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# MAPPING OF WASHINGTON, D.C. AND VICINITY WITH THE LANDSAT 4 THEMATIC MAPPER

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## INTRODUCTION

For over 10 years the National Mapping Division of the U.S. Geological Survey has been creating experimental image maps from Landsat data. The multispectral scanners (MSS) on Landsats 1, 2, and 3, which have resolution elements of 75 m, have produced images suitable for presentation at the 1:250,000 scale. The Landsat-3 single-band return-beam-vidicon data, with approximately 30-m resolution elements, have been presented in black-and-white image-map form at scales as large as 1:100,000.

On July 16, 1982, NASA launched Landsat 4 with the Thematic Mapper (TM) which produces multispectral data of 30-m resolution elements. Thus the opportunity to produce multicolored image maps at the 1:100,000 scale presented itself. The 1:100,000 scale is rapidly becoming a popular scale for U.S. Geological Survey line-map quadrangles, and the Dyersburg Landsat image map followed this format. This image map was printed back-to-back with the conventional 1:100,000-scale line map during 1983.

On November 2, 1982, at 10:14 a.m. (e.s.t.) the Washington, D.C. area was recorded by the TM as Landsat image E40109-15140. The data quality is excellent and the scene is generally devoid of clouds, haze, or other detracting anomalies. The heavy deciduous leaf cover in the area had turned brown (or fallen), and thus conditions were near ideal for recording by the multispectral TM. The TM records seven spectral bands, but the one thermal band (band 6, 10.4 to 12.5 µm) was not considered suitable for such a project. The six remaining bands are listed as follows:

| Band | Wavelength |
|---|---|
| 1 blue | 0.45 - 0.52 µm |
| 2 green | 0.52 - 0.60 µm |
| 3 red | 0.63 - 0.69 µm |
| 4 near IR | 0.76 - 0.90 µm |
| 5 near IR | 1.55 - 1.75 µm |
| 7 near IR | 2.08 - 2.35 µm |

## PROCEDURES

Upon receipt of the TM data, NASA performs a digital resampling which uses the cubic convolution algorithm. Geometric corrections are also imposed, based on the spacecraft ephemeris and attitude data, the sensor geometry and, if possible, ground control. Up to this time ground control has not been generally applied to TM data by NASA but the corrections made, do result in internal scene geometry of excellent fidelity. In general, NASA utilizes the Space Oblique Mercator (SOM) projection for such image processing, as was the case with this image. The EROS Data Center (EDC), after receipt of this data in digital form from NASA, performed a second cubic convolution resampling in this case. About 20 control points, based on large-scale maps, were used to convert the data to the Universal Transverse Mercator projection and to insure absolute as well as relative positional accuracy. Tests indicate that the published map approached U.S. standards for positional map accuracy. In addition to applying geometric constraints, EDC utilized a 5-by-5-pixel edge enhancement algorithm in this resampling. The digital data were then printed by EDC on their laser beam recorder at 1:553,000 scale,

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which is the largest scale that the format would accommodate. This printing involved a density range from about 0.08 to 1.38 as measured on a standard density scale. The resulting image (black-and-white) transparencies of the six bands were then processed on a Hell* scanner plotter. The functioning of the Hell scanner is described by Kidwell and McSweeney (USGS) in an as yet unpublished paper titled "Processing and Lithographic Printing of Image Maps," the scanner plotter produced screened reproducibles at the correct 1:100,000 scale with the desired density range and contrast, and with no apparent loss of resolution even though a 5.53-enlargement factor and another resampling was involved. Litho printing on coated map stock paper was accomplished in three colors, yellow, magenta, cyan, for the image, and black for the line work.

## BAND AND COLOR SELECTION

The six TM bands (thermal excluded), as opposed to the three principal bands of the Landsat MSS, present a highly complex problem to the mapmaker. Six bands provide no less than 20 basic combinations and 120 permutations with respect to a three-color image map. By applying various enhancements and processing algorithms, the variations possible in the final product are literally endless. Furthermore, nearly every variation seems to have its own unique attribute and to display certain features better than others. The U.S. Geological Survey at their Flagstaff, Arizona, facility, is conducting basic research on the effects of combining spectral bands. This work has been documented (Chavez, Berlin, and Sowers, 1982) and is based on the six ratios that can be derived from the four MSS bands of Landsat. With the recent availability of the six TM bands, Chavez has used this analysis for various TM scenes.

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Instead of using ratios, he used the digital data itself of the six TM bands which provided the same number of combinations (20) obtained from the ratios of the four MSS bands on which the cited research is based. The following two tables (prepared by Chavez) show a statistical analysis of the six TM bands for the Washington, D.C. and Vicinity image map. The color combination finally selected is the result of visual comparisons made by earth scientists and mapmakers and represents more of a subjective consensus than an objective scientific decision. The bands chosen were 1, 3, and 5 (OIF #9) printed in the subtractive colors of yellow, magenta, and cyan, respectively. Table 1 is a matrix of

Table 1.--TM-Six-band matrix of correlation coefficients (CC) for Washington, D.C. and Vicinity Landsat 4 Image E 40109-15140, November 2, 1982

| TM Bands | 1 | 2 | 3 | 4 | 5 | 7 |
|---|---|---|---|---|---|---|
| 1 | 1.00 | | | | | |
| 2 | .91 | 1.00 | | | | |
| 3 | .83 | .89 | 1.00 | | | |
| 4 | .27 | .42 | .34 | 1.00 | | |
| 5 | .45 | .56 | .62 | .67 | 1.00 | |
| 7 | .65 | .72 | .78 | .46 | .90 | 1.00 |
| Bands | 1 | 2 | 3 | 4 | 5 | 7 |
| Response (avg.) | 60.90 | 24.80 | 26.10 | 40.90 | 52.10 | 20.20 |
| Standard Deviation (SD) | 5.68 | 3.78 | 5.32 | 10.93 | 15.77 | 7.69 |

See Chavez, Berlin and Sowers, 1982

correlation coefficients which also includes the average response (based on the 0-255 digital range) and the standard deviation of the data. Table 2 lists the 20 combinations based on what Chavez refers to as the Optimum Index Factor (OIF). A footnote on this table indicates the mathematical

Table 2.--Optimum Index Factor (OIF) for Washington, D.C. and Vicinity using six TM bands (see Chavez, Berlin, and Sowers, 1982)

| OIF RANK | COMBINATION* | $\sum_{j=1}^{3} \lvert CC_j \rvert$ | $\sum_{i=1}^{3} SD_i$ | OIF** |
|---|---|---|---|---|
| 1 | (1, 4, 5) | 1.380 | 32.38 | 23.46 |
| 2 | (3, 4, 5) | 1.630 | 32.02 | 19.64 |
| 3 | (2, 4, 5) | 1.683 | 30.48 | 18.61 |
| 4 | (1, 4, 7) | 1.373 | 24.30 | 17.70 |
| 5 | (4, 5, 7) | 2.023 | 34.39 | 17.00 |
| 6 | (1, 3, 4) | 1.439 | 21.93 | 15.24 |
| 7 | (3, 4, 7) | 1.583 | 23.94 | 15.12 |
| 8 | (1, 5, 7) | 1.994 | 29.14 | 14.61 |
| 9 | (1, 3, 5) | 1.901 | 26.77 | 14.08 |
| 10 | (2, 4, 7) | 1.596 | 22.40 | 14.04 |
| 11 | (1, 2, 5) | 1.914 | 25.23 | 13.18 |
| 12 | (1, 2, 4) | 1.590 | 20.39 | 12.82 |
| 13 | (2, 5, 7) | 2.175 | 27.24 | 12.52 |
| 14 | (3, 5, 7) | 2.300 | 28.78 | 12.51 |
| 15 | (2, 3, 4) | 1.642 | 20.03 | 12.20 |
| 16 | (2, 3, 5) | 2.062 | 24.87 | 12.06 |
| 17 | (1, 3, 7) | 2.263 | 18.69 | 8.26 |
| 18 | (1, 2, 7) | 2.281 | 17.15 | 7.52 |
| 19 | (2, 3, 7) | 2.389 | 16.79 | 7.03 |
| 20 | (1, 2, 3) | 2.627 | 14.78 | 5.63 |

* Six bands combined three at a time gives 20 combinations.

** $OIF = \sum_{i=1}^{3} SD_i \div \sum_{j=1}^{3} \lvert CC_j \rvert$

definition of OIF. In essence, it says that the OIF will be large when the sum of the standard deviations (SD's) is large and the sum of the correlation coefficients (CC's) is small and vice versa. The larger the OIF, the more information portrayed. However, this must be tempered by what is really important in the scene and on the use of the image or image map. One combination, which may be of low ranking, may better show a particular type of information than one of much higher ranking (Chavez, Guptill, and Bowell, 1984).

According to the OIF's developed by Chavez, bands 1, 4, and 5, should have been used for the Washington, D.C. area. Unfortunately, both bands 4 and 5 are highly reflective with respect to growing vegetation, and in image form cultural features such as roads and runways, which are of obvious high importance, tend to be subdued in this combination. Another interesting problem arises from the color selection, which involves permutations. Instead of printing bands 1, 4, and 5 in yellow, magenta, and cyan, respectively, a change was made to yellow, cyan, and magenta; reversing the color role of bands 4 and 5. This particular permutation appears to provide the most information of those tried. It was not selected for printing because growing vegetation, particularly grass, appears yellow. After several years of educating the user to the red portrayal of infrared reflective vegetation, it did not seem quite right to change its color again. Also note that the approximation of an MSS false-color presentation (2, 3, 4) ranks 15 and true color (1, 2, 3) ranks 20 as to OIF.

## PIXEL TO SCALE RELATIONSHIP

The optimum scale for printing of an image map from digital data of specified pixel size is controversial and deserves considerable attention. First one must accept the premise that both line and image maps are designed to be viewed by the unaided eye. The map user expects to be able to readily see map detail without the use of a magnifying glass, and since lithographic printing is relatively inexpensive, the map scale should be sufficiently large to permit his unaided viewing. One reference indicates the human eye can resolve up to 10 high contrast line pairs (ℓp) per mm (Thomas, 1973) although other references indicate this number may be as low as 5; and 7.5 appears to be a reasonable number to use. The estimated relationship of pixel* to line pair varies from 1.6 to 2.83 pixels per line pair, and the value of 2 is commonly used and also considered reasonable. Thus it would appear that any map (line or image) made from digital data would require a spatial frequency of 15 pixels per mm to

* In this paper the pixel size referred to is that of the original acquisition system. Resampling normally involves pixels of smaller size (higher frequency), but the original pixel dimension and spacing are the key factors in a digital imaging system.

fully depict all information that might be resolved by the unaided eye. Based on this reasoning, researchers in the fields of mapping and remote sensing (Konecny, Schuhr, and Wu, 1982; Doyle, 1982; Light, 1983) have indicated that a good image map should, in fact, be composed of 10 to 20 pixels per mm at printed scale. However, the study of existing line and image maps does not appear to support such a criterion.

First one should look at line maps and the spatial frequency shown on such products. Contour lines as they close up in steep terrain are, in effect, bar targets or line pairs. However, line mapping, as specified by the U.S. Defense Mapping Agency (and followed by the U.S. Geological Survey), does not permit contours to be spaced closer than 3.3 ℓp/mm (DMATC, 1971). If one uses the 2 pixels per-line-pair criterion, this would require 7 (6.7) pixels per mm to properly show contours at such spacing. Before relating such spatial frequency to image mapping, one should note the following:

- Contour lines are of high contrast and acuity (edge sharpness) and of uniform width.

- It is virtually impossible to find natural linear features which have the characteristics of a contour line when recorded on an image map. Because of lower contrast, acuity, and variable width, natural linear features recorded on an image map require lower frequency (more space) to be resolved by the unaided eye. In dealing with resolution targets, it has been found that low contrast (1.6 to 1) as compared to high contrast (100 to 1 or 1,000 to 1) will reduce resolution by a factor of 2, and the natural Earth scene exhibits many linear features of contrasts no greater than 1.6 to 1 when viewed from space. Thus it appears safe to say that the proper portrayal of linear features on an image map will require a frequency of no more than 1.7 linear feature or 3.3 pixels per mm.

On large-scale line maps which show equidimensional objects such as closely spaced houses, both the Defense Mapping Agency (DMATC, 1971) and the Geological Survey (Thompson, 1981) permit a minimum spacing of only 1.7 houses per mm. Let us assume it takes 4 pixels (in each direction) to portray a building and a space between them. This means at least one pixel will have the full radiometric value of the building and one the full value of the space between. This also indicates that equidimensional objects require twice the pixel frequency to portray in digital mode as do linear objects of the same spacing. One comes back to 7 pixels per mm to properly portray equidimensional objects on a line map. As with linear features, natural equidimensional objects as recorded by an imager will not have the contrast, acuity, or regularity of buildings as shown on a line map. Again one may assume a 2-to-1 resolution loss due to the natural low contrast (1.6 to 1) as compared to the high contrast of the buildings on the line map. This puts one back to 3.3 pixels per mm and a frequency of only 0.83 equidimensional object (buildings) per mm on the printed image map.

In the case of the Washington, D.C. and Vicinity image map, the 30-m pixels reduce to 0.3 mm or 3.3 pixels per mm at the printed map scale of 1:100,000. This criterion of 3.3 pixels per mm should be further validated by the objective evaluation of image maps produced at different pixel-to-scale relationships and which involve different type areas and image processing procedures. The following table, based on the typical pixel sizes, results from this 3.3-pixels-per-mm criterion (table 3).

Table 3.--Pixel to map scale relationship

| Ground scale pixel size | Image map scale |
|---|---|
| 75 m (MSS) | 1:250,000 |
| 30 m (TM-RBV) | 1:100,000 |
| 15 m | 1:50,000 (by extrapolation) |
| 7.5 m | 1:25,000 (by extrapolation) |

If one accepts this criterion, it follows that line maps and image maps of the same scale will not present the same detail of information. The line map may show lines spaced at only 0.3 mm or objects (buildings) of 0.67-mm spacing. There is no known way an image map can expect to show such fine detail except in isolated cases. A comparison of the street patterns on image and line maps quickly shows this at the 1:100,000 scale. At larger scales such as 1:50,000 and 1:24,000 where individual houses are shown on the line map, this same lack of defined detail is evident on an image map of similar scale. The image map could be made at higher resolution but, because of the limitations indicated, the unaided eye would see little or no more detail. This is analogous to using a 300 ℓ/inch* (lines per inch) screen as opposed to a 150 ℓ/inch screen in the halftone process. In theory it improves resolution, but in practice the differences are marginal.

The argument that the image map cannot show the same fine detail as the same scale line map deserves further discussion. Because the line map consists of selected symbols, an enormous amount of information which appeared on the original image (photo) from which the map was made has been omitted. Many map users find this to be unacceptable and want the very information that has been omitted. The image maps formerly produced by the U.S. Soil Conservation Service and USGS orthophotoquads are examples which attempt to portray this information. Unfortunately these image products are generally monochromatic and lack the information that color can provide. According to one theory, the use of color can increase information content in a graphic (map or image) according to the following: 1 color = 1! = 1; 2 colors = 2! = 2; 3 colors = 3! = 6. In practice such an increase in information, as recorded by the human eye, is probably not possible, but it is believed that the proper use of multispectral sensing and color will at least double the useful information content of a typical image map as compared to monochromatic (normally black and white) portrayal. An extensive agricultural study on this matter was conducted jointly by NASA and The Department of Agriculture from 1973 to 1978 but was not published (U.S. Department of Agriculture, 1978). This study found the use of color (color infrared) film permitted 2.6 times as many requirements to be met as did black-and-white film of the same scale.

* The abbreviation "ℓ/inch" is equivalent to "ℓp/inch" but is used by convention.

## SUMMARY

TM data as processed for the Washington, D.C. and Vicinity image map (and previously for the Dyersburg image map) clearly demonstrate that such data are applicable to image mapping at the 1:100,000 scale. However, this conclusion is based on the fact that an image map does not (and cannot) show the same type of detail as a line map of the same scale. Both the image and line-map forms have the primary purpose of transmitting information to the human eye, and the two forms are considered complementary rather than duplicatory. The pixel-to-scale relationship of 3.3 pixels per mm at map scale is considered suitable until further experimentation might alter this criterion. In any case it would appear that the 10-m pixel, as defined for the French SPOT and other satellites, will be fully adequate for 1:50,000 image mapping. From the geometric standpoint TM data meet 1:100,000-scale planimetric mapping requirements in areas where suitable geodetic control is available. Earth-sensing satellites such as the Landsats and their successors which are designed with mapping as one of their primary functions promise to be powerful tools of cartography.

## REFERENCES

Chavez, P.S., Jr., Berlin, G.L., and Sowers, L.G., 1982, Statistical Method for Selecting Landsat MSS Ratios: Journal of Applied Photographic Engineering, vol. 8, no. 1, pp. 23-30.

Chavez, P. S., Jr., Guptill, S. C., and Bowell J.A., 1984, Image Processing Techniques for Thematic Mapper Data: Technical papers 50th Annual Meeting, ASP, Washington, D.C.

Defense Mapping Agency Topographic Center (DMATC), July 1971, DMATC-TM S-1, chapter 6.

Doyle, F. J., 1982, Satellite Systems for Cartography: Proceedings of the 1st Symposium on Remote Sensing of Environment: First Thematic Conference, Environmental Research Institute of Michigan, Ann Arbor, Michigan, vol. 1, pp. 111-120.

Konecny, G., Schuhr, W., and Wu, J. 1982, Investigations of Interpretability of Images by Different Sensors and Platforms for Small Scale Mapping: Proceedings of the Symposium of Commission I, International Society of Photogrammetry and Remote Sensing, International Archives of Photogrammetry, vol. 24, part 1, pp. 11-22.

Light, D., 1983, Mass Storage Estimates for the Digital Mapping Era: Technical Papers 43rd Annual Meeting American-Congress on Survey and Mapping, pp. 152-164.

Thomas, Woodlief Jr., 1973, SPSE Handbook of Photographic Science and Engineering: New York, John Wiley & Sons, pp. 380-381.

Thompson, M.M., 1981, Maps for America (2nd Ed.): U.S. Geological Survey, p. 56.