Map Production Using Print-On-Demand Capabilities

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INTRODUCTION

The printing industry is being revolutionized by recent technological advances allowing direct digital printing to plate, press, or plotter. This print-on-demand technology has become increasingly popular from the small printing shops to the large publishing houses. This technology eliminates many of the traditional steps necessary to produce the final printed product--thereby cutting costs while speeding output (Niden, 1995). The journal "Graphic Arts Monthly" (Sharples, 1994b) defines print-on-demand as "...printing directly from digital information without intermediate film (often without plates), in smaller quantities, rapid turnaround, and, in full color." The U.S. Geological Survey (USGS) is interested in exploring print-on-demand technology. In an era of declining budgets and limited resources, direct digital color printing will be important in the USGS's ability to reduce overhead costs associated with traditional lithographic technology while satisfying the customer's needs for fast, convenient, high-quality map products.

This paper reviews the current status of print-on-demand technology from two different perspectives based on the USGS's current map production needs. The first perspective focuses on producing high-quality printed map products with direct digital color printing and platemaking technologies. Short-run (less than 5,000 copies), four-color, digital printing presses that are available from several vendors can produce very high-quality printed products in hours direct from an IBM-compatible personal computer (IBM PC), Macintosh (Mac) computer, or workstation. The advances in digital platesetters have allowed printers to take digital data straight from the computer to the press plate--eliminating costly film intermediates and other materials,

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reducing labor hours, while improving overall print quality. The second perspective focuses on a fast, efficient, and cost-effective approach to filling customer orders for out-of-stock maps. Large-format digital color printers/plotters using ink jet, thermal wax transfer, and electrostatic printing technologies are examined based on cost, speed, quality, and image durability. This scenario represents low-end (in terms of quality and hardware costs) print-on-demand capabilities.

The results and recommendations described in this paper represent an investigation and evaluation of current technological advances in the printing industry. It is anticipated that the printing industry will continue to evolve as the need for faster printed output of digital data becomes more important.

CURRENT USGS LITHOGRAPHIC MAPMAKING PROCESSES

To illustrate the advantages of print-on-demand technologies, a brief review of current USGS lithographic map reproduction methods is necessary. The flow chart depicted in figure 1 follows the mapmaking process from original compilation to ultimate distribution in the USGS's Earth Science Information Centers (ESIC)(Palm, 1984; Soller, 1990; Shapiro, 1974; International Paper Company, 1970). Table 1 lists the advantages and disadvantages of using the current USGS lithographic mapmaking process.

The advent of computer cartography and geographic information systems (GIS) software has allowed cartographers to gather, process, and manipulate digital geospatial data and incorporate these data into revising old maps or producing new thematic maps. Advanced, computerized cartographic techniques play an increasing role and are an integral part of the map reproduction cycle in the USGS. However, the current process to take digital information directly to the final printed map is still similiar to the process of 10 to 20 years ago. The USGS has stayed on the

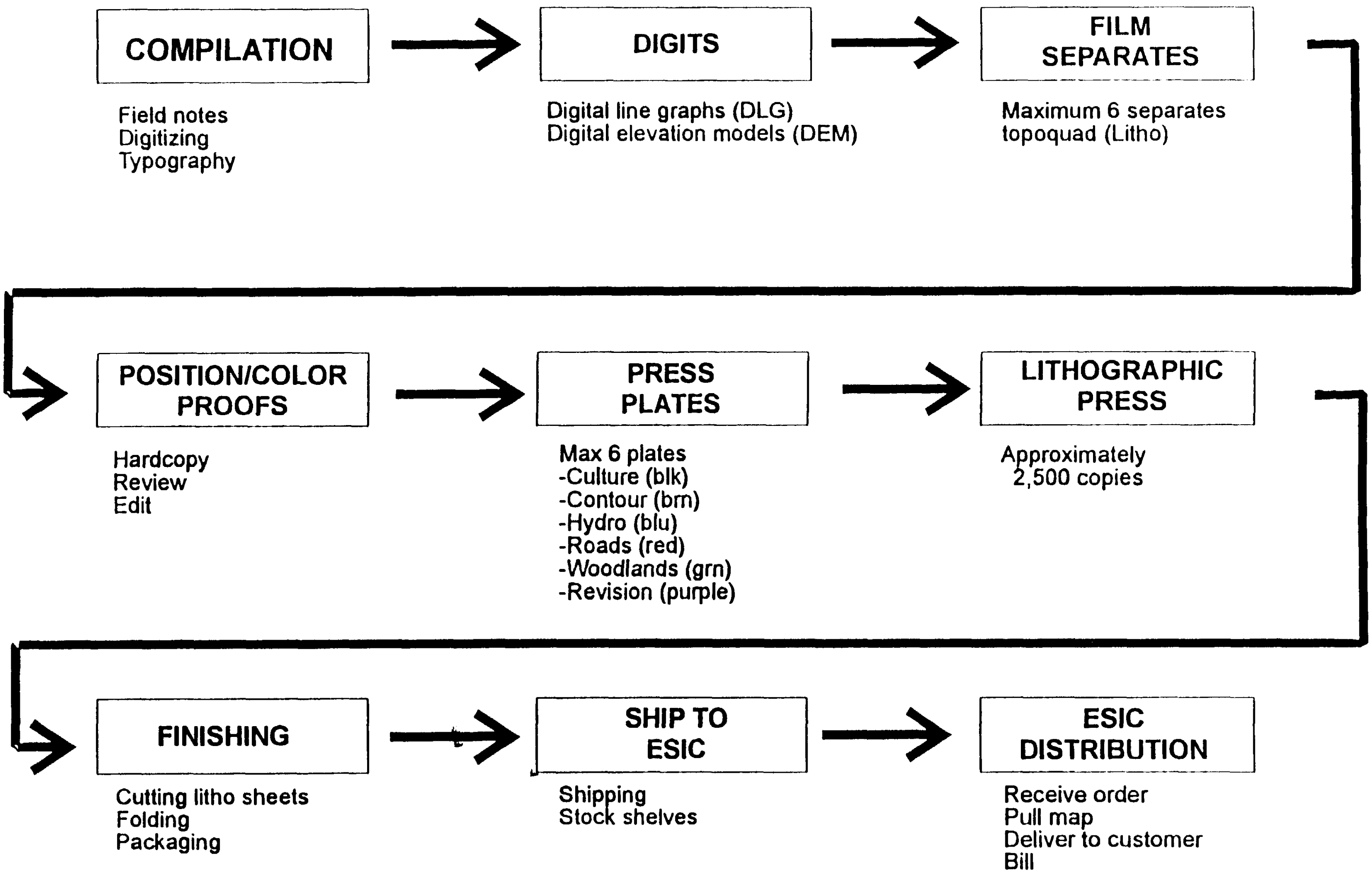

Figure 1. Current U.S. Geological Survey map production process.

Table 1. Advantages and disadvantages of current USGS lithographic mapmaking process

ADVANTAGES	DISADVANTAGES
Less expensive per map	Long time lag between start to finish
Established process	Numerous steps
High quality product	Complex procedure
Established standards	Expensive equipment
Worldwide conventional process	Slow response to change
Updates relatively easy	Too many people/experts
Reprints easy	Too many variables
Standard product	Work flow geographically disjointed
Effective means to produce product	Nonefficient in short runs (in runs over 1,000, it is still the most efficient)
Consumable materials readily available by numerous vendors	Product cannot be customized to specific customer requirements

forefront of the technology for updating digital map compilation techniques. The next step is to update the reproduction of hardcopy maps from their digital cartographic data bases.

New state-of-the-art digital printing technologies can eliminate USGS's present reliance on producing color-separated films and plates. Figure 1 shows that after a map is compiled, either by hand or through manipulation of digital data, then color-separates are produced through a photographic process. Up to six pieces of film are generally used to produce separates for a typical 7.5-minute topographic quadrangle. After a hardcopy proof is made to check the films for errors, presensitized aluminum plates are exposed and developed from the color-separated films. The printing plates are used on the offset press where production runs typically are around 2,500 copies.

The existing conventional photographic and platemaking processes require expensive photographic film, offset printing plates, and other consumables. These are the most inefficient steps of the lithographic process requiring much of the labor and throughput time necessary for reproducing maps. Cartographers in the USGS have access to computer hardware with sophisticated GIS and desktop publishing software that are capable of simulating electronically the prepress steps now being used. Digital manipulation of map data from compilation to plate or press will also allow for quick, inexpensive updates if changes become necessary due to corrections or new information.

Large-format digital color plotters/printers are available that can solve the USGS's problem of reprinting out-of-stock maps by conventional lithographic techniques. Under the current map printing process, it takes approximately 90 to 180 days to fill a customer request for an out-of-stock map (Durant and others, 1995). Using print-on-demand technologies, the USGS map distribution facilities could print out-of-stock maps virtually on-demand through workstations that are interfaced with digital color plotters or printers. Many types of large-format printers are available that use a variety of printing technologies, such as ink jet, thermal wax transfer, or electrostatic. These systems will allow the USGS to cut costs by reducing storage of thousands of topographic quadrangles and improve customer service by providing USGS map products without lengthy delays.

COMPUTER-TO-PLATE TECHNOLOGY

It is now possible to eliminate the photographic process of making film color-separates by taking digital data directly to plate (Lamparter, 1994, 1995; Romano, 1994, 1995; Southern Graphics, 1994; Karsh, 1994; Seybold, 1994c; Seybold, 1994d; Sharples, 1995). This computer-to-plate (CTP) technology has many important benefits compared with traditional lithographic techniques. Elimination of the photographic process cuts production costs by reducing personnel, cutting out expensive film and photographic chemicals, and speeding map production. In this era of environmental awareness, CTP is very attractive because printers will no longer need to handle and dispose of the chemicals associated with film and developing solutions. Print quality is also improved in the CTP process. Because the digital data can be generated straight to the plate without the intermediate steps required for film separates, potential errors are reduced or eliminated. Figure 2 shows how the current USGS map production process could be streamlined by converting to computer-to-plate technology. Table 2 lists the advantages and disadvantages of this process.

Large-format digital platesetters comprise the essential hardware component of the CTP process. These platesetters transfer digital information to a printing plate by using several techniques (Romano, 1995). Instead of using high intensity ultraviolet light, lasers are often used to etch the printing plates; or, in the case of light-sensitive plates, visible light lasers are used to expose the plates. In some platesetters, heat sensitive plates can be exposed by infrared radiation. These platesetters can produce press-ready plates up to sizes suitable for USGS map products. Aluminum offset printing plates are now available in varying emulsions and coating materials, such as photopolymer, silver halide, and polyester, depending on the user's printing needs in regard to line screen image quality or number of printing impressions required. Leading vendors of large-format platesetting hardware are shown in table 3 (Lamparter, 1995; Romano, 1995; Wilson, 1995).

Digital data must first be manipulated through a raster image processor (RIP) before they are compatible with platesetting hardware. A RIP can either be the computer hardware or the software that translates digital information into a format suitable for the platesetter equipment to use (Joss, 1995). Software driven RIP's are preferable because they can be easily upgraded as RIP technology continually advances. Printers who choose dedicated hardware RIP's may soon find that the hardware

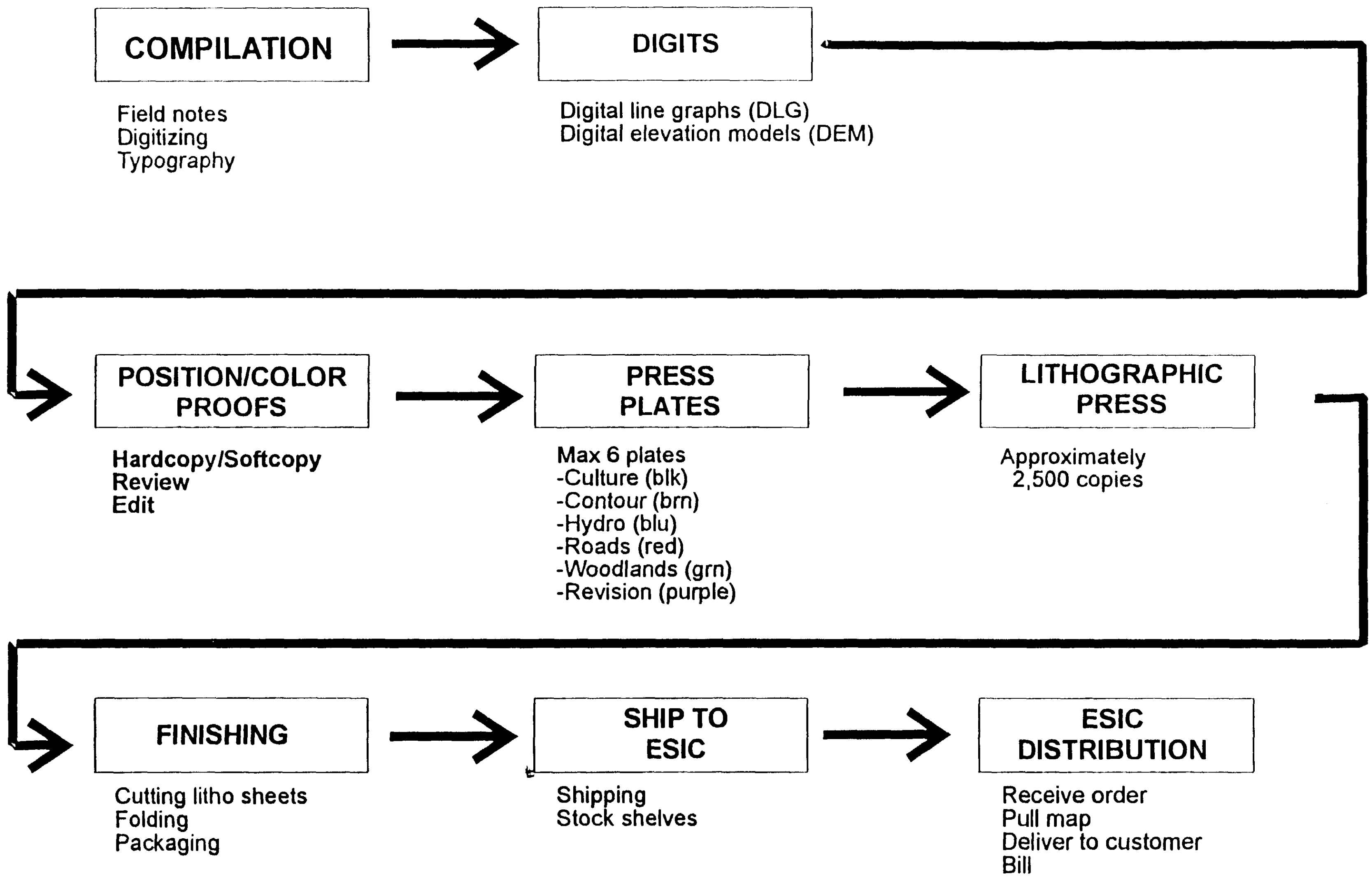

Figure 2. Direct digital printing process to plate.

Table 2. Advantages and disadvantages of direct digital printing process to plate or press

ADVANTAGES	DISADVANTAGES
Reduced one or two steps (photographic, platemaking)	Change
Quicker response to change or data manipulation	Potentially easier to produce errors
Less high paid skilled personnel required	Expensive
Transmission of data electronically	Size limitation on direct-to-press

RIP's become obsolete as faster computer processors and electronics are developed. Also, computer hardware RIP's can limit the size of data sets due to the available hard disk space. In most cases, high-end, large-format platesetter vendors generally offer a file server with some type of RIP software included. These RIP's are compatible with file formats generated from virtually any computer platform, such as IBM PC, Mac, or Unix-based systems (Callaghan, 1994). However, PostScript (PS) and Encapsulated PostScript (EPS) appear to be the industry standard in terms of ease of interpretation by most image and platesetting hardware as well as digital color printing devices.

Electronic imposition is an important factor in the CTP process. Electronic imposition enables the cartographer to electronically arrange collars and set typography. This further enhances time and cost savings by eliminating film, goldenrod, and other materials as well as labor costs associated with these manual image composition steps. This type of electronic prepress make-ready is already being performed in the USGS on various special projects and thematic maps. Widespread use will further facilitate map production.

Critics of CTP systems point out that high costs (more than $200,000) and the lack of an effective color proofing mechanism are drawbacks to converting completely to a filmless process (Lamparter, 1995). Although there are numerous digital color proofing systems available (dye sublimation, ink jet, thermal

Table 3. Leading vendors of large-format, digital platesetters [Romano, 1995; Lamparter, 1995; Wilson, 1995]

VENDOR	MODEL	COST	MAX. SIZE (in)	RESOLUTION (dpi)
Autologic	APS 2820	$235,000	20 x 28	723 to 2,500
Corton	5500 Digital	$450,000	57 x 77	1,270 to 2,540
Creo Products Inc.	Platesetter 3244	$300,000	32 x 44	1,200 to 3,600
Dupont-Crosfield	Magnasetter 650	$250,000	26 x 18	800 to 1,829
Ektron	64471R	$250,000	48 x 64	1,800
Escher-Grad	EG8100	$200,000	30 x 40	100 to 6,000
Gerber Systems Corp.	Crescent/42	$300,000	32 x 42	1,270 to 3,810
Komori	PTP-20	$400,000	44 x 35	1,000 to 4,000
Krause	LX170	$600,000	43 x 67	1,016 to 2,540
Linotype-Hell Company	Gutenberg System	$450,000	32 x 42	1,270 to 3,385
Misomex	Platesetter 5040	$300,000	42 x 53	1,000 to 4,000
Mitsubishi	Digiplater 1800	Not Available	18 x 27	900 to 1,800
Monotype	Plate Express	$280,000	22 x 28	1,446
Optronics	Optronics Platesetter	$285,000	35 x 44	4,000
Polychrome	Crescent/42	$300,000	32 x 42	1,270
Printware	1440APF	$150,000	16 x 27	1,200
Presstek	Pearlsetter	$130,000	29 x 24	1,016 to 2,540
Purup	Magnum	$185,000	32 x 47	1,270 to 5,080
Scitex	DoPlate 800	$300,000	22 x 26	1,016 to 4,000
Screen	PI-R1080	$300,000	32 x 42	1,200 to 4,000
Strobbe	Platesetter	$200,000	22 x 28	723 to 2,169

transfer, color laser printers, and others), some experts contend that proofs from film separates are the best indicator of how the final press product will ultimately look (Wilson, 1995). Most industry experts agree, however, that improved digital proofing systems will be continually developed. The technology driving color management hardware and software will help advance digital proofing systems by standardizing and controlling color from the computer monitor to the printed product.

DIRECT DIGITAL PRINTING PRESSES

True print-on-demand technology is now available enabling the printer to go from digital data files direct to the printed paper product (Alexander, 1994; Feeley, 1995; Strashun, 1994; Shields, 1994; Hayes, 1994; Reilly, 1994; Seybold, 1994a; Graphic Arts Monthly, 1994). Several vendors offer four-color (black, cyan, magenta, and yellow) small-format digital presses that can produce high-quality printed products in a short time at costs far below offset processes for short run or specialty printing. These presses eliminate the need for film, ink, or chemicals because most utilize a dry toner printing process. There are primarily four vendors offering direct digital presses. These are: Heidelberg's GTO-DI; Indigo's E-Print 1000; Xeikon's DCP-1; and Agfa's Chromapress (see table 4). Manufacturers marketing their digital presses focus primarily on customers requiring relatively short press runs, typically below 5,000 impressions. Costs for short run printing on digital presses are far lower than compared with conventional offset printing because prepress time and materials account for a large portion of the costs of offset press runs (Shields, 1994).

Digital data files typically are manipulated with desktop publishing software before undergoing a RIP in the file management server of the digital printing presses. Most presses can RIP any PostScript or compatible file format. Color management is generally handled by software programs, such as

Table 4. Digital presses [Shields, 1994; Reilly, 1994]

VENDOR	MODEL	COST	MAX. SIZE (in)	RESOLUTION (dpi)
Agfa	Chromapress	$300,000	11 x 17	2,400
Heidelberg	GTO-DI	$600,000	14 x 20	2,540
Indigo	E-Print 1000	$500,000	11 x 17	800
Xeikon	DCP-1	$200,000	11 x 17	600

Aldus PressWise, Adobe Photoshop, or similar product. Agfa's Chromapress, however, uses its FotoTune software running under ChromaPost for color management. Additional color management provided on most presses utilize densitometer equipment to adjust color gradation.

Industry experts generally agree that the print quality produced from digital presses is excellent, often approaching the quality expected from conventional offset presses (Shields, 1994). Large publishing houses such as R.R. Donnelley are so confident of the capabilities of direct digital printing that they have constructed a print-on-demand facility using Xeikon, Indigo, and Heidelberg presses (Graphic Arts Monthly, 1994). Given the costs associated with offset printing, customers requiring fast, high-quality, short-run color printing feel that digital presses provide an excellent cost-effective product. Alexander (1994) points out that the continual advancements and improvements in speed and print quality in digital presses will soon result in a corresponding decline in the market share of printed materials produced by traditional offset methods.

Digital presses are ideally suited to USGS's demands for producing up-to-date topographic and GIS generated geospatial maps. As more maps are produced or archived in a digital format, revisions to those maps can be completed quickly when new information is obtained. The digital presses could be integrated into a communication network linking the presses to GIS and electronic prepress workstations. Depending on the demand for the revised map product, cartographers could schedule print runs as needed, requiring as little as a 1-day turnaround time. The warehousing of hundreds or thousands of maps will no longer be necessary, and customers of USGS map products will be assured of the most up-to-date information possible. Figure 3 shows the map production process using direct digital printing to press. Table 2 lists the advantages and disadvantages of this process.

The costs for these direct digital presses are high and can run as much as $600,000 for the Heidelberg GTO-DI. At the low end of the digital press market is Xeikon's DCP-1, which sells for approximately $220,000. Unfortunately, no large-format presses are available today to satisfy the USGS's needs for large printed map products. Heidelberg's GTO-DI handles the largest paper sheet at 14 x 20½ inches. As technology advances in this area, large-format digital presses will become available.

DIRECT DIGITAL PRINTING TO LARGE-FORMAT PLOTTERS OR PRINTERS

Print-on-demand technologies are especially important to the USGS's ability to make out-of-stock maps available. Small quantities (less than 100 copies) can be printed using the on-demand printing capabilities available today. A relatively inexpensive IBM PC, Mac, or workstation with maps archived in a digital data base interfaced with an equally inexpensive plotter or printer can adequately address the customer needs for fast, reasonable quality map reproduction. The quality of maps produced this way is not as high as those produced by offset lithographic techniques but is probably sufficient for the casual purchaser of USGS map products. Certainly, the issues of quality and map accuracy are important in this scenario; and these issues need to be appropriately addressed and policies decided before the USGS releases these products to the public. Figure 4 shows how an ESIC map distribution office could use a large-format

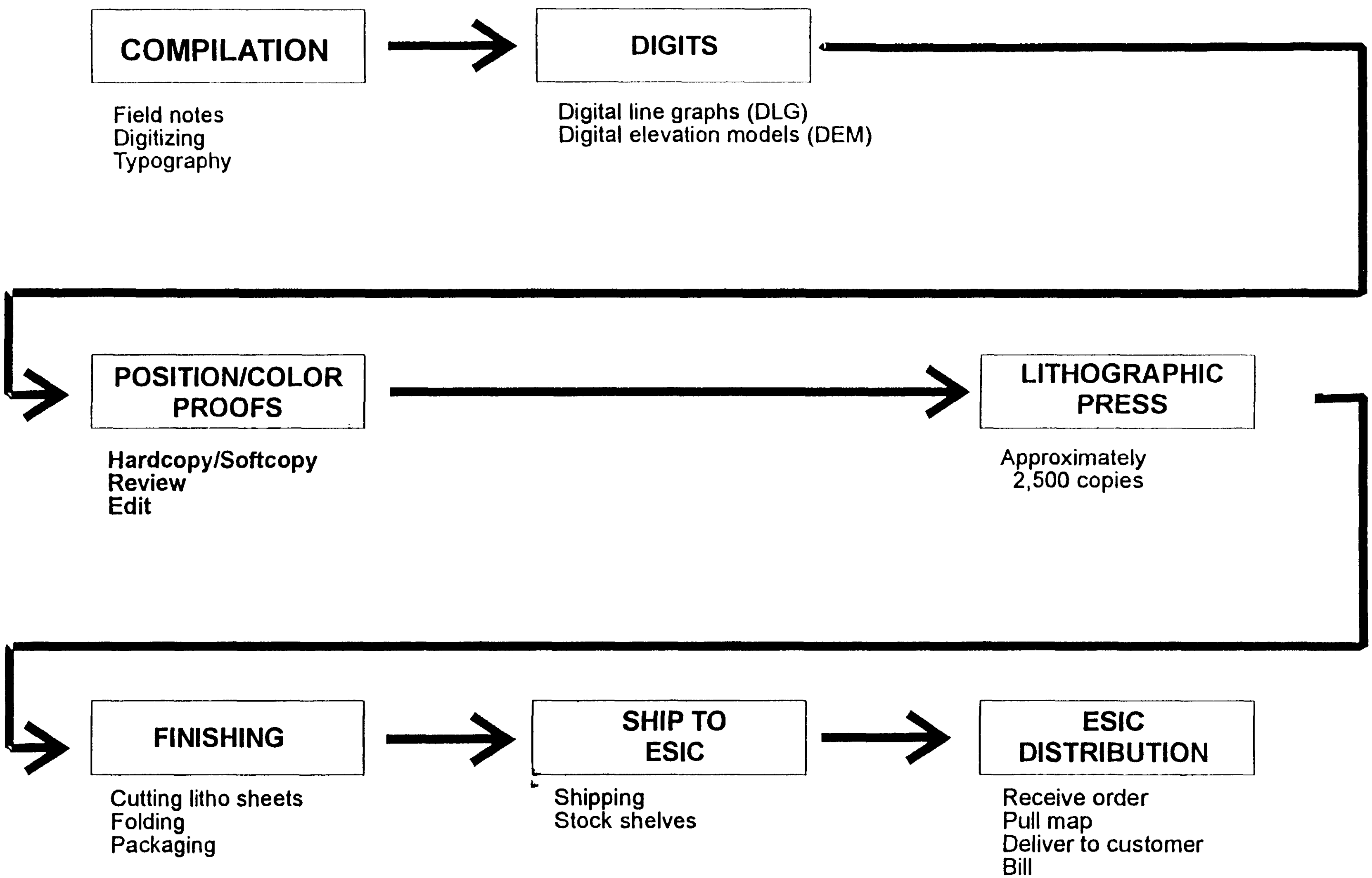

Figure 3. Direct digital printing process to press.

plotter to provide maps on demand. Table 5 lists the advantages and disadvantages of this process.

There are a number of large-format printers/plotters on the market today that can generate good quality maps within a reasonable length of time (less than one hour). These large-format digital color printers utilize either ink jet, thermal wax transfer, or electrostatic printing technologies (Dilger, 1995; Seybold, 1994b). Table 6 list the most popular large-format digital color printers for the above three printing technologies and compares each in terms of cost, width, printing technology, and image durability (In-Plant Printer, 1995; Raines, 1995; Dilger, 1995; Seybold, 1994b; Bojorquez, 1995; Morgenstern, 1994; Edwards, 1995; Kumar, 1995; Wallace, 1995).

Ink jet Printers

The most popular large-format printers on the market today utilize ink jet technology to transfer liquid or solid ink to paper. Liquid ink is transferred to the paper substrate by boiling the ink in a reservoir and shooting droplets of the heated liquid at the paper surface. Ink jet printers using solid, wax-based inks utilize a similar transfer process (Freund, 1995). These ink jet printers are very affordable (usually less than $10,000 for a liquid-ink-based ink jet printer) compared with other large-format systems, which primarily accounts for their popularity. Print resolution is generally around 300-400 dots per inch (dpi), although some systems can reach 600 dpi. Printing speeds for the ink jet printers tend to be relatively slow and therefore are not suitable for large volume output. By comparison, electrostatic printers are approximately three times faster than an ink jet printer (Dilger, 1995). Originally designed for computer aided design applications and engineers, ink jet printers have become increasingly popular in the graphic arts industry (Edwards, 1995; Neubauer, 1995). Vendors, such as Hewlett Packard and Canon, have recognized the tremendous growth

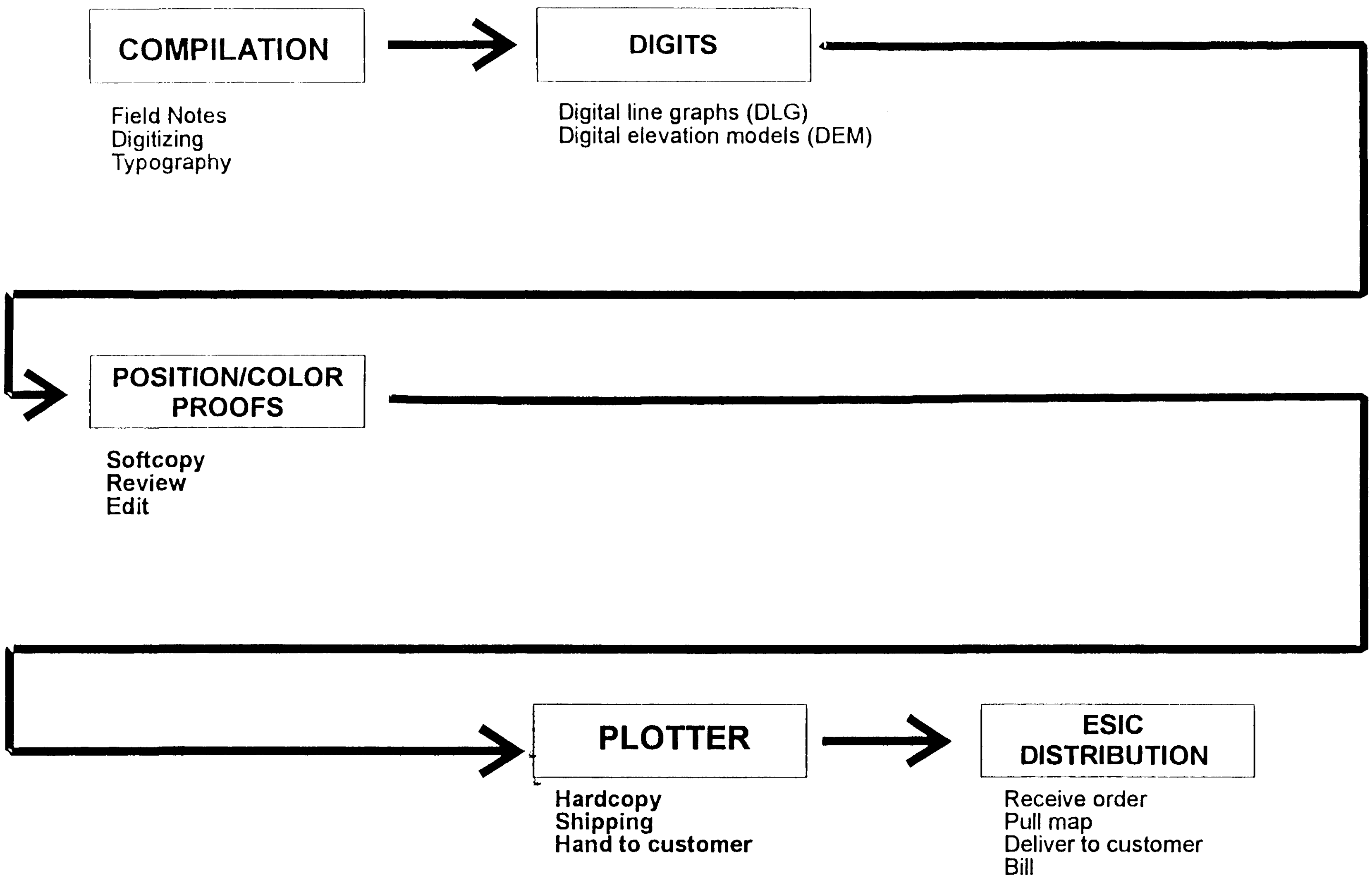

Figure 4. Direct digital printing to large-format plotter.

Table 5. Advantages and disadvantages of direct digital printing to large-format plotter

ADVANTAGES	DISADVANTAGES
Less expensive process	Material longevity
Quick!	Does it meet customer needs?
No transportation costs	No standards
No warehousing costs	Presumed low quality
Customize: size, color, features, number of copies	No controls (USGS)
Printing on-demand	Accuracy (spatial, data, relational)

in this area and have tried to redesign their systems to satisfy the needs of the graphic arts field (Edwards, 1995).

After the initial equipment purchase, the other major expenses involved with ink jet printers are the costs for inks, paper, and general maintenance. Ink costs account for the majority of consumable expenses. Liquid ink cartridges generally run around $40.00/cartridge for each of the four colors (cyan, magenta, yellow, and black). Liquid inks are water-based and therefore are not water-fast and also have poor ultraviolet (UV) radiation resistance. With little UV resistance, ink tends to fade over short periods of time when exposed to UV light. This is a major consideration for print-on-demand capabilities for the USGS. Topographic quadrangles printed with liquid inks on ink jet printers will fade quickly and run or smear under wet conditions. Although these maps can be laminated to reduce UV fading and increase water fastness, laminators are an additional expense and will require additional time and materials for print-on-demand facilities. Industry experts strongly believe that liquid-ink-based ink jet printers will be redesigned within the next few years to solve the problems associated with fading and water solubility (Freund, 1995; Neubauer, 1995).

Ink jet printers using a wax or resin-based solid ink show remarkable image durability. These solid inks are UV and water

Table 6. Large-format digital color printers using ink jet, thermal wax transfer, or electrostatic printing technologies [In-Plant Printer, 1995; Raines, 1995; Dilger, 1995; Seybold, 1994b; Bojorquez, 1995; Morgenstern, 1994; Edwards, 1995; Wallace, 1995; Kumar, 1995]

VENDOR	MODEL	COST	WIDTH	UV RESISTANCE	WATER RESISTANCE	TYPE OF PLOTTER
HP	650C/PS	$10,595	36"	Poor	Poor	Ink jet (liquid)
Encad	Novajet III	$8,495	36"	Poor	Poor	Ink jet (liquid)
Alpha Merics	5248PR	$54,900	56"	Good	Good	Ink jet (solid)
Laser Master	Display Maker	$29,995	36"	Poor	Poor	Ink jet (liquid)
Laser Master	Express	$79,995	48"	Good	Good	Ink jet (solid)
Canon	2436	$99,000	24"	Good	Good	Ink jet (liquid)
NewGen	Vista	$19,995	36"	Poor	Poor	Ink jet (liquid)
Itochu	A-1	Not available	24"	Not available	Not available	Ink jet (not available)
Scitex	Outboard	Not available	7.7'	Good	Good	Ink jet (not available)
Calcomp	Techjet 5336	Not available	36"	Not available	Not available	Ink jet (not available)
Phoenix	360	$34,750	36"	Good	Good	Electrostatic
Raster Graphics	DCS5400	$100,000	54"	Good	Good	Electrostatic
3M	ScotchPrint	$70,000	36"	Good	Good	Electrostatic
Calcomp	68000GA	Not available	44"	Good	Good	Electrostatic
Xerox	8954	Not available	54"	Good	Good	Electrostatic
Datametrics	Cymax 3010	$30,000	12"	Good	Good	Thermal wax
Summa Graphics	Summa Chrome	Not available	24"	Good	Good	Thermal wax
Gerber	Not available	Not available	15"	Good	Good	Thermal wax

resistant and have an additional advantage over liquid inks in terms of drying time. Depending on the amount of liquid ink transferred to a paper substrate, the printed material can take as long as 24 hours to completely dry. Solid inks, however, dry virtually on contact.

For USGS print-on-demand map reproduction, solid-ink-based ink jet printers have several distinct advantages in terms of UV resistance, water fastness, and drying times. These systems are typically more expensive than liquid-ink-based ink jet printers. LaserMaster's new large-format ink jet printer, the LaserMaster Express, uses solid inks and costs approximately $80,000 (Woolwine, 1995). The cost per square foot for materials (ink and paper) is also high, approximately $1.50/square foot (Kumar, 1995).

Most of the research and development (R&D) for ink jet printer technology is focused on liquid-ink-based ink jet printers. The two industry leaders in this R&D effort are Hewlett Packard and Canon. There are few major companies, however, developing new products that use solid inks for their ink jet printers. The most notable are LaserMaster and Tektronix. Because it is widely believed that improved liquid inks will be on the market relatively soon, liquid ink jet technology and products will continue to hold the greater market share for this type of large-format color printer.

Thermal Wax Transfer Printers

Large-format systems utilizing thermal wax transfer technology comprise the smallest market share of the large-format color printer industry. There are now only two major vendors marketing thermal systems, SummaGraphics and Gerber (Dilger, 1995; Wallace, 1995). These systems sell for approximately $40,000 and use a wax or resin-based ink that is transferred to the media substrate by use of a thermal print head. Rather than reservoirs holding liquid or solid ink as in the ink jet systems, thermal systems use single-color ribbons that contain the colored pigments (Dilger, 1995).

A comparison of thermal systems and ink jet systems shows that thermal systems surpass ink jets when examining several different criteria (Wallace, 1995). The cost per square foot for thermal systems is cheaper than ink jet systems. Thermal systems also offer a distinct advantage over liquid-ink-based ink jet systems in terms of water resistance, UV resistance, and media versatility. Thermal systems will print on polyvinyl chloride materials as well as coated paper stock. No lamination is needed with thermally printed materials; however, this may also be a disadvantage because the wax or resin-based ink can be scraped off or melted when put through a copier. Speeds for thermal systems are about twice as fast as ink jets. Although the costs of the thermal systems are higher than ink jets, the specifications described above show that the thermal systems are superior (except for heat sensitivity) when weighed among several factors that are important to USGS print-on-demand capabilities. However, thermal systems comprise only a relatively minor share of the printer industry; and, without any major printer manufacturer supporting this type of technology, it is doubtful that thermal transfer systems will capture a greater market share of the large-format color printing industry in the near-term.

Electrostatic Printers

Electrostatic printers rank second only to ink jet systems in terms of potential growth and market share in the large-format color printer industry (Wallace, 1995). Printers using electrostatic technology transfer ink toner to the media substrate by electrical attraction (Edwards, 1995; Dilger, 1995). The substrate and toner have opposite electrical charges so when the writing head passes over the substrate, the toner is released and attracted to the receiving media. These ink pigments are not water soluble and show excellent UV resistance. Electrostatic printers will also print on a variety of media that are suitable for long outdoor exposure times (Dilger, 1995).

The most attractive feature of the electrostatic printers is their ability to handle long print runs (over 100 copies) with extremely fast speeds, up to 500-600 square feet per hour (Kumar, 1995). The cost per square foot is very low and typically start at $0.30 per square foot, depending on the media used. Although some entry level electrostatic printers sell for approximately $30,000, these systems generally cost more than $100,000. High initial equipment costs for electrostatic printers are the main reason consumers turn to ink jet printers for their large-format reproduction requirements (Seybold, 1994b). However, when printing speed and longer print runs are required, electrostatic printers are far superior to the ink jet systems (Dilger, 1995). For USGS print-on-demand capabilities, electrostatic printers possess several important and distinguishing criteria: water resistance, UV resistance, low costs per square foot (media dependent), extremely fast print speeds, and high-quality/high-resolution final prints. However, setting up a print-on-demand facility with electrostatic printers will require (1) a room with stable environmental conditions (temperature and relative humidity) because these have a direct influence on the paper and the ink's ability to hold an electrical charge, (2) a specifically purchased substrate media because the printers tend to be sensitive to the coating on the media used, and (3) a routine daily maintenance to make certain the printing heads and ink fountains do not become clogged.

COLOR MANAGEMENT SYSTEMS

As printers increase their reliance on digital printing techniques and print-on-demand facilities are more firmly established, a method for standardizing and controlling color will become extremely important. Most industry experts define color management as the hardware or software to maintain accurate color reproduction, from digital image creation to the final printed product (Seybold, 1994e; Stone, 1995; Schaffel, 1995; Bristow, 1995; Hevenor, 1994; Lovig-Neale, 1994; T. Paul, written commun., 1993; Sharples, 1994a). Color management systems will utilize a standard profile format so that digital images will maintain color uniformity regardless of the media environment.

Graphic artists must often deal with wide variability in color reproducibility as a digital image is transferred from the computer monitor to digital printer or press. The problem is compounded because the same digital image will appear different on different monitors. A cartographer in the USGS manipulating geospatial information on a Data General workstation may see an entirely different color interpretation of his map than the graphic artist manipulating the map information on a Macintosh computer. Further, as a computer monitor ages, its ability to maintain color integrity decreases. Variability in paper and ink materials will also affect color reproducibility. Lighting conditions can affect how an image is perceived on both computer monitors and in the final printed product. Application software products may use a different color scale for color adjustments. All of the above factors can account for fluctuations of color reproducibility or how color is perceived (T. Paul, written commun., 1993).

The most notable factor causing color discrepancies between digital images viewed on electronic hardware and images reproduced on printed material is the models created to interpret the visible color light spectrum for transmitted or reflected light (LaForge, 1995; Schaffel, 1995; T. Paul, written commun., 1993). The visible color light spectrum is resolved into three primary colors (red, green, and blue) for transmitted light similar to televisions, computer display monitors, and other video display units. Because cyan, magenta, and yellow (CMY) are the complementary spectral equivalents to red, green, and blue (RGB), these colors are used for printing so that the eyes will perceive the appropriate reflected RGB components. Printers

$1,200 Colortron is a desktop color management system that contains a spectrophotometer, densitometer, and color management software that is easily interfaced with a Macintosh computer. At the date of this writing, it is reported that Microsoft will be releasing some color management software bundled within its Windows 95 operating system.

Color management systems will play an important role for USGS print-on-demand facilities. Map customers will expect high quality color reproductions of topographic quadrangles produced on digital printers as they currently have in maps printed by traditional lithographic techniques. Therefore, procurement of large-format digital printers for print-on-demand capabilities should also include state-of-the-art color management systems.

ISSUES

The USGS has a critical need to understand, assess, and evaluate print-on-demand technology. Print-on-demand is one of the major themes for the USGS's new mission for the next decade. Although this technology is relatively new, it is important that USGS personnel assess its applicability to current USGS map production capabilities. As the hardware and software advancements driving print-on-demand technology continue to evolve, the USGS will monitor these developments to understand how it can impact future USGS map printing techniques.

There are several important issues that must be addressed before the USGS procures and utilizes print-on-demand map production capabilities. Some of these issues are described in "Product Supply for the USGS Information Dissemination System" (Durant and others, 1995). Other issues are:

1. Conversion to computer-to-plate technology in the USGS printing branch will facilitate map production while eliminating costs associated with the photographic process. Initial first-year expenditures for hardware, software, and training will be

greater than $200,000. The USGS must decide whether the long-term benefits of conversion to a CTP process outweighs initial start-up expenses.

2. Four-color, direct digital printing presses provide print quality comparable to that of conventional, lithographic techniques. However, no large-format digital presses are currently available. Costs for these presses are high ($220,000 for a Xeikon DCP-1 and over $600,000 for a Heidelberg GTO-DI). Large-format digital presses should be available in the next 1 to 3 years. The USGS should continue to monitor developments in this area to determine if conversion to digital printing presses is a viable addition or alternative to conventional, lithographic techniques.

3. Print-on-demand capabilities are especially attractive for solving USGS's out-of-stock map problem. Under the current system, a customer must wait 90 to 180 days for reprinting an out-of-stock map. Large-format plotters/printers are available to print digital maps on-demand, virtually in minutes after a customer makes a request for the map. Costs for these systems are relatively inexpensive (less than $10,000 for an ink jet printer to over $100,000 for some electrostatic printers). Before purchasing these systems, the USGS must consider the following:

a. These systems are for low volume output (less than 100 copies).

b. Speed of the system is important. Ink jets can take 20 minutes or more to print a typical topographic quadrangle. Although more expensive, electrostatic printers print the same map in 5 minutes or less.

c. Image durability must be evaluated on each system. Important factors are UV resistance, water resistance, heat sensitivity, and ability to print on a variety of paper stocks.

d. The plotter/printers must be evaluated in terms of a complete package, which includes computer workstations, file servers, and RIP hardware or software.

e. Special environmental and maintenance requirements should be noted. Electrostatic printers require rooms with regulated temperature and relative humidity. Ink jets have no special environmental considerations. Both types of printers require daily attention to replenishing ink fountains or cartridges; and, the electrostatic printers need daily cleaning of the printing head and ink fountains to prevent clogging.

4. Map accuracy and quality are important considerations if the USGS decides to produce topographic quadrangles on-demand and sell these in ESIC's and map distribution centers. Current large-format plotters and printers will not reproduce the quality of maps produced by offset press. Accuracy of geospatial information on these maps cannot be guaranteed. The USGS must decide whether it is willing to provide an inferior product to its customers.

5. Most ground breaking advancements in print-on-demand technology are being done for small-format capabilities. As print-on-demand technology evolves, large-format capabilities will improve and digital presses will become available. The USGS may want to consider, therefore, producing quarter quads of its 7.5-minute topographic quadrangles for sale to capitalize on existing print-on-demand, high-quality small-format technology. The traditional 7.5-minute topographic quadrangle could be easily dissected into four sections at the same scale (1:24,000) using image processing software (such as ERDAS), type and collars could be produced, and these quarter quads could be printed on digital presses. Quality and accuracy would be higher than those printed on other large-format plotters/printers, and printing costs would be reduced. Further, producing quarter quads may increase demand for these topographic quadrangles by creating a new customer market.

6. Establishing print-on-demand facilities will increase USGS's customer base by allowing the USGS to sell data based on unique customer requirements. A customer will be able to choose which specific data sets are needed to display on a customized map. Using print-on-demand capabilities, a hardcopy map could then be produced. The USGS should explore new ways to market its digital cartographic data bases to satisfy these specialized requests.

7. Conventional lithographic techniques are still the most cost effective means to produce maps where long print runs (over 1,000 copies) are required. This type of printing process provides the highest print quality that is available today. The USGS should consider, therefore, establishing a map printing facility with both offset printing and newer print-on-demand capabilities.

Print-on-demand technology can provide an opportunity for the USGS to establish exciting, innovative ways to communicate its geospatial data to the user community. Digital printing technology will allow fast, efficient reproduction of map information. The USGS must maintain a high level of awareness of print-on-demand developments and advancements to effectively respond to the needs and requirements of its customers. This report is intended to be a technological assessment of current print-on-demand capabilities as they relate to map production in the USGS. A continuation of this investigation is necessary to establish benchmark criteria to evaluate the print-on-demand hardware and software products that can be utilized in the USGS printing facilities.

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