Production Procedures for an Oversize Satellite Image Map

Abstract

For almost 20 years the U.S. Geological Survey (USGS) has used remotely sensed image data captured by the Landsat series of satellites to produce a variety of experimental color and black-and-white image maps. With this experience the USGS developed guidelines and standards (U.S. Geological Survey, 1987) for producing these maps. These guidelines and standards were used to produce and print two 44- by 65-inch, oversized, color image maps of the United Arab Emirates.

Introduction

In 1972 the United States launched the first in a series of five civilian, Earth orbiting, remote sensing Landsat satellites. The U.S. Geological Survey (USGS) uses data gathered by these systems to produce remotely sensed image maps covering many geographic areas of the world. After almost 20 years, the production process for making these experimental image maps remains an emerging art.

This paper describes the procedures used for producing the two sections of the mosaic map of the United Arab Emirates (UAE). These 1:250,000-scale color maps are part of a joint ground-water assessment project between the Governments of the United States and the Emirate of Abu Dhabi.

Background

Satellite image mapping is an efficient and economical method to display large spatial areas as a geometrically accurate black-and-white or color image map. The production procedures for image maps are slowly evolving from experience gained as each new map is published and from advances in technology. Current USGS production procedures and guidelines are a result of analyzing historical data from many tests and experiments conducted over the past 19 years. A key ingredient that has aided the improvement in image mapping production is the continuing dialogue between map authors and mapmakers. Communication is the critical element in developing production standards for obtaining proper radiometry, image contrast, and colors. As requirements for these maps become more clearly defined, the mapmaker can adapt production techniques to meet these needs. By establishing these techniques and monitoring them through each phase of the production process, the quality of these maps has steadily improved.

The USGS has often been asked to aid other countries in their scientific mapping and Earth resource programs, and many small-scale image maps of these countries have been made. Financial support for these activities comes from either the principal country, other Federal agencies, or international organizations (U.S. Geological Survey, 1990). Usually there is a limited amount of money and time for making these maps. Innovative procedures that save time and money, therefore, have been designed. The USGS currently uses these procedures for producing domestic maps.

UAE Image Maps

The UAE consists of seven Emirates located in the northeastern section of the Arabian Peninsula. To the north they are bordered by the southern section of the Arabian Gulf. Their land borders the countries of Saudi Arabia, Qatar, and Oman (Figure 1). The country, approximately the size of Maine, covers nearly 83,600 square kilometres. Abu Dhabi is the largest and most politically influential Emirate, controlling most of the country's oil reserves.

Like neighboring countries, the UAE is abundant with crude oil but is in short supply of ground water. Their requirements for fresh water for public and industrial use far exceed known natural resources. In an attempt to meet increasing demands for fresh water, the government has developed desalination plants located on the Arabian Gulf (Joel Kimrey *et al.*, unpublished data, 1987). However, these plants are only a partial solution to the fresh water problem, and other solutions are needed.

Request for USGS Involvement

During the mid-1980s scientific methods for conserving and managing ground water became a primary government objective (Thomas, 1990; Joel Kimrey *et al.*, unpublished data, 1987). In 1986, at the request of the Crown Prince of Abu Dhabi, the American Ambassador to the UAE established a formal scientific program to assess Abu Dhabi's ground water using scientific methods (Thomas, 1990). A team of U.S. scientists, consisting of a hydrologist, geologist, and cartographer specializing in remote sensing and a computer specialist, conducted a reconnaissance of the Emirate and reported their recommendations.

Their recommendation was to expand the area of study beyond the Abu Dhabi oases to include ground-water resources of the entire country. To do this they needed to obtain geologic and hydrologic data of the entire country (Thomas, 1990). The scientists emphasized the importance of assessing and developing the water resources in the eastern section of the Emirate. They stressed that the highest priority should be given to performing a quantitative evaluation of the recharge rates, drawls, and remaining reserves of fresh and brackish water as potential sources for continuous aquifers in eastern Abu Dhabi (Joel Kimrey *et al.*, unpublished data, 1987). This meant mapping the major geomorphic structures within the Abu Dhabi Emirate and nearby geographic areas.

Country Map

In 1987 the government of Abu Dhabi accepted the basic recommendations of the USGS assessment team. The USGS and the National Drilling Company, an agency of Abu Dhabi Gov-

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Fig. 1. The United Arab Emirates.

ernment, began a cooperative project to assess ground-water locations within the Emirate. A Memorandum of Understanding between the United States and the UAE officially authorized this cooperative project. Their goal was to appraise known ground-water resources in the Al Ain and Liwa Oases of Abu Dhabi (Thomas, 1990).

The quickest means to analyze hydrologic data (such as well profiles and well flow) was to view them spatially, but accurate geomorphologic maps of the area were not available. The most expedient and cost-effective method to obtain this type of mapping base was to use satellite imagery, supplemented with field studies. By analyzing the various available bands of satellite data, the scientist could quickly make assessments of physical and cultural features affecting the ground-water systems.

After reviewing available satellite imagery, the project team selected Thematic Mapper (TM) image data from the Landsat 6 satellite. TM's 30-metre ground resolution permits sufficient detail for analysis. After viewing the available data, the team suggested making an image map of the entire country to assess the geomorphic and cultural infrastructure. 1:250,000 scale was chosen because it is small enough to view the entire country, yet has enough detail to detect significant ground features that could impact ground-water resources.

Production Procedures

Data Selection

The U.S. scientists selected TM bands for image data on the basis of availability, recent acquisition dates, and low percentages of cloud coverage. The criteria for band selections were to obtain as much visual information of important surface and rock features as possible. Compositing TM bands 7 (red), 4 (green), and 2 (blue) visually enhanced the cultural and physical landscape features. TM band 7 (2.08 to 2.35 μm) discriminates between limonitic and nonlimonitic rocks, band 4 (0.76 to 0.90 μm) delineates the interfacing between water and land, and band 2 (0.52 to 0.60 μm) responds to vegetation (Colvocoresses, 1986). Unlike typical infrared image maps where vegetation is represented as red, this combination assigns vegetation growth to the green printer, which gives the map a natural color appearance. This natural color scheme is to aid the map user in interpreting spatial locations and information.

Digital Processing

After selecting the scenes and bands, the digital compilation for the maps began. The Environmental Research Institute of Michigan (ERIM)* was selected to handle the resampling and mosaicking for these data. At the time, the data were ready for processing, ERIM had the resources available to handle the large amount of data required to map the entire UAE.

Each of the three bands for the nine TM scenes covering the UAE was processed and digitally mosaicked (Table 1 and Figure 2). Then every 10th pixel was displayed on a color workstation where the scientists could interactively manipulate image tones and band hues using multilinear stretching routines. The tones and hues were subjectively selected by

*Any use of trade, product, or firm names in this publication is for descriptive purposes only and does not imply endorsement by the U.S. Government.

the scientists on the basis of their knowledge of the terrain discrimination observed on field surveys. After finding an acceptable workstation display, the image data set was processed with the stretching algorithms used to produce the display image on the workstation.

Image Processing Artifacts

Although image processing procedures are standardized, the dynamic image contrast of the UAE imagery presented unique artifacts. The saturated hues and complex textures of the oases contrasted sharply with the almost monochrome hues and smooth textures of the sand. Haloing describes the appearance of light pixel values on the boundaries between the two highly contrasted features. These low radiometric pixel values are an anomaly of the standard digital processing algorithm.

To overcome this problem, ERIM developed a data processing technique using an adaptive filter. Using this filter, the radiometric values of an area are sampled with algorithms to detect any radiometric pixel values that are extremely different from surrounding pixels. When found, these original values are not used in the smoothing algorithms but are processed with a different calculation to produce a smooth transition zone of pixel values between the two features. This filtering eliminates the undesirable halo effect.

The accepted image required a large amount of computer time to process new values. Even with high-speed data processing equipment, data processing took approximately 210 hours of computation time.

Color Correction

After subjectively evaluating and accepting a display image, a color film transparency was made on the Fire 240 filmwriter. Because the Fire 240 can only write to a 9.5- by 9.5-inch film, the mosaicked data set was digitally resubdivided into six image scenes, at 1:1,000,000 scale (approximate). These transparencies were used to ensure that the color and tones displayed on the computer's monitor could be reproduced as a paper map. These transparencies served as an unscaled color guide.

When all color transparencies were accepted, a continuous tone, black-and-white film of each band was plotted from the six scenes (Figure 3). These films were used as the reproduction medium.

Continuous Tone Film Format

Each continuous tone film was formatted with the same graphic elements (Figure 4):

- Image corner tics— computer-generated corner tics, embedded in the imagery to delineate the image boundary.
- Registration tics— four crosshair tics embedded into the imagery just beyond the image corner that are used for film-to-film overlay registration.
- Identification box— contains alphanumeric scene information regarding a data source and row and path numbers and identifies image band numbers.
- Gray scale— a series of 16 blocks having a uniform density value ranging in ascending order and representing the range of image values. Monitoring this scale through the entire production cycle ensures maintaining the proper balance of color and tone.

Each of these film elements is an important aid in closely monitoring image quality.

Color Photographic Prints

Enlarged photographic color composite prints were made from each of the six sets of continuous tone films. These optically enlarged prints were used to evaluate the map's size, to verify color reproduction, and to ensure overall image quality.

After accepting the color prints, the sets of 1:1,000,000-scale, black-and-white continuous tone films were color composited at the same size onto color transparent film (Figure 5). Care in monitoring the exposure to obtain proper color and density was important to ensure each film matched the accepted color photographic prints.

This method produces high image quality with fewer contaminated colors than recording directly to color film. Typically, only color transparencies are recorded on the Fire 240, and these transparencies are then used for image reproduction.

Graphic Arts Scanner Separations

To transform a color transparency into a scaled set of halftone films suitable for printing requires separating the varied colors of the transparencies into the four printing hues of yellow (Y), magenta (M), cyan (C), and black (K). Electronic color graphic arts scanners have proven the most efficient method to achieve optimum image quality and accurate color reproduction from a color transparency (Kidwell and McSweeney, 1985).

A scanner reads the colors and radiance values for each color image and then electronically separates these readings into four files that represent the printing colors (YMCK). The scanner then converts these radiometric values for each file into preprogrammed halftone dot values. Scanners are programmed to separate the colors of the transparency into a balanced set of four halftone films that, when printed, will closely approximate the color and tone balance of the origi-

TABLE 1. THE NINE LANDSAT TM SCENES USED FOR UAE MOSAIC

Row/path	Date
160/42	20 Sep 1987
161/42	6 Oct 1987
162/43	13 Oct 1987
161/43	6 Oct 1987
160/43	23 Sep 1987
159/43	4 Feb 1985
162/44	13 Oct 1987
161/44	6 Oct 1987
160/44	23 Sep 1987

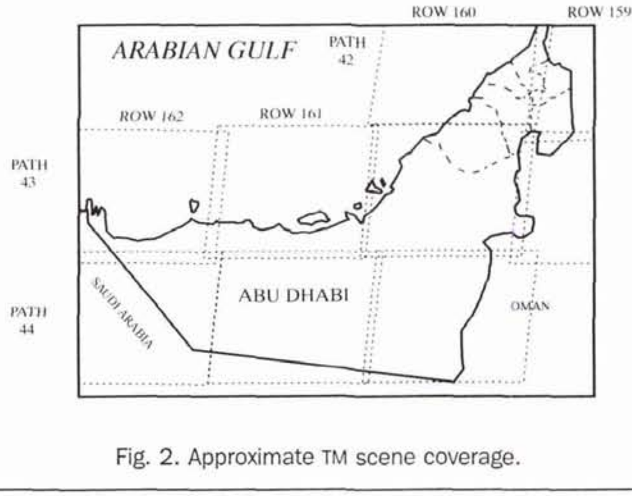

Fig. 2. Approximate TM scene coverage.

nal color transparency. Finally, the scanner writes these halftone dot values for each file onto a piece of high-contrast lithographic film. When printed on paper, these small halftone dots present the illusion to the viewer of a continuous tone color image. Figure 5 illustrates the flow of this process.

Film Scale

Because the USGS does not have an in-house graphic arts electronic color scanner, a commercial vendor was contracted to separate and enlarge the six UAE color transparencies. Each transparency was converted from a 9.5- by 9.5-inch color composite film into four enlarged halftone films. When plotted, these halftones were enlarged approximately four times to match the map scale. The enlargement factor was an approximate value because accurate measurements between the original transparency film, separation film, and control points are all relative numbers and equipment dependent. The correct size was achieved only by manually measuring the plotted film control points. As a safeguard, prior to separating and imaging, a test plot of image tics was generated to establish proper x and y enlargement scale factors. Deviations in scale were calculated, data reentered into the scanner, and new plots made until proper scale was achieved.

Color Balance

The next step was establishing a color balance for the halftones. This process of generating halftone dots for each film separate to accurately portray the original color transparency depends primarily on the scanner operator's experience in adjusting hue balances and image tones to match the colors in the transparency to the printing inks.

Color proofs of each set of halftone images were made. Color proofs serve three purposes. First, they establish that the four halftone films will register to each other when overlaid or printed. Second, they confirm proper balance of color and tones. Finally, they detect image imperfections. Each of these problems is easier to correct at this point in the process than at the time of printing.

Film Reproduction Problems

The UAE image presented several unique challenges for the contractor who did the color separations. Although accustomed to producing high-quality color work for magazine and commercial advertisers, the contractor had not worked on maps where precision in scaling is critical. The ± 0.002-inch tolerances over a 65-inch sheet of film proved an extremely arduous task.

Color was another problem because choosing colors and tones for image mapping is a subjective process. Image enlargement alters the visual perceptions of color when compared to the original. Many tests were made to get the proper colors before a set of halftone films was finally accepted.

Mosaicking

What proved the most time-consuming part of this process was the photomosaicking of halftone images to make each

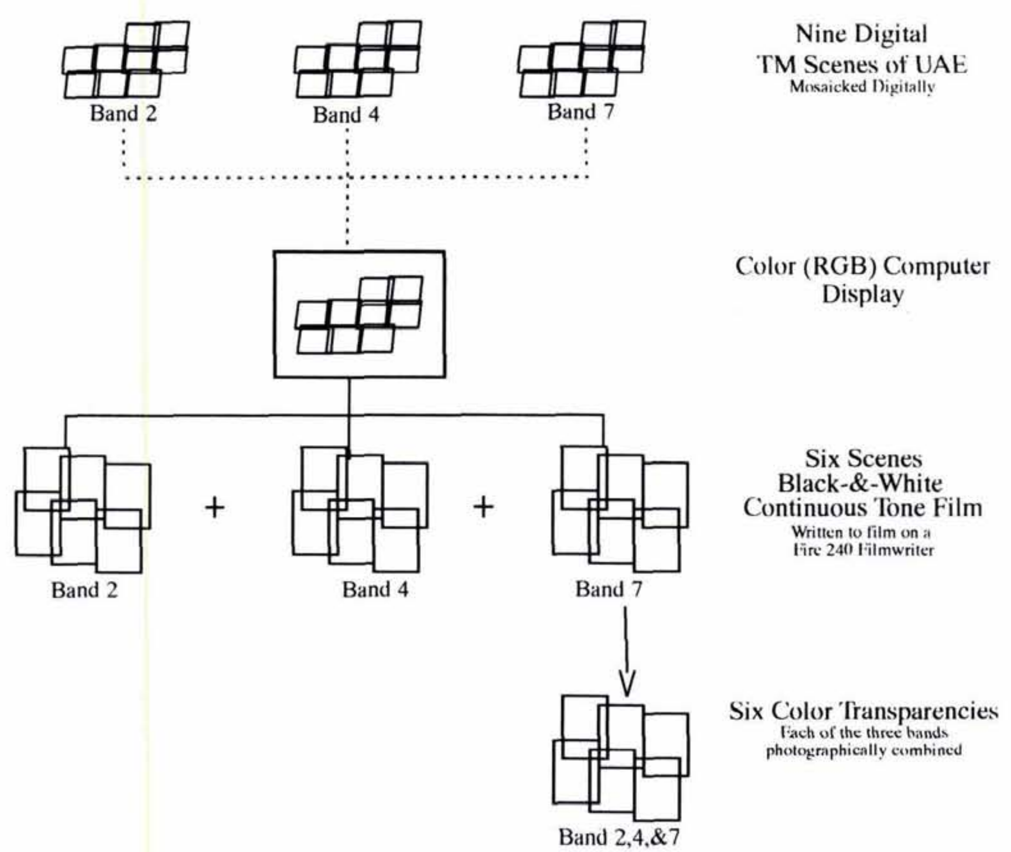

Fig. 3. Digital and continuous tone film mosaicking.

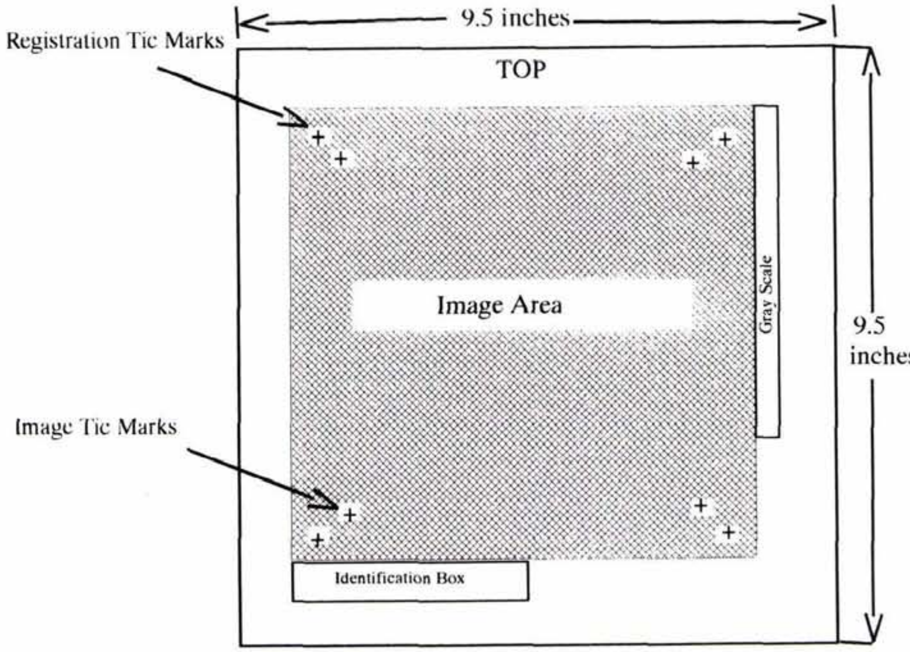

Fig. 4. Format for continuous tone film.

map. Each map consisted of three transparencies. After separating the transparencies, the four sets of scaled halftones were photomechanically mosaicked together, which recombined the image into one 45- by 68-inch sheet of film (trim size 44 by 65 inches). At the time of scanning, the contractor could only procure stable base film in a 31- by 33-inch size. This problem of film size meant scanning and plotting each color transparency twice, then mosaicking these two pieces together into a halftone that represented the area of the color transparency. When these films were mosaicked, another mosaic was required to reunite each map into a contiguous film, one film for each of the four colors. The number of pieces of film that were mosaicked grew from 24 to 48. Photographic mosaicking, a highly complex process, requires extreme care in handling the film, masking the area windows, and calculating the photographic exposures (Warren, 1980).

Halftone mosaicking is the photomechanical combining of two or more halftone images at a common image edge to create a seamless, single, halftone film. This photographic technique remains an art. It is a labor intensive, trial-and-error procedure. It is extremely difficult to create smoothly blended tones and matching colors without showing lines and changes of colors at the join areas.

The vast area of sand landscape in the UAE imagery made mosaicking difficult because of its smooth tones and textures. Join lines are easiest to mask at transition areas of cultural or physical features having sharp contrast changes. Road and hydrology networks make excellent features for this, having natural breaks in texture and (or) color to help mask the joins. The procedure for mosaicking the UAE image halftones was done in two stages. First, because each transparency was separated into two sets of halftone films during scanning, these films needed to be rejoined before making the two mosaicked map sheets. This was done by photographically mosaicking the two sets of 31- by 33-inch films back into one set of halftones representing the six original color transparencies.

Next, the six sets of halftones were divided into the two sections that represented coverage for the two UAE maps. The three sets of halftone films representing each map were then photographically mosaicked into one set of 45- by 68-inch halftone films. These two sets of halftone films were eventually used for the final production of the maps.

Film Handling

Another issue was the large size of the film, which was difficult to handle physically. Bending or kinking of halftone film results in poor quality of the dots, which affects and changes colors.

Also, cleanliness during photographic mosaicking and copying became an acute problem. Because of the physical size of the film (45 by 68 inches) and the large number of exposures for mosaicking each map, static electricity quickly built up in the film. This static attracted loose hairs and dust to the film that were difficult to see under darkroom lighting conditions. This debris was not obvious until after the halftone's process was completed.

Press Proofs

When the halftones for each map were mosaicked, a Cromalin color proof was made and reviewed. The Cromalin proof is a standard in the graphic arts industry as a means to illustrate color and imposition of halftone images before printing (Bruno, 1986). The Cromalin proof is the standard used at the USGS for color image maps. The Cromalin proof is created by using color powder toners that represent and match the process ink hues of the lithographic printing process (Bruno, 1986).

Several small blemishes were detected on the map proofs that required the halftone films to be hand-corrected

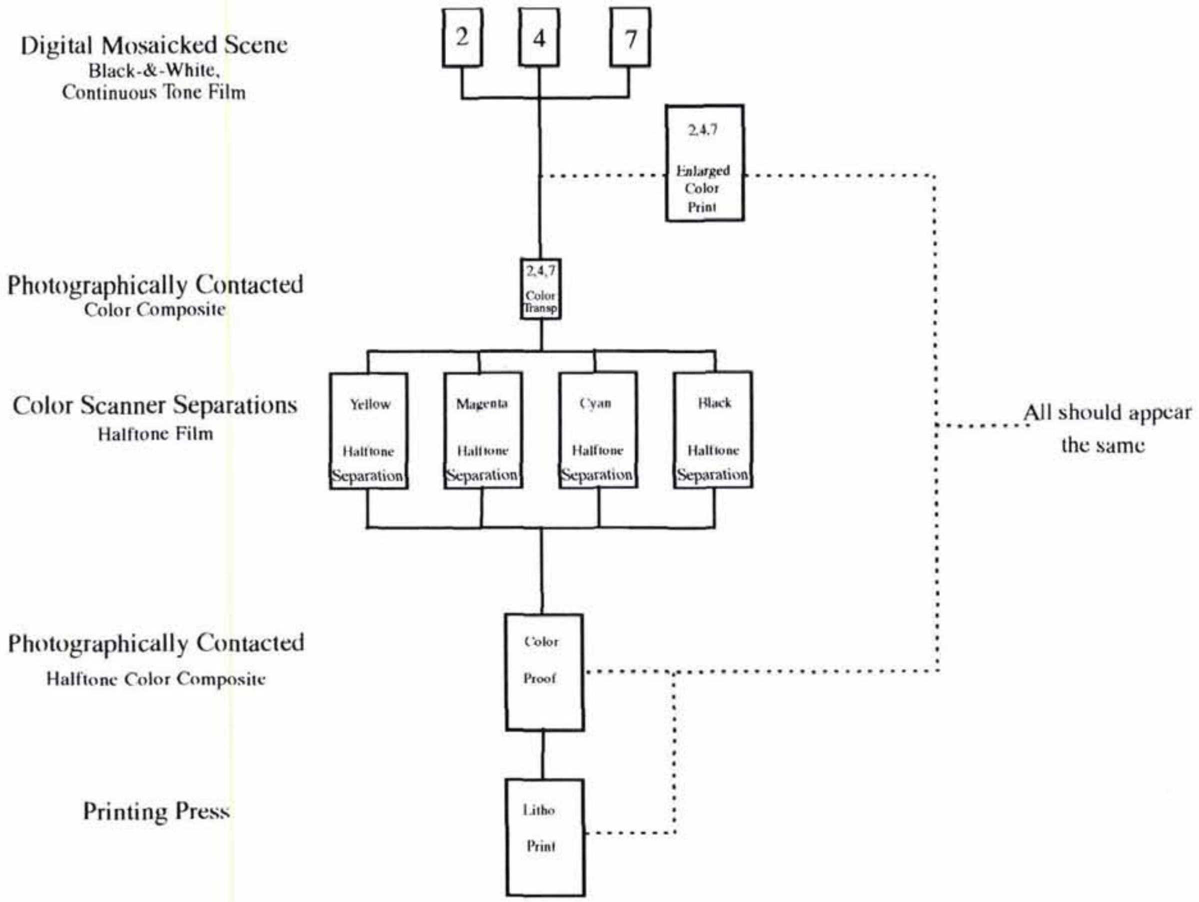

Fig. 5. Production flow of an image scene.

by an artist. When corrected and approved, the film was proofed again, this time including all text and linework. These proofs became the press color proofs that are discussed in the next section.

Printing

The printing of the UAE maps was completed during the autumn of 1991. Because of size limitations, the USGS could not print the maps. A commercial printer was contracted to handle the platemaking and printing. The contractor was furnished with all film materials and a set of printing standards used by the USGS (USGS, 1987). By carefully adhering to these standards, the contractor was able to print these two maps and match the color press proof.

The empirical and quantitative correlations between the color proofs and the press sheet are important for predicting how the image maps will print. The following is a brief summary of the standards used to print the UAE maps.

Press Color Proofs

The press color proofs show all film plates as they will appear when finally printed. These proofs are used by press personnel as a visual guide for matching colors and image registration. The final printed maps must match the proofs. To be valid as a press color proof requires careful monitoring during the making of the press proofs to ensure that they meet guidelines that will replicate how the final map will appear in print.

The color separator, when making these proofs, carefully monitors exposure times and the density of toners. This is done visually and by quantitative methods using a Graphic Arts Technical Foundation (GATF) 21-step Sensitivity Guide. The GATF is an organization that assists the printing community by establishing guidelines for monitoring the many variables in the printing system. The GATF continuous tone 21-step guide is one such device. This scale guide is a small piece of film (1/2 inch by 5 inches) that is divided into blocks or steps of density that increase in density values in ascending order by 0.15. By exposing this scale along with each halftone on the proofing material and then observing the hue densities during toning, the proof maker can closely approximate how the film will print on press.

Along with the GATF scale guide, a USGS Tint Scale was attached and imaged on the proofs. This is a 17-step scale similar to the GATF 21-step scale. However, instead of having continuous tone values, each step represents a different halftone percent dot value, ranging from 100 to 5 percent. Monitoring these dot values on the proof ensures that the exposures will reproduce the proper and desired dot sizes that will emulate the printed map.

Both of these scales are imaged on the proof material outside the map's trim marks. These scales give quantifiable information that is used to correlate the appearance of the proofs with a press image. After each proof has an image exposed, the halftone image and scales are toned with their respective color (YMCK). A reflective densitometer is used to read density values for the 100 percent dot value for each hue on the USGS Tint Scale. To be accepted, these values must fall within the established printing ink densities shown in Table 2.

After ensuring that the 100 percent dot is accurate, the 50 percent (midtone) dot on the USGS Tint Scale is densitometricaly read using the Yule-Nielsen equation for calculating the physical dot area (Southworth and Southworth, 1989). Dot gain is the increase in dot size caused by the reproduction process and interaction of materials. Ink spreading on the paper or incorrectly exposed printing plates are examples that affect dot gain. Although most of the reasons for dot gain cannot be corrected, the process can be monitored and controlled. If dot gain is not monitored and the dots become too large, or even too small, the color and tones of the map can be dramatically altered. Dot gain can be simulated in the proofing process by altering exposure times. By carefully monitoring the exposure, the dot gain should match the printed press sheet, which is acceptable between the 7 to 13 percent range at the 50 percent dot (Bruno, 1986).

Platemaking

Platemaking is the photographic process of capturing halftone and line film images onto a light-sensitive emulsion coating of a metal substrate. Plates are the medium for transferring the photographic halftone images to the printing press. One plate is made for each color to be printed.

For each halftone image exposed to a plate on the UAE maps, a GATF Platemaker's Guide was exposed with it. This 21-step scale guide is the same as the one used for monitoring the press color proofs. The scale helps the platemaker evaluate the light exposures and emulsion developments for each plate.

Another process monitoring tool exposed on the plate but outside the image trim area is a printing color bar. The USGS uses the GATF Color Test Strip to monitor printing. This strip is a series of small blocks approximately 1/4 by 1/4 inch in size. Each block has either a halftone tint or is solid (100 percent dot value). This pattern of blocks is repeated every 9 inches. For each of the four printing colors there is a color bar. These color bars are designed to integrate as one color image when printed together. Imaging this bar across the width of the map sheet permits close monitoring of ink density, flow, and evenness during printing. These color bars capture an enormous amount of data on printing conditions by showing a picture of the entire printing process to press and quality control personnel.

The contractor used all of these quality control devices to monitor the platemaking process of the UAE maps. When all plates were made, they were visually examined to ensure that all image elements were in their proper position, the plate was properly exposed and developed, and there were no image blemishes. The plates were then moved into the press area for printing.

TABLE 2. PRINTING SEQUENCE FOR INK AND WET DENSITIES

Printing sequence	Ink		Wet density
1	Black	001*	1.25 - 1.40+
2	Cyan	096*	1.20 - 1.30+
3	Magenta	009*	1.20 - 1.30+
4	Yellow	003*	0.81 - 0.89+

* USGS ink internal number.

+ Solid reflective ink densities with white paper zeroed out.

Press

Printing image maps is not unlike line map printing. Care in registration among color images and close monitoring of the color ink density across the width of the sheet are the most critical variables to observe to obtain a quality product.

Press registration ensures that each press plate prints the image at exactly the same place on a sheet of paper as it passes through the four (YMCK) printing units of the press. Any misregistration between plates will cause the image to blur and shift ink hues.

Because of careful planning, the registration and printing of the two UAE maps were uneventful.

Ink

The inks used for printing the UAE maps were USGS formulation inks similar to basic process hues listed in the Pantone Matching System. Each map was printed to the wet ink density readings shown in Table 2. To ensure quality printing, maintain a consistent color balance through the entire press run, and have historical records for future printing, density values for each ink were recorded throughout the entire press run using a reflective densitometer.

During the press run, at intervals of 200 to 300 sheets, a map sheet was pulled and inspected for ink density values, color balance, and printing flaws. If an irregularity was detected during or after the press run, information from these samples was used to help isolate groups of maps having the problem. These maps could then be evaluated and considered for disposal. Throughout the entire production process, the quality of each phase was carefully observed.

Conclusion

The high quality of the two UAE maps was not a surprise. The entire production process, from film imaging to printing, had been tightly controlled and orchestrated through each series of production steps. Preparation for producing these maps began at the USGS almost 20 years ago. The appearance of the UAE maps is a result of experiences gained from printing many earlier image maps. The successes and failures of those experiences have helped to develop a predictable production process and a set of production standards to convert remotely sensed image data into color lithographic maps.

Techniques in data gathering, processing, and image enhancing are continually changing. By adjusting to and building on these techniques, the quality of image maps will continue to improve. The existing USGS production procedures work; if the color press proof looks good, the printed image will match.

The next big hurdle for image mapping is to move digital data directly to the press. No film will be needed, only digits imaged directly onto a plate, and a means to proof the data before printing. The technology for this process is almost in place; only experience and time is needed to meet this goal.

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