UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PHOTO-OPTICAL ENHANCEMENT OF LANDSAT IMAGERY FOR LAND USE IN SOUTH-CENTRAL IOWA

FROM LAND CLASSIFICATION OF SOUTH-CENTRAL IOWA

FROM COMPUTER ENHANCED IMAGES

(NAS 5-20832)

TYPE II REPORT #5

By James R. Lucas, James V. Taranik, and

Frederick C. Billingsley

Sioux Falls, South Dakota

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In the course of writing this NASA Type II Progress Report, there have been several individuals who have made valuable contributions to its completion. Richard L. Nelson, Assistant Supervisor of the EDC Custom Color Laboratory, and Darrell C. Ramerth, also of the EDC Custom Color Laboratory, are two such individuals who are sincerely thanked for their help and guidance in producing imagery and documentation for the EDC color compositing process. Keith Maas and T. Lincoln Perry of EDC are also thanked for their comments and evaluations concerning this project. These four individuals mentioned above are all employees of Technicolor Graphic Services, Incorporated.

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LAND CLASSIFICATION OF SOUTH-CENTRAL IOWA FROM COMPUTER ENHANCED IMAGES

James R. Lucas, Technicolor Graphic Services, Inc.
James V. Taranik, U.S. Geological Survey
and Frederick C. Billingsley,
National Aeronautics and Space Administration

ABSTRACT

Because the photographic laboratory at the Jet Propulsion Laboratory found it difficult to estimate what were the optimal color renditions of the Iowa landscape for land classification purposes, the Iowa Geological Survey developed its own capability for producing color products from digitally enhanced Landsat data. Research has now shown that efficient production of enhanced images requires full utilization of both computer and photographic enhancement procedures. Experimental photo-optical enhancement techniques carried out at the EROS Data Center (EDC) for a Landsat-1, 29 August 1972 scene, proved to be more easily interpreted for land classification purposes than the EDC standard color composite. If digital processing can be minimized by using photographic enhancement techniques, then costs of enhanced products could be greatly reduced. Perhaps one of the major objectives of computer processing

of Landsat data should be to produce high quality cosmetically enhanced (eliminate striping and line drops) data which has a range of digital values that can be completely recorded by film media. If digital processing can distribute reflectance data throughout the entire recording range of photographic film, then photographic enhancement techniques could be employed cheaply by users familiar with the type of information they wish to extract from the imagery. Alternatively, if custom enhanced imagery is to be produced for users not having a photographic capability, different enhancements may be tried in an iterative fashion in the photographic laboratory, without having to reprocess digital data in the computer for each iteration. The savings in time and money should be considerable using this approach.

INTRODUCTION

This NASA Type II Progress Report presents a detailed discussion of the EROS Data Center (EDC) procedure for producing Landsat standard product false-color composites. Also discussed is an experimental approach used to produce a photo-optically enhanced (POE) Landsat image. Tone reproduction diagrams are used to document this process

This work was undertaken because of photographic problems identified early in the research on digital processing. Specifically, the photographic laboratory at the Jet Propulsion Laboratory found it difficult to estimate what were the optimal color renditions of the Iowa landscape for land-use interpretation. This led the Iowa Geological Survey (IGS) to develop its own capability for producing color products from digitally enhanced Landsat data (see NAS5-20832 Type II Progress Report #3, 3 November 1975). Research has now shown that efficient production of enhanced images requires full utilization of both computer and photographic enhancement procedures.

EDC PROCESS FOR THE PRODUCTION OF

LANDSAT COLOR COMPOSITES

The production of a false color composite at the EROS Data Center begins with a second generation negative (N-2) which is received from the Goddard Space Flight Center. The N-2 is an unsprocketed 70 mm film, type SO-467, which has been processed to a system gamma of 1.0.

From the N-2, a 70 mm third generation positive (P-3) is contact printed on Kodak film type 2421. This P-3 is sometimes referred to as a UVP-3 because the tungsten printing lights used to print the P-3 are filtered through a Corning 5970 glass filter. This filter is highly transparent to ultraviolet light while almost entirely blocking visible light. The use of the Corning filter reduces the halation, the loss of sharpness in contours between high and low densities, which is a problem associated with the large density ranges in Landsat negatives. This filter is very effective when used for contact printing, but is very inefficient for optical printing. The P-3 is processed to a 1.0 system gamma in a Model 11CM Versamat with MX-885 developer at 85°F (29.4°C).

A 9.5 inch (241 mm) fourth generation negative (N-4) is printed from the 70 mm P-3. Tests have shown that the halation which is introduced by enlargement can be best controlled when the enlargements are made from a positive rather than a negative. For this reason, the 70 mm P-3 is printed to a 9.5 inch (241 mm) N-4 on an enlarger with a fixed magnification of 3.369 resulting in an image scale of 1:1,000,000. The exposure to make the N-4 is determined using a density analyzer with a light integrating head which measures the integrated scene density of the P-3 image of band 5. The objective of this step in the composite production is to prepare an N-4 from a P-3 which will have an average density near 1.0 density units. Exposure adjustments are made for only band 5. Bands 4, 6, and 7 of the same scene are printed with the same exposure as band 5. The N-4 enlargement is printed on Kodak 2421 film and is processed in a 11CM Versamat with MX-885 developer at 85°F (29.4°C).

The 9.5 inch (241 mm) N-4 is roll-to-roll contact printed on a modified Colorado printer to produce a 9.5 inch (241 mm) fifth generation positive transparency (P-5). A Corning 5970 filter is also used to reduce the halation on the P-5 (or UVP-5) transparency. The P-5 film is Kodak type 2421 which is processed in a 11CM Versamat with MX-885 developer at 85°F (29.4°C). A system gamma of 1.5 is achieved for the fifth generation positive. This increased contrast of the P-5 is introduced to enhance the color contrast and to provide better color saturation on the color composite during printing.

Before a color composite can be printed, the positive transparencies must be registered as a set by using the tick marks in the four corners on each Landsat image. Only bands 4, 5, and 7 are used for making a standard false-color composite; band 6 is not registered. The equipment required for registering transparencies consists of a light table, registration punch, and a magnifying eyepiece. One P-5 transparency, usually band 4, is taped to the light box, emulsion-side down. A second P-5 transparency is placed over the image taped to the light box and is aligned to the diagonal tick marks by using the magnifying eyepiece. This second transparency is taped in position and both transparencies are simultaneously punched. After the second transparency is unfastened and removed, the third transparency is placed over the first, aligned, and punched. The registration of the transparencies is checked by mounting the punched images on registration pins and viewing the aligned scenes over a light table.

The printing of the P-5 black and white transparencies onto color film to produce a false-color composite is done with a vacuum easel with registration pins mounted on the bed, a point light source with a filter wheel, three primary filters and a filter selector, a timer for the light source, and a registration punch for the color film. Before the color composite printing is executed, however, the enlarger light source is calibrated for color balance. To do this, a test exposure is made through each filter to a neutral step tablet on the color film. All three filters used in the production of the color composite are adjusted with neutral density filters until equal exposure produces neutral densities near the 1.0 step on the color film. When using a 21 step grey scale, the eighth step of increasing density (about 1.06 density units) is used for the color balance.

To determine the exposures to be used in printing the false-color composite for each band, the input densities from the P-5 transparencies are read by a transmission densitometer from the step annotation grey scale nearest (but not exceeding) the 1.0 density step. These density values, from bands 4, 5, and 7, are used to adjust the exposures for each band so the neutral density of about 1.0 will be reproduced on the color transparency. The actual adjustments in printing times for each band, however, are determined by a density/exposure chart. By making the annotation scale neutral at the 1.0 step, the relationships of the image densities of bands 4, 5, and 7 are retained. In addition, the calibration to the 1.0 step will help ensure that the same general color will always be reproduced without the need for subjective visual evaluation. The variations in the relative densities of the black and white transparencies are also partially corrected by this process.

Once the exposures and color balance have been determined, the color film positive (CFP-6) can be printed. The first step in this process starts with the previously registered and punched band 7 which is placed over a sheet of unexposed Kodak Aerochrome color reversal film type 2447. The film and transparency are exposed for a predetermined time to red light through a Wratten #29 red filter. Band 7 (infrared spectral band) is removed from the easel and is replaced by band 5 (red spectral band) which is registered and exposed to green light through a Wratten #58 green filter. Band 5 is then removed, being replaced by band 4 (green spectral band), which is registered and exposed to blue light through a Wratten #47 blue filter. When this procedure is completed, the exposed 2447 film is processed in a Versamat model 1811 with EA-5 chemistry to form a sixth generation film-positive color transparency.

The CFP-6 is first inspected and then entered into the data base file at the EROS Data Center. Color standard product (CSP-7) film copies of this composite are produced by contact printing the CFP-6 on a modified Mark II printer using Kodak 2447 color-reversal film. Before printing, however, the light source is color balanced by test printing, developing, and evaluating a 21 step tablet to ensure that all densities on the wedge have as neutral a grey tone as possible. The exposure for the color transparency is determined by taking an integrated scene density for the composite. After printing, the CSP-7 is processed in a Versamat model 1811 with EA-5 chemistry to form a film positive color transparency.

Paper prints at 1:1,000,000 scale are optically printed from the CFP-6 transparency. Color balancing the light source is accomplished by test printing and processing a 21 step tablet. Exposure is determined from the integrated scene density for the color composite. The paper used for printing is Kodak 2212 color reversal type which is processed in a color Simplex processor with R-5 chemistry.

A summary of the EDC process for producing Landsat color composites is found on Figure 1. A color composite

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Figure 1 near here.

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print (CSP-7) for the Landsat-1, 29 August 1972 subscene is displayed on Figure 2 (a location map shown on Figure 3).

Figures 2 and 3 near here.

This false-color composite was printed at the Iowa Geological Survey (IGS) on Cibachrome color photographic paper, which is now available as a product from the EROS Data Center. Cibachrome paper was utilized at IGS because it was easily processed with limited darkroom facilities. Examples of EDC standard product fourth generation negatives (N-4[bands 4, 5, and 7]) and fifth generation positives (P-5[bands 4, 5, and 7]) are shown on Figures 4, 5, 6, 7, 8, and 9.

Figures 4 through 9 near here.

Figure 1.--EROS Data Center process for the production of Landsat color composites.[1]

Step #	Film Production Generation	
1	N-2 70 mm	The N-2 is furnished by the Goddard Space Flight Center. It is a contact print made from the first generation positive (P-1) produced on the Electron Beam Recorder. The N-2 is an unsprocketed 70 mm film, type SO-467, which has been processed to a system gamma of 1.0.
2		The N-2 is contact printed on Kodak 2421 film using a Corning 5970 filter which is transparent to ultraviolet light to produce the third generation positive (P-3).
3	P-3 or UVP-3 70 mm	The P-3 is processed to a system gamma of 1.0 in a 11CM Versamat with MX-885 developer at 85°F (29.4°C).

Figure 1.--EROS Data Center process for the production of Landsat color composites--Continued.

Step #	Film Production Generation	
4		The P-3 is printed on Kodak 2421 film at a fixed enlargement scale of 3.369 to produce a 9.5 inch fourth generation negative (N-4). The exposure for the N-4 is determined by taking an integrated scene density of band 5.
5	N-4 9.5 inch (241 mm)	The N-4 is processed to a system gamma of 1.0 in a 11CM Versamat with MX-885 developer at 85°F (29.4°C).
6		The N-4 is contact printed on Kodak 2421 film using a Corning 5970 filter to produce a fifth generation positive (P-5).
7	P-5 or UVP-5 9.5 inch (241 mm)	The P-5 is processed to a system gamma of 1.5 in a 11CM Versamat with MX-885 developer at 85°F (29.4°C).

Figure 1.--EROS Data Center process for the production of Landsat color composites--Continued.

Step #	Film Production Generation	
8		Bands 4, 5, and 7 of the P-5's are registered, punched, and contact printed on Kodak Aerochrome 2447 to produce the color film positive (CFP-6)-/. The multiple exposures for the composite are calculated from the annotation grey scale of each band so the 1.0 step will be neutral.
9	CFP-6 9.5 inch (241 mm)	The CFP-6 is processed in a Versamat 1811 with EA-5 chemistry.
10		The CFP-6 is entered into the EDC data base file to act as the master from which the standard product color transparency and color paper products are printed.

Figure 1.--EROS Data Center process for the production of Landsat color composites--Continued.

Step #	Film Production Generation	
11	CSP-7 9.5 inch (241 mm)	The color standard products (CSP-7) are contact printed from the CFP-6 on Kodak 2447 film and 2212 paper. The Kodak color reversal film is processed in a 1811 Versamat with EA-5 chemistry. The 2212 color reversal paper is processed in a Simplex Color Processor with R-5 chemistry.

_/ The data for this figure were extracted in part from the "Production Procedures for Preparation of Landsat Color Products," EROS Data Center, Sioux Falls, South Dakota, April 28, 1977. This reference is an EDC interoffice memorandum written by Keith Maas of Technicolor Graphic Services, Inc.

_/ Cibachrome Type D (CCT-D661) color reversal film processed with a modified P-10 process in an Autopan color automat may be substituted at a future data in place of Kodak 2447.

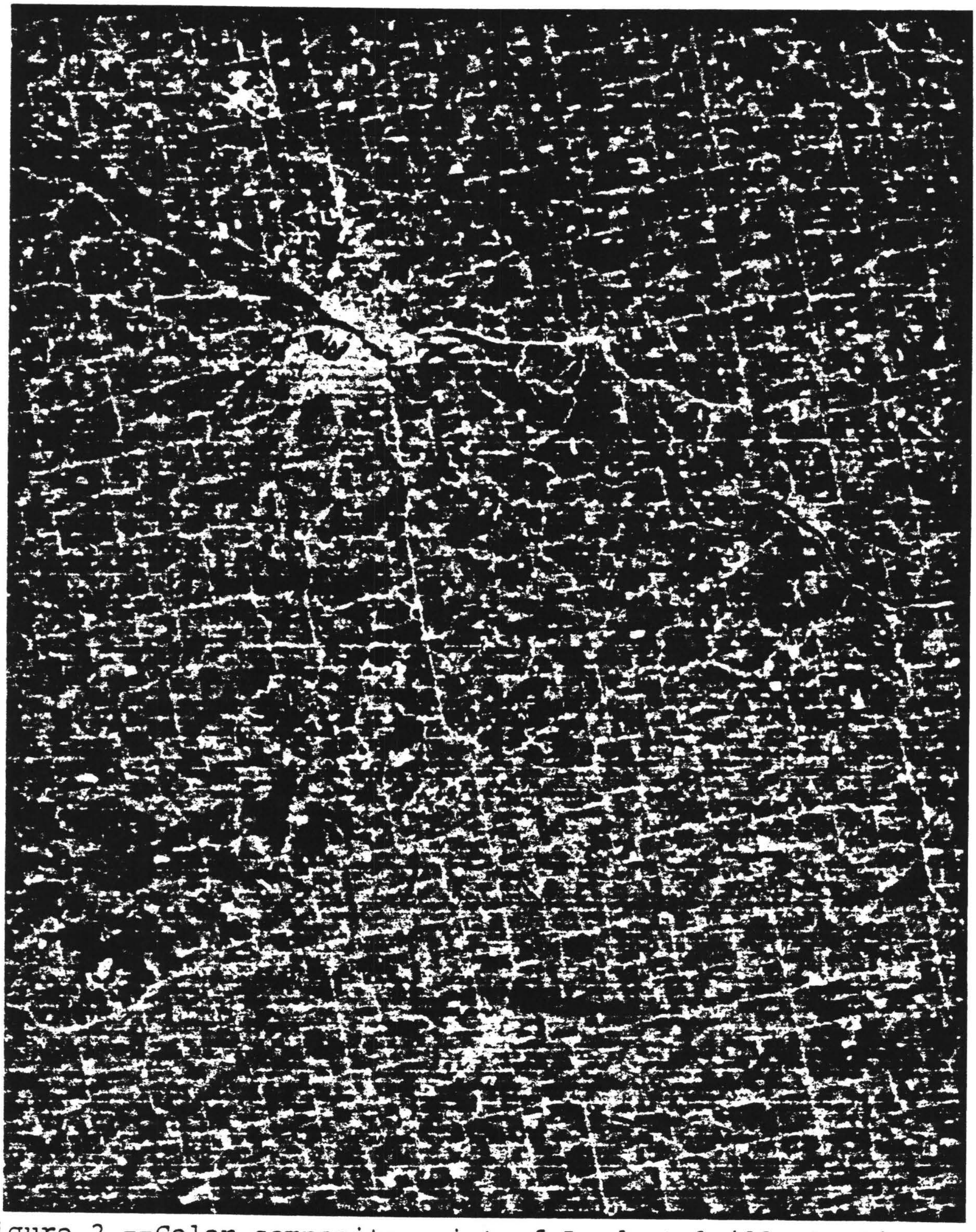

Figure 2.--Color composite print of Landsat-1 illustrating characteristics of an EDC standard product (CSP-7). IGS Photo Lab; NAS5-20832.

Figure 3-/.--Location map for Figures 2 through 23.

_/ USGS NK Map Series Scale 1:250,000. Quadrangles used to produce this map: Des Moines (NK 15-8) and Centerville (NK 15-11).

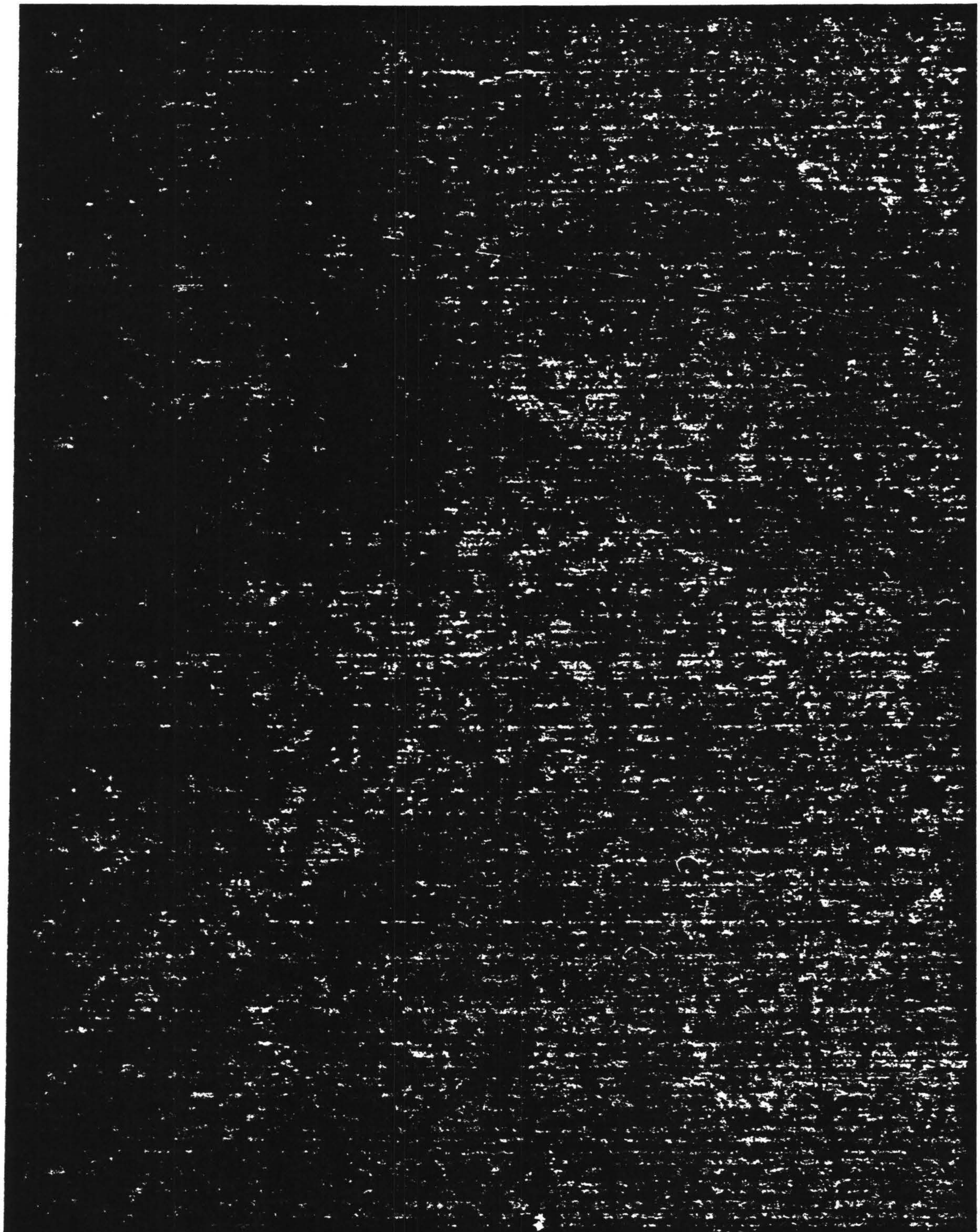

Figure 4.--Negative print of Landsat-1 band 4 illustrating characteristics of an EDC standard product N-4. IGS Photo Lab; NAS5-20832.

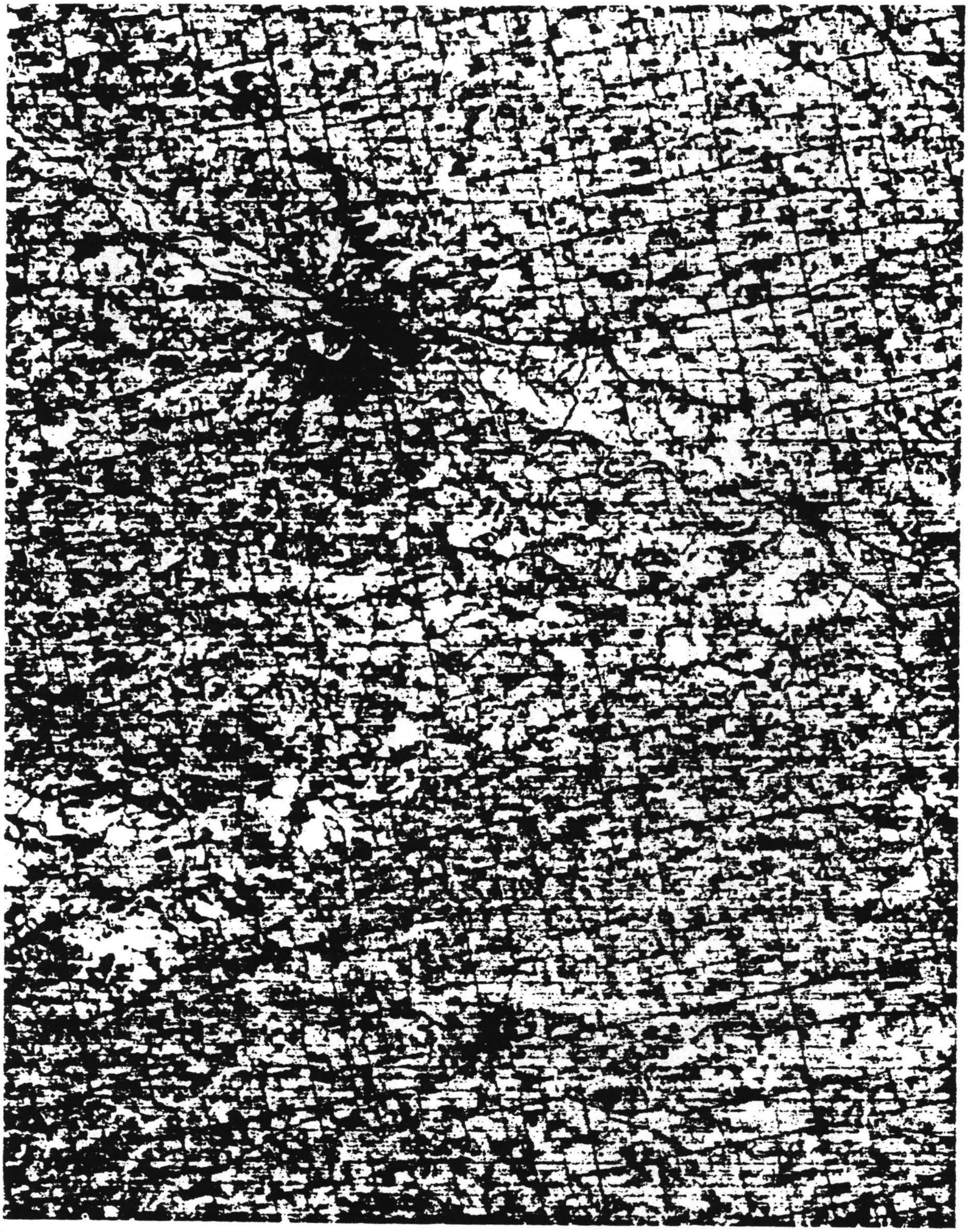

Figure 5.--Negative print of Landsat-1 band 5 illustrating characteristics of an EDC standard product N-4. IGS Photo Lab; NAS5-20832.

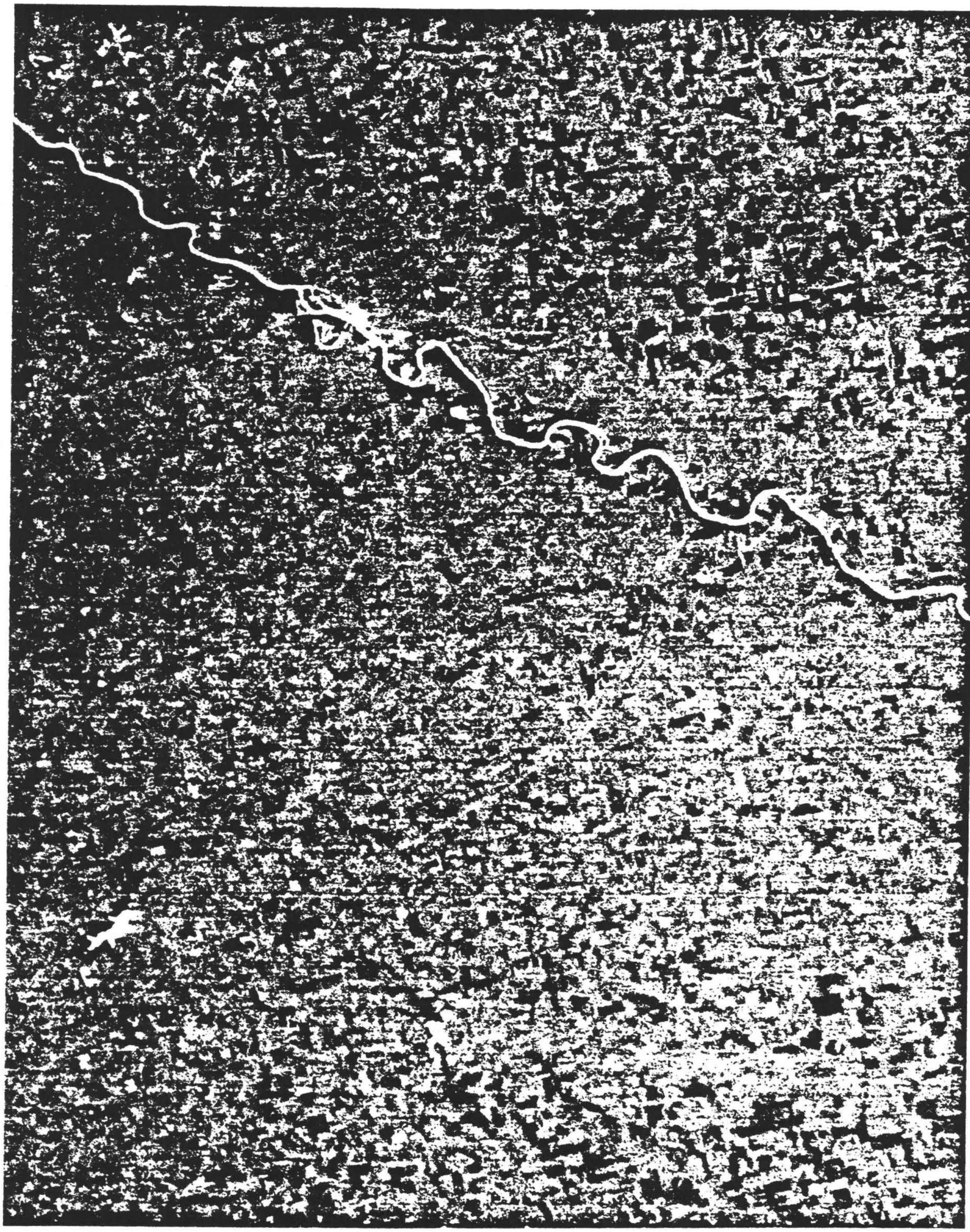

Figure 6.--Negative print of Landsat-1 band 7 illustrating characteristics of an EDC standard product N-4. IGS Photo Lab; NAS5-20832.

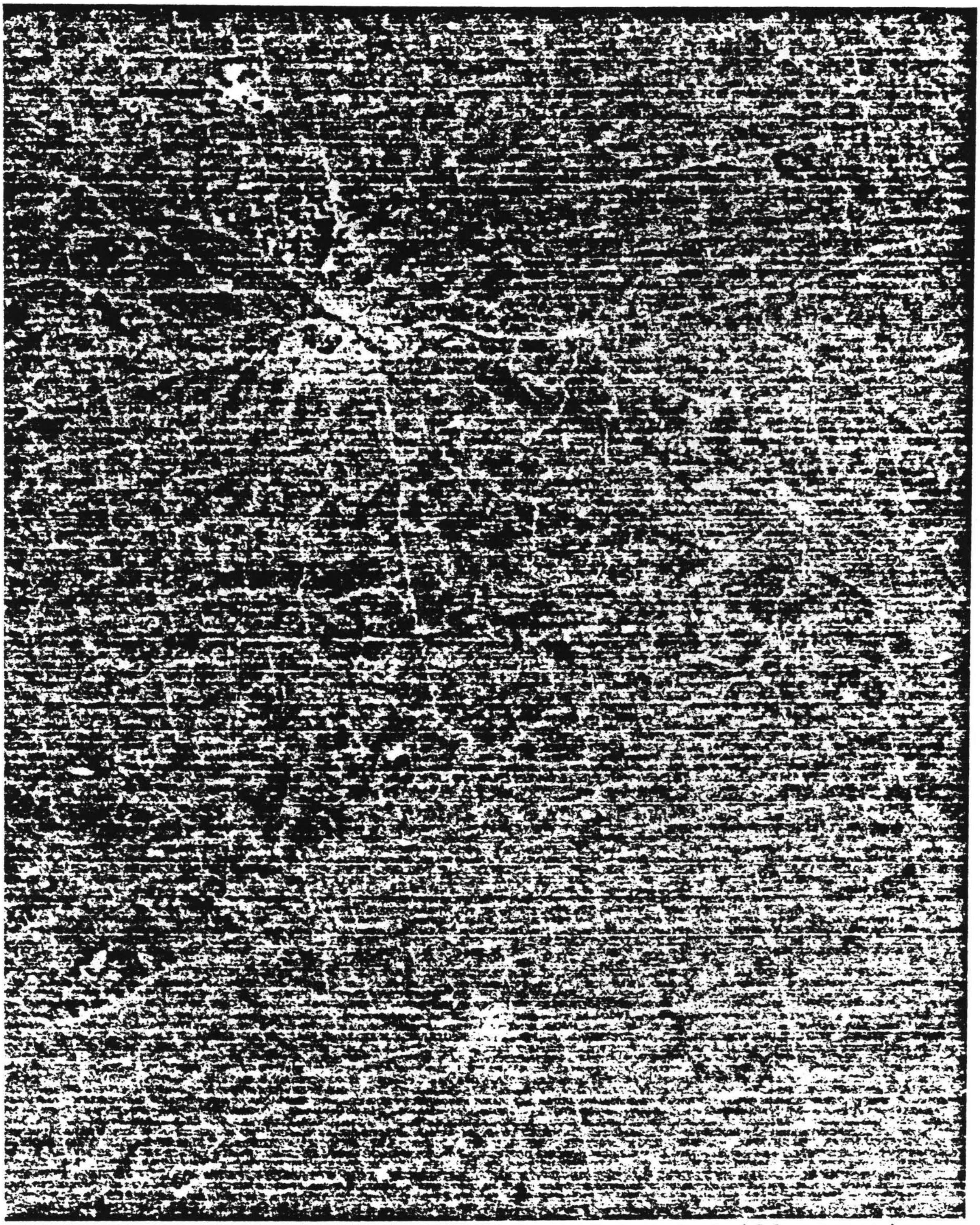

Figure 7.--Positive print of Landsat-1 band 4 illustrating characteristics of an EDC standard product UVP-5. IGS Photo Lab; NAS5-20832.

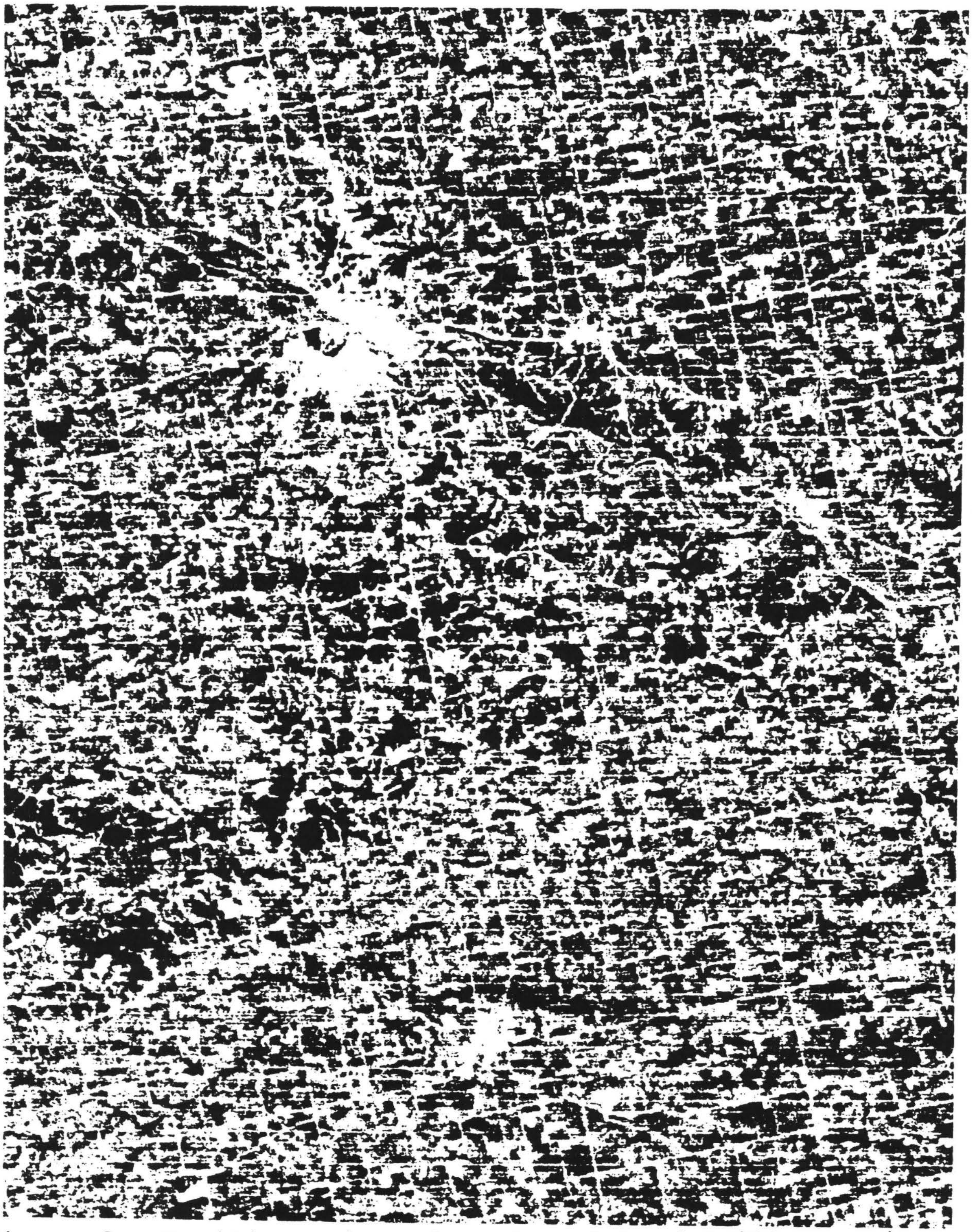

Figure 8.--Positive print of Landsat-1 band 5 illustrating characteristics of an EDC standard product UVP-5. IGS Photo Lab; NAS5-20832.

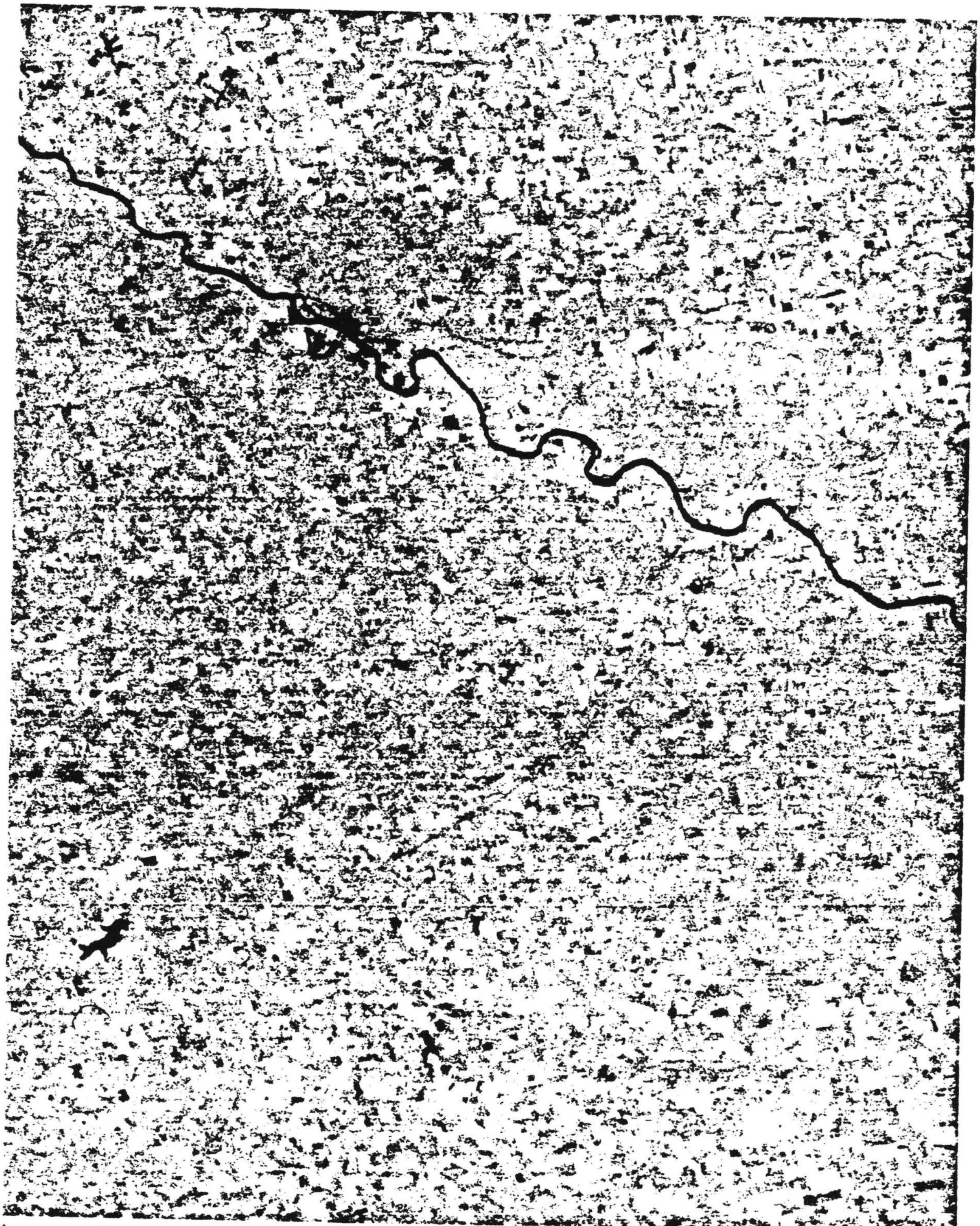

Figure 9.--Positive print of Landsat-1 band 7 illustrating characteristics of an EDC standard product UVP-5. IGS Photo Lab; NAS5-20832.

PHOTO-OPTICAL ENHANCEMENT PROCESS FOR LANDSAT COLOR COMPOSITES

To provide better color saturation and color contrast, a photo-optical enhancement (POE) procedure has been experimentally introduced for the 29 August 1972 Landsat-1 scene. This work has been conducted at the EROS Data Center by Darrell C. Ramerth under the supervision of Richard L. Nelson, Assistant Supervisor of the EDC Custom Color Laboratory.

The first step in contrast enhancing the Landsat black and white film products is introduced in the fourth generation negative (N-4). All photographic steps prior to this are the same as those used to produce the standard color composite (see Figure 1). The POE N-4 is printed in the same manner as the standard product N-4, but is processed to a slightly higher system gamma of 1.5 instead of the 1.0 on the standard product. The increased contrast POE N-4 is contact printed in the standard manner onto the fifth generation positive (P-5) which is also processed to a system gamma of 1.5 in a 11CM Versamat with MX-885 developer. The POE P-5 is then contact printed on a direct positive super speed graphic arts film, Kodak SS-7 to produce a sixth generation positive (P-6). The objective of utilizing this high speed duplicating film is to introduce in the P-6 black and white bands a further increase in contrast. The amount of contrast to be introduced for each band is determined by the band's scene input densities. Band 4, for example, possesses a relatively low scene contrast on the POE P-5. When it was duplicated on the SS-7, the film was exposed for a $D_{min.}$ aim point of 0.40 $\pm$ 0.10 and a $D_{max.}$ not to exceed 1.60. The $D_{max.}$ for the processed film (with a system gamma of 6.8) was 0.97. Bands 5 and 7, on the other hand, both have greater scene contrasts than band 4. For this reason, the SS-7 film was flash exposed to limit the upper density ranges for the bands before they were contact printed on the film. The amount of flash exposure for band 5 was determined from the POE P-5 (band 5) average scene density (ASD = $D_{min.}$ + $D_{max.}$ / 2) which was input to the exposure calculation to produce a 1.0 $\pm$ 0.20 ASD on the POE P-6. For band 7, however, the average scene density was determined for areas containing no water. This strategy was followed for band 7 because image densities associated with water are very high in comparison to other scene densities. Table 1 lists the

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Table 1 near here.

POE scene output densities for the 29 August 1972 scene. For band 7, two $D_{max.}$ values are listed--one value for areas excluding water bodies and one for water bodies. The average scene density for the POE P-5 band 7 excluding water is 0.54, while the ASD including water is 1.26. If the 1.26 ASD is used to produce a 1.0 ASD on the P-6, the land areas would possess a much lower contrast than if the 0.54 ASD was used. Because this contract's objective is land classification in Iowa, the subtle density variations in water bodies are not critical. For this reason, the lower average scene density was used as the input to the P-6. To produce the optimal scene contrast results, band 5

Table 1[1].--POE scene output densities for the P-3, P-5, and P-6 film positives for the 29 August 1972 scene (1037-16213).

	P-3 Scene Output Densities		P-5 Scene Output Densities		P-6 Scene Output Densities	
Band	$D_{min.}$	$D_{max.}$	$D_{min.}$	$D_{max.}$	$D_{min.}$	$D_{max.}$
4	0.59	0.71	0.65	0.90	0.30	0.97
5	0.67	1.01	0.83	1.65	0.48	1.30
7	0.43	0.56	0.45	0.62	0.45	1.40
		1.22 (water)		2.07 (water)		3.20 (water)

_/ Data generated by Darrell C. Ramerth under the supervision of Richard L. Nelson, Custom Color Laboratory, EROS Data Center.

had a gamma of 1.1 and band 7 had a gamma of 2.5 on the SS-7 film. Tone reproduction curves for this film have been generated from a calibrated step wedge for each band of the POE P-6 (Figure 10). The exposure aim point of all these

---

Figure 10 near here.

P-6 bands was a $D_{min.}$ of 0.40 $\pm$ 0.10. All of the Kodak SS-7 film used in this enhancement step were processed in a Kodak 242 film processor using Kodak Supermatic developer.

Densities from calibrated

step tablet

Band 4

Gamma approx. = 6.8

Band 5

Flash exposed before

contact printing.

Gamma approx. = 1.1

Band 7

Flash exposed before

contact printing.

Gamma approx. = 2.5

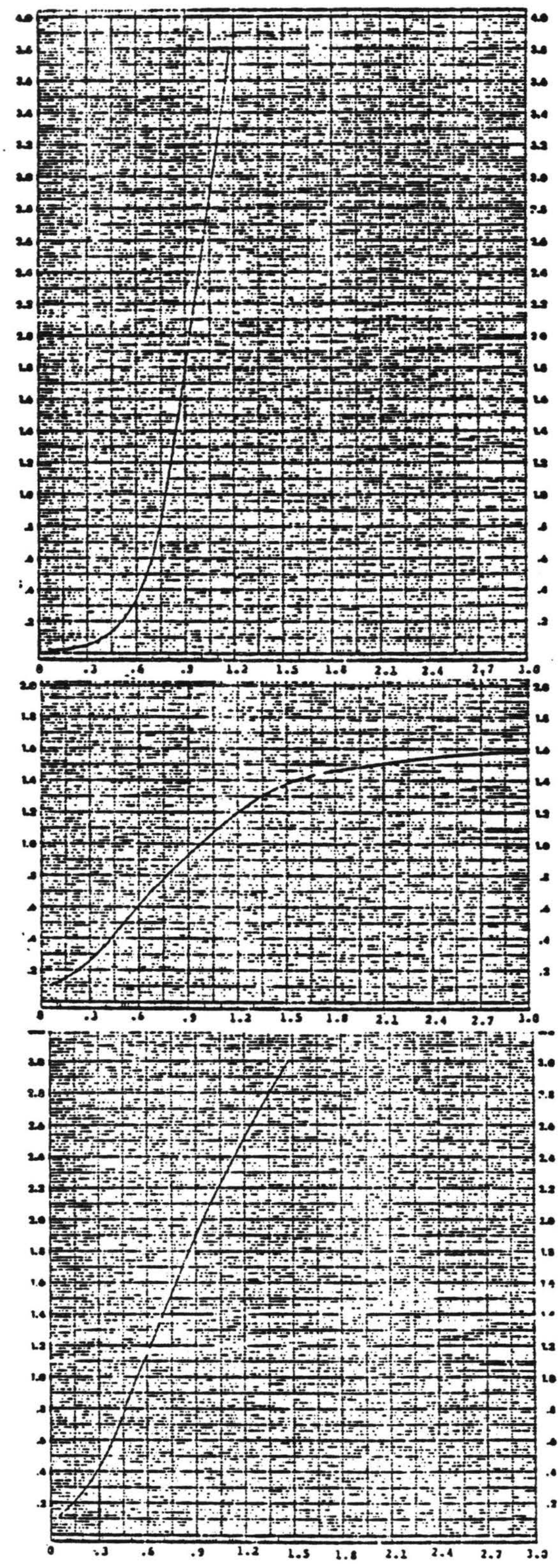

Figure 10.--Tone reproduction curves for POE (P-6) Kodak SS-7 film for Landsat-1, 29 August 1972 scene, bands 4, 5, and 7.

A summary of the exposure strategy for the POE P-6 Kodak Super Speed-7 film is listed below:

1. The $D_{min.}$ aim point for all bands was 0.40 ± 0.10.

2. The $D_{max.}$ aim point was limited to 1.60 ± 0.20 P-6 scene output density. These $D_{min.}$ and $D_{max.}$ aim points are within the densities that can be recorded on the color film and color paper products used at EDC. In addition, these aim points provide optimal color saturation on color products.

3. Band 4 P-6 film was processed to produce the greatest scene output density range possible from the SS-7 film.

4. Band 5 was flash exposed based on the POE P-5 average scene density to produce an ASD of 1.0 ± 0.20 on the POE P-6.

5. Band 7 is flashed exposed based on the POE P-5 ASD (excluding water) to produce an ASD of 1.00 ± 0.20 on the POE P-6.

Bands 4, 5, and 7 of the POE P-6 generation were registered, punched, and contact printed on Kodak Aerochrome 2447 film. The exposures used to print the POE color composit were determined from the average scene densities for the individual bands. The enhanced color film positive (ECFP-7) was processed in a Versamat 1811 with EA-5 chemistry. Tone reproduction curves for both the standard product and POE color composite emulsion layers are shown in Figure 11 (data on Table 2) and Figure 12 (data on Table 3). Enhanced color paper products (ECP-8) were

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Figure 11, Table 2, Figure 12, and Table 3 near here.

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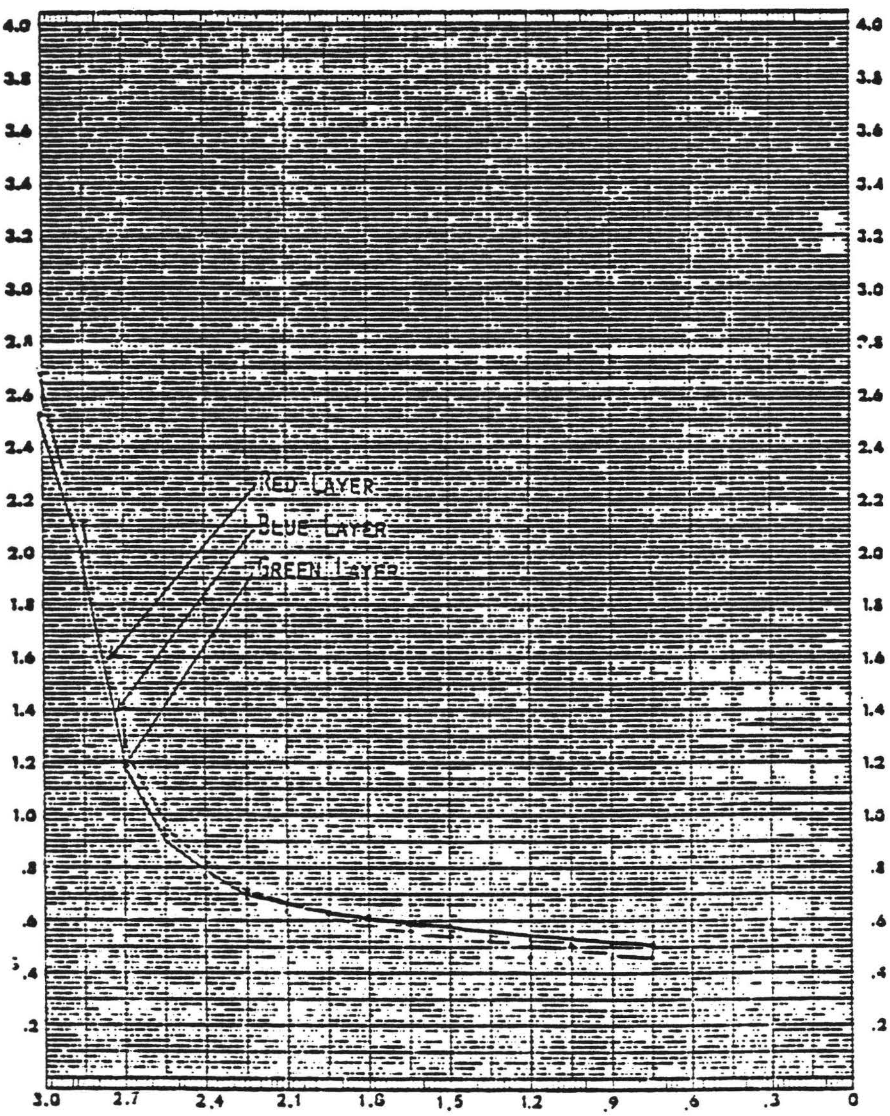
printed from the enhanced composite on Kodak 2212 color reversal paper which is processed in a Color Simplex processor.

Figure 11-/.--Tone reproduction curves for the standard product color composite transparency for the 29 August 1972 scene (1037-16213).



_/ Data generated by Darrell C. Ramerth under the supervision of Richard L. Nelson, Custom Color Laboratory, EROS Data Center.

Table 2[1].--Standard product color composite optical transmission density readings for a calibrated step wedge.

Landsat-1, 29 August 1972 scene (1037-16213)

Step #	Green Filter	Blue Filter	Red Filter
1	2.67	2.52	2.59
2	1.98	1.99	2.11
3	1.19	1.20	1.27
4	0.94	0.92	0.98
5	0.80	0.77	0.81
6	0.71	0.69	0.72
7	0.66	0.66	0.66
8	0.62	0.63	0.62
9	0.60	0.62	0.59
10	0.58	0.59	0.56
11	0.56	0.58	0.54
12	0.53	0.56	0.52
13	0.50	0.53	0.47
14	0.50	0.53	0.47
15	0.50	0.53	0.47

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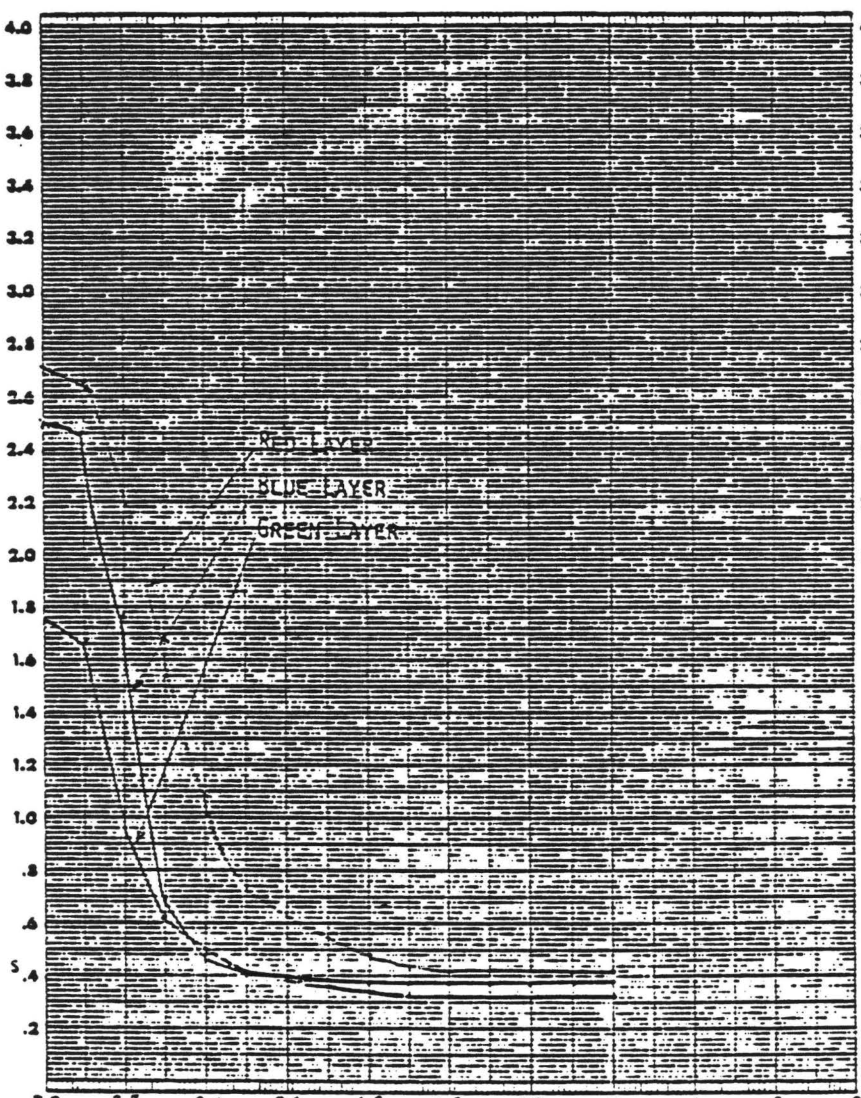
[1] Data generated by Darrell Ramerth under the supervision of Richard L. Nelson, Custom Color Laboratory, EROS Data Center.

Figure 12-/.--Tone reproduction curves for the POE color composite transparency for the 29 August 1972 scene (1037-16213).



_/ Data generated by Darrell C. Ramerth under the supervision of Richard L. Nelson, Custom Color Laboratory, EROS Data Center.

Table 3[1].--Photo-optically enhanced color composite optical transmission density readings for a calibrated step wedge.

Landsat-1, 29 August 1972 scene (1037-16213)

Step #	Green Filter	Blue Filter	Red Filter
1	1.74	2.49	2.69
2	1.67	2.47	2.66
3	0.96	1.77	2.19
4	0.62	0.68	1.54
5	0.49	0.45	1.09
6	0.41	0.40	0.75
7	0.38	0.39	0.62
8	0.36	0.38	0.54
9	0.34	0.37	0.48
10	0.33	0.37	0.43
11	0.32	0.37	0.42
12	0.32	0.37	0.42
13	0.32	0.37	0.42
14	0.32	0.37	0.42
15	0.32	0.37	0.42

[1] Data generated by Darrell Ramerth under the supervision of Richard L. Nelson, Custom Color Laboratory, EROS Data Center.

A summary diagram outlining the EDC photo-optical enhancement process for Landsat color composites is found on Figure 13. In addition, examples of POE N-4 (bands 4,

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Figure 13 near here.

5, and 7), P-5 (bands 4, 5, and 7), and P-6 (bands 4, 5, and 7) products for a 29 August 1972 subscene are shown on Figures 14, 15, 16, 17, 18, 19, 20, 21, and 22. When these

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Figures 14 through 22 near here.

POE photographs are compared to the standard product black and white prints, the higher contrast of the POE subscenes can be seen. The POE color composite print for the same subscene is displayed on Figure 23. When it is compared

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Figure 23 near here.

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to the standard product color composite print, (Figure 2), the enhanced color contrast and better color saturation of the POE image are also evident.

Figure 13.--EROS Data Center photo-optically enhanced color composite process for Landsat images.

Procedure Step	Film Production Generation	
1 through 4		These steps are the same as those used to produce the EDC standard Landsat color composite.
5	N-4 9.5 inch (241 mm)	The N-4 is processed to a system gamma of 1.5 in a 11CM Versamat with MX-885 developer at 85°F (29.4°C).
6		The N-4 is contact printed on Kodak 2421 using a Corning 5970 filter which is transparent to ultraviolet light to produce the P-5.
7	P-5 or UVP-5 9.5 inch (241 mm)	The P-5 is processed to a system gamma of 1.5 in a 11CM Versamat with MX-885 developer at 85°F (29.4°C).

Figure 13.--EROS Data Center photo-optically enhanced color composite process for Landsat images--Continued.

Procedure Step	Film Production Generation	
8		The P-5 is contact printed onto a direct positive super speed graphic arts film (Kodak type SS-7) to produce the P-6. Band 4 is contact printed directly on the SS-7 film using an exposure calculated to give a $D_{min.}$ aim point of 0.4 $\pm$ 0.10 on the P-6. Bands 7 and 5 requires that the SS-7 film be flash exposed to burn off high densities (see Table 5). The P-5 transparencies are then printed using an exposure to give a 1.0 ASD on the P-6.

Figure 13.--EROS Data Center photo-optically enhanced color composite process for Landsat images--Continued.

Procedure Step	Film Production Generation	
9	P-6 9.5 inch (241 mm)	The P-6 film is processed in a Kodak 242 film processor with Kodak Supermatic developer. The system gammas for the P-6 bands vary with the input densities and exposure: band 4's gamma--6.8; band 5's gamma--1.1; band 7's gamma--2.5.
10		Bands 4, 5, and 7 of the P-6's are registered, punched, and contact printed on Kodak Aerochrome 2447 using multiple exposures calculated from the average scene density to produce the enhanced color film positive (ECFP-7).

Figure 13.--EROS Data Center photo-optically enhanced color composite process for Landsat images--Continued.

Procedure Step	Film Production Generation	
11	ECFP-7 9.5 inch (241 mm)	The enhanced color film positive (ECFP-7) is processed in a Versamat 1811 with EA-5 chemistry.
12		The ECFP-7 is printed on Kodak 2212 color reversal paper to produce the enhanced color paper product (ECPP-8). The exposure for the color print is determined from the ECFP-7 integrated scene density.
13	ECPP-8 9.5 inch (241 mm)	The enhanced color paper product (ECPP-8) is processed in a Simplex Color Processor.

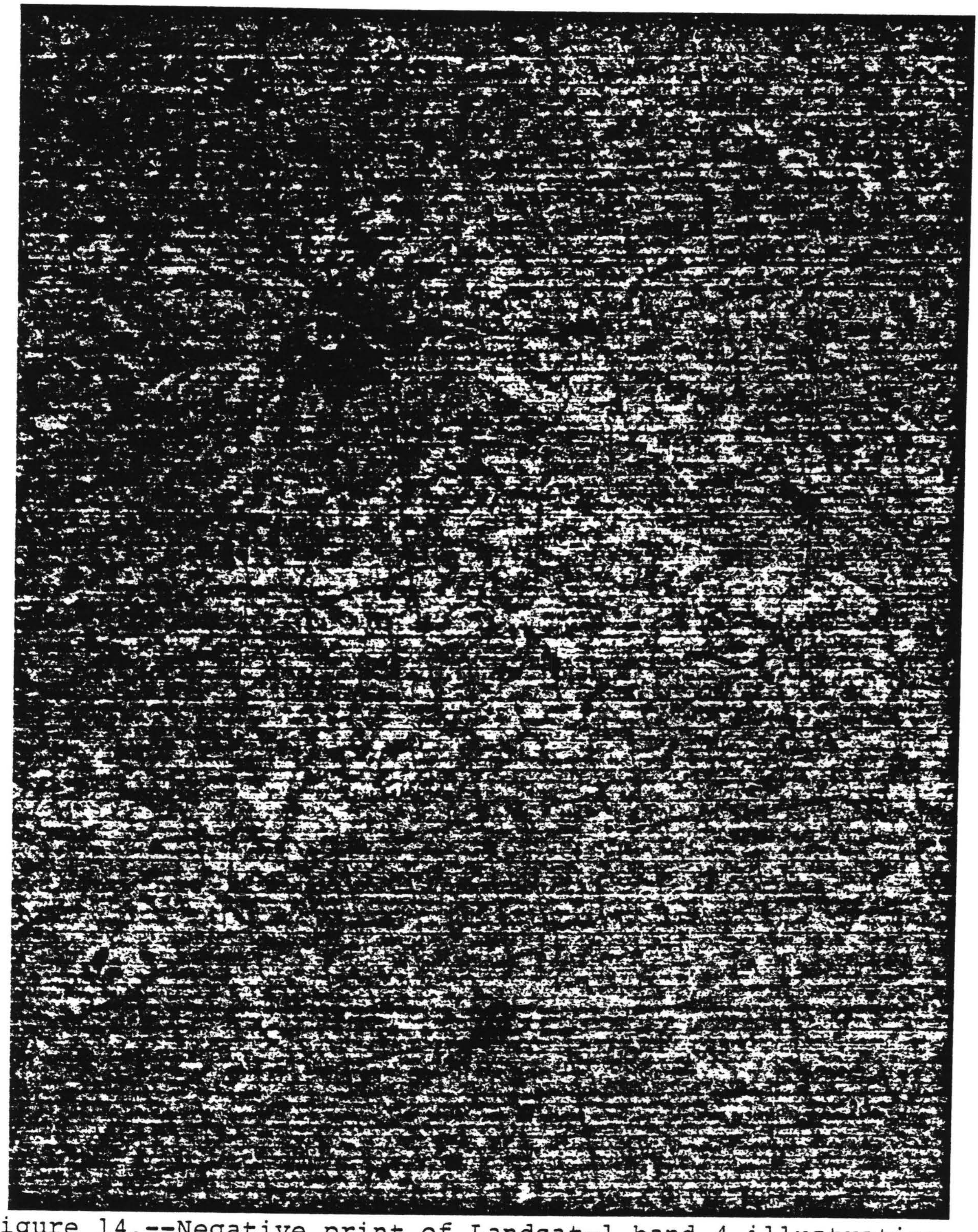

Figure 14.--Negative print of Landsat-1 band 4 illustrating characteristics of an EDC photo-optically enhanced product (POE) N-4. IGS Photo Lab; NAS5-20832.

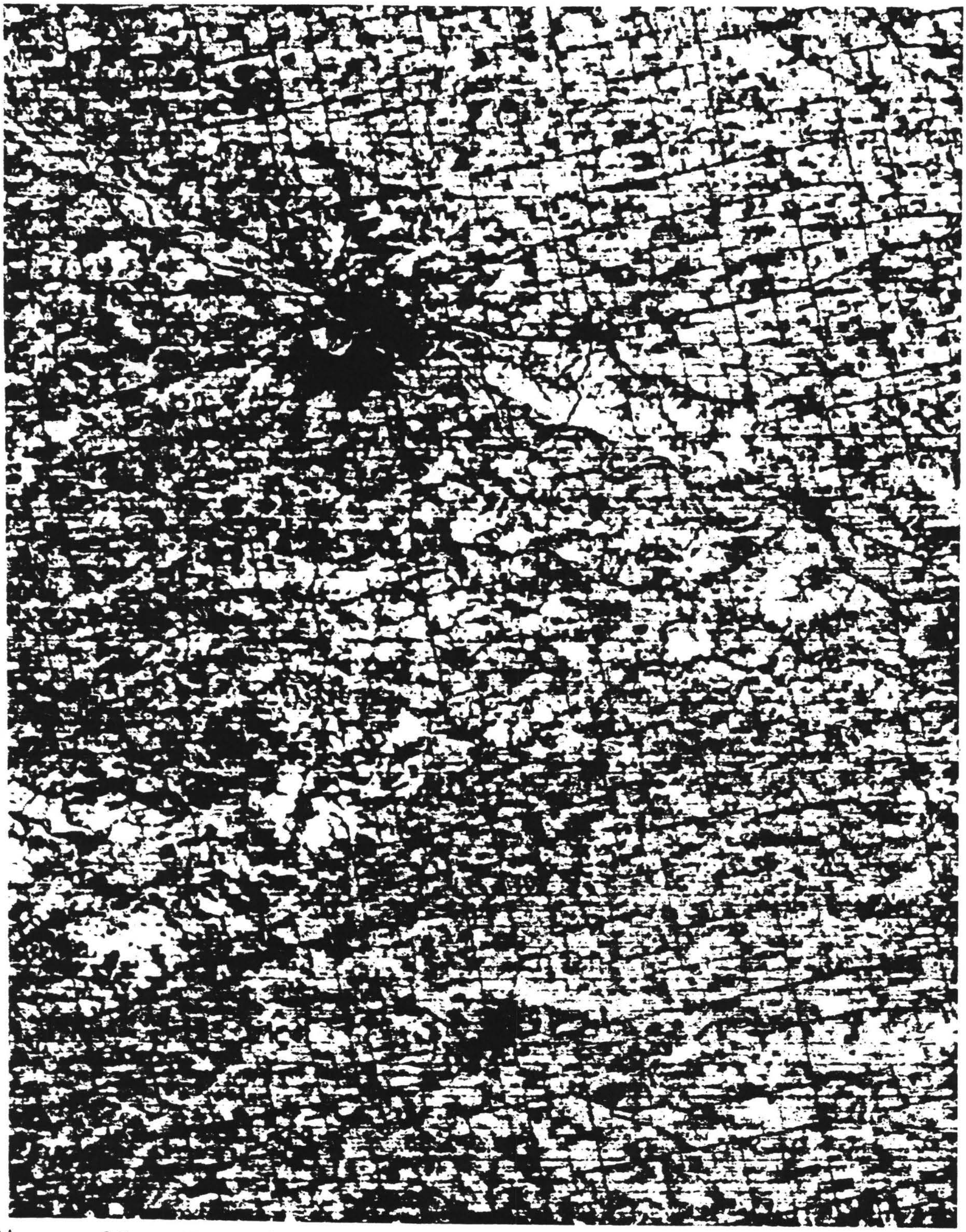

Figure 15.--Negative print of Landsat-1 band 5 illustrating characteristics of an EDC photo-optically enhanced product (POE) N-4. IGS Photo Lab; NAS5-20832.

Figure 16.--Negative print of Landsat-1 band 7 illustrating characteristics of an EDC photo-optically enhanced product (POE) N-4. IGS Photo Lab; NAS5-20832.

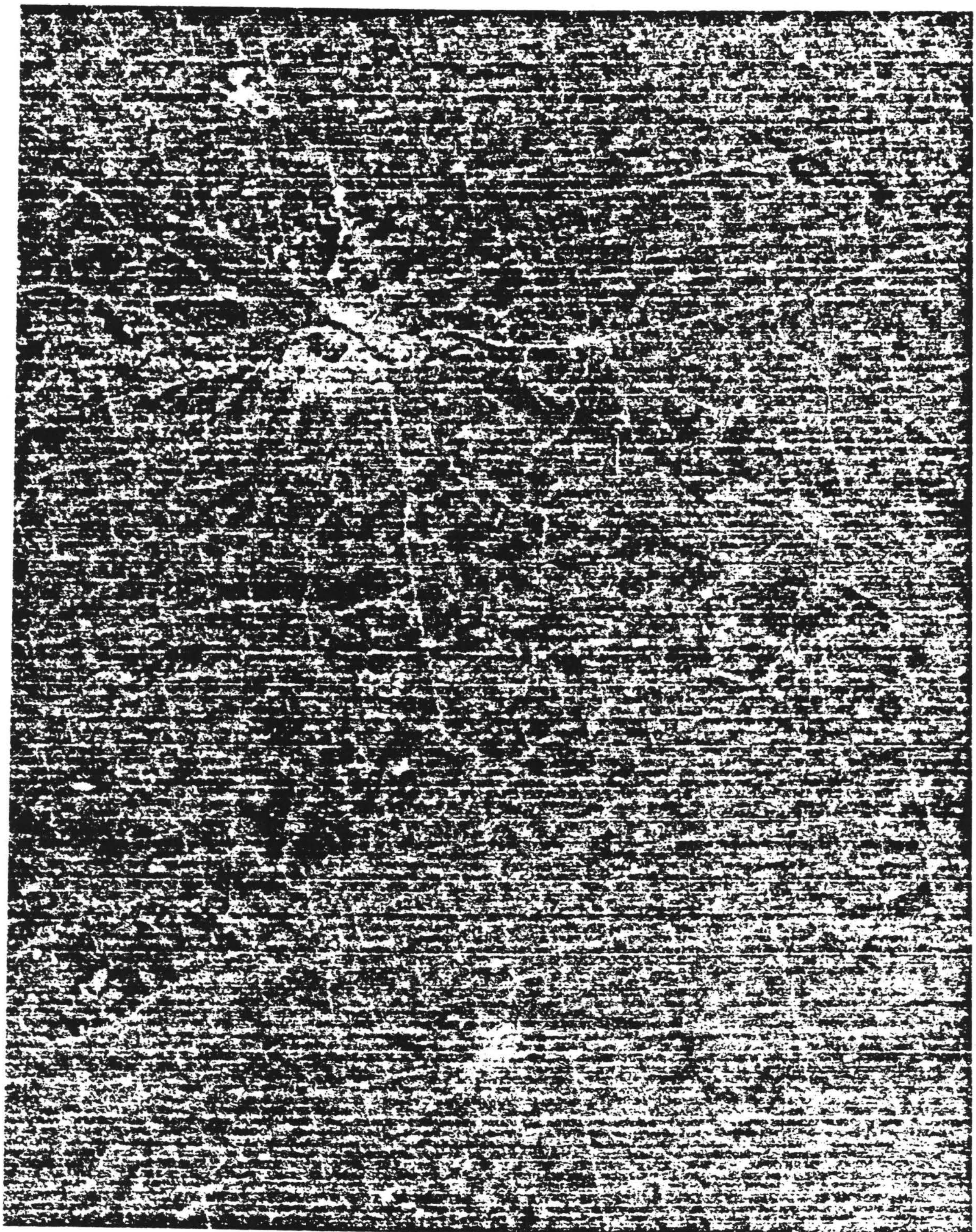

Figure 17.--Positive print of Landsat-1 band 4 illustrating characteristics of an EDC photo-optically enhanced product (POE) P-5. IGS Photo Lab; NAS5-20832.

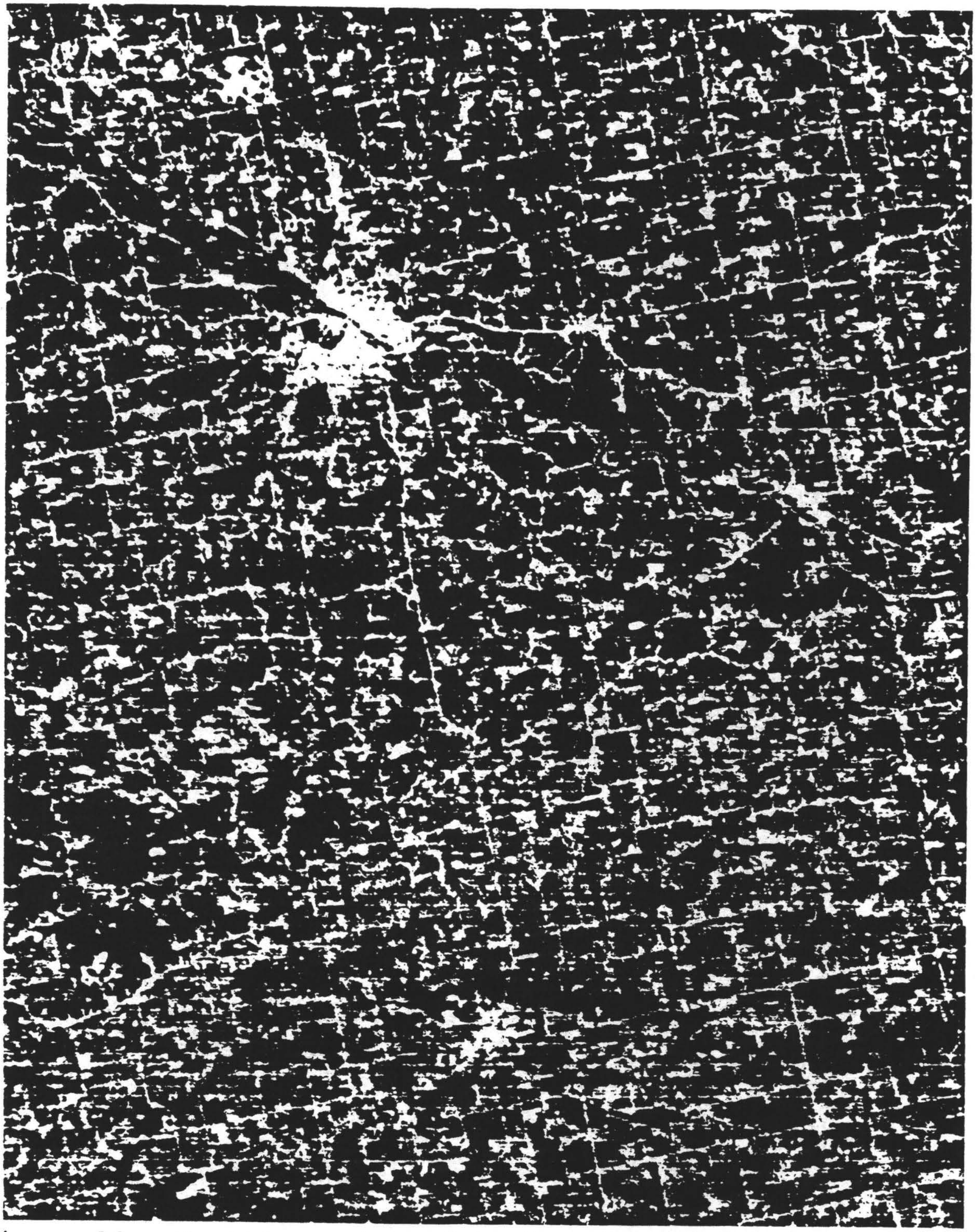

Figure 18.--Positive print of Landsat-1 band 5 illustrating characteristics of an EDC photo-optically enhanced product (POE) P-5. IGS Photo Lab; NAS5-20832.

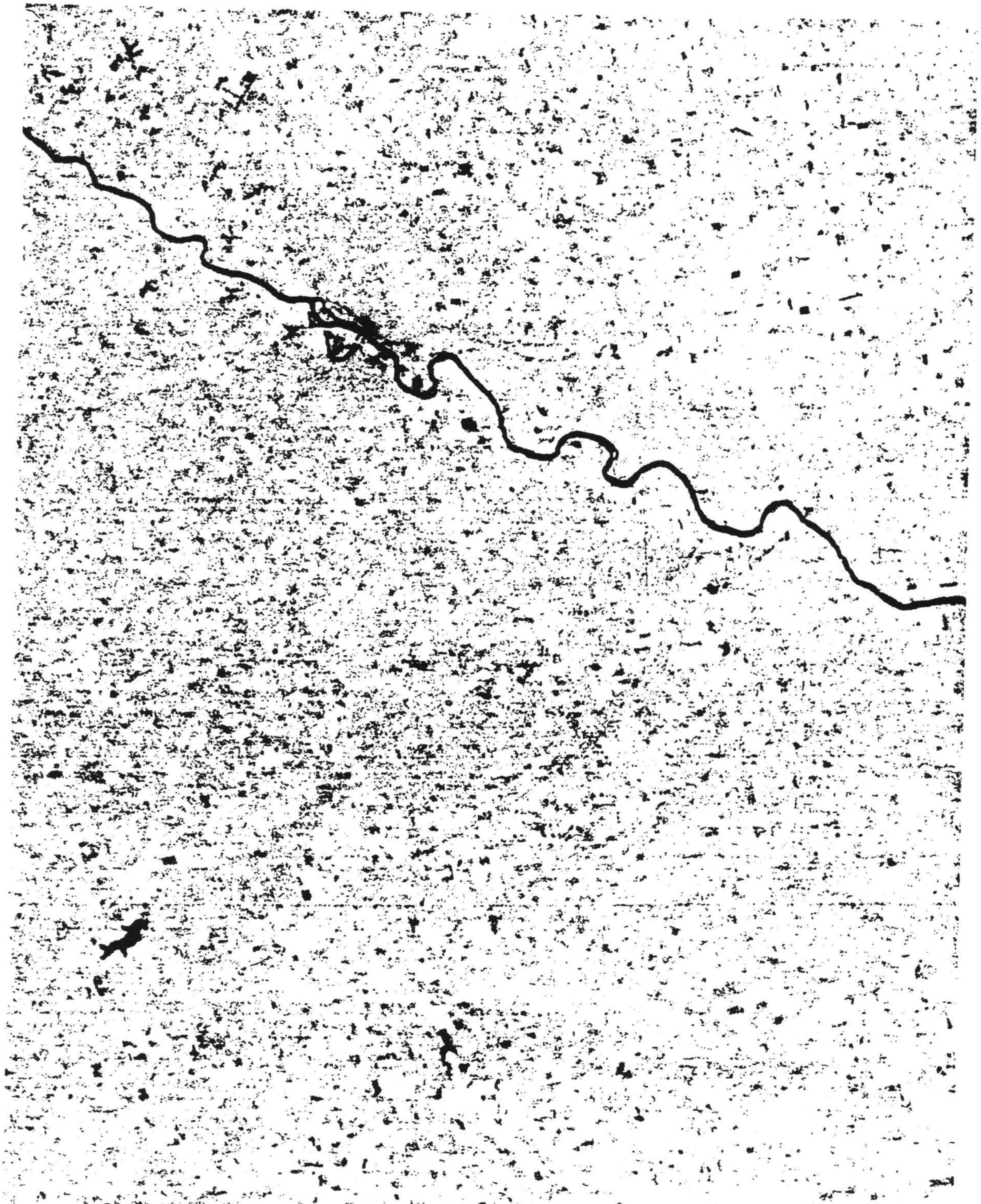

Figure 19.--Positive print of Landsat-1 band 7 illustrating characteristics of an EDC photo-optically enhanced product (POE) P-5. IGS Photo Lab; NAS5-20832.

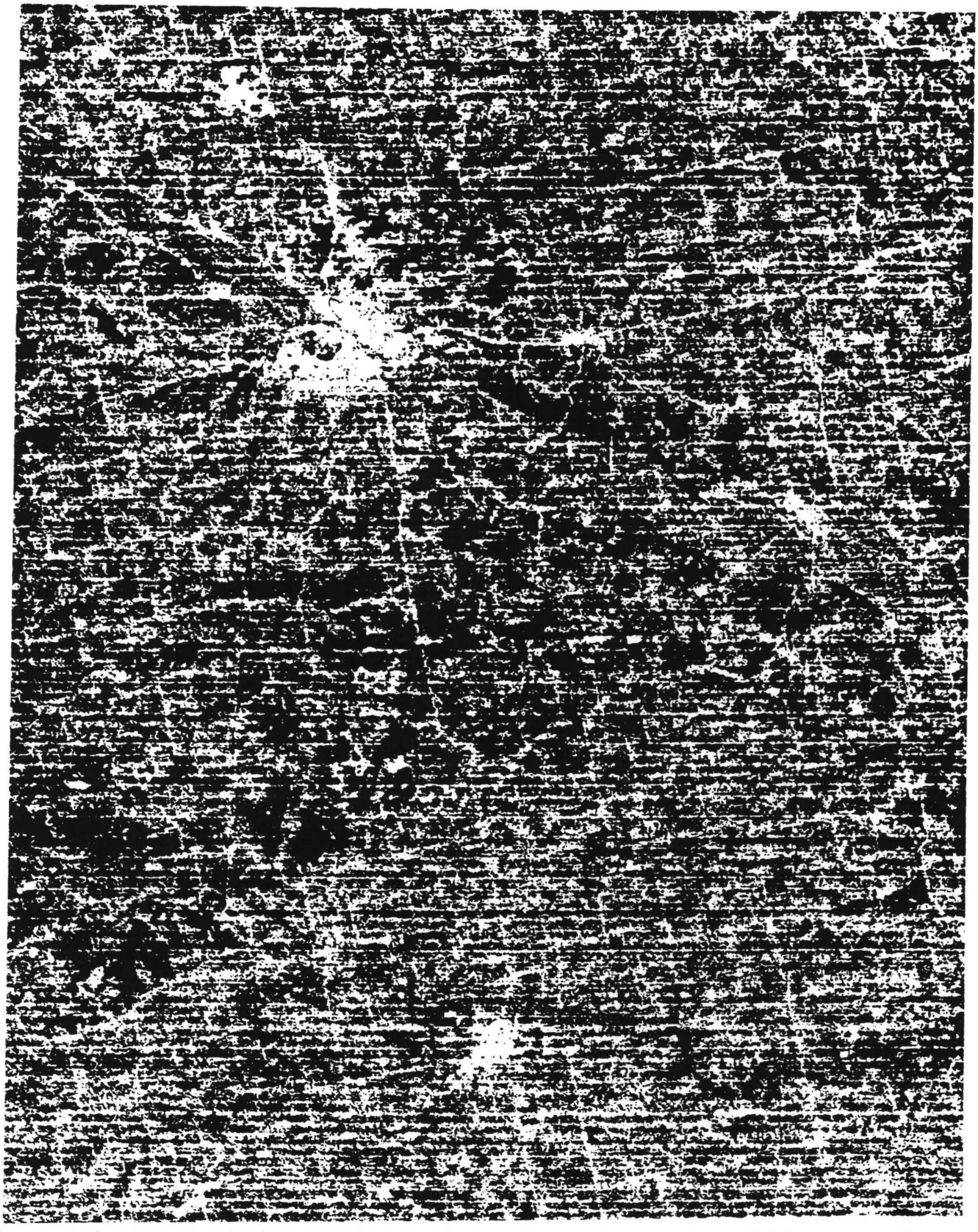

Figure 20.--Positive print of Landsat-1 band 4 illustrating characteristics of an EDC photo-optically enhanced product (POE) P-6. IGS Photo Lab; NAS5-20832.

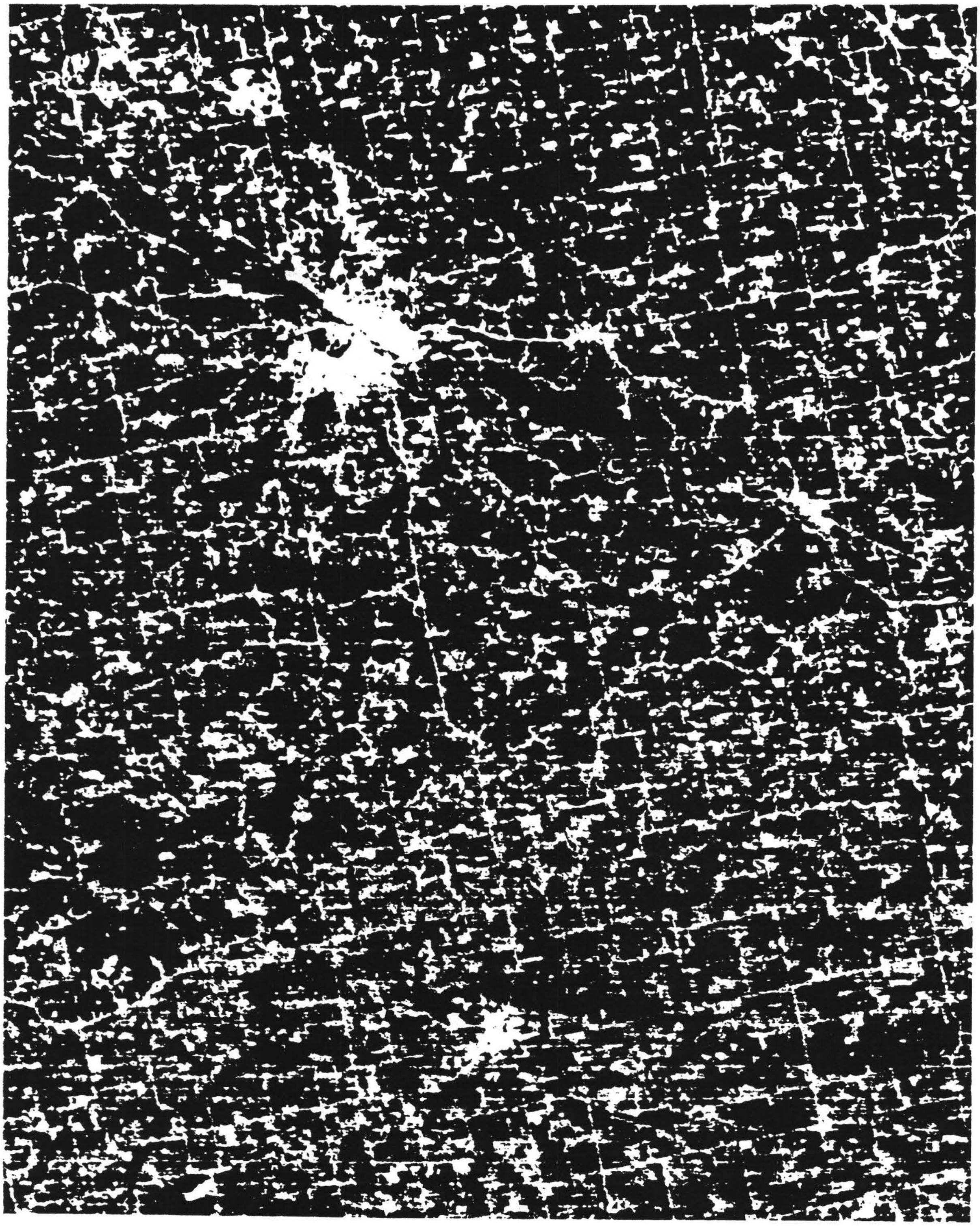

Figure 21.--Positive print of Landsat-1 band 5 illustrating characteristics of an EDC photo-optically enhanced product (POE) P-6. IGS Photo Lab; NAS5-20832.

Figure 22.--Positive print of Landsat-1 band 7 illustrating characteristics of an EDC photo-optically enhanced product (POE) P-6. IGS Photo Lab; NAS5-20832.

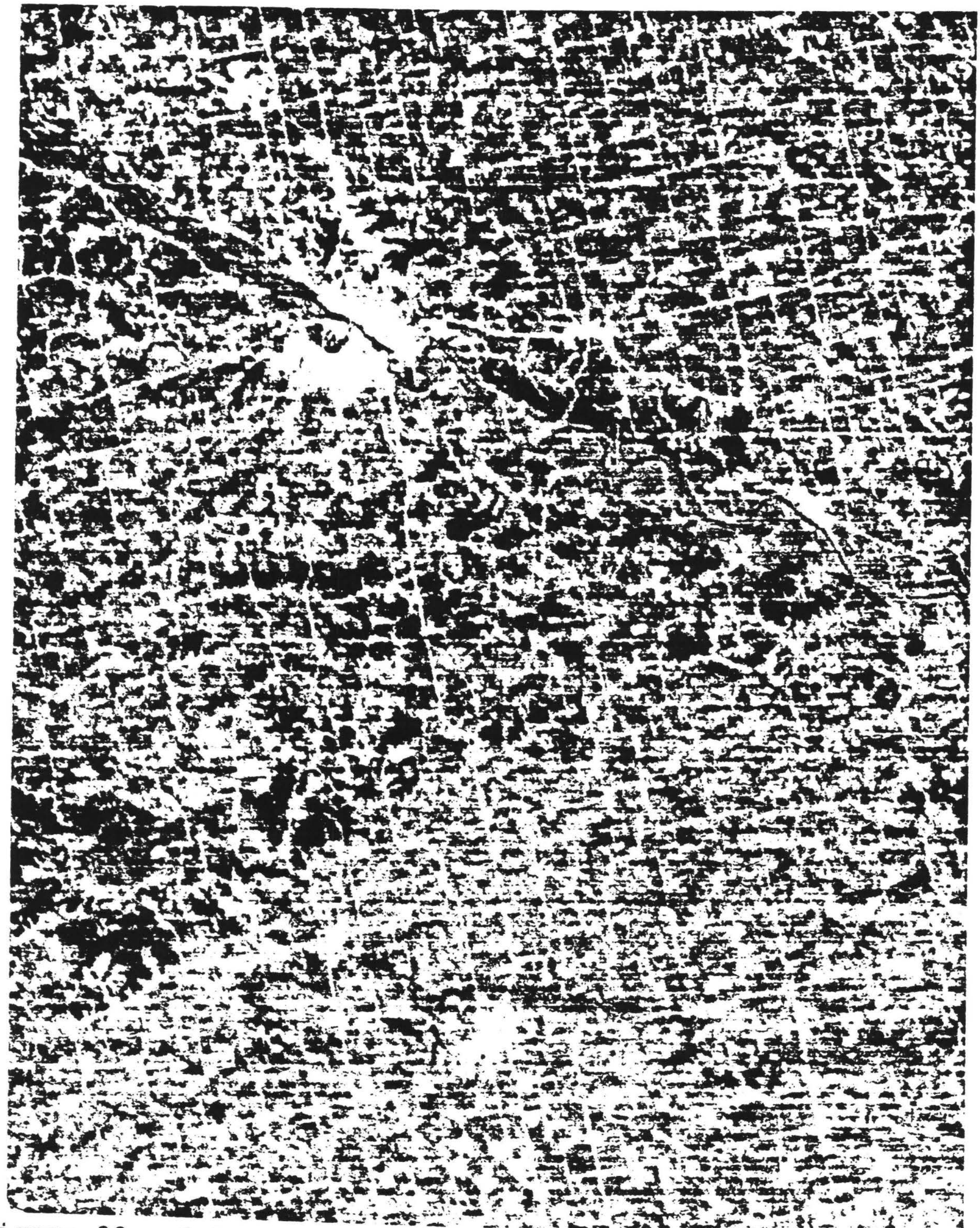

Figure 23.--Color composite print of Landsat-1 illustrating characteristics of an EDC photo-optically enhanced product ECPP-8. IGS Photo Lab; NAS5-20832.

TONE REPRODUCTION DIAGRAMS

To graphically display the step by step effects of contrast enhancement on the film product generations, a series of tone reproduction diagrams were drawn for both the standard product and the photo-optically enhanced bands (see Figures 24, 25, 26, 27, 28, and 29). The curves in

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Figures 24 through 29 near here.

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the diagrams represent the input and output film densities starting with the P-3 to the P-5 (or P-6 in the POE examples). The data used to produce the film curves were read from a calibrated step wedge taken from each film product step (see Tables 4 and 5). The output scene

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Tables 4 and 5 near here.

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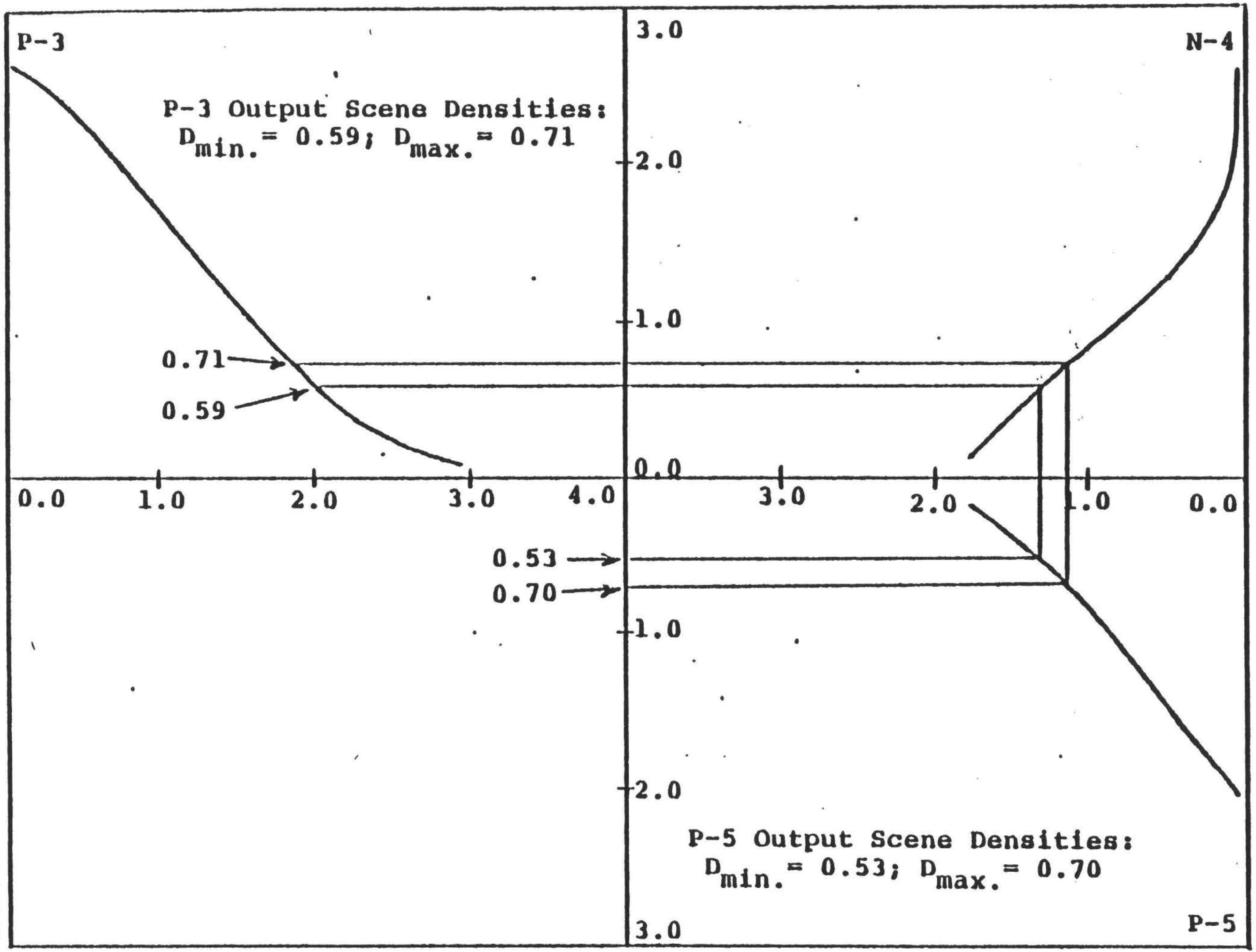
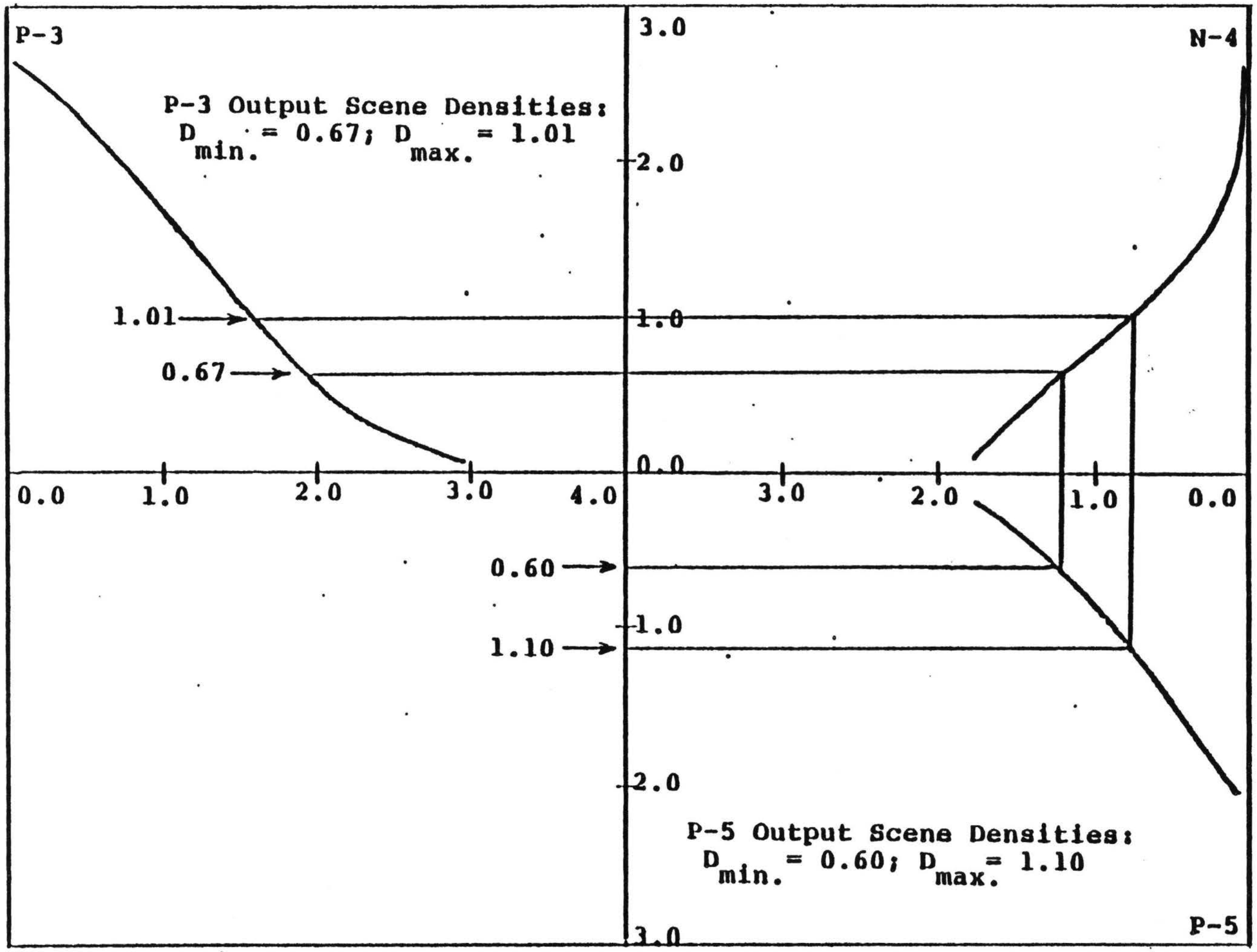
densities on the particular P-3 bands were read by a transmission densitometer. The changes in a band's minimum density ($D_{min.}$) and maximum density ($D_{max.}$) as traced through the curves are related to film and processing characteristics. For example, the tone reproduction diagram for the EDC standard product band 4 (Figure 24) shows the input scene densities for the P-3 to range from a $D_{min.}$ of 0.59 to a $D_{max.}$ of 0.71. The output densities

Figure 24-/.--Tone reproduction diagram for the Landsat-1 standard product band 4 of the 29 August 1972 scene (1037-16213).



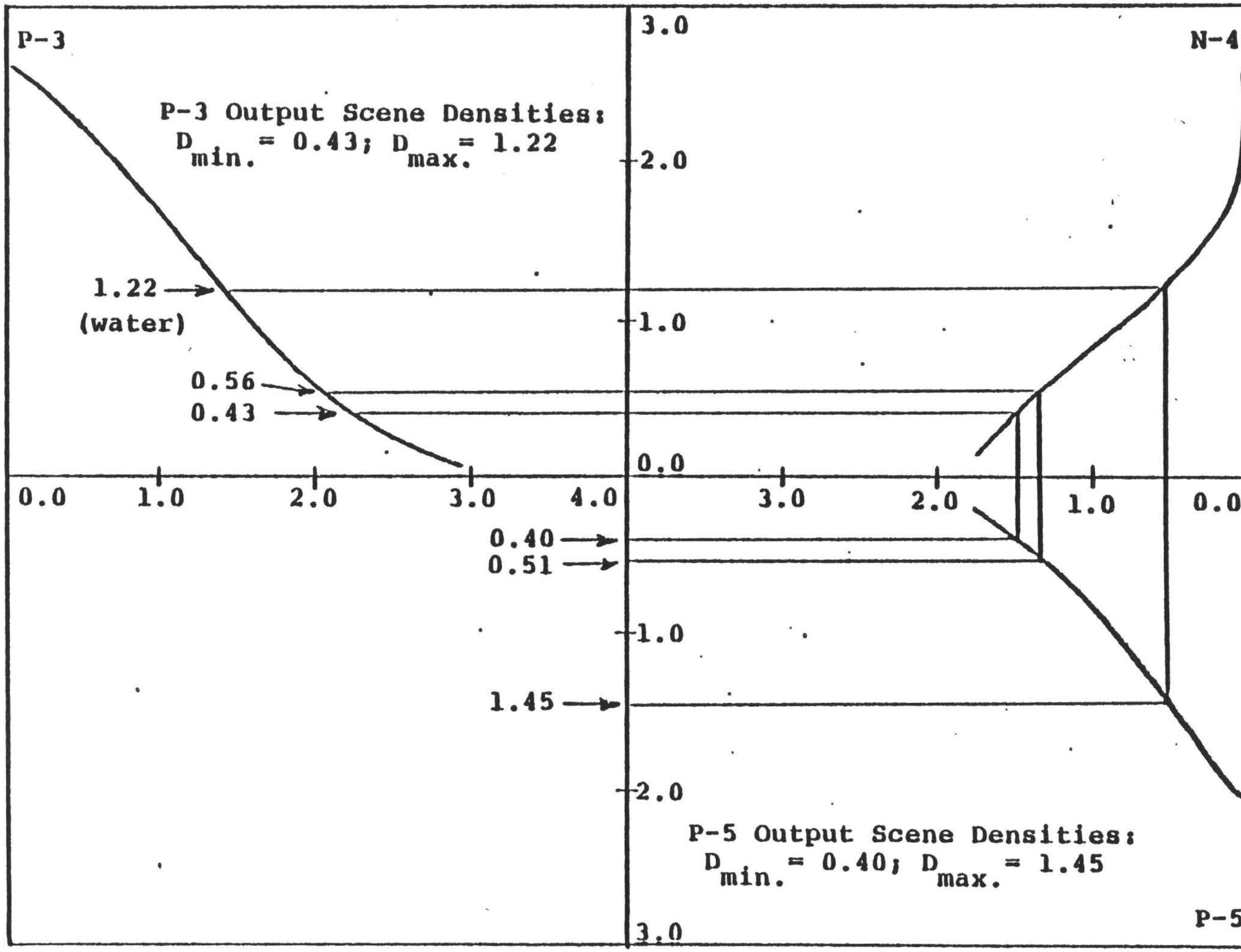
_/ Data generated by Darrell C. Ramerth under the supervision of Richard L. Nelson, Custom Color Laboratory, EROS Data Center.

Figure 25-/.--Tone reproduction diagram for the Landsat-1 standard product band 5 of the 29 August 1972 scene (1037-16213).



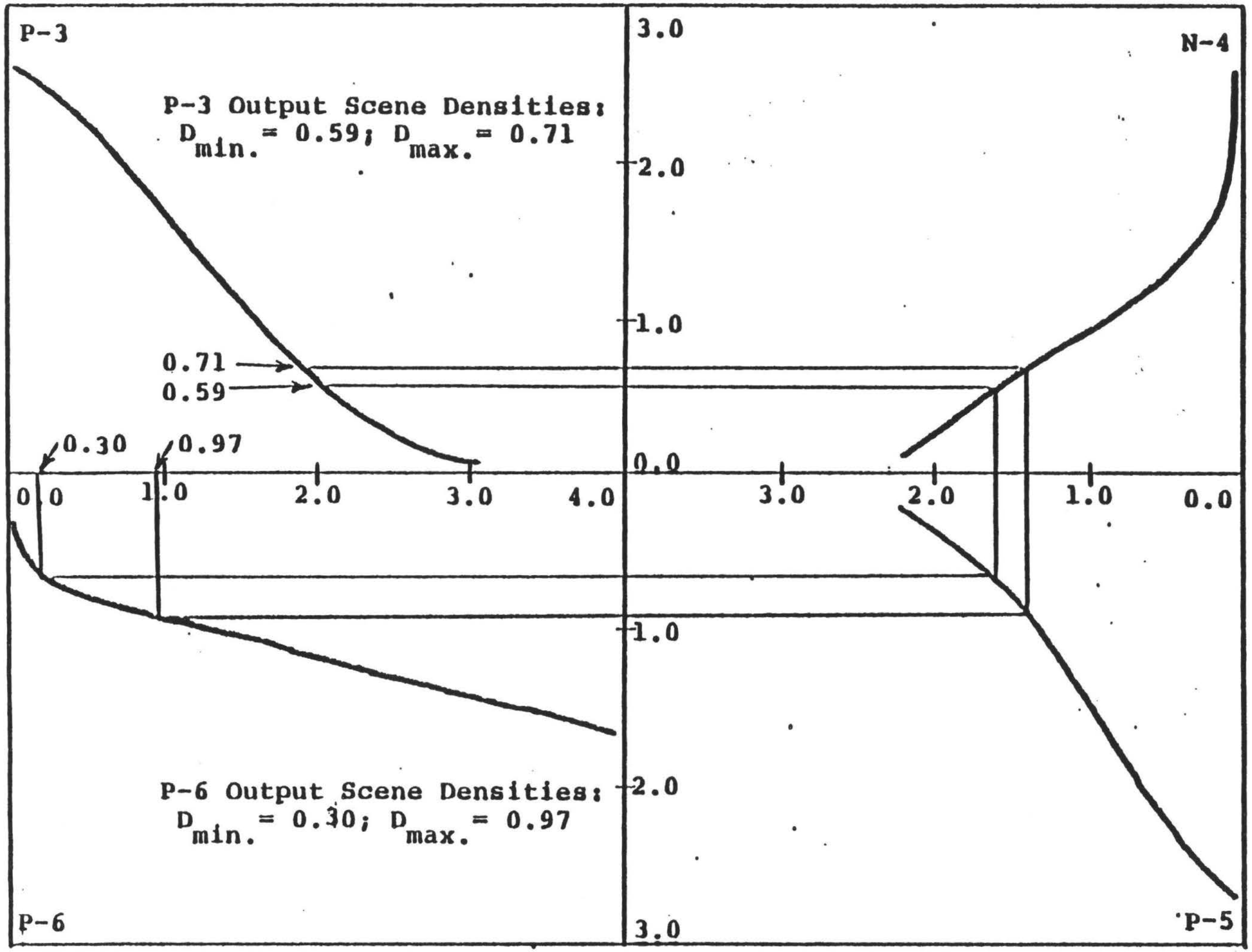
_/ Data generated by Darrell C. Ramerth under the supervision of Richard L. Nelson, Custom Color Laboratory, EROS Data Center.

Figure 26—/.--Tone reproduction diagram for the Landsat-1 standard product band 7 of the 29 August 1972 scene (1037-16213).



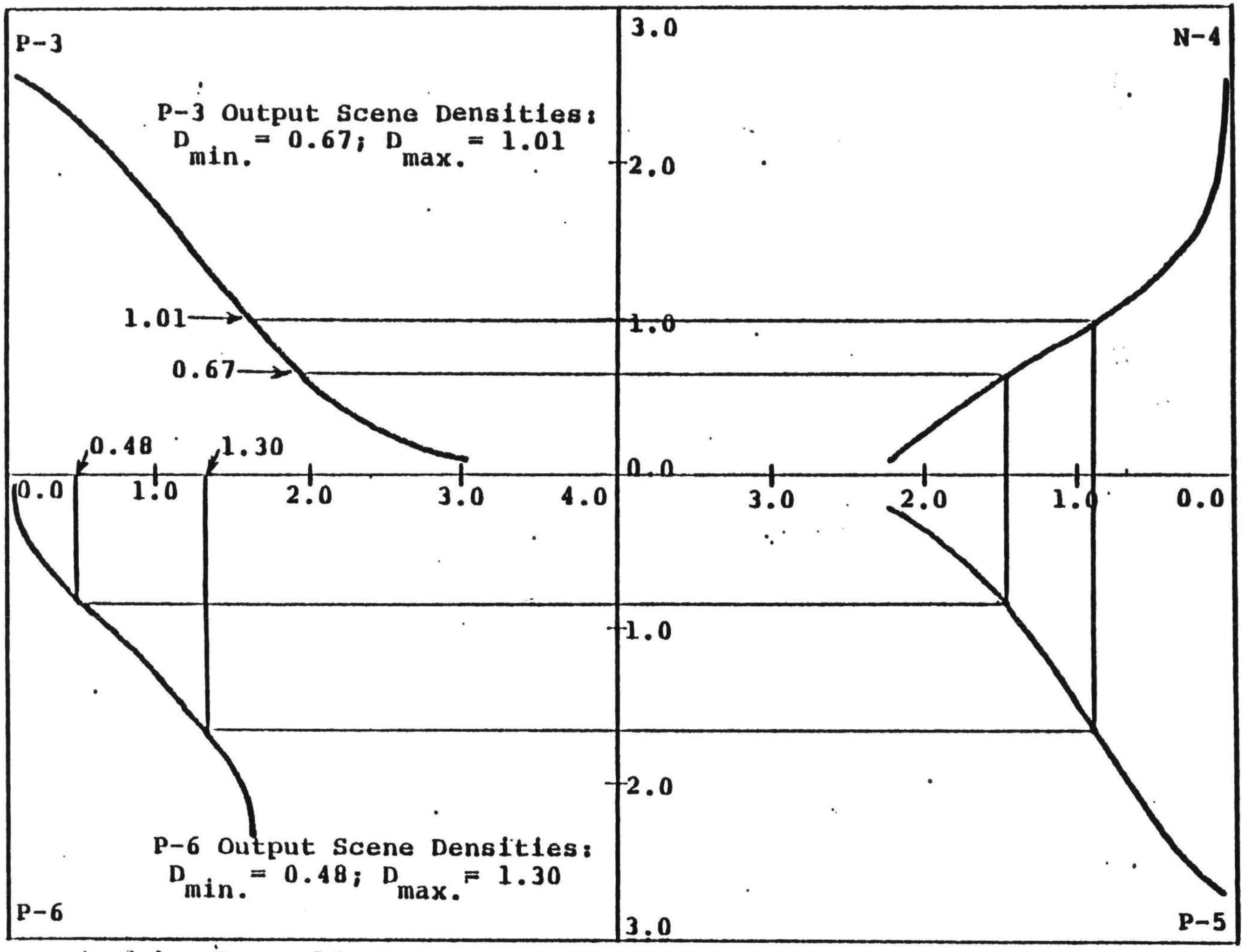
_/ Data generated by Darrell C. Ramerth under the supervision of Richard L. Nelson, Custom Color Laboratory, EROS Data Center.

Figure 27-/.--Tone reproduction diagram for the Landsat-1 photo-optically enhanced band 4, 29 August 1972 scene (1037-16213).



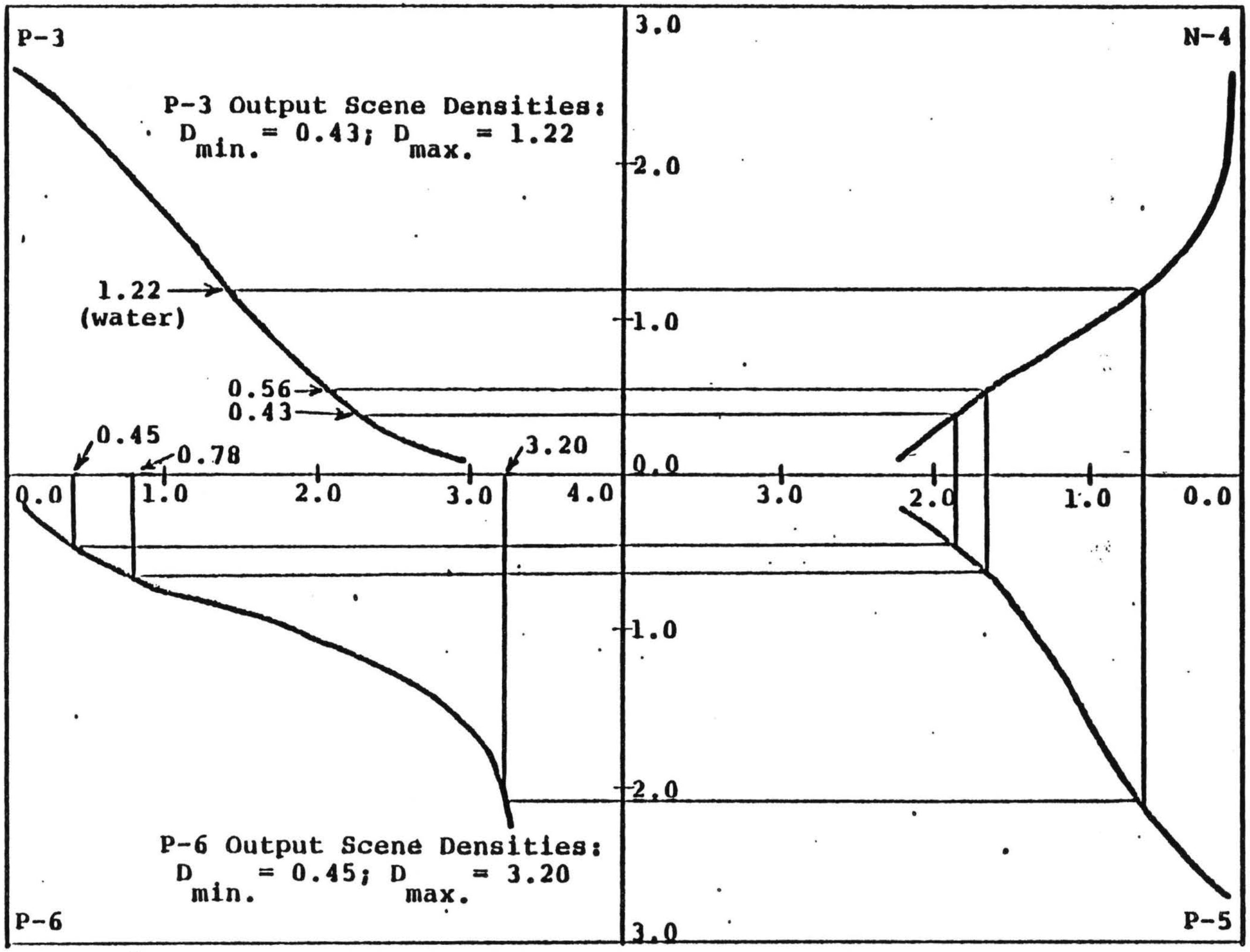
_/ Data generated by Darrell C. Ramerth under the supervision of Richard L. Nelson, Custom Color Laboratory, EROS Data Center.

Figure 28[/] .--Tone reproduction diagram for the Landsat-1 photo-optically enhanced band 5, 29 August 1972 scene (1037-16213).



_/ Data generated by Darrell C. Ramerth under the supervision of Richard L. Nelson, Custom Color Laboratory, EROS Data Center.

Figure 29-/.--Tone reproduction diagram for the Landsat-1 photo-optically enhanced band 7, 29 August 1972 scene (1037-16213).



_/ Data generated by Darrell C. Ramerth under the supervision of Richard L. Nelson, Custom Color Laboratory, EROS Data Center.

Table 4[1].--Data for the standard product Landsat tone reproduction curves.

Landsat-1, 29 August 1972 scene (1037-16213)

Film Product Generation

Step #	N-2	P-3	N-4	P-5
1	0.04	2.61	0.04	2.11
2	0.20	2.52	0.04	2.11
3	0.35	2.40	0.05	2.11
4	0.51	2.27	0.06	2.09
5	0.66	2.11	0.08	2.07
6	0.81	1.94	0.11	2.04
7	0.95	1.77	0.16	1.99
8	1.11	1.58	0.26	1.86
9	1.26	1.41	0.40	1.68
10	1.41	1.24	0.57	1.46
11	1.56	1.04	0.75	1.20
12	1.67	0.93	0.90	1.01
13	1.80	0.79	1.09	0.79
14	1.96	0.65	1.26	0.62
15	2.10	0.53	1.40	0.49
16	2.25	0.43	1.52	0.39
17	2.40	0.32	1.62	0.30
18	2.53	0.25	1.70	0.25
19	2.68	0.19	1.75	0.23

Table 4.--Data for the standard product Landsat tone reproduction curves--Continued.

Landsat-1, 29 August 1972 scene (1037-16213)

Film Product Generation

Step #	N-2	P-3	N-4	P-5
20	2.82	0.15	1.77	0.21
21	2.97	0.12	1.80	0.19

Density readings taken from a 21 step tablet for the black and white film products used to produce the Landsat color composite.

_/ Data generated by Darrell Ramerth under the supervision of Richard L. Nelson, Custom Color Laboratory, EROS Data Center.

Table 5-/.--Data for photo-optically enhanced Landsat scene tone reproduction curves.

Landsat-1, 29 August 1972 scene (1037-16213)

Film Product Generation

Step #	N-2	P-3	N-4	P-5	P-6 Band 4	P-6 Band 5	P-6 Band 7
1	0.04	2.61	0.04	2.70	4.00	1.59	3.27
2	0.20	2.52	0.04	2.70	4.00	1.59	3.27
3	0.35	2.40	0.04	2.70	4.00	1.59	3.27
4	0.51	2.27	0.05	2.70	4.00	1.59	3.27
5	0.66	2.11	0.07	2.70	4.00	1.59	3.27
6	0.81	1.94	0.10	2.70	4.00	1.59	3.27
7	0.95	1.77	0.16	2.60	4.00	1.59	3.27
8	1.11	1.58	0.26	2.50	4.00	1.59	3.27
9	1.26	1.41	0.41	2.34	4.00	1.59	3.27
10	1.41	1.24	0.62	2.06	4.00	1.58	3.25
11	1.56	1.04	0.85	1.71	4.00	1.38	3.09
12	1.67	0.93	1.03	1.42	3.27	1.09	2.64
13	1.80	0.79	1.29	1.08	1.70	0.78	2.06
14	1.96	0.65	1.50	0.78	0.47	0.45	1.29
15	2.10	0.53	1.69	0.60	0.12	0.25	0.75
16	2.25	0.43	1.85	0.45	0.06	0.15	0.44
17	2.40	0.32	1.98	0.36	0.04	0.11	0.27
18	2.53	0.25	2.08	0.30	0.04	0.09	0.20
19	2.68	0.19	2.15	0.26	0.04	0.08	0.15

Table 5.--Data for photo-optically enhanced Landsat scene tone reproduction curves--Continued.

Landsat-1, 29 August 1972 scene (1037-16213)

Film Product Generation

Step #	N-2	P-3	N-4	P-5	P-6 Band 4	P-6 Band 5	P-6 Band 7
20	2.82	0.15	2.20	0.23	0.04	0.07	0.13
21	2.97	0.12	2.22	0.21	0.04	0.07	0.12

Density readings taken from a 21 step tablet for the black and white film products used to produce the Landsat color composite.

_/ Data generated by Darrell Ramerth under the supervision of Richard L. Nelson, Custom Color Laboratory, EROS Data Center.

on the band P-5, which are used to print the standard product color composite, are $D_{min.}$ = 0.53 and $D_{max.}$ = 0.70. This diagram illustrates that very little contrast change is introduced in this standard product band from the P-3 image. The tone reproduction diagram for the POE band 4 (Figure 27), however, starts with the same P-3 scene output densities, but the P-6 scene output densities ($D_{min.}$ = 0.30; $D_{max.}$ = 0.97) have been increased by the POE process. This increased scene contrast is the objective of the photo-optically enhanced P-6 film product. A summary table of the standard product P-5 and POE P-6 output densities are listed on Table 6.

Table 6 near here.

Table 6-/.--Summary Table for scene density ranges as traced through tone reproduction diagrams on Figures 6 through 11.

	P-3 Scene Output Densities		P-5 Standard Product Output Densities		P-6 POE Product Output Densities	
Band	$D_{min.}$	$D_{max.}$	$D_{min.}$	$D_{max.}$	$D_{min.}$	$D_{max.}$
4	0.59	0.71	0.53	0.70	0.20	0.97
5	0.67	1.01	0.60	1.10	0.48	1.30
7	0.43	0.56	0.40	0.51	0.45	0.78
		1.22 (water)		1.45 (water)		3.20 (water)

_/ Data generated by Darrell Ramerth under the supervision of Richard L. Nelson, Custom Color Laboratory, EROS Data Center.

COLOR COMPOSITE EVALUATION

The higher scene contrast existing in the P-6 film generation transparencies are in turn printed through to the composite thereby producing better color contrast and saturation. For land classification purposes, the photo-optically enhanced color composite was judged to be a better interpretation product for all land classification categories. The bases for this statement is summarized in Table 7.

Table 7 near here.

For the purpose of this report, these interpretation conclusions are generalized. A more detailed evaluation of the POE versus standard product color composites is planned for the final report to this contract.

Table 7.--Comparison of the POE and standard product color composites.

Land Category	Comments on Interpretation
1. Urban Commercial/ Industrial	The higher contrast in the overall urban area tends to make the commercial/industrial district a darker blue-green color and therefore more easily interpretable on the POE color composite.
2. Urban Residential	The higher contrast of the POE composite makes the residential areas more distinct from the surrounding agricultural lands.
3. Forest	The forested areas are deeper red on the POE composite than on the standard product composite. In areas where the forest cover is not very dense, the POE is more easily interpreted because of the better color contrast.
4. Water	Smaller bodies of water are more distinct on the POE composite.

Table 7.--Comparison of the POE and standard product color composites--Continued.

Land Category	Comments on Interpretation
5. Transportation Network	Roads are brighter and therefore more distinct on the POE composite.
6. Extractive	Strip mines are slightly more distinct on the POE composite.

COST COMPARISON OF THE POE VERSUS STANDARD PRODUCT COLOR COMPOSITE

If no standard product color composite exists in the EDC data base file, a $50.00 charge is made for the printing of a color transparency. A copy of this color film positive transparency costs $15.00; a 1:1,000,000 scale color paper print costs the user $12.00. To produce a photo-optically enhanced color composite, the EDC Custom Color Laboratory must be utilized. The cost of obtaining a POE color transparency is $150.00 (Richard L. Nelson, Personal Communication, 1976) which is three times the amount charged for the EDC standard product color composite.

If digital processing procedures can be minimized by the utilization of photographic enhancement techniques, then costs for enhanced products could be greatly reduced in terms of both time and money. Perhaps one of the major objectives of computer processing of Landsat data should be to produce high-quality cosmetically enhanced (eliminate striping and line drops) data which has a range of digital values that can be completely recorded by film media. If digital processing can produce a digital distribution of data which fills the entire recording range of photographic film, then photographic enhancement techniques could be employed cheaply by serious users familiar with the type of information they wish to extract from the imagery. Alternatively, if custom enhanced imagery is to be produced for users not having a photographic capability, different enhancements may be tried in an iterative fashion in the photographic laboratory, without having to preprocess digital data in the computer. The savings in time and money should be considerable using this approach.

RELATIONSHIP OF OPTICAL FILM DENSITY TO DIGITAL NUMBERS

In an attempt to relate optical image densities to digital numbers, the General Electric IMAGE 100 video scanner was utilized to transform the standard product P-5 and the POE P-6 image densities into discrete digital values. Spectral histograms were generated for all the photographic images via the IMAGE 100 software program. The resulting histograms for the P-5 and P-6 transparencies are illustrated on Figures 30 and 31. The spectral bounds

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Figures 30 and 31 near here.

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of these histograms indicate how much of the digital dynamic range each photographic transparency covers. The POE P-6 transparencies cover almost twice the digital dynamic range of the standard product P-5 transparencies. Approximately half of the digital dynamic range, however, is not used.

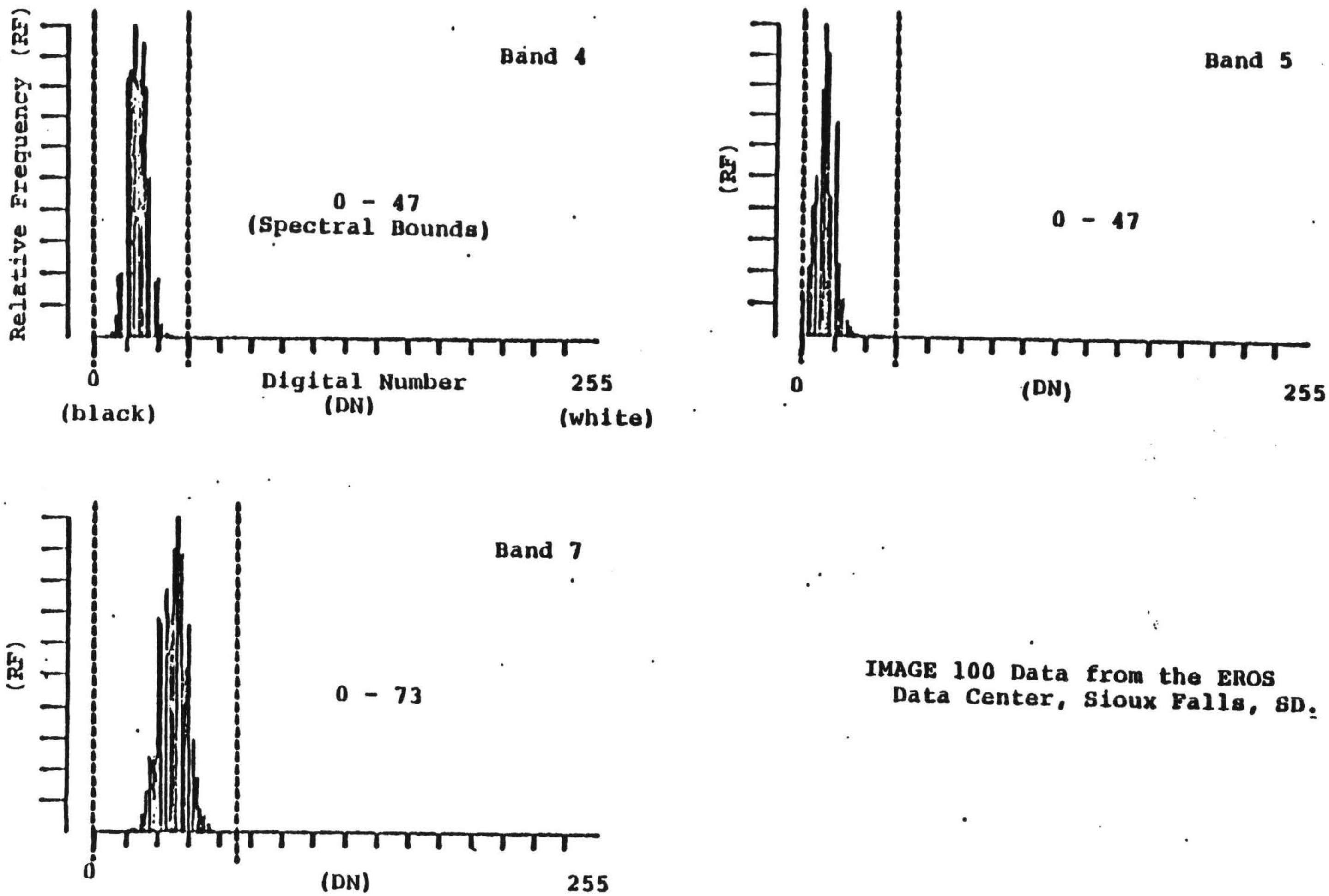

Figure 30.--IMAGE 100 spectral histograms from the EDC standard product P-5 transparencies for the 29 August 1972 scene (1037-16213). IMAGE 100 data from the EROS Data Center, Sioux Falls, SD.

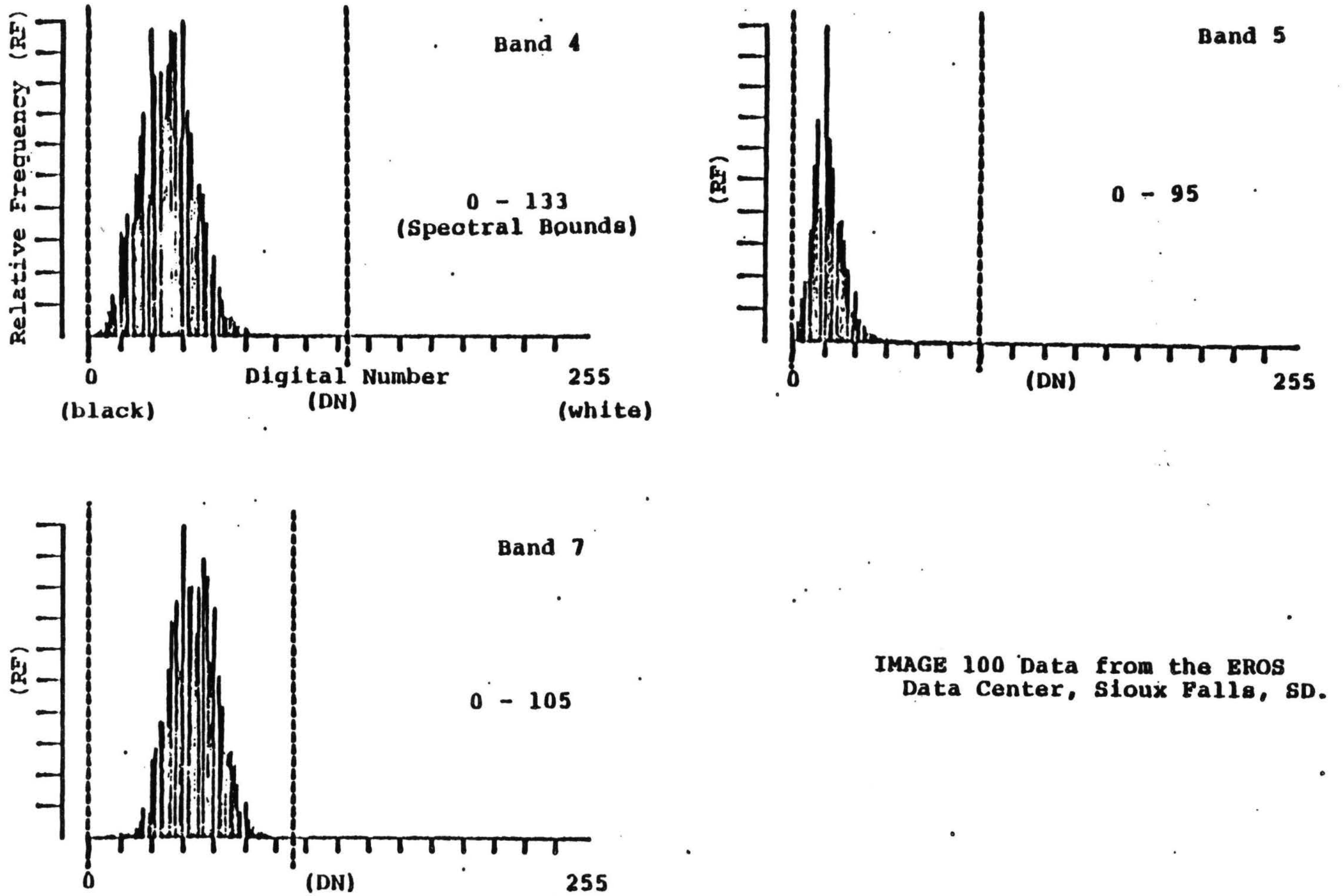

Figure 31.--IMAGE 100 spectral histograms from the EDC photo-optically enhanced P-6 transparencies for the 29 August 1972 scene (1037-16213). IMAGE 100 data from the EROS Data Center, Sioux Falls, SD.

In addition to generating spectral histograms for the black and white transparencies, the IMAGE 100 has the capability of producing a densitometer trace across an image corresponding to a line that has been scanned into the computer. Examples of such traces are shown on Figures 32 and 33 for the P-5 and POE P-6 transparencies. These

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Figures 32 and 33 near here.

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images were scanned into the computer approximately parallel to the scan lines (nearly east/west). The particular video scan line used for the densitometer traces passed directly through the city of Ottumwa, Iowa. On band 7 the Des Moines River's low reflectance is apparent. The high reflectance of the Ottumwa urban cover can also be discerned.

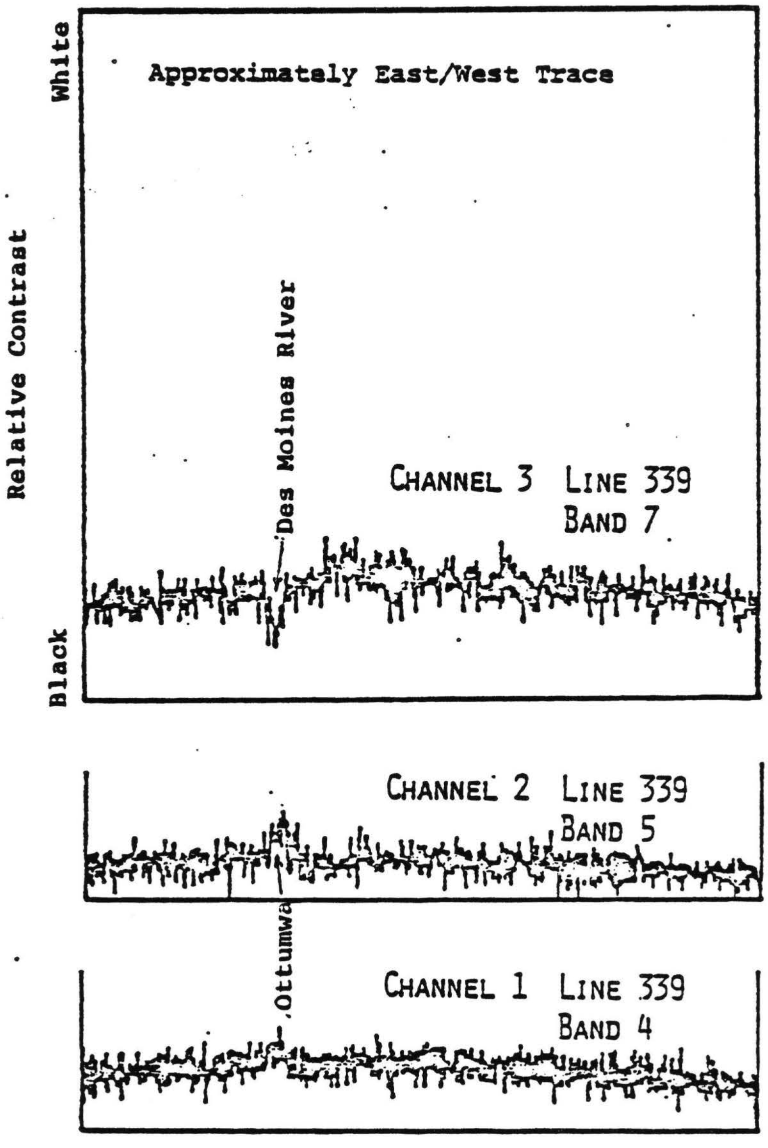

Figure 32.--IMAGE 100 densitometer trace across EDC standard product P-5 transparencies for the 29 August 1972 scene (1037-16213). IMAGE 100 data from the EROS Data Center, Sioux Falls, SD.

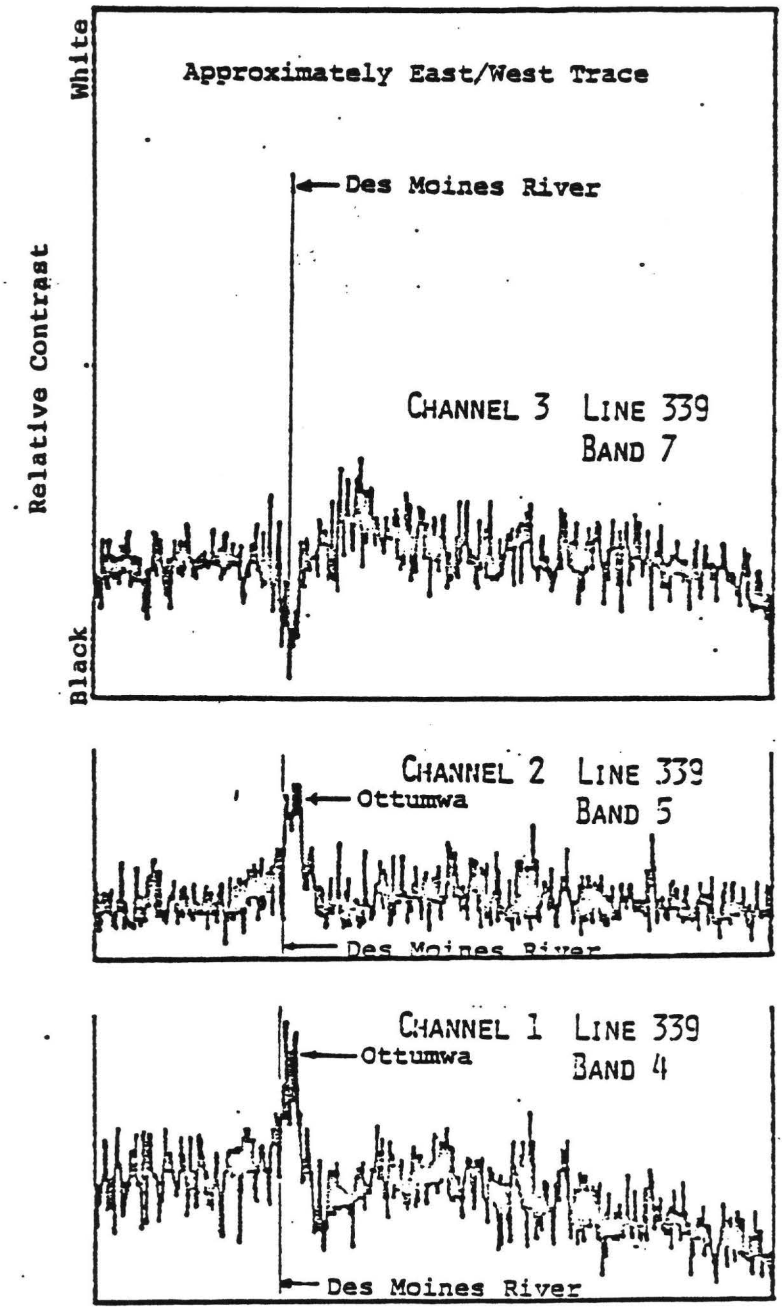

Figure 33.--IMAGE 100 densitometer trace across EDC photo-optically enhanced P-6 transparencies for the 29 August 1972 scene (1037-16213). IMAGE 100 data from the EROS Data Center, Sioux Falls, SD.

These traces, like the spectral histogram, illustrate that the POE P-6 possesses a greater relative contrast range than the standard product P-5 transparencies. These density traces also show the ground location of differences in radiometric contrast. The histograms, on the other hand, only display the total distribution of contrast differences without relation to their ground location. Consequently, histogram displays are alone difficult to evaluate when trying to determine photographic parameters required for color composite products. A combination of histograms and density trace data might be utilized to determine optimal procedures for computer enhancement to fit the dynamic range of the film recording media and optimal photographic exposures for the generation of standard or enhanced photographic products. For instance, the blue-green urban saturation problem (see NAS5-20832 Type II Report for 3 February 1976) can be identified in the densitometer traces. The Ottumwa urban area shows high reflectance values on bands 4 and 5, while on band 7 the urban area is characterized by low reflectance values. When a color composite is printed, the densities in band 7 produce dyes that subtract red light (cyan dye)--the result being, urban areas in which blue/green may dominate.

FUNDS EXPENDED

Table 8 summarizes the budget allotted by NASA and the

Table 8 near here.

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funds expended by the Iowa Geological Survey in execution of contract NAS5-20832.

SUMMARY CONCLUSIONS

1. Because the photographic laboratory at the Jet Propulsion Laboratory found it difficult to estimate what were the optimal color renditions of the Iowa landscape for land classification purposes, the Iowa Geological Survey developed its own capability for producing color products from digitally enhanced Landsat data.

2. Research has now shown that efficient production of enhanced images requires full utilization of both computer and photographic enhancement procedures.

3. If digital processing procedures can be minimized by the utilization of photographic enhancement techniques, then costs for enhanced products could be greatly reduced in terms of both time and money.

4. Perhaps one of the major objectives of computer processing of Landsat data should be to produce high-quality cosmetically enhanced (eliminate striping and line drops) data which has a dynamic range that fits the dynamic range of the film recording media.

Table 8.--Budget allotted by NASA and funds expended by IGS1/.

Land classification of south-central Iowa from computer enhanced images

Element of Cost	Budget Allotted by NASA	Expended Funds by IGS to Date
Salary for Project Manager based on 16 months	$16,874.00	$15,554.00
Employee benefits for Project Manager	2,038.00	1,712.20
Travel related to project - transportation	2,400.00	2,180.95
- per diem	1,600.00	1,142.12
Expendable materials and photographic supplies	863.00	820.11
Publication expense	5,000.00	3,389.25
Subtotal	$28,775.00	$24,788.63
Funding to the Jet Propulsion Laboratory (JPL) by NASA		
Salary for JPL scientific and technical staff and computer processing time (billed to NASA by JPL directly)	20,000.00	
Total funding by NASA for Contract NAS5-20832	$48,775.00	

Table 8.--Budget allotted by NASA and funds expended by IGS--Continued.

Payments received to May 3, 1976 by IGS from Government $24,788.63

_/ Contract NAS5-20832. Contractor: Iowa Geological Survey, 123 North Capitol Street, Iowa City, Iowa 52242.

5. The 29 August 1972 photo-optically enhanced color composite is more easily interpreted for land classification purposes than the EROS Data Center standard product color composite.

6. Because of the great photographic variability that can be introduced into Landsat bands, photo-optical enhancement should be approached with specific objectives in mind.

7. Histogram displays alone are difficult to evaluate when trying to determine exposures required for color composite photographic products. A combination of histograms and density trace data could be utilized to determine optimal procedures for computer enhancement to fit the dynamic range of the film recording media and optimal photographic exposures for the generation of standard or enhanced photographic products.