	0.091	0.071	1.090	0.824	0.286
Intermediate Polychrome								
Image 9	1.100	0.312	0.187	0.120	0.091	1.100	1.080	0.367
Image 10	1.100	0.333	0.214	0.110	0.082	1.090	1.080	0.340
Image 11	1.100	0.329	0.211	0.114	0.086	1.090	1.060	0.355
Image 12	1.100	0.341	0.209	0.130	0.099	1.090	1.130	0.348
Complex Polychrome								
Image 13	1.100	0.230	0.127	0.078	0.057	1.090	0.951	0.373
Image 14	1.090	0.218	0.126	0.079	0.060	1.090	0.926	0.365
Image 15	1.100	0.329	0.185	0.090	0.059	1.090	1.180	0.383
Image 16	1.110	0.413	0.232	0.135	0.100	1.100	1.240	0.381
Image 17	1.100	0.449	0.260	0.147	0.109	1.100	1.30	0.382

Table 4. 400 dpi, File Sizes in Megabytes

File Name	PICT	JPGMax	JPGHigh	JPGMed	JPGLow	TIFF	LZW	IDX 8
Monochrome Line								
Image 1	0.031	0.129	0.102	0.009	0.078	0.084	0.016	N/A
Monochrome Continuous Tone								
Image 2	1.810	0.616	0.342	0.222	0.165	1.930	1.790	0.581
Image 3	1.800	0.396	0.254	0.121	0.096	1.930	1.630	0.568
Image 4	1.930	0.292	0.165	0.100	0.075	1.930	1.370	0.622
Image 5	0.646	0.153	0.091	0.062	0.045	0.649	0.386	N/A
Simple Polychrome								
Image 6	1.950	0.548	0.345	0.187	0.143	1.930	2.010	0.632
Image 7	1.940	0.461	0.265	0.156	0.115	1.930	1.609	0.614
Image 8	1.820	0.411	0.238	0.142	0.107	1.930	1.490	0.503
Intermediate Polychrome								
Image 9	1.930	0.562	0.305	0.186	0.135	1.940	1.910	0.636
Image 10	1.930	0.628	0.411	0.189	0.139	1.930	1.950	0.614
Image 11	1.940	0.616	0.389	0.194	0.144	1.930	1.940	0.623
Image 12	1.940	0.599	0.353	0.203	0.152	1.930	2.050	0.590
Complex Polychrome								
Image 13	1.930	0.463	0.218	0.127	0.087	1.930	1.850	0.660
Image 14	1.920	0.398	0.203	0.118	0.085	1.930	1.730	0.640
Image 15	1.950	0.711	0.42	0.206	0.146	1.930	2.370	0.667
Image 16	1.950	0.927	0.634	0.283	0.212	1.940	2.520	0.665
Image 17	1.940	0.978	0.682	0.299	0.223	1.940	2.510	0.665

Table 5. 75 dpi, Reduction Factors

File Name	PICT	JPGMax	JPGHigh	JPGMed	JPGLow	TIFF	LZW	IDX 8
Monochrome Line								
Image 1	1.00	0.30**	0.35	0.37	0.39	0.21	0.58	N/A
Monochrome Continuous Tone								
Image 2	1.00	2.93	3.76	4.39	4.94	1.01	0.93	1.88
Image 3	1.00	3.60	4.50	5.14	5.54	0.94	1.26	1.89
Image 4	1.00	3.16	3.76	4.39	4.94	1.00	1.25	1.88
Image 5	1.00	2.00	2.43	2.83	3.09	1.10	1.26	N/A
Simple Polychrome								
Image 6	1.00	2.52	3.19	3.61	3.95	1.01	1.04	1.98
Image 7	1.00	2.37	3.07	3.61	3.95	1.01	1.06	2.08
Image 8	1.00	2.25	2.79	3.38	3.68	0.99	1.16	2.08
Intermediate Polychrome								
Image 9	1.00	1.98	2.58	3.15	3.40	1.01	0.90	2.02
Image 10	1.00	2.48	3.28	3.9	4.32	1.01	1.09	2.00
Image 11	1.00	2.41	3.15	3.73	4.10	1.01	1.04	2.00
Image 12	1.00	2.18	2.86	3.46	3.77	1.01	0.90	1.93
Complex Polychrome								
Image 13	1.00	2.89	3.86	4.50	5.06	1.01	1.08	1.93
Image 14	1.00	2.56	3.28	3.90	4.31	1.01	1.06	1.95
Image 15	1.00	2.52	3.32	3.95	4.37	1.01	1.01	1.98
Image 16	1.00	1.95	2.53	2.97	3.31	1.02	0.88	2.00
Image 17	1.00	1.98	2.66	3.15	3.54	1.01	0.85	1.98

**RF values less than 1.00 mean the compressed file is larger than the uncompressed file.

Table 6. 150 dpi, Reduction Factors

File Name	PICT	JPGMax	JPGHigh	JPGMed	JPGLow	TIFF	LZW	Idx 8
Monochrome Line								
Image 1	1.00	0.26	0.31	0.34	0.38	0.11	0.69	N/A
Monochrome Continuous Tone								
Image 2	1.00	2.86	4.41	5.72	6.73	0.95	0.94	2.54
Image 3	1.00	5.26	7.97	10.96	12.52	0.94	1.36	2.83
Image 4	1.00	4.48	6.71	8.81	10.07	1.00	1.42	3.03
Image 5	1.00	2.64	3.81	4.90	6.06	1.04	1.32	N/A
Simple Polychrome								
Image 6	1.00	3.54	5.22	7.00	8.44	1.01	1.13	2.68
Image 7	1.00	3.15	4.70	6.52	7.76	1.01	1.18	2.87
Image 8	1.00	3.31	4.79	6.62	7.72	0.98	1.30	3.24
Intermediate Polychrome								
Image 9	1.00	2.63	3.91	5.56	6.72	1.01	0.94	2.68
Image 10	1.00	3.21	4.85	7.33	8.94	1.01	1.16	2.75
Image 11	1.00	3.01	4.54	6.65	7.94	1.01	1.11	2.75
Image 12	1.00	2.64	3.89	5.65	6.70	1.01	0.98	2.67
Complex Polychrome								
Image 13	1.00	3.96	6.20	8.64	10.96	1.01	1.10	2.61
Image 14	1.00	3.75	5.70	7.92	9.50	1.00	1.12	2.71
Image 15	1.00	3.79	5.88	8.23	9.93	1.01	1.10	2.62
Image 16	1.00	2.32	3.54	5.27	6.44	1.01	0.88	2.64
Image 17	1.00	2.18	3.33	5.09	6.17	1.01	0.83	2.61

Table 7. 300 dpi, Reduction Factors

File Name	PICT	JPGMax	JPGHigh	JPGMed	JPGLow	TIFF	LZW	IDX 8
Monochrome Line								
Image 1	1.00	0.24	0.31	0.34	0.4	0.06	0.81	N/A
Monochrome Continuous Tone								
Image 2	1.00	2.96	5.12	7.52	9.72	0.94	1.02	3.12
Image 3	1.00	4.95	7.86	14.93	19.07	0.94	1.17	3.27
Image 4	1.00	6.16	10.28	16.03	20.57	1.00	1.52	2.99
Image 5	1.00	3.81	6.02	8.48	11.3	1.01	1.57	N/A
Simple Polychrome								
Image 6	1.00	3.65	5.85	10.28	13.25	1.00	0.99	3.08
Image 7	1.00	4.17	6.88	10.78	14.01	1.01	1.22	3.33
Image 8	1.00	4.47	7.34	11.54	14.79	0.96	1.27	3.67
Intermediate Polychrome								
Image 9	1.00	3.53	5.88	9.71	12.09	1.00	1.02	3.00
Image 10	1.00	3.30	5.14	10.00	13.41	1.01	1.02	3.24
Image 11	1.00	3.34	5.21	9.65	12.79	1.01	1.04	3.10
Image 12	1.00	3.23	5.26	8.46	11.11	1.01	0.97	3.16
Complex Polychrome								
Image 13	1.00	4.79	8.66	14.10	19.30	1.01	1.16	2.95
Image 14	1.00	5.00	8.65	13.80	18.17	1.00	1.18	2.99
Image 15	1.00	3.34	5.95	12.22	18.64	1.01	0.93	2.87
Image 16	1.00	2.69	4.78	8.22	11.10	1.02	0.90	2.91
Image 17	1.00	2.45	4.23	7.48	10.09	1.01	0.85	2.89

Table 8. 400 dpi, Reduction Factors

File Name	PICT	JPGMax	JPGHigh	JPGMed	JPGLow	TIFF	LZW	Idx 8
Monochrome Line								
Image 1	1.00	0.24	0.30	0.34	0.40	0.37	1.94	N/A
Monochrome Continuous Tone								
Image 2	1.00	2.94	5.29	8.15	10.97	0.94	1.01	3.12
Image 3	1.00	4.55	7.09	14.88	18.75	0.93	1.10	3.17
Image 4	1.00	6.61	11.70	19.30	25.73	1.00	1.41	3.10
Image 5	1.00	4.22	7.10	10.42	14.36	0.99	1.67	N/A
Simple Polychrome								
Image 6	1.00	3.56	5.65	10.43	13.64	1.01	0.97	3.09
Image 7	1.00	4.21	7.32	12.44	16.87	1.01	1.15	3.16
Image 8	1.00	4.43	7.65	12.82	17.01	0.94	1.22	3.62
Intermediate Polychrome								
Image 9	1.00	3.43	6.33	10.38	14.30	0.99	1.01	3.03
Image 10	1.00	3.07	4.70	10.21	13.88	1.00	0.99	3.14
Image 11	1.00	3.15	4.99	10.00	13.47	1.01	1.00	3.11
Image 12	1.00	3.24	5.50	9.56	12.76	1.01	0.95	3.29
Complex Polychrome								
Image 13	1.00	4.17	8.85	15.20	22.18	1.00	1.04	2.92
Image 14	1.00	4.82	9.46	16.27	22.59	0.99	1.11	3.00
Image 15	1.00	2.74	4.64	9.47	13.36	1.01	0.82	2.92
Image 16	1.00	2.10	3.08	6.89	9.20	1.01	0.77	2.93
Image 17	1.00	1.98	2.84	6.49	8.70	1.01	0.77	2.92

4.2.1 File Sizes

Within each table (Tables 1 through 4), notice that the PICT files (that is, the original uncompressed scans) for colour images are very close in size. The file sizes fluctuate less than 5% from one image to the next. As discussed in Section 2.3, the only factors which contribute to the size of an uncompressed digital image file are the number of bits per pixel, the length and width of the image, and the scanning resolution. As all the uncompressed images within each table have the same bit depth (24 bpp), the same area (2" x 2"), and the same scanning resolution, the file sizes are similar. Furthermore, converting the images from PICT to TIFF causes little change in file size. Therefore, there is no advantage to be gained in terms of disk storage space from the file format. The uncompressed digital image may be saved in either format, depending upon the needs of the preservationist, as some software applications support only certain file formats.

The compressed files display more variation in size. The sizes of the JPEG files fluctuate up to 40% from one image to the next. This is a result of the unique nature of the images - each image is different from the others, and the amount of redundant information within each image varies. While the files compressed using LZW do not fluctuate as much as the JPEG files, it should be noted that in many cases, the compressed files either remained the same size as the uncompressed files, or actually increased in size. For example, in Table 1 the file size for Image 9 in PICT format is 0.085 Mbytes.

However, the same image compressed using the LZW algorithm is 0.094 Mbytes in size, an increase of over 10%. Likewise, in Table 4, the uncompressed file size for Image 16a is 1.95 Mbytes while the LZW compressed version is 2.52 Mbytes, a 30% increase in size. In the four tables outlining file sizes (Tables 1 through 4), 25 of the 68 LZW files (36.76%) are larger than their uncompressed counterparts. This is caused by the presence of low frequency noise introduced during scanning that defeats the algorithm's ability to recognize repeating substrings (see Sections 2.5.2 and 2.5.3).

4.2.2 Reduction Factors

In the tables outlining the Reduction Factors (Tables 5 through 8), notice that the RF values for the JPEG images tend to increase as the resolution increases. This suggests that there is a positive relationship between scanning resolution and the amount of data redundancy present within the digital image. This relationship is illustrated in Figure 4.11.

Figure 4.11 Demonstration of Relationship Between Scanning Resolution and Data Redundancy.

4.11a

4.11b

Figure 4.11a represents an image that is to be digitized. It is comprised of two 1 square inch boxes, each of which are a different colour. If the scanning resolution were set at 1 dpi, then one pixel would be created for each box. In this instance, there would be very little data redundancy, for the value of either of the pixels could not be predicted based on the value of its neighbour. However, if the scanning resolution were increased, as represented in Figure 4.11b, then the amount of data redundancy is also increased. That is, there are many pixels whose values can be accurately predicted based on the value of the neighbouring pixels.

The RF values for the LZW images tend to hover around 1.00. That is, the compression ratio is close to 1:1, meaning there is little or no compression whatsoever. Furthermore, those LZW images that have RF values less than 1.00 are larger than the uncompressed files. This led the researcher to the conclusion that the LZW algorithm is inadequate for the purposes of this thesis, and as such, it was not used for any of the images in the questionnaire.

Chapter 5.

Compilation of Questionnaire Results and Analysis

This chapter is divided into two sections, between colour reproduction and legibility. Furthermore, each section is subdivided into two subsections; the first provides a compilation of the questionnaire responses, the second provides an analysis of the results.

5.1 Colour Reproduction

The questionnaire contained three questions concerning the digital colour reproduction of Complex Polychrome images, resulting in 168 possible responses; that is, 56 responses to each of the three questions. The respondents were given three choices within those questions, namely to choose between JPEG Max, JPEG Low and 8 bpp indexed images (the JPEG Q factor terms "Max" and "Low" refer to the resultant image quality, not to the compression ratio). Of the 168 possible responses, some were disqualified due to improper answers. For example, when given the task of choosing which image presented the best colour reproduction (as in Question 16a), a number of respondents chose all of the images as the best. These responses are considered to be spoiled, and are not included in the analysis of the questionnaire.

The questionnaire contained one question concerning the colour reproduction of Intermediate Polychrome images. The respondents were given a choice between an uncompressed, 24 bpp RGB image and its 8 bpp counterpart. Again, some responses were disqualified due to the

BG-11 Algal Medium

	g/L of solution
Salts	
$MgSO_4$-$7H_2O$	0.75
Na_2CO_3	0.02
Nutrients	
$CaCl_2$-$2H_2O$	0.036
$NaNO_3$	1.5
KH_2PO_4	0.04
Additional Components	
Na_2EDTA	0.001
TMS buffer	1 mL
Agar	10

Appendix II

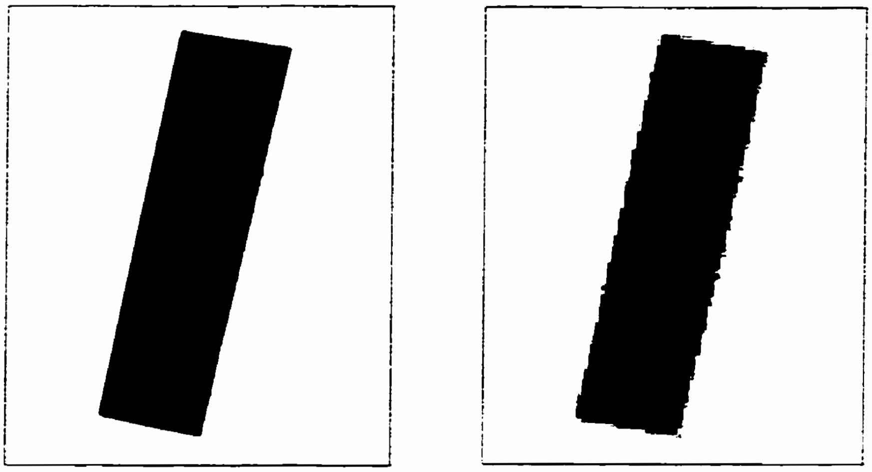
List of Abbreviations

ST_{50} (Starvation Time) -	represents the time to 50% mortality in unfed *Daphnia* populations.
RT_{50} (Response Time) -	represents the time to 50% mortality in *Daphnia* populations allowed to graze on pre-conditioned bacteria.
TR (Toxicity Ratio) -	represents the ratio of the time to 50% mortality in an unfed *Daphnia* population to the time to 50% mortality in a *Daphnia* population fed pre-conditioned bacteria (a ratio less than 1 indicates a toxic response)
0_2-dH_2O/NaCl -	represents oxygen-saturated distilled water containing 0.5% NaCl (w/v) (the bioassay exposure solution).

> For example, a scanning resolution of one dpi would result in a digital image that has one pixel per square inch of the original document. All the colours present within the area represented by that pixel would be combined and a single number would be assigned that represents the average reflectance value for that pixel.... If, however, the scanning resolution were increased, meaning that pixel size is decreased, then more colours could be portrayed within that same one square inch area because more pixels would be required to depict the same size area at the greater resolution; each pixel would be assigned its own separate colour value that represented the reflectance of that smaller pixel area on the original document (Ray, 1996: 4).

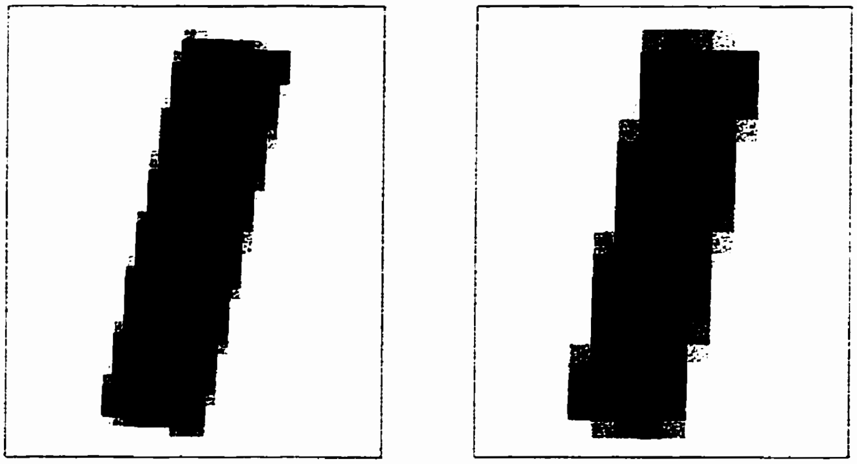
Rarely do all the pixels in a digital image fall completely within the area dominated by one colour or another. Usually there are a number of pixels that fall along the line separating areas of different colours. These are referred to in this thesis as "edge pixels". This principle is illustrated in Figure 5.1. Because the heavy black lines are diagonal in relation to the pixel grid, there are many edge pixels in the lower resolution versions which fall both within the body of the line and within the white background. Notice that these edge pixels are various shades of gray, the darkness of which is dependent upon how much of the pixel falls within the body of the line. In other words, those edge pixels that have the majority of their area covered by the line are darker than those which are mostly within the white background. In these instances, the process of digitization has produced images that contain very few black pixels while producing many shades of gray that were not present in the originals.

Figure 5.1 Comparison of Images Scanned at Different Resolutions.



72 dpi

36 dpi



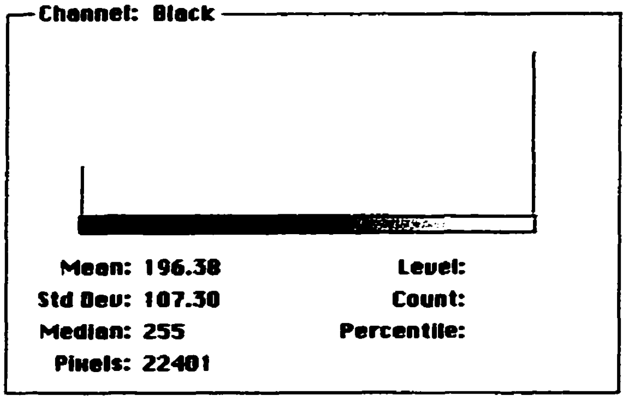
18 dpi

9 dpi

The differences in colour reproduction can be quantified and illustrated using the histogram feature of Adobe Photoshop. Figure 5.2 contains the histograms for the images in Figure 5.1. The x-axes of these histograms represent the colour values from 0 (black) on the left to 255 (white) on the right while the y-axes represent the number of pixels in the image that have that particular value. The graph for the 72 dpi version clearly shows that there are only two colours present within that image, namely black and white. Notice that there are no other values depicted on this graph, meaning that there are no other colours present within the image. However, on the histograms for the lower resolution versions, there are lines all along the graphs, meaning that there are a substantial number of pixels that have intermediate values; they are various shades of gray. Furthermore, as the resolution decreases, the number of grey shades increases. The 72 dpi version contains two grey shades, black and white; the 36 dpi version contains 5 grey shades; the 18 dpi version, 17 grey shades, and; the 9 dpi version, 32 grey shades (see Table 10). Since the only colours contained within the original image were black and white, one can conclude that there is a strong positive relationship between increased scanning resolution and better colour reproduction.

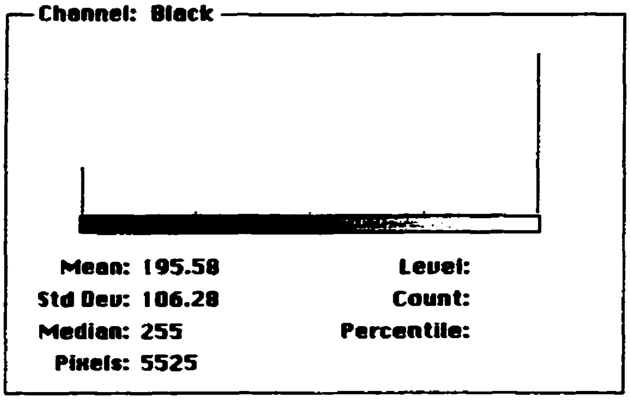
The principle of edge pixels can have some very interesting effects on colour images. On Intermediate and Complex Polychrome images, there could be a great number of edge pixels present in the digital image. For

Figure 5.2 Histograms for Images in Figure 5.1.


Channel: Black

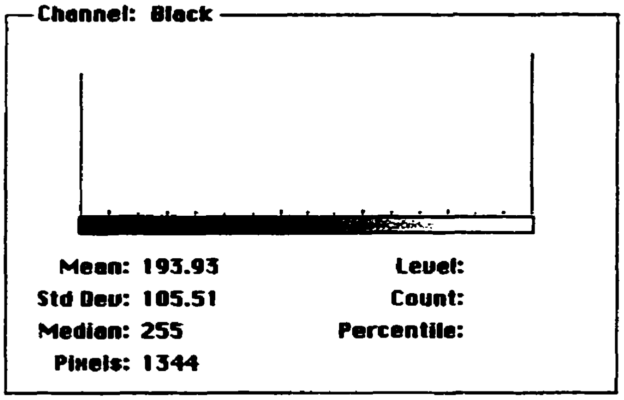
Mean: 196.38
Std Dev: 107.30
Median: 255
Pixels: 22401
Level:
Count:
Percentile:

72 dpi


Channel: Black

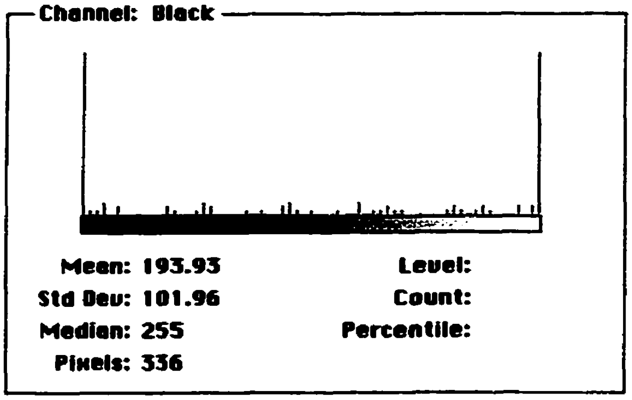
Mean: 195.58
Std Dev: 106.28
Median: 255
Pixels: 5525
Level:
Count:
Percentile:

36 dpi


Channel: Black

Mean: 193.93
Std Dev: 105.51
Median: 255
Pixels: 1344
Level:
Count:
Percentile:

18 dpi


Channel: Black

Mean: 193.93
Std Dev: 101.96
Median: 255
Pixels: 336
Level:
Count:
Percentile:

9 dpi

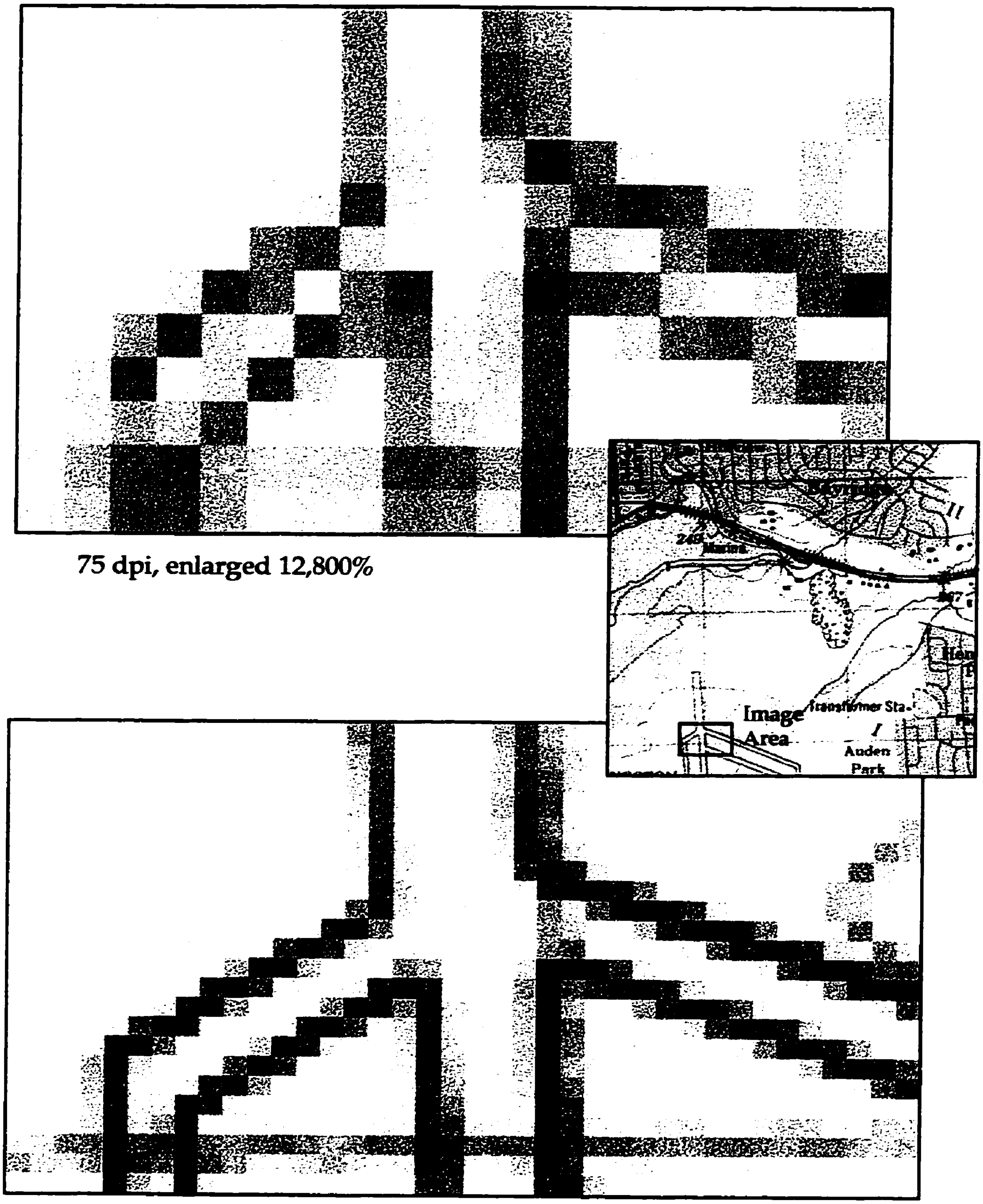
Table 10. Number of Pixels by Colour Value and Scanning Resolution

Colour Value	9 dpi	18 dpi	36 dpi	72 dpi
0 (Black)	57	279	1,222	5150
4	1	x	x	x
8	1	x	x	x
12	3	x	x	x
16	x	9	x	x
20	2	x	x	x
32	x	3	x	x
48	2	6	x	x
52	1	x	x	x
64	1	7	41	x
68	3	x	x	x
72	2	x	x	x
80	x	4	x	x
92	1	x	x	x
96	x	3	x	x
100	1	x	x	x
112	2	8	x	x
116	3	x	x	x
120	1	x	x	x
128	1	6	47	x
143	1	2	x	x
155	3	x	x	x
159	x	8	x	x
163	1	x	x	x
167	1	x	x	x
171	2	x	x	x
175	1	6	x	x
179	1	x	x	x
191	x	6	45	x
203	1	x	x	x
207	2	8	x	x
211	1	x	x	x
219	1	x	x	x
223	2	3	x	x
227	1	x	x	x
239	x	7	x	x
243	2	x	x	x
251	2	x	x	x
255 (White)	232	979	4,170	17,251
Total Number of Colours	32	17	5	2

example, Figure 5.3 portrays four images of the same portion of the National Topographic Series 1:50,000 Bath sheet (number 31C/2, edition 5, 1979) scanned at different resolutions. This is a detail of the runways of a small airport (see the location map). Notice in the 75 dpi version that the image is very pale and washed out. There is a pale blue column of pixels, just right of centre, that is intersected near the bottom of the image by a row of pale blue pixels. Also, on the upper right edge of the image is a semi-circle of light tan pixels. In the 150 dpi version, the blue lines have become brighter - on the original paper document, these are lines representing the UTM grid on the map. The brown semi-circle has become darker and more clearly defined - on the original map, this is a portion of a brown contour line. Furthermore, the parallel diagonal lines on the left half of the image, representing one of the runways, are partially composed of purple pixels. This is very intriguing, for the NTS legend contains eight colours - red, orange, blue, brown, black, gray, green and white. There are no features portrayed in purple on the original map sheet. This means that the colours present in the original which are contained within the purple pixel area were combined by the scanner to produce new colours that are not found on the original map. Also, notice that the vertical lines outlining the runway contain tan and blue pixels. Again, these shades are peculiar to the digital image and are not found on the original.

In the 300 dpi and 400 dpi versions, notice that the blue UTM lines are

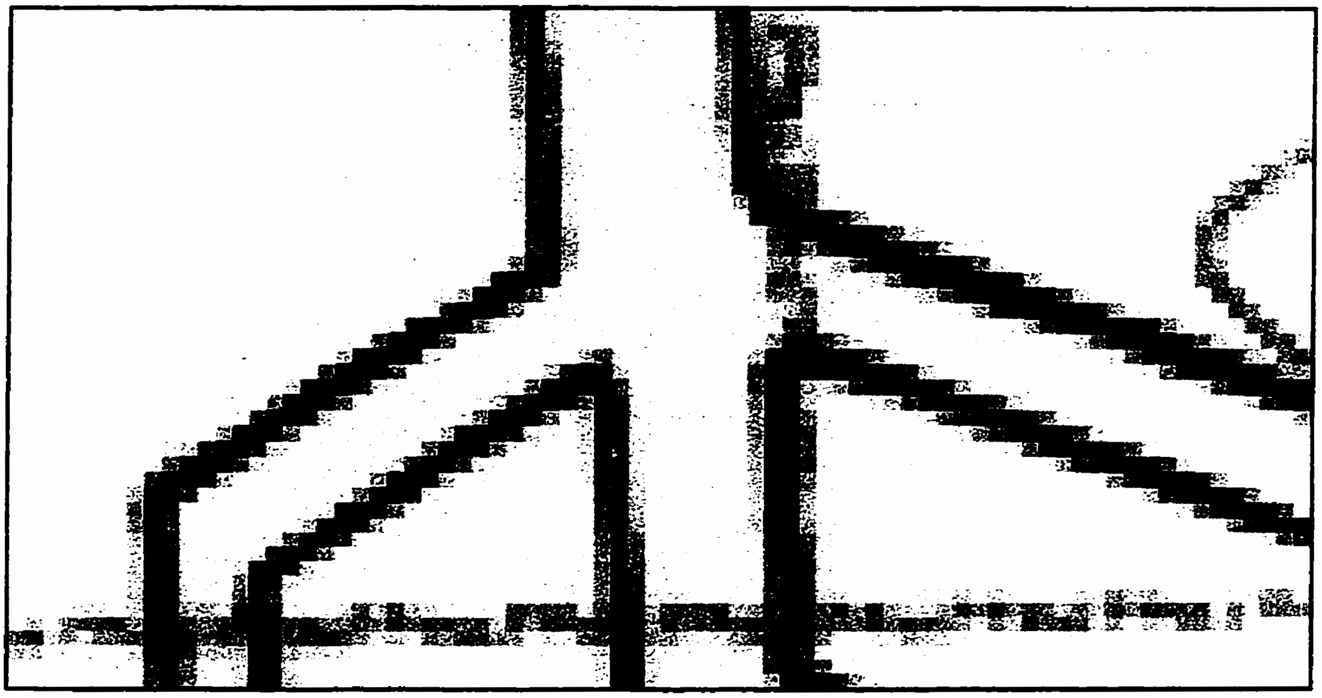
Figure 5.3a The Effects of Scanning Resolution on Colour Reproduction



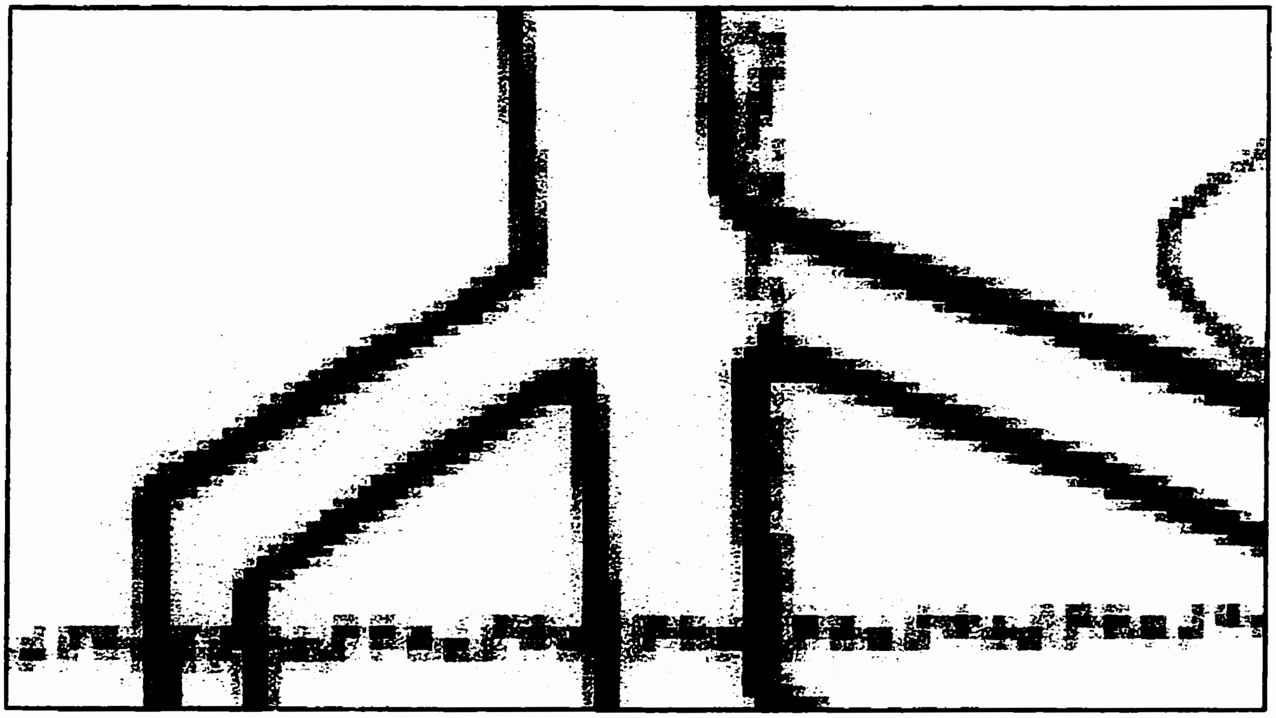
75 dpi, enlarged 12,800%

150 dpi, enlarged 6,000%

Figure 5.3b The Effects of Scanning Resolution on Colour Reproduction.



300 dpi, enlarged 3200%



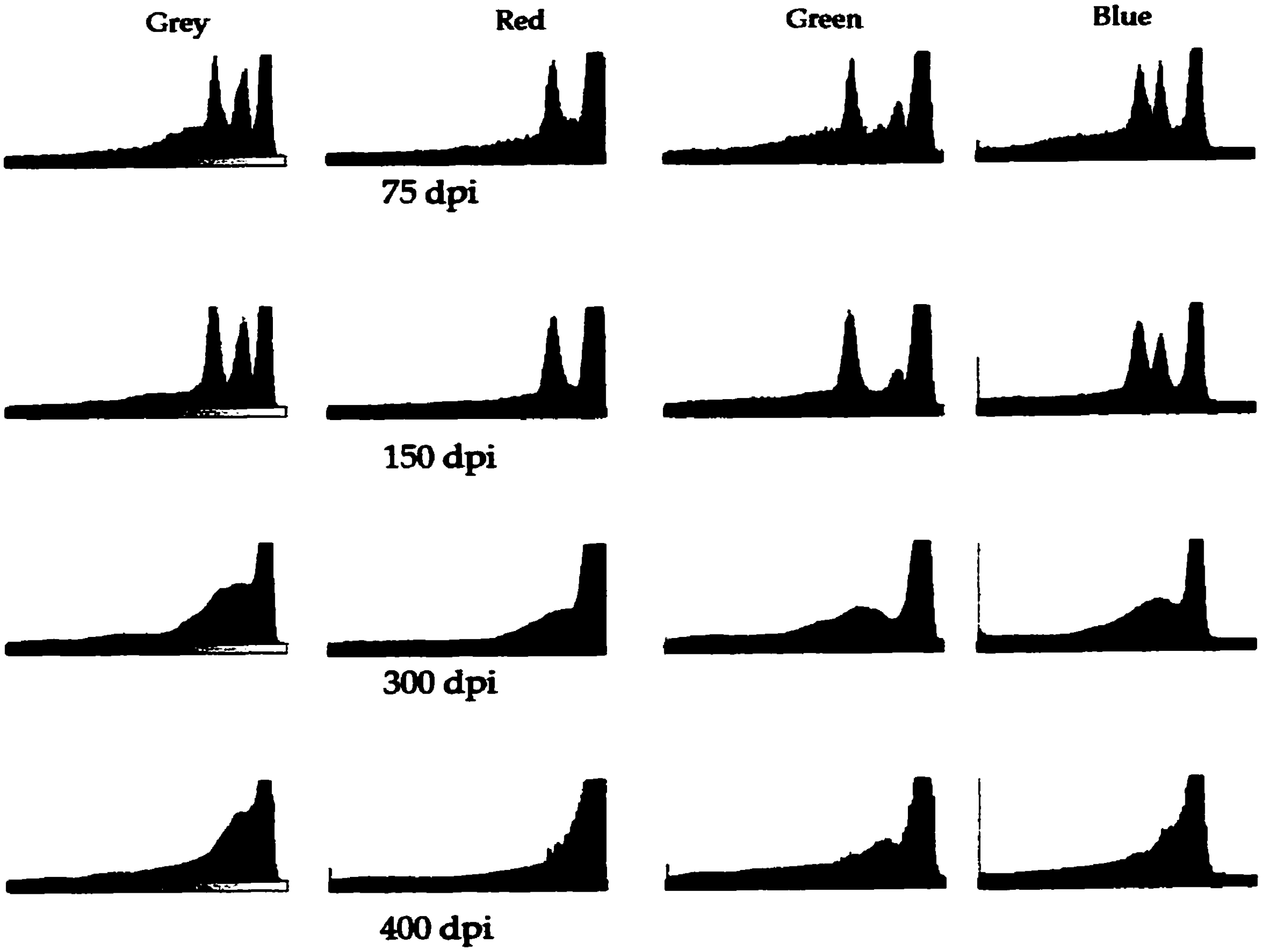
400 dpi, enlarged 2400%

becoming increasingly well defined. Furthermore, while artifactual colours are still present, the colour of the lines is closer to that of the original map. Also, the contour line has become darker brown rather than pale tan or taupe; again, this is closer to the original. The diagonal runway lines still contain purple pixels, but they are becoming darker as the resolution increases. One could expect that if the resolution were to be increased further (impossible with the scanner used in this research), that the lines would eventually become black; indeed, the runway lines on the left half of the image are almost black in the 400 dpi version.

While these higher resolution images both contain artifactual colours, because more and more pixels are beginning to portray colours which are in the original, one can conclude that there is a positive relationship between scanning resolution and the quality of colour reproduction. In other words, as pixel size decreases (or as scanning resolution increases), the effect of the edge pixel phenomenon is mitigated and a closer reproduction of the colours of the original document is the inevitable result.

The histograms of these images highlight the differences in colour reproduction between the increasing scanning resolutions. Photoshop 3.0 will generate a separate histogram for each colour channel, plus a gray histogram that represents the overall brightness of the image (see Figure 5.4). The histograms for the higher resolution images depict a relatively broad colour range with a spike on the right side that dominates the graph. As the

Figure 5.4 Histograms for Images in Figure 5.3.



resolution decreases, the graphs become strikingly multi-modal in nature. That is, multiple spikes of equal height are scattered along the graph. This indicates that the digital images are portraying many variations of colour. As the only difference between the digital images is the scanning resolution, the differences in the histograms are products of the increased resolution.

5.2 Legibility and Sharpness of Fine Detail

The distinction between legibility and sharpness of fine detail is found within the wording of the questions rather than within the subject images themselves. That is, in questions dealing with legibility, the respondents were asked directly, "What is this word (or number, or symbol)?", whereas in questions dealing with sharpness of fine detail, respondents were simply asked, "Which image is sharper?" The respondents were given a choice, and were asked to view the entire image, rather than a small portion of it, to decide which version was sharper.

5.2.1 Legibility

The questionnaire contained 17 questions concerning the legibility of text and symbols. The text was of various fonts and styles. For example, in question 1, the text was a 1 mm high contour label on a NTS 1:50,000 map sheet; in question 3, the text was a 2 mm high latitude/longitude coordinate label in the margin of the same NTS map sheet; in questions 12 through 14, the text was handwritten, of various heights and in a foreign language. In questions 9 through 11, the respondents were asked to differentiate between symbols for schools and symbols for churches. In all cases, the scanning resolution was the only digital attribute that varied; all the images were digitized in 24 bpp RGB colour. Again, as in the previous section, some responses were disqualified due to the inappropriateness of the answers.

In Section 4.1.1, Image 3, question 6 asks for the elevation of a specific place. In question 7, the respondents are asked, "The feature at 'B' is:" - the correct answer is a fire lookout tower. However, six respondents gave the answer, "7,900 feet", which is in fact the elevation of the fire lookout tower. Obviously the question was not stated clearly enough, and following so closely after a question asking for the elevation, it is believed by the researcher that the question was misinterpreted by the respondents. Therefore those six "incorrect" responses are considered to be correct, and are included under the heading "Number Right" in Table 11.

Table 11. Questionnaire Responses: Legibility

Scanning Resolution	Number Right	Number Wrong	Number Cannot Read	Number Spoiled	Total Number Responses
75 dpi	119 (35.95%)	105 (31.72%)	107 (32.33%)	5	336
150 dpi	258 (77.48%)	53 (15.92%)	22 (6.61%)	3	336
300 dpi	217 (78.06%)	59 (21.22%)	2 (0.72%)	2	280
300 dpi (b)	182 (81.25%)	39 (17.41%)	2 (0.90%)	2	224

As one might expect, the percentage of correct answers increases as the scanning resolution increases. At 75 dpi, the percentage of right answers, wrong answers and the percentage of respondents who stated that they could not read the text are almost equal. This leads to the conclusion that 75 dpi scanning is inadequate for proper legibility. At 150 dpi, over three-quarters of the respondents gave the correct answer. At 300 dpi, the number of respondents who correctly answered the questions increased marginally. The researcher believes that this number is so low because a large portion of the respondents cannot properly read contour lines on topographic maps. That is, question 6 asks for the elevation of a specific place (see Section 4.1.1, Image 3 of this thesis). A contour label was included in the image, and the contour interval was given to the respondents in the question itself. Despite the high resolution, 20 of 56 respondents answered incorrectly. If the results of question 6 are excluded from Table 11, the percentage of correct responses increases (see the Table 11, 300 dpi (b)).

While the percentage of correct responses for 300 dpi is only about 3.75% higher than the percentage of correct responses for 150 dpi (excluding the results from question 6), the percentage of respondents who stated they could not read the text drops dramatically from 150 dpi (6.61%) to 300 dpi (0.90%). In other words, more than 7 times as many respondents stated they could not read the text at 150 dpi as at 300 dpi. Furthermore, the percentage of respondents who stated they could not read the text at 75 dpi is almost 36 times higher than the corresponding figure for 300 dpi. This leads to the conclusion that there is a strong positive relationship between increased scanning resolution and increased legibility of the resulting digital image.

5.2.2 Sharpness of Fine Detail

This subsection is divided between questions dealing with Complex Polychrome images and Intermediate Polychrome images. In both cases, it is the bit depth and/or the compression algorithm that varies; the scanning resolution remains constant at 150 dpi.

In the JPEG compression algorithm, the larger the DCT quantization coefficient, the more data is lost (see step three, Section 2.5.3 of this thesis). This loss of data results in lower image quality, which could manifest itself in colour palette shifts, blurring of edges and lines, or both. This phenomenon is detailed in the first section of Table 12a and in Table 12b, wherein the JPEG Max images, which have low DCT quantization coefficients, are heavily favoured over the other choices.

The numbers in the second section of Table 12a, dealing with Intermediate Polychrome images, leads to the conclusion that 8 bpp is more adequate than 24 bpp for Intermediate Polychrome images. The reasons for this are outlined in the following subsection.

Table 12a. Questionnaire Responses: Sharpness of Fine Detail

Image Attributes	Number of Responses	Total Responses	Spoiled Responses	Percent (not incl. spoiled)
Complex Polychrome				
JPEG Max	28	56	0	50.0%
JPEG Low	11	56	0	19.64%
8 bpp	17	56	0	30.36%
Intermediate Polychrome				
8 bpp	87	112	2	79.09%
24 bpp, RGB	23	112	2	20.91%

Table 12b. Questionnaire Responses: Ratings of the Sharpness of Fine Detail of a Complex Polychrome Image

	Rank	1 Good	2	3 Medium	4	5 Poor
JPEG Low	3	1	4	12	17	21
JPEG High	2	5	19	24	6	0
JPEG Max	1	14	26	12	1	1

5.2.3 The Effect of Colour Bit Depth on Image Sharpness

The literature dealing with issues of bit depth is concerned with the colour reproduction capabilities of the various depths. The majority of articles state that 8 bpp is insufficient to capture the image adequately (for example, see Tilton, 1995; Gartner, 1994, and others). Furthermore, according to Cartolano *et al.* (1995), 24 bpp colour depth is a fundamental requirement in order to produce a faithful digital replica of colour originals. However, the results of this questionnaire suggest that, for Intermediate Polychrome images, 8 bpp is more than adequate; in Table 9a, over two-thirds of the respondents preferred the colour reproduction of the 8 bpp Intermediate Polychrome image over its 24 bpp counterpart. Furthermore, in Table 12a, almost 80% preferred the sharpness of the 8 bpp image over the 24 bpp image. Based on these results, one can conclude that 24 bpp colour depth is in fact not absolutely required to adequately capture all the colour and details of an Intermediate Polychrome image.

That the 8 bpp indexed images were preferred for sharpness over the 24 bpp, RGB images results from a combination of two factors; first, Intermediate Polychrome images contain a limited number of textures and colours (usually fewer than ten), and; second, 24 bpp is capable of reproducing almost 16.8 million discrete colours. The combination of these two seemingly unrelated factors can lead to degradation of the digital image.

As defined in Section 5.1.2, edge pixels are created whenever a pixel overlaps the line separating areas of different colour on the original. In effect, the colours are combined by the process of digitization to produce a new, artifactual colour not found on the original. The result is that the line between the two areas of different colour is fuzzy, or hazy, because there is a buffer of pixels between them containing artifactual colours. Furthermore, many of these artifactual colours may be unique within the image. That is, a particular pixel may be the only one in the image with that specific artifactual colour.

In an Intermediate Polychrome image, such as a NTS topographic map, the combination of lines, edges and textures creates numerous opportunities for the production of edge pixels containing artifactual digital colours. A typical NTS 1:50,000 topographic map contains eight colours - white, black, grey, red, orange, green, blue, and brown. There exists opportunity to create artifactual digital colours every place where a border between two or more colours is present - this is especially true when the image is digitized using 24 bpp. With a colour palette containing over 16.7 million colours, the digitization process can produce an extremely high number of artifactual colours. However, by using an 8 bit adaptive colour palette, the digital preservationist can force the computer to drop many of the artifactual colours. That is, the computer selects the 256 most dominant colours contained within the image to produce the colour table. Many of the pixels containing unique artifactual colours are converted to the closest colour value within the new colour table.

Using a program entitled "Graphic Converter" (version 1.7.6, © Thorsten Lemke, 1993), the user can determine the number of colours in a digital image. The four Intermediate Polychrome images used in the questionnaire were loaded into Graphic Converter, and the number of colours for both the 24 bpp and 8 bpp versions were recorded (see Table 13).

Table 13. Number of Colours Used in Intermediate Polychrome Images: 24 bits per pixel and 8 bits per pixel.

	24 bpp	8 bpp
"Map no. 25e..." (geological map)	5951	255
NTS, Bath, edition 5	6431	255
NTS, Bath, edition 7	6677	256
NTS, Lake Louise	2794	255

One can readily see that the 24 bpp images contain a significantly greater number of colours than their 8 bpp counterparts. Interestingly, in three of the cases, the 8 bpp versions did not utilize all of the 256 available colours. This suggests that there were several thousand pixels in each image which contained unique artifactual colours.

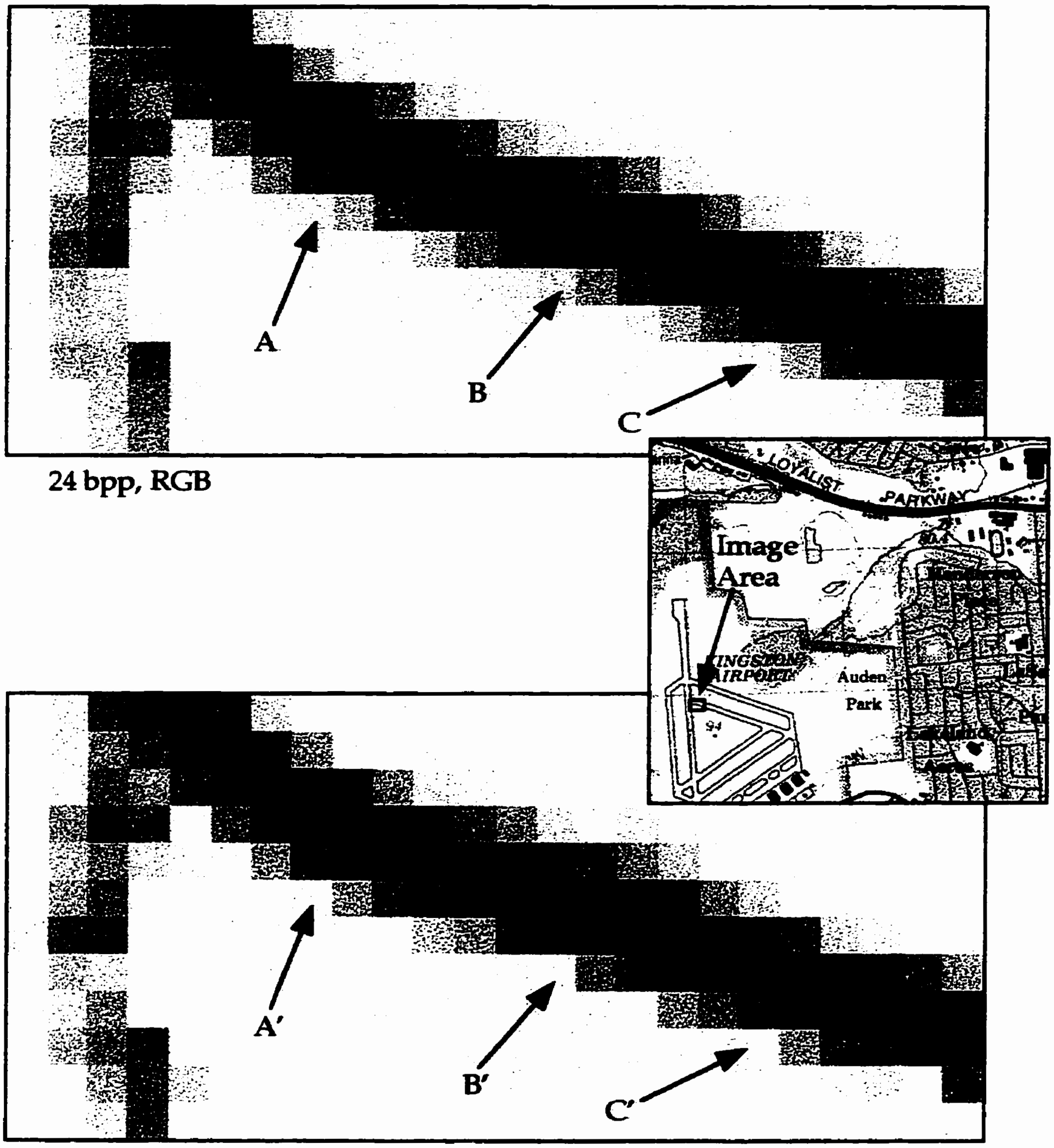
Paradoxically, the loss of these colours may actually increase the quality of the digital image, in terms of the sharpness of the image. That is, along lines, edges, and borders between areas of uniform colour, the presence of edge pixels containing unique artifactual colours can cause the image to become blurry. When the image is indexed from 24 bpp to 8 bpp, edge pixels which contained artifactual colours in the 24 bpp version are forced to adapt to the new colour table; that is, they change from a unique shade to a colour contained in the new 8 bit colour table. The result is that the edge pixels in the 8 bpp version are closer in value to their neighbours than they were in the 24 bpp version, thus causing the edges, lines and borders to appear sharper. That is, the buffer of edge pixels containing unique artifactual colours is replaced by pixels of a more uniform colour.

This is illustrated in Figure 5.5. In the line that comprises the main body of the image, about half the pixels are shades of green and half are shades of pink. Closer to the edges of the line, the pixels become lighter in colour. Notice in the 24 bpp version that the pixels labelled A, B, and C all have a slight red or pink hue. They are similar in colour to neighbouring pixels. That is, the pixels to the right are slightly darker while the pixels to the left are lighter. However, despite this similarity, these pixels are distinct from their neighbours, and from one another. Photoshop 3.0 will allow the user to determine the value of each of the RGB colour components of a given pixel (see Table 14).

Table 14. RGB Colour Values for Pixels Specified in Figure 5.5

Pixel		Colour Values	
	Red	Green	Blue
A	239	215	219
B	226	205	215
C	242	213	219
A′	239	231	222
B′	239	231	222
C′	239	231	222

Figure 5.5 Comparison of 24 Bit and 8 Bit Images.



24 bpp, RGB

8 bpp, indexed

The numbers in Table 14 refer to the colour values, from 0 to 255, of the three colour components for the specified pixels. Notice that the colour values for A, B, and C are different from one another; that is, each pixel is a different shade. These pixels, and ones of similar colour along the edge of the line, make the line appear blurry when viewed at a lesser magnification (the images in Figure 5.5 are enlarged 10,000%).

Notice in the 8 bpp version of Figure 5.5 that the pixels labelled A′, B′, and C′ (which correspond to A, B, and C in the 24 bpp version) have changed colour. This occurred when the colour table was indexed from 24 bpp to 8 bpp. These pixels have lost the pinkish hue present in the 24 bpp version, and now have a uniform colour, similar to that of the background shade. This is reflected in Table 14, wherein the colour values for A′, B′, and C′ are identical to one another. Furthermore, when viewed at a lesser magnification, the line appears sharper as there is now greater distinction between the dark pink pixels and the background colour. Therefore, image quality, with respect to sharpness, is improved.

Chapter 6.

Conclusion

When digitizing a colour image, the digital preservationist must ask him/herself the following question: are the images to be used for research purposes, or for browsing and/or indexing? The answer to this question will have an impact upon the standards used in the digitization process. Different researchers have different uses for digital images. If the image is to be used in an application where the quality is not critical, for example as an index image, then considerations such as file size and minimum legibility requirements must take priority. However, another researcher may be concerned with the paper stock on which the original work was produced. For example, he/she may be interested in identifying the watermark, or seeing the chain lines and laid lines in an attempt to identify the paper manufacturer. Likewise, another researcher may be interested in the inks and dyes used in the printing process. In these instances, digital images are typically used by researchers either in lieu of handling the fragile originals, or because the originals are not easily accessible due to their location, and therefore increased image quality will be invaluable to the researcher.

This thesis has dealt with many combinations of colour bit depth, scanning resolution and compression and the researcher has reached several subjective conclusions regarding the appropriate combinations of these digital attributes for the different map types under different conditions of use. Conclusions regarding each digital attribute will be discussed separately.

6.1 Conclusions Regarding Scanning Resolution

For research and archival uses, images should be scanned at as high a resolution as possible. As indicated by the responses to the questionnaire, 75 dpi and 150 dpi are inadequate, even for access copies. Even at 300 dpi, the highest resolution used in the questionnaire, a substantial percentage of the respondents gave incorrect answers. This resolution may be acceptable for browsing or indexing purposes, but archival copies must be as accurate as possible; this can be achieved by increasing the scanning resolution.

Another important finding stemming from this research is that there is a positive relationship between increased resolution and better colour reproduction. That is, as scanning resolution approaches infinity, colour reproduction must inevitably improve; as the sampling pitch becomes smaller, the production of edge pixels is diminished, thereby ameliorating colour reproduction.

6.2 Conclusions Regarding Bit Depth

As indicated by the results of the questionnaire, 24 bpp is required to adequately capture the colour of Complex Polychrome images; 8 bpp was deemed inadequate. However, for Intermediate Polychrome images, 8 bpp was actually preferred by the respondents for colour reproduction over the 24 bpp versions; one could reasonably conclude that this applies to the other image categories (Simple Polychrome, Monochrome Continuous Tone, and

Monochrome Line) as well. Furthermore, this research found that, for Intermediate Polychrome images, there is a negative relationship between bit depth and image sharpness. The paradox inherent in this conclusion is that despite the limited colour table, and the forced conversion of colours concomitant with indexing, image quality was actually improved. This is contrary to all current literature on the subject of digital preservation of colour images.

6.3 Conclusions Regarding Compression Algorithms

The JPEG Maximum algorithm did not significantly diminish image quality. However, the more heavily quantized the JPEG "Q" factor, the lower the image quality. Therefore, the JPEG Maximum compression scheme is better suited for purposes of digital access than its more heavily compressed counterparts. As indicated in Tables 1 through 8, the LZW compression algorithm is inadequate for scanned images, and should not be considered for use in this application.

6.4 Conclusions Regarding Standards for Digitizing Paper Based Colour Images

The most important conclusion to come from this thesis is that the optimal combination of digital attributes varies between image category (see Table 15). For instance, regarding Intermediate Polychrome images, 8 bpp was preferred over the 24 bpp version. However, 8 bpp was deemed inadequate by the respondents for colour reproduction of Complex Polychrome images,

Table 15.
Simple Methodologies for Digitizing Paper-Based Colour Maps and Images

Image Category	Scanning Resolution	Bit Depth	Compression Algorithm
Monochrome Line	150 dpi	1 to 8 bit	n/a
Monochrome Continuous Tone	300 dpi	8 bit	JPG Max
Simple Polychrome	300 dpi	8 bit	n/a
Intermediate Polychrome	300 dpi	8 bit	n/a
Complex Polychrome	300 dpi	24 bit	JPG Max

who preferred the 24 bpp versions. This suggests that standards must be customized for each image type. That is, the digital preservationist must take an heuristic, pragmatic approach when digitizing paper based colour images; the combination of digital attributes that works best for one image may not necessarily be the best for the next image.

6.5 Limitations of the Study

The researcher discovered several limitations to this study, either while the study was underway or during the analysis and write up of the results. First, while a sample size of 56 respondents may be statistically significant, the sample group was not selected in a rigorous statistical manner. A properly selected statistical sample would lend more weight to the analysis and conclusions drawn from the questionnaire. Furthermore, a longer, more detailed questionnaire, which explores more possibilities, would also lend more credibility to the conclusions. However, there was neither the time nor the money to undertake a larger, more detailed survey.

Bias may have been introduced to the questionnaire results by the lighting conditions under which the images were viewed. Different lighting conditions - sunny, cloudy, lights on, lights off - can produce subtle changes to the colours on the screen. Furthermore, as the monitor heats up, colour fidelity changes, possibly introducing bias to the answers. The researcher had no control over these conditions, and no effort was made to overcome them. However, as all the images were viewed on the same screen, and there were no questions wherein respondents had to compare on-screen images with the paper originals, this problem is minor.

6.6 Beyond the Scope of this Study

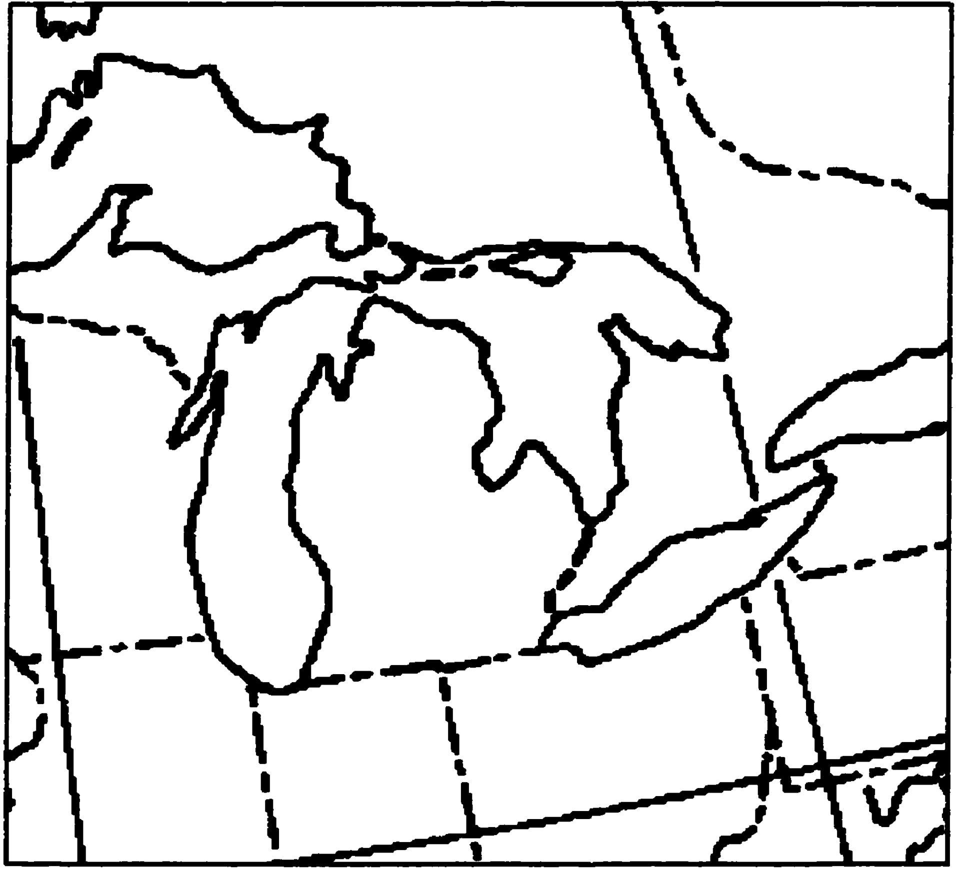
This research has delved into the issues surrounding digital colour reproduction and legibility. However, this thesis merely skims the surface of many important questions in its study of colour perception and legibility.

A fuller analysis of the legibility of digital images might have a large group of people and multiple scans of text at different resolutions, including variations in font, size, text colour and background colour. The images could then be presented in ever decreasing resolutions; once a certain percentage of the subject group can no longer distinguish the text, it is deemed illegible. As another alternative, rather than using a Comparative Scale, as in this thesis, a researcher could use Pairway Comparison, comparing pairs of images and creating a matrix of values which reflects the weights of significance. This is in fact a more statistically robust approach than the one used in this thesis. Furthermore, another research study could examine the tasks different people perform with paper based maps, and assess the applicability of digitized versions to these tasks. Finally, a study to test the geometric accuracy of scanners should be undertaken. For example, a map with a UTM grid could be scanned, the pixel locations recorded and a determination could be made regarding the spacing and alignment of the pixels.

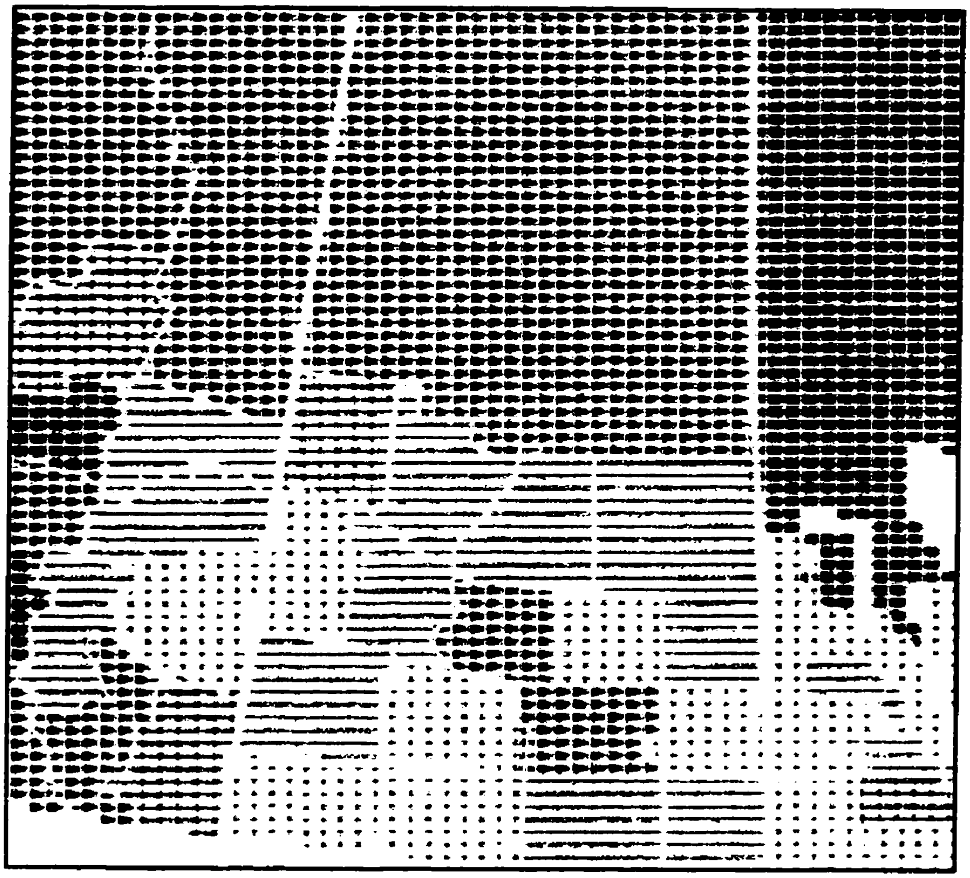
6.7 Final Thoughts

Images intended for research purposes need to be much more accurately reproduced than those intended for browsing or indexing. Therefore, research images should be digitized using the highest possible quality standards. As one of the tenets of digital preservation is to produce a faithful replica of the original, it is ironic that most research into digital imaging is concerned with finding that quality which is simply "good enough." That is, in the search for the "perfect" compromise between file size and image quality, all too often the priority is to minimize the disk space required to store an image rather than to find the optimal image quality. However, it is impossible for a digital preservationist today to know what will be required of digital images in the future. Therefore, if the image is to be used for archival/research purposes, it is imperative that the image be captured at the highest possible quality. Given that the technology for capturing, storing, retrieving and viewing images is constantly improving, images that are "good enough" today likely will be wholly inadequate in the near future.

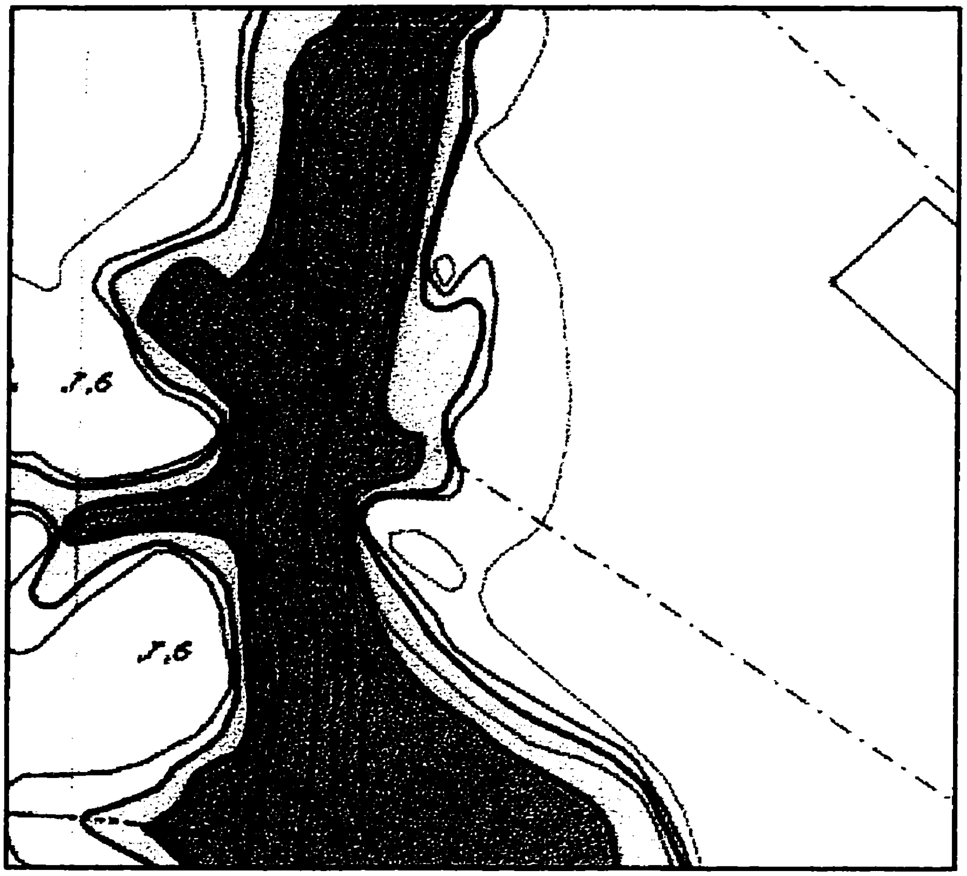
Appendix 1. "The Great Lakes", Cartographic Section, Department of Geography, University of Western Ontario.



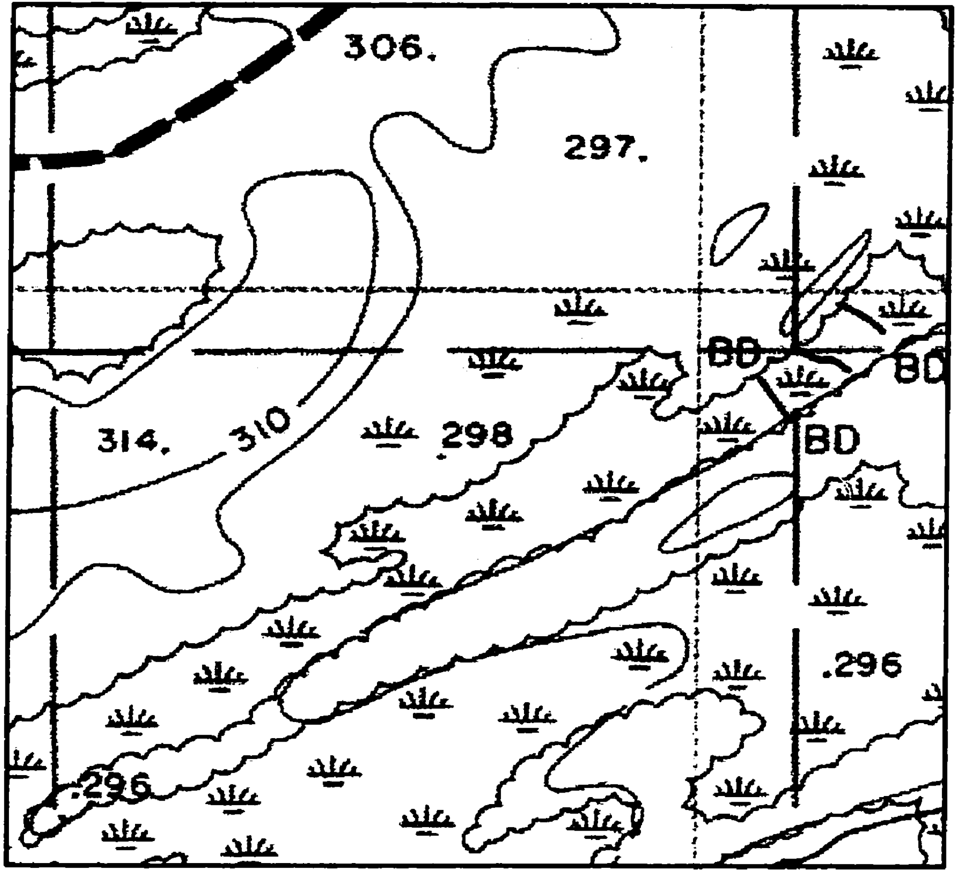
<u>Appendix 2.</u> "Population Change by Census Divisions 1966-71",
1971 Census of Canada.



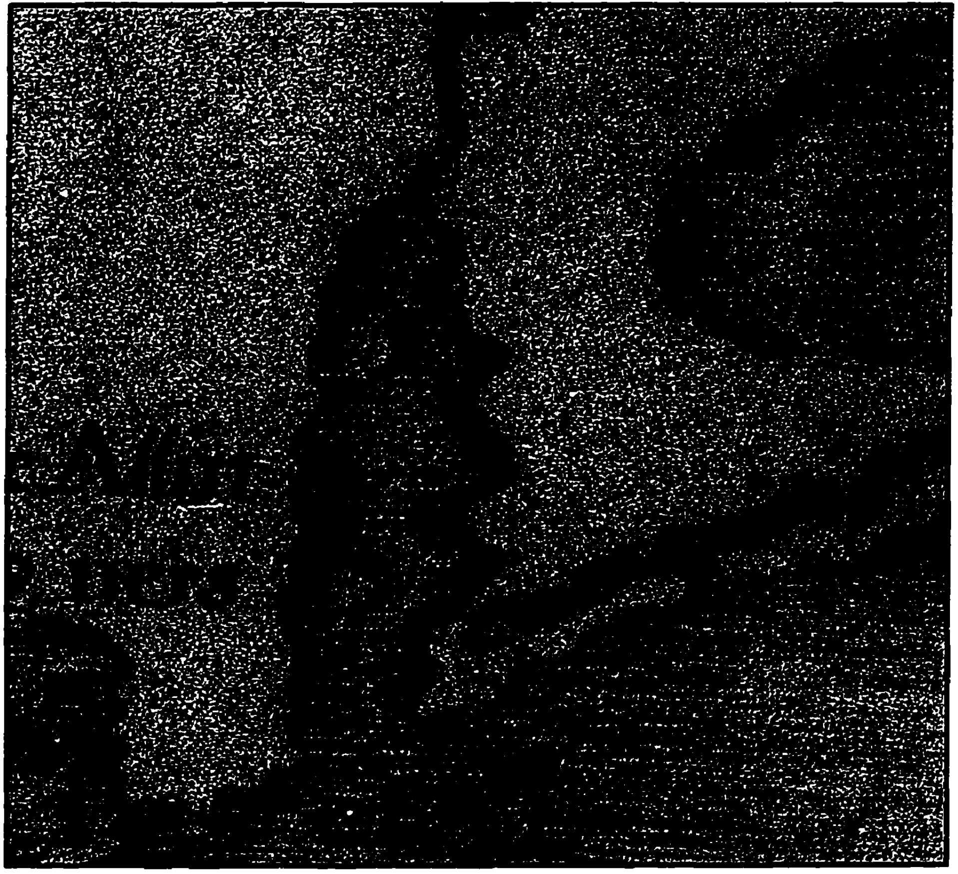
Appendix 3. "Flood Risk Map, Champlain, Fleuve St-Laurent", sheet no. 31/08-020-1506-0, Environment Canada.



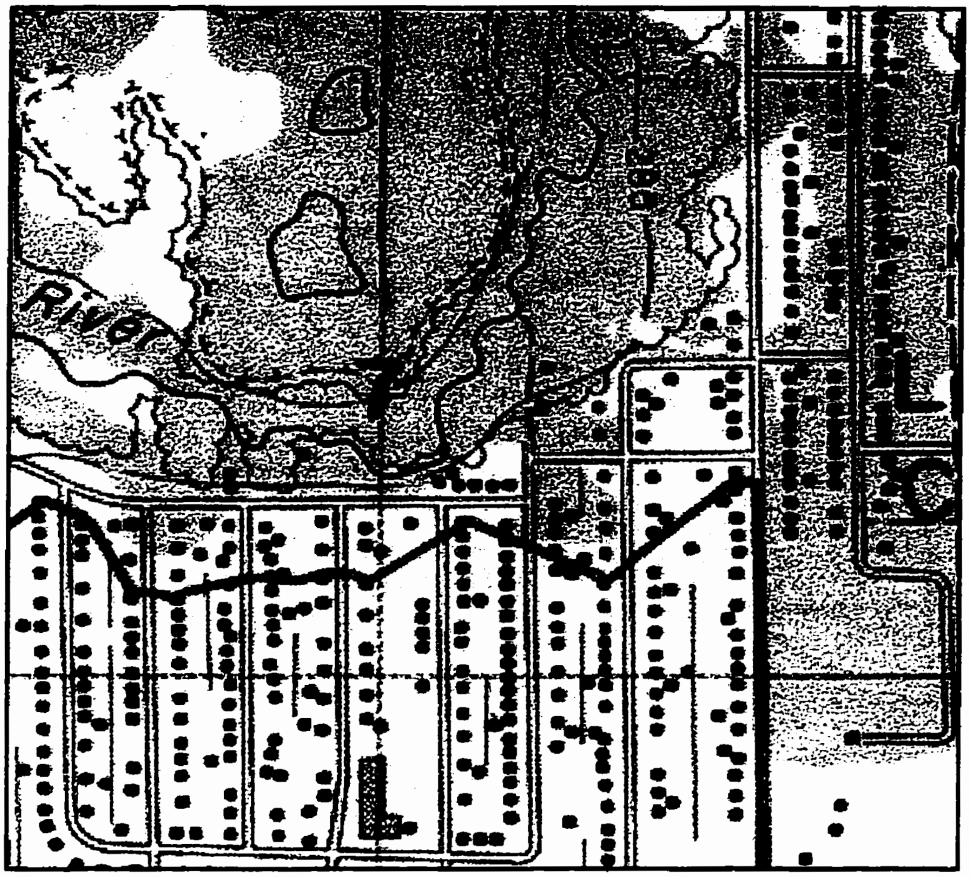
Appendix 4. "Flood Risk Map", sheet no. 20 17 4900 51600, Nickel District, Environment Canada, Inland Waters Directorate, Ministry of Natural Resources.



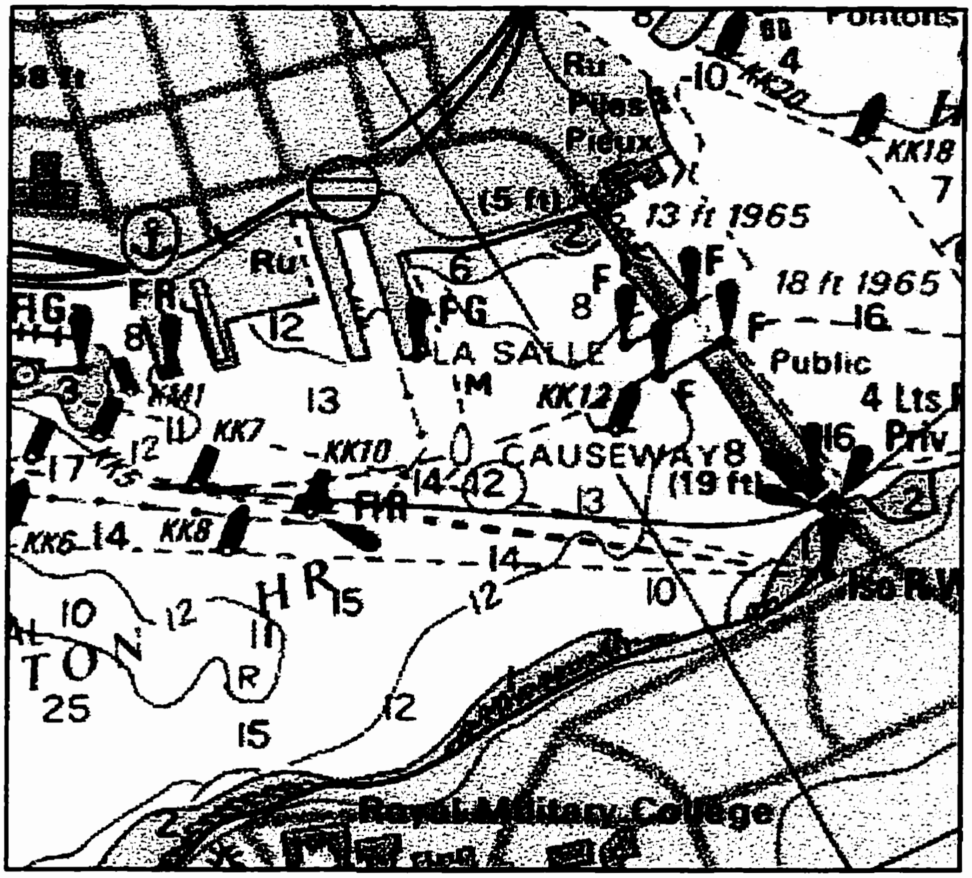
Appendix 5. "Lac Superieur et autres lieux..." Fathers Claude Allouez and Claude Dablon, originally published in "Jesuit Relations", 1670-71, reproduction available in the Serge Sauer Map Library, Department of Geography, University of Western Ontario.



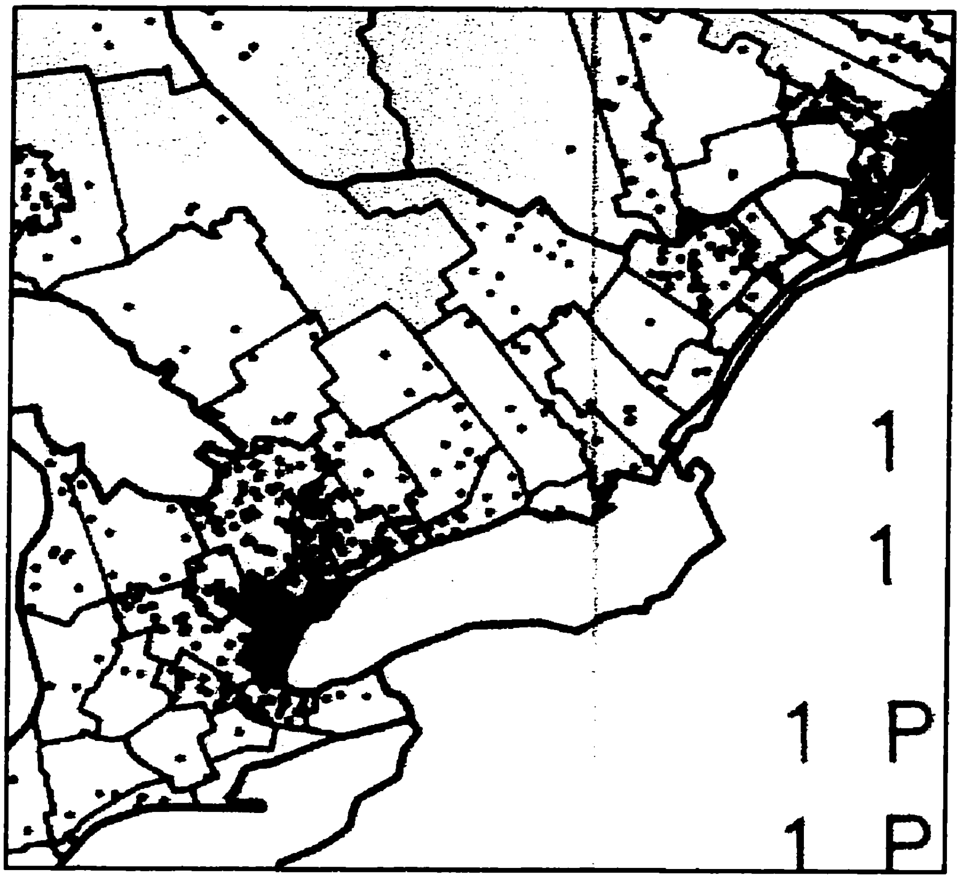
Appendix 6. "Flood Risk Map", sheet no. 20 17 4900 51600, Nickel District, Environment Canada, Inland Waters Directorate, Ministry of Natural Resources.



Appendix 7. "Rideau Waterway Small Craft Chart, no. 1513, Smith Falls to Kingston, sheet 5", Canadian Hydrographic Service.

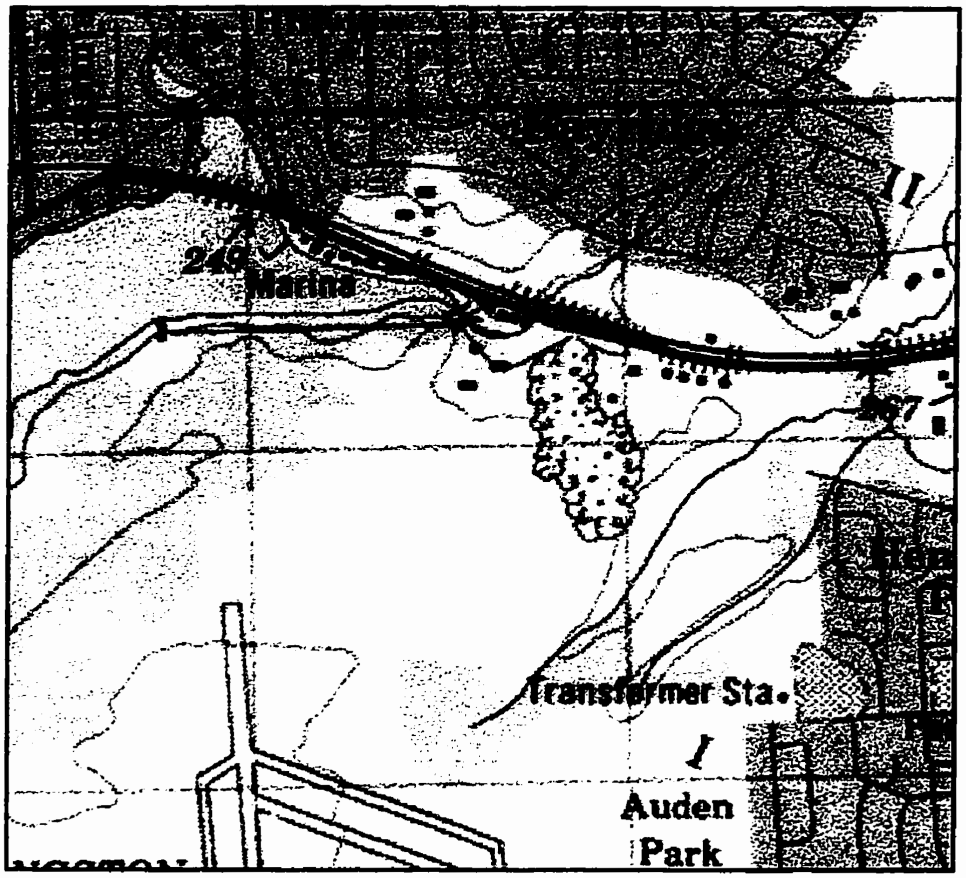


Appendix 8. "Net Internal Migration for Population 5 Years and Over, by Census Division, 1976", 1976 Census of Canada.

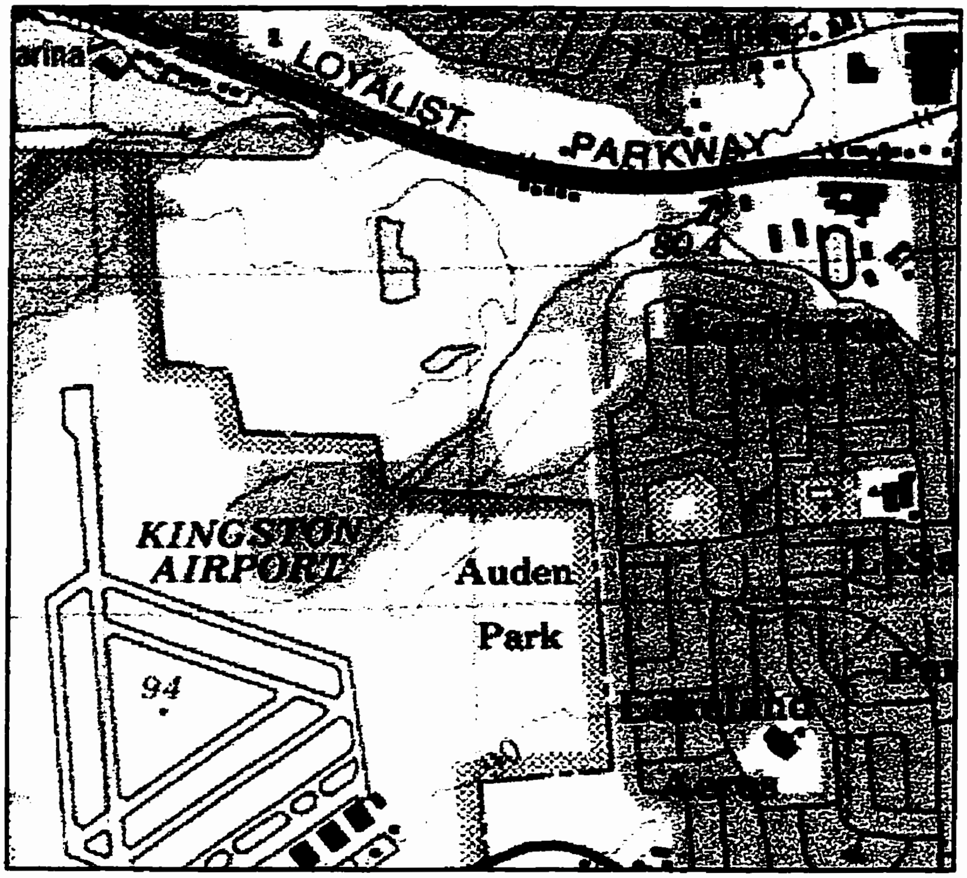


Appendix 9. "Map no. 25e, South Part of Frontenac County, Eastern Ontario, to accompany report by M.B. Baker, in Part III, Volume 25, Report of the Ontario Bureau of Mines, 1916."

Appendix 10. National Topographic Series, 1:50,000
"Bath", sheet no. 31 C/2, edition 5, 1979.

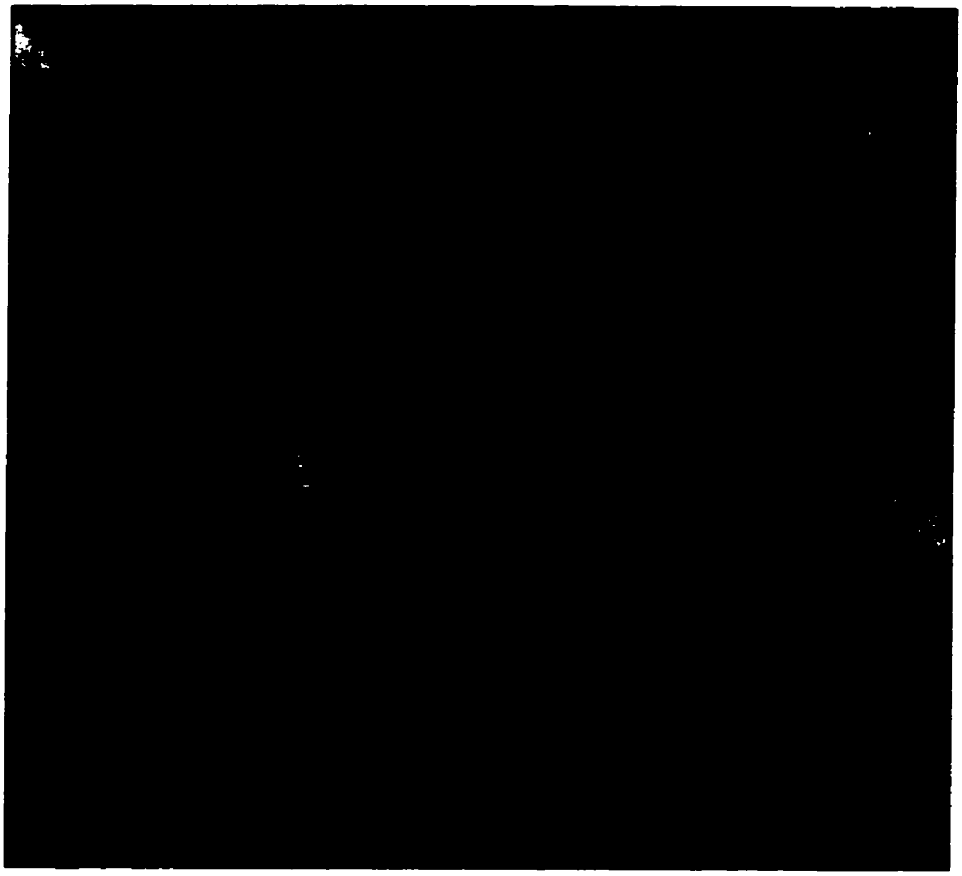


<u>Appendix 11.</u> National Topographic Series, 1:50,000 "Bath", sheet no. 31 C/2, edition 7, 1991.



<u>Appendix 12.</u> National Topographic Series, 1:50,000
"Lake Louise", sheet no. 82 N/8 West, edition 5, 1972.

Appendix 13. Air photo, part of Lambton County, 1973,
no. RSA 30719-127.



Appendix 14. Air photo, part of Lambton County, 1973, no. RSA 30720-6.

Appendix 15. World Map of Vesconte Maggiolo from his portolan atlas 1511, reproduced by Rand McNally, no date.

Appendix 16. "The Pacific Ocean in 1589", reproduced from an engraving in the collection of Historic Urban Plans, Ithaca, New York.

Appendix 17. "The Pacific Ocean in 1589", reproduced from an engraving in the collection of Historic Urban Plans, Ithaca, New York.

Appendix 18. The Questionnaire.

Geography 142a

Experimental Computer Exercise

This exercise is designed to help the instructor find out the best way to create images of maps on the screen. It is not intended to test your understanding of maps - the purpose is to find out what kinds of images are easiest to read and work with. The questions are mostly designed to show if a certain version of an image is easy to interpret, or which of several images looks best. It is just as useful to say 'can't read it' as to give a 'correct answer, since that will help avoid problems in future classes.

Students who have used a Macintosh computer before will have no difficulty doing this lab on their own. Students who have used "Windows" will find this system very similar as well. If you have no experience with either, you should be able to follow the instructions easily, but you may find it easier to team up with somebody else who can guide you through the steps. In fact I encourage everyone who can to work with a partner, either to help with the operation of the computer or to reduce the time that the system is tied up with this project.

The instructor will make some time available to help students who particularly need assistance. The hour before lecture (6.00 to 7.00 every Wednesday) will be available for this purpose - just go to the Map Library. Other times can be booked in advance - see your instructor. In addition, a graduate student (who will be helping analyze the results) will also make some time available, as announced in class.

INSTRUCTIONS:

1. You will find the computer we will use in the small room at the rear of the Map Library at the end of a long row of bookshelves - ask at the desk for the "Air Photo Room".

2. Turn on the computer. There is only one button to press - the one with the triangle symbol at top right of the keyboard.

3. When the computer has started up, look for two symbols on the screen, one labelled "142 Experiment", the other "JPEGView SlideShow". Use the computer mouse to move the arrow pointer onto the box labelled "142 Experiment". Hold down the mouse's button and drag the "142 Experiment" until it is on top of "JPEGView SlideShow". Let go of the button. If nothing happens, try again until it works.

4. Now the pictures will appear one at a time on the screen. Answer the questions for each one, the move the arrow pointer to the control box at the bottom of the screen. Put the pointer on the right-facing arrow and click the mouse button once to see the next picture.

5. When the last image appears, a message box flashes up to tell you that the slide show has finished. Click the mouse button with the pointer in the "OK" box to remove that message, and answer the last question.

6. After answering the last question, click the mouse button with the pointer in the black background area. A "menu bar" appears at the top of the screen. Move the pointer to the word "FILE". Hold the mouse button down on FILE and a menu appears. Keep holding the button down, pull the pointer down to the word QUIT and let go of the button.

7. To shut down the computer, move the pointer to the word SPECIAL in the menu bar. Hold down the button, pull the pointer down to the SHUT DOWN menu and let go of the button. There are no other buttons or keys to press.

THANK YOU for your help with this experimental project.

QUESTIONS:

<u>Image 1</u> (don't worry - it is supposed to be hard to read)

1) The elevation indicated at "A" is ____________________

2) The name inside the box at "B" is ____________________

<u>Image 2</u>

3) The latitude and longitude at "A" are ____________________

4) The name at "B" is ____________________

5) The elevation at "C" is ____________________

<u>Image 3</u>

6) The elevation at "A" is ____________________

7) The feature at "B" is ____________________

Image 4 (test of colour reproduction)

NOTE: if you have trouble distinguishing colours, please indicate here (__) and proceed to the next question.

Using the large letters indicated beside the legend boxes, identify all the colours in the small maps (figures i, ii, and iii). Be warned, though - not all the colours in the legend will be in every map and not all colours in a map will necessarily be in the legend. If you find a colour in a map which does not appear to be in the legend, simply write a name for the colour (e.g. blue, pink) at the end of the answer.

For example, if you think a certain figure contains only legend items A, E, and G, write "A,E,G" as your answer.

8.i) Figure i contains ____________________
8.ii) Figure ii contains ____________________
8.iii) Figure iii contains ____________________

Image 5

In Figure i, "A" is a church and "B" is a school.

9) In Figure ii, is "C" a church or a school? ____________________

10) How many churches and how many schools are there in Figure iii?
churches ____________________ schools ____________________

11) How many churches and how many schools are there in Figure iv?
churches ____________________ schools ____________________

Image 6 (don't worry - it is expected to be hard to read).

NOTES:

1. If you can't read it, just say so.
2. If you can't tell what a letter is because of the old-fashioned script, just copy its shape.

Image 6a: Give the placenames indicated at "A", "B", and "C"

12a) "A" ____________________
12b) "B" ____________________
12c) "C" ____________________

Image 6b: Give the placenames indicated at "A" and "B":

13a) "A" ____________________
13b) "B" ____________________

Image 6c: Give the placenames indicated at "A" and "B":

14a) "A" ____________________
14b) "B" ____________________

Image 7

NOTE: if you have trouble distinguishing colours, please indicate here (__), omit part A and proceed to part B.

This is part of a colour air photo showing land and water. Assume that Figure i is a good representation of the original.

A: rate the colour reproduction of the other figures:

	GOOD		MEDIUM		POOR
15a) Figure ii	1	2	3	4	5
15b) Figure iii	1	2	3	4	5
15c) Figure iv	1	2	3	4	5
15d) Figure v	1	2	3	4	5

B: rate the sharpness of fine details in the other figures:

	GOOD		MEDIUM		POOR
15e) Figure ii	1	2	3	4	5
15f) Figure iii	1	2	3	4	5
15g) Figure iv	1	2	3	4	5
15h) Figure v	1	2	3	4	5

Image 8

NOTE: if you have trouble distinguishing colours, please indicate here (__) and proceed to the next question.

Compare the objects indicated at "A" and "B" in the various figures. Assume that Figure i is a good representation of the original photograph.

16a) Which figure (ii, iii, or iv) gives the best representation of the COLOUR of object "A" ____________________

16b) Which figure (ii, iii, or iv) gives the best representation of the COLOUR of object "B" ___________________

Image 9

NOTE: if you have trouble distinguishing colours, please indicate here (__), omit part A and proceed to part B.

Assuming Figure 9a is a good representation of the original photo, and concentrating on the areas outlined with black boxes,

PART A:

17a) compare colours - which other figure
(9b, 9c or 9d) is the closest to 9a? ___________________

PART B:

17b) compare sharpness of details - which other figure
(9b, 9c or 9d) is the closest to 9a? ___________________

Image 10

Compare Figure 10a to Figure 10b.

18a) Which figure (a or b) is easiest to read? ___________________
18 b) Which figure (a or b) is clearest overall? ___________________

NOTE: if you have trouble distinguishing colours, please indicate here (__) and skip the last question.

18c) Which figure (a or b) gives the best colour
reproduction for the brown contour lines? ___________________

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