Simulation of Thematic Mapper Performance as a Function of Sensor Scanning Parameters

NASA CR-152436

(NASA-CR-152436) SIMULATION OF THEMATIC MAPPER PERFORMANCE AS A FUNCTION OF SENSOR SCANNING PARAMETERS Final Report (Bendix Corp.) 57 p HC A04/MF A01 CSCL 08B
N77-18534
Unclas
G3/43 16321

Bendix Aerospace Systems Division

Simulation of Thematic Mapper Performance as a Function of Sensor Scanning Parameters

Final Report

BSR 4202

1 October 1975

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SECTION 1

INTRODUCTION

1.1 BACKGROUND AND GENERAL COMMENTS

This report describes the investigation and results of the Thematic Mapper Instrument Performance Study. The Thematic Mapper is the advanced multispectral scanner initially planned for the Earth Observation Satellite (EOS) and now planned for Landsat D. This study was conducted by the Bendix Aerospace Systems Division of Ann Arbor, Michigan, under NASA GSFC Contract NAS5-26904/031.

The use of existing digital airborne scanner data obtained with the Modular Multispectral Scanner (M^2S) at Bendix provided an opportunity to simulate the effects of variation of design parameters of the Thematic Mapper. Analysis and processing of this data on the Bendix Multispectral Data Analysis System (M-DAS) was used to empirically determine categorization performance on data generated with variations of the sampling period and scan overlap parameters of the Thematic Mapper. The Bendix M^2S data, with a 2.5 milliradian instantaneous field of view (IFOV) and a spatial resolution (pixel size) of 10-m from 13,000 ft altitude, allowed a direct simulation of Thematic Mapper data with a 30-m resolution. The flight data chosen were obtained on 30 June 1973 over agricultural test sites in Indiana.

1.2 SUMMARY OF SECTIONS

Section 1 is an introduction and background discussion.

Section 2 discusses the Thematic Mapper simulation model. The direct application of Bendix M^2S data is discussed and the simulation concept is reviewed. The scanning model cases used for comparison are presented.

The M^2S data with 10 by 10-m resolution were processed as Case 1, and the same data with noise added to the level to simulate the Thematic Mapper were processed as Case 2. Three variations of the data sampling period and scan-to-scan overlap parameters were simulated and processed; Case 3 having a sample period of 30 m (equal to the IFOV) and a zero scan overlap, Case 4 having a 20-m sample period and a zero overlap, and Case 5 having a 20-m sample period and a 10-m overlap. The procedure by which the data for each of these cases were generated is described.

Section 3 presents the categorical processed results for each case. These results include color-coded thematic images produced for each case, printouts of data on the separability of the training set clusters, and area tables for the entire processed strip and for selected sections of the processed strip. Section 3 also contains the study conclusions and recommendations.

1.3 RESULTS

Comparison of all aspects of the categorization performance was difficult to summarize in tabular form. Visual comparison of categorized images provides the best comprehensive evaluation of the categorization performance.

The evaluation of the data printouts shows that, in general, 30-m sample period and zero scan-to-scan overlap case provides the most accurate results. Further interpretation of this data and additional simulations will be required to more completely understand the effects of variation of these and other Thematic Mapper design parameters.

SECTION 2

THEMATIC MAPPER SIMULATION

The Thematic Mapper data were simulated from Bendix M^2S data with a 10-m resolution (pixel size). The Thematic Mapper data, with a 30-m resolution, were directly simulated by integration of M^2S data sectioned into three-by-three pixel arrays. In addition, variations involving the 20-m (0.67 IFOV) sampling period and 10-m (33%) scan overlap were generated on the M-DAS System. Predetermined noise for the Thematic Mapper was added to the simulated data for each study case. The simulated data were then converted to the original M^2S format to provide coherent training set substitution and a strip size which was 798 pixels wide. This pixel count provides the same strip size for all study cases and allows a direct comparison of analysis results and categorized images.

An assumption of this simulation is that the general effects of the sampling rate and overscan parameters do not vary with the exact placement of spectral bands. Six of the M^2S bands were selected, as indicated in Table 2-1. The table shows the spectral channels of the M^2S data available. The bands were selected as follows. Six bands were desired to provide the same dimensionality as that used in processing the six visible and near-visible bands of the Thematic Mapper. (The bands are listed in Table 2-2). M^2S Band 4 was selected to approximately correspond to the shortest wavelength band of the Thematic Mapper, as was M^2S Band 6. Bands 7 through 10 then remain in the visible/near-visible IR spectrum, although they do not go as far into the IR as the Thematic Mapper's Bands 5 and 6.

Table 2-1

M^2S Spectral Channels

Band	λ_c (μm)	$\Delta\lambda$ (μm)
2	0.465	0.05
3	0.515	0.04
4*	0.560	0.04
5	0.600	0.04
6*	0.640	0.04
7*	0.680	0.04
8*	0.720	0.04
9*	0.810	0.10
10*	1.015	0.09

Note: An asterisk denotes Thematic Mapper simulation.

Table 2-2

Interim Design Parameters of the Thematic Mapper

Band	Spectral Region (μm)	Assumed Radiance, N_1 ($w\ m^{-2}\ sr^{-1}$)	IFOV (approximate μrad)	Signal-to-Noise (peak-to-peak volt per rms volt at N_1 and MTF=1)
*1	0.5 to 0.6	2.2	35	10
*2	0.6 to 0.7	1.9	35	7
*3	0.7 to 0.8	1.6	35	5
*4	0.8 to 1.1	3.0	35	5
5	1.55 to 1.75	0.8	35	5
6	2.1 to 2.35	0.3	35	5
7	10.4 to 12.6	20.0 at 300K	140	0.5K NEΔT at 300K

Note An asterisk denotes that spectral bandwidth may be reduced.

2.1 SIMULATION CONCEPT

Figure 2-1 shows the overall flow diagram of the simulation program.

The simulated Thematic Mapper data were produced from the M^2S data on the M-DAS System, as shown in the figure. M^2S data were processed through the M-DAS System to produce simulated data corresponding to three specific Thematic Mapper parameter variations; Cases 3, 4, and 5. Analysis and processing were performed on the M-DAS System for the original M^2S data (Case 1 and Case 2 with noise added) and the simulated Thematic Mapper cases, using training sets initially selected from the M^2S data. The study results are (1) statistical differences, as shown by M-DAS printouts, between the original M^2S data and the simulated Thematic Mapper data, and (2) color-coded categorized (or thematic) images produced for each case.

2.2 SCANNING MODEL CASES

To provide comparison of M^2S data and simulated Thematic Mapper data, five individual study cases were generated. The cases are:

1. M^2S original data.
2. M^2S noise-injected data (this case has 10-by-10-m pixels but has noise added to the level necessary for Case 3).
3. 30-m (100% IFOV) sampling period, zero scan-to-scan overlap.
4. 20-m (0.67 IFOV) sampling period, zero scan-to-scan overlap.
5. 20-m (0.67 IFOV) sampling period, 10-m (33%) scan-to-scan overlap.

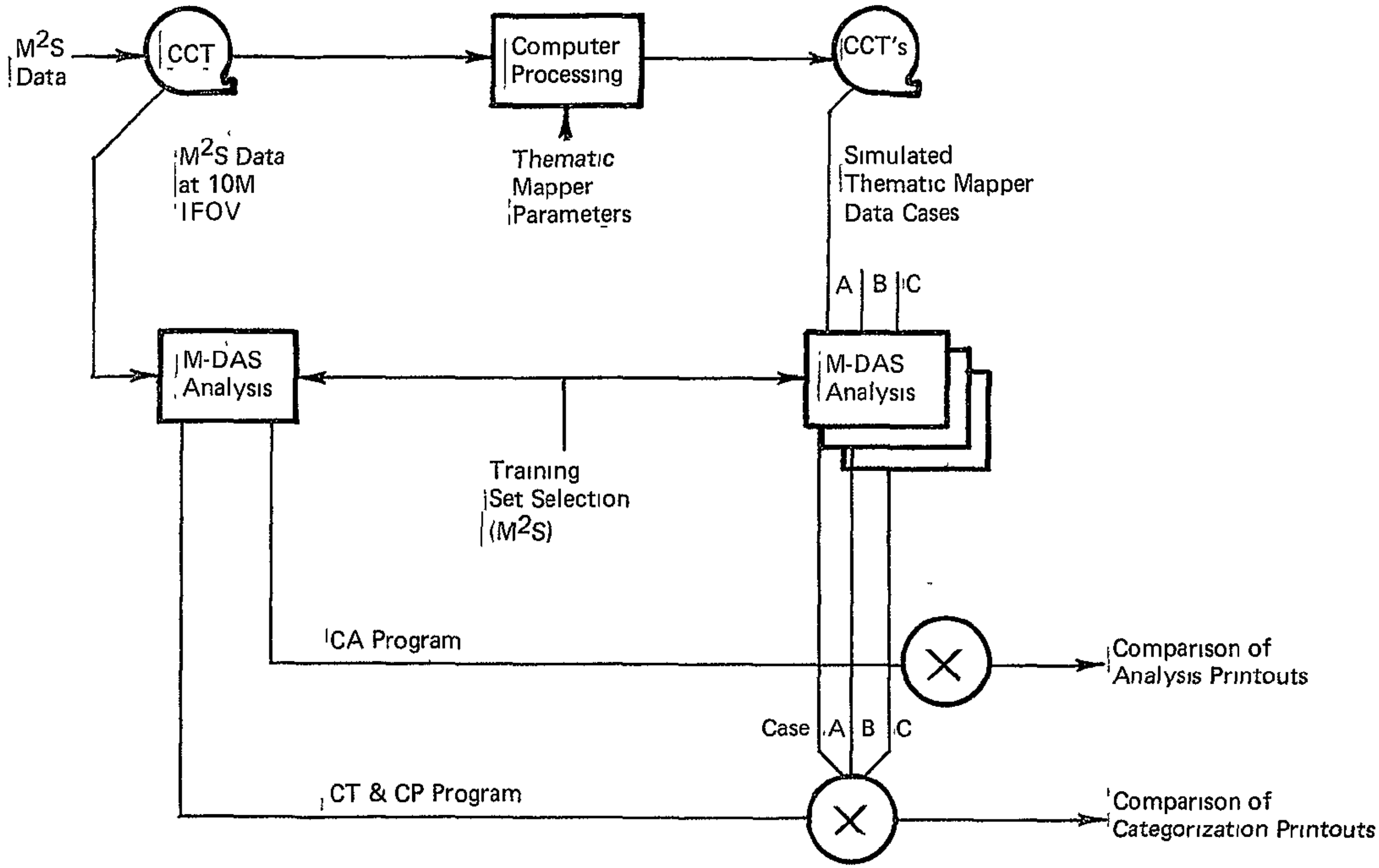

Figure 2-1 Thematic Mapper Simulation Flow Diagram

2.3 M^2S DATA SELECTION

The M^2S data for the study were obtained from a NASA/JSC flight on 30 June 1973 over agricultural areas near Shelbyville, Indiana. The data were obtained at an altitude of 13,500 ft from the flight line shown in Figure 2-2. The 11 bands of data were provided on a high density digital tape (HDDT) as bi-phase-modulated digital data on a 14-track magnetic tape having a 10,000 bit-per-inch (bpi) packing density. The data were transformed into two standard format raw data computer-compatible tapes (CCTs) having nine tracks with 800 bpi records in ASCII code.

The raw data CCTs were processed on the M-DAS System, using standard methods and techniques. The M-DAS System is described later.

2.4 THEMATIC MAPPER DATA SYNTHESIS (CASES 3, 4, AND 5)

This task required generation of a simulated Thematic Mapper CCT for each of the scanning parameter cases. The synthesis of the geometrics for each of the three cases is shown in Figure 2-3a, b, and c.

To simulate the case for 1.00-IFOV sampling and 0.0 scan overlap parameters, the M^2S data were sectioned into three-by-three pixel arrays, and data from the nine pixels were integrated and reduced to represent one M^2S pixel. Predetermined noise was added, as described below, and a new Thematic Mapper-simulated pixel (with 30-m resolution) was generated by repeating the single pixel data in a three-by-three pixel array.

Successive simulated Thematic Mapper raw data were obtained by shifting three pixels and then three scan lines throughout the M^2S original data.

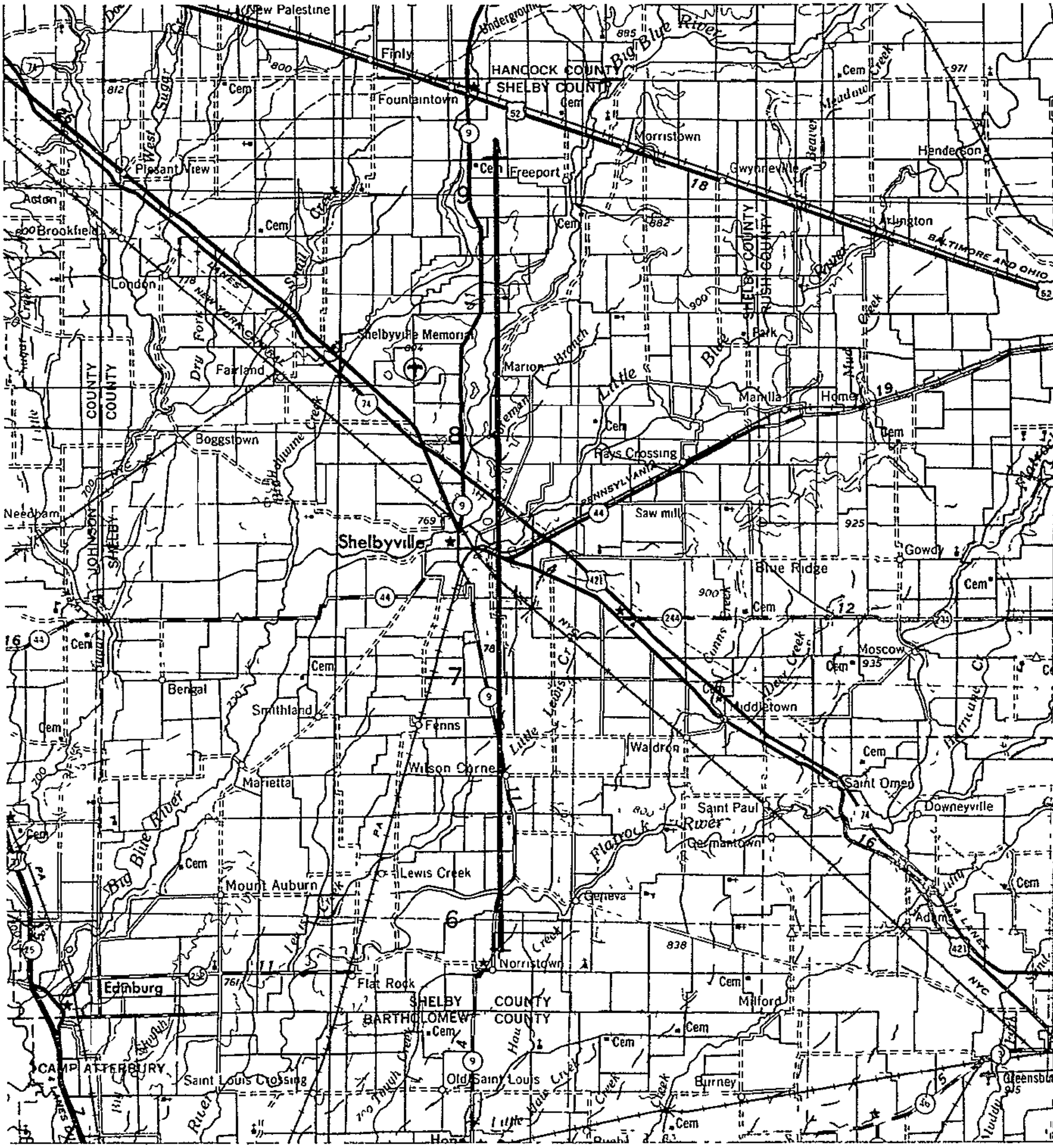

Figure 2-2 Flight Line

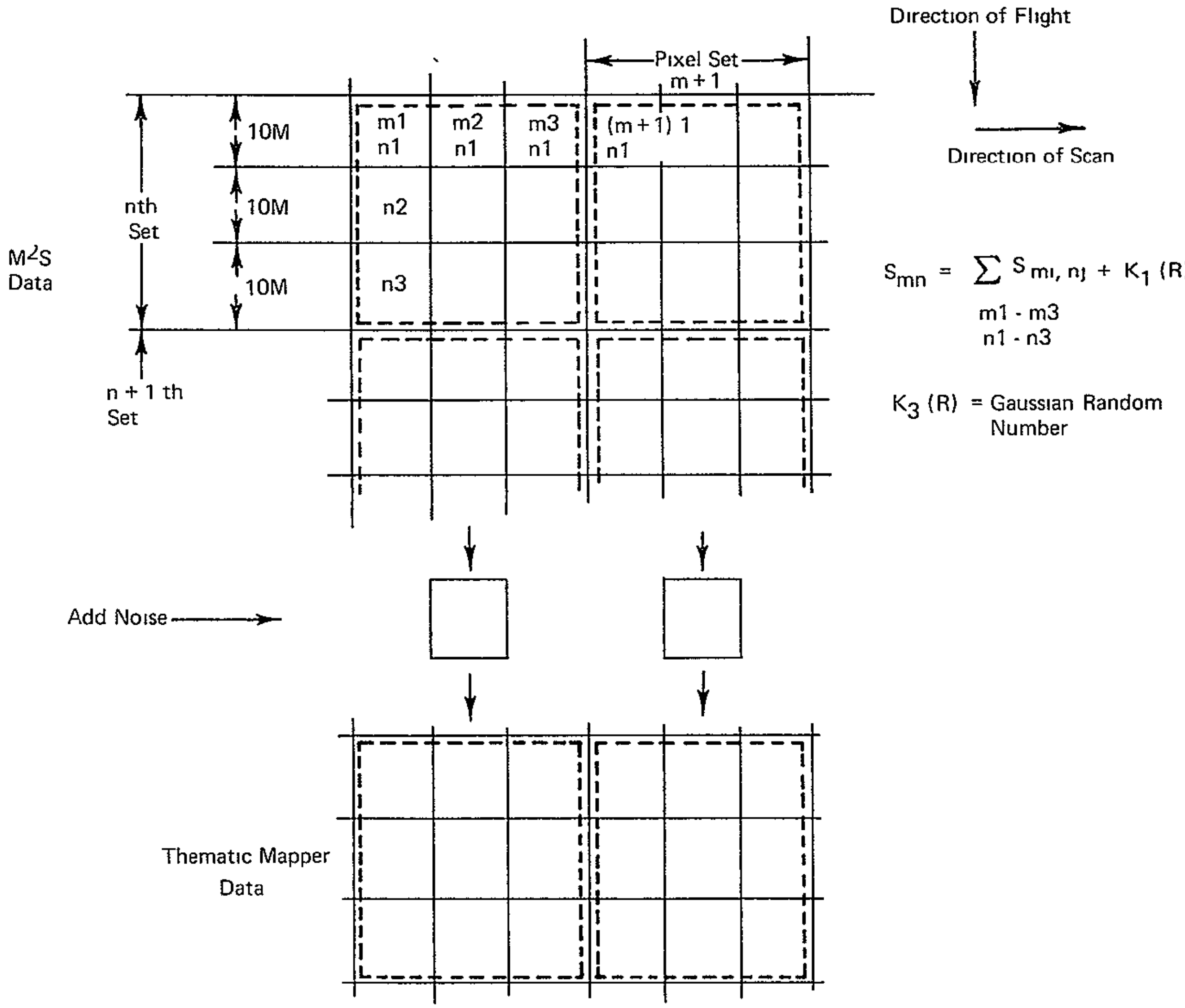

Figure 2-3a Synthesis Geometry; 1.00 IFOV Sampling - 0.0 Scan Overlap

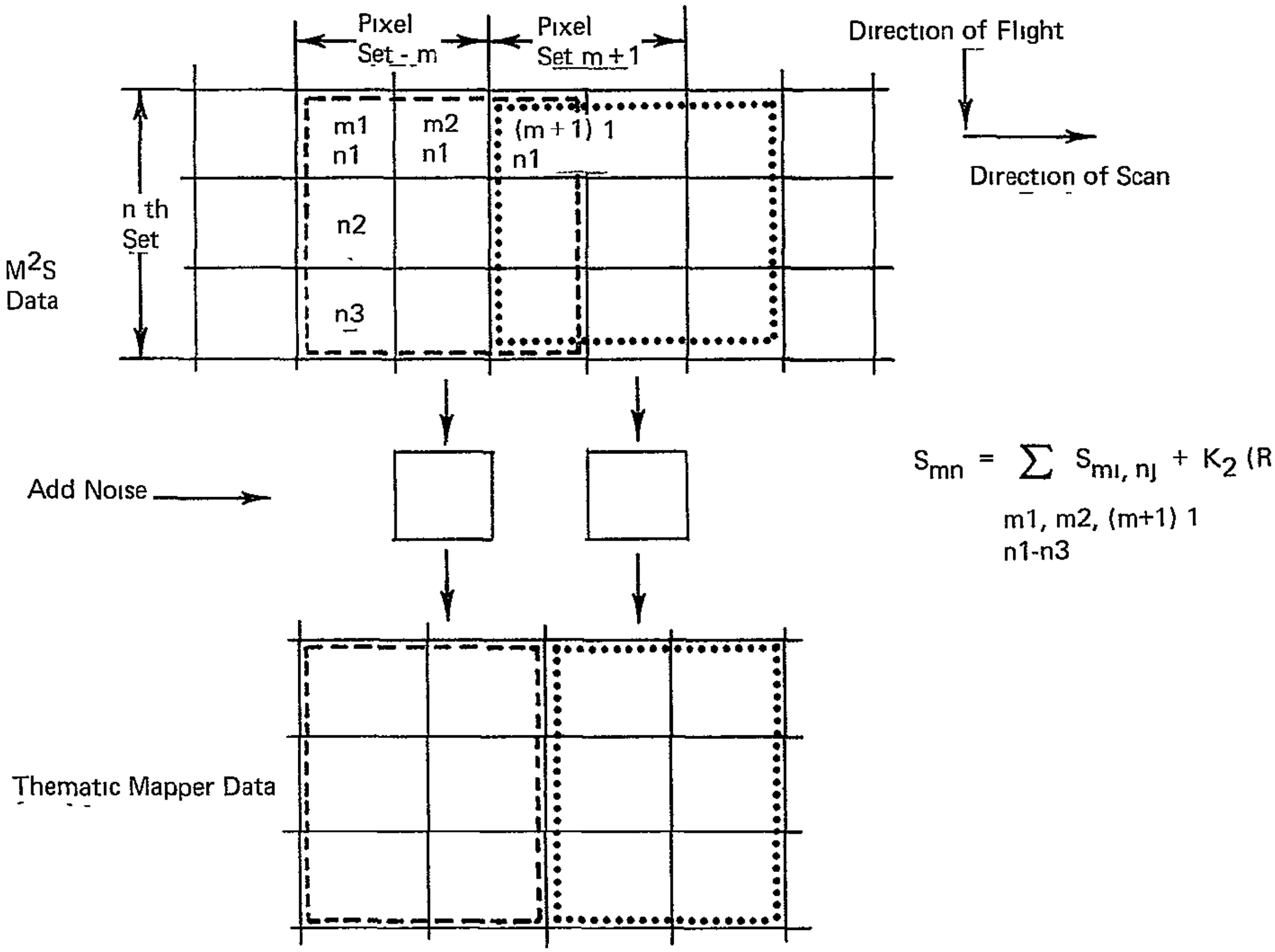

Figure 2-3b Synthesis Geometry; 0.67 IFOV Sampling – 0.0 Scan Overlap

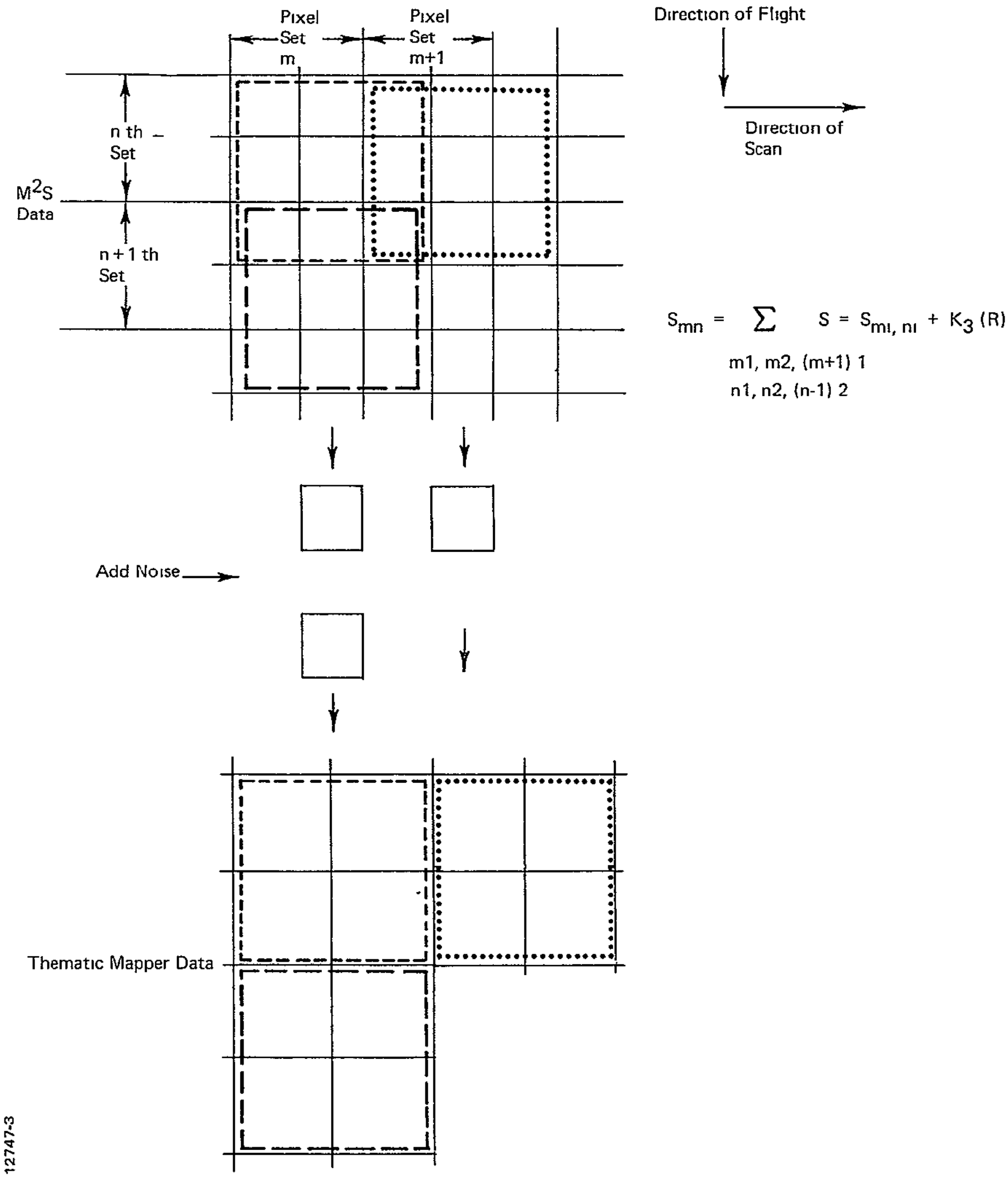

Figure 2-3c Synthesis Geometry; 0.67 IFOV Sampling - 0.33 Scan Overlap

Figure 2-3b shows the data synthesis for the 0.67 IFOV sampling and 0.0% scan overlap scanning parameter case, in which M^2S original scan lines were shifted only two pixels for the 0.67 IFOV sampling parameter. Similar integration and noise addition operations were performed. This Thematic Mapper pixel was obtained by generating successive two-by-three pixel arrays.

2.4.1 Noise Addition

The three simulated Thematic Mapper CCTs were processed on the M-DAS System to add the noise. The noise addition is summarized in Table 2-3.

The noise requirements for the baseline Thematic Mapper model used for the simulation study are shown in Tables 2-4 and 2-5. The model was submitted to NASA/GSFC and approved in February of 1975. The noise was added to each spectral band for each of the three cases.

2.5 M-DAS PROCESSING OF M^2S AND THEMATIC MAPPER DATA

The procedures for processing the M^2S and simulated Thematic Mapper data on M-DAS are briefly described in this section. A key aspect of this processing is the categorization technique used by M-DAS. The M-DAS categorization techniques (Refs 1 and 2), primarily using aircraft multispectral scanner data, have been under continued development at Bendix for the past ten years. More recently, Landsat/MSS and Skylab/EREP-S192 data have been used. The overall operation of the M-DAS System is described in BSR-4146B, "M-DAS System Description," (Ref. 3). The data were displayed on the M-DAS display as picture elements,

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Rerefence are listed in Section 2.7.

Table 2-3

Computation of Noise Injection to M^2S Data Required to Simulate Thematic Mapper Performance

Band No	Bandwidth (μm)	ρ_{eq} of L 31 in the Sphere (%)	Sphere Mean Count	Black Body Mean Count	ΔC Sphere	Sphere Std Dev Count	Signal to Noise Ratio	Cal Lamp Mean Count	ρ_{eq} of Cal Lamp Filter 3 (%)
2	0 44 0 49	17 27	101 32	23 96	77 36	1 38	56 05	134 73	24 72
3	0 49-0 54	25 62	151 66	19 73	131 93	0 96	137 12	224 41	39 75
4	0 54 0 58	34 12	133 33	20 61	112 72	0 84	134 19	226 31	62 26
5	0 58 0 62	40 76	122 53	18 40	104 13	0 50	208 26	219 20	78 59
6	0 62 0 66	43 67	122 44	20 48	101 96	0 95	107 33	222 28	86 43
7	0 66 0 70	43 91	119 25	17 83	101 43	0 76	133 44	226 04	90 14
8	0 70 0 74	31 77	77 27	20 87	56 10	0 52	108 16	171 20	84 68
9	0 77-0 86	7 61	33 29	21 16	12 11	0 44	27 52	127 83	67 03
10	0 97-1 06	6 66	32 83	26 17	6 66	0 39	17 08	90 05	63 88

Band No	ΔC for Cal Lamp Filter 3 (%)	ρ_{eq} of Cal Lamp Filter 4 (%)	NEΔρ Sphere (%)	Thematic Mapper Specification (%)	Lamp Mean Count	Black Body Mean Count	Δ Count Lamp	Std Dev for Flight for Thematic Mapper	Noise Present in M^2S (Std Dev)
2	110 8	10 98	0 308	1 5	80 61	1 14	79 47	10 86	2 238
3	204 7	17 67	0 186	1 0	149 17	24 10	125 07	7 09	1 325
4	205 7	18 87	0 254	1 0	222 9[illegible]	22 36	200 56	10 69	1 32
5	200 8	33 68	0 196	1 0	233 65	24 94	208 71	6 19	1 214
6	201 8	35 25	0 406	1 0	238 78	22 98	215 80	6 14	2 493
7	208 2	38 44	0 329	1 0	239 27	31 14	208 13	5 42	1 783
8	150 3	35 65	0 293	1 0	238 57	25 45	213 12	5 98	1 752
9	106 6	28 94	0 276	1 0	127 64	24 06	103 58	3 58	0 992
10	63 9	27 03	0 390	1 0	130 58	28 47	102 11	3 78	1 472
					67 80	24 85	42 95		

Standard deviation for data = sphere standard deviation × $\frac{NE\Delta\rho \text{ Thematic Mapper}}{NE\Delta\rho\ M^2S}$ × $\left(\frac{\Delta C}{\rho_{eq}}\right)_{flight}$ × $\left(\frac{\rho_{eq}}{\Delta C}\right)_{sphere}$ = 1 38 × $\frac{1\ 5}{0\ 308}$ × $\frac{79\ 47}{10\ 98}$

Table 2-4

Summary of Noise Injection for Simulated Thematic Mapper Cases

Case 1			Case 2 and Case 3				Case 4				Case 5			
Original Data			Noise injected M^2S original data, 1 00 IFOV sampling rate and zero scan overlap				0 67 IFOV sampling rate and zero scan overlap				0 67 IFOV sampling rate and 0 33 scan overlap			
M^2S Band	M^2S Noise (σ) (Counter)	σ^2	σA	σA^2	$\sigma A^2 - \sigma^2$	$\sqrt{\sigma A^2 - \sigma^2}$	σB	σB^2	$\sigma B^2 - \sigma^2$	$\sqrt{\sigma B^2 - \sigma^2}$	σC	σC^2	$\sigma C^2 - \sigma^2$	$\sqrt{\sigma C^2 - \sigma^2}$
1	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2	2 23	4 97	10 86	117 93	112 96	10 62	13 29	176.62	171 65	13 10	16 29	265 36	260 39	16 14
3	1 32	1 74	7.09	50 27	48 53	6 97	8 69	75.52	73 78	8 59	10 64	113 21	111 47	10 56
*4	1 32	1 74	10 64	113 21	111 47	10 56	13.02	169 52	167 78	12 95	15 96	254 72	252 98	15 91
5	1 21	1 46	6 19	38 32	36 86	6.07	7 58	57.46	56 00	7 48	9 29	86 30	84 84	9 21
*6	2 49	6 20	6 14	37 70	31 50	5 61	7 52	56 55	50 35	7.10	9 21	84 82	78 62	8 86
*7	1 78	3 17	5.42	29 38	26 21	5 12	6 63	43 96	40.79	6 39	8 13	66 10	62 93	7 93
*8	1 75	3 06	5.98	35 76	32.70	5 72	7.32	53 58	50 52	7 11	8 97	80 46	77.40	8 80
*9	0 99	0 98	3 58	12 82	11 83	3 44	4 38	19 18	18 20	4 27	5 37	28.84	27 84	5 28
*10	1 47	2.16	8 78	14.29	12 13	3 48	4 63	21.44	19 28	4 39	5 67	32 15	29 99	5 48
11	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Note Asterisk indicates bands used in final analysis.

Table 2-5

M^2S Processing Results

Group	Interpreted Category Type	Color	Training Set
1	Agriculture 1	red (700)	1, 3, 23, 24, 25, 71, 74, 76, 77, 78, 79, 80
2	Deciduous Vegetation	green (070)	5, 6
3	Water 1	blue (007)	7, 8, 9
4	Agriculture 2	green (050)	10, 11, 12
5	Sparse Growth 1	gray (444)	13, 14, 15
7	Bare Soil 1	blue-green (254)	7, 26
8	Agriculture 1	red (500)	17, 18, 19
9	Water 2	blue (005)	20, 21, 22
11	Water 3	blue (003)	27, 28, 29
12	Agriculture 1	red (500)	30, 31, 32, 75
15	Sparse Growth 2	purple (707)	35, 36, 37
16	Agriculture 3	red (700)	38, 39, 40
17	Sparse Growth 2	purple (707)	41, 42
18	Sparse Growth 3	yellow (770)	43, 44, 45, 70
19	Agriculture 1	red (700)	46, 47, 48
20	Sparse Growth 2	purple (707)	49, 50, 51
21	Deciduous Vegetation	green (070)	52, 53, 54
22	Grassland	brown (431)	55, 56, 57
23	Bare Wet Soil	orange (740)	58, 59, 60
24	Agriculture 1 (thick growth)	white (777)	61, 62, 63
25	River Water	blue (004)	64, 65, 66, 67, 68

called pixels. A group of pixels, called a training set, representing specific land-water cover types, were identified from color IR imagery since ground truth data were not available. Since the determination of category types was made from interpretation of the color IR images, the images may not directly agree with the actual ground truth types which existed at the time of flight. Whereas this study is concerned with comparison of the simulated and original data, mis-interpretation of some category types from images should not be deleterious to the study results.

The coordinates of training sets as viewed in the data were then designated to the computer by placing a cursor over a selected area and then assigning a category number, training set number, and color code for each respective training set. Table 2-6 shows the categories selected during the processing. To avoid non-homogeneous training sets in the simulated Thematic Mapper cases, relatively small training sets were chosen. The data were categorized into 21 groups using 73 training sets.

Categorical analysis was performed using M^2S Bands 4, 6, 7, 8, 9, and 10, as shown by comparison of Tables 2-1 and 2-2.

One output of the training and analysis processing is a categorization accuracy table which indicates the performance of the processing when applied back to the training sets. Table 2-6 shows the final categorization table for Case 1. Entries in the table indicate the percentage of each of the training sets (listed by number in the left column) which were categorized into the various selected land-water cover types referred to as groups. These categorization results will be used as a reference for comparison with results from the other simulated study cases.

CATEGORIZATION TABLE   15-OCT-75   17:08:22

REJECTION LEVEL =6.0 STANDARD DEVIATIONS

NOV =11

NUMBER OF GROUPS =21

NUMBER OF BANDS DELETED = 5

BANDS DELETED = 1 2 3 5 11

Table 2-6

An Example of a Categorization Table for Case 1

TNG	PERCENT CATEGORIZED AS GROUP															
SET	0	1	2	3	4	5	7	8	9	11	12	15	16	17	18	19
1	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	1.79	98.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	1.79	98.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	98.21	0.00	0.00	0.00	0.00	1.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	0.00	0.00	0.00	0.00	0.00	98.21	0.00	0.00	0.00	0.00	0.00	1.79	0.00	0.00	0.00	0.00
14	0.00	0.00	0.00	0.00	0.00	98.21	0.00	0.00	0.00	0.00	0.00	1.79	0.00	0.00	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00	98.21	0.00	0.00	0.00	0.00	0.00	1.79	0.00	0.00	0.00	0.00
16	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	0.00	5.36	0.00	0.00	0.00	0.00	0.00	94.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	0.00	1.79	0.00	0.00	0.00	0.00	0.00	98.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	0.00	1.79	0.00	0.00	0.00	0.00	0.00	98.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	0.00	0.00	0.00	1.23	0.00	0.00	0.00	0.00	98.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	0.00	96.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 2-6 (Cont.)

TNG SET	0	1	2	3	4	5	7	8	9	11	12	15	16	17	18	19
	PERCENT CATEGORIZED AS GROUP															
25	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00
28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00
29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00
31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00
32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00
35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00
36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00
37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00
38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00
39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00
40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00
41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00
42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00
43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	97.62	0.00
44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	97.62	0.00
45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	95.24	0.00
46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00
47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00
48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00
49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.76	0.00
55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
58	2.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 2-6 (Cont.)

60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
61	0.00	2.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
67	6.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00
71	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
74	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00
76	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
77	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
78	0.00	96.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
79	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TNG SET	PERCENT CATEGORIZED AS GROUP					
	20	21	22	23	24	25
1	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00
13	0.00	0.00	0.00	0.00	0.00	0.00
14	0.00	0.00	0.00	0.00	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00	0.00
16	0.00	0.00	0.00	0.00	0.00	0.00

Table 2-6 (Cont.)

TNG SET	PERCENT CATEGORIZED AS GROUP 20	21	22	23	24	25
17	0.00	0.00	0.00	0.00	0.00	0.00
18	0.00	0.00	0.00	0.00	0.00	0.00
19	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00
21	0.00	0.00	0.00	0.00	0.00	0.00
22	0.00	0.00	0.00	0.00	0.00	0.00
23	0.00	0.00	0.00	0.00	3.33	0.00
24	0.00	0.00	0.00	0.00	0.00	0.00
25	0.00	0.00	0.00	0.00	0.00	0.00
26	0.00	0.00	0.00	0.00	0.00	0.00
27	0.00	0.00	0.00	0.00	0.00	0.00
28	0.00	0.00	0.00	0.00	0.00	0.00
29	0.00	0.00	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00	0.00	0.00
31	0.00	0.00	0.00	0.00	0.00	0.00
32	0.00	0.00	0.00	0.00	0.00	0.00
35	0.00	0.00	0.00	0.00	0.00	0.00
36	0.00	0.00	0.00	0.00	0.00	0.00
37	0.00	0.00	0.00	0.00	0.00	0.00
38	0.00	0.00	0.00	0.00	0.00	0.00
39	0.00	0.00	0.00	0.00	0.00	0.00
40	0.00	0.00	0.00	0.00	0.00	0.00
41	0.00	0.00	0.00	0.00	0.00	0.00
42	0.00	0.00	0.00	0.00	0.00	0.00
43	0.00	2.38	0.00	0.00	0.00	0.00
44	0.00	2.38	0.00	0.00	0.00	0.00
45	0.00	2.38	0.00	0.00	2.38	0.00
46	0.00	0.00	0.00	0.00	0.00	0.00
47	0.00	0.00	0.00	0.00	0.00	0.00
48	0.00	0.00	0.00	0.00	0.00	0.00
49	100.00	0.00	0.00	0.00	0.00	0.00
50	100.00	0.00	0.00	0.00	0.00	0.00
51	100.00	0.00	0.00	0.00	0.00	0.00

Table 2-6 (Cont.)

TNG SET	PERCENT CATEGORIZED AS GROUP 20	21	22	23	24	25
52	0.00	100.00	0.00	0.00	0.00	0.00
53	0.00	97.62	0.00	0.00	2.38	0.00
54	0.00	92.86	0.00	0.00	2.38	0.00
55	0.00	0.00	100.00	0.00	0.00	0.00
56	0.00	0.00	100.00	0.00	0.00	0.00
57	0.00	0.00	100.00	0.00	0.00	0.00
58	0.00	0.00	0.00	97.14	0.00	0.00
59	0.00	0.00	0.00	97.14	0.00	2.86
60	0.00	0.00	0.00	100.00	0.00	0.00
61	0.00	4.76	0.00	0.00	92.86	0.00
62	0.00	7.14	0.00	0.00	92.86	0.00
63	0.00	2.38	0.00	0.00	97.62	0.00
64	0.00	0.00	0.00	0.00	0.00	100.00
65	0.00	0.00	0.00	0.00	0.00	100.00
66	0.00	0.00	0.00	0.00	0.00	100.00
67	0.00	0.00	0.00	6.25	0.00	87.50
68	0.00	0.00	0.00	0.00	0.00	100.00
70	0.00	0.00	0.00	0.00	0.00	0.00
71	0.00	0.00	0.00	0.00	0.00	0.00
74	0.00	0.00	0.00	0.00	0.00	0.00
75	0.00	0.00	0.00	0.00	0.00	0.00
76	0.00	0.00	0.00	0.00	0.00	0.00
77	0.00	0.00	0.00	0.00	0.00	0.00
78	0.00	0.00	0.00	0.00	3.33	0.00
79	0.00	0.00	0.00	0.00	0.00	0.00
80	0.00	0.00	0.00	0.00	0.00	0.00

PROGRAM RUN TIME = 00:03:35

The M-DAS data processing steps used and the results achieved in transforming M^2S and simulated Thematic Mapper CCTs into the desired data and images are summarized in the following paragraphs.

2.5.1 Establishing Thematic Categories

The first step in the processing of the CCTs was to locate and designate to the computer a number of M^2S picture elements or pixels that best typified the land and water categories of interest, the "training areas." These areas of known characteristics were established from color IR photography and were located on the Landsat CCTs by viewing the taped data on the M-DAS color moving-window display. The coordinates of the training areas were designated to the computer by placing a cursor over the desired area and assigning a training area designation, category code, and color code. Several training areas, typically 20 to 50 pixels in size, were picked for each category, with each pixel corresponding to a ground coverage of 10 m. The color code was used in later playback of the tapes when the computer-categorized data are displayed or film is recorded in the designated colors.

2.5.2 Developing Processing Coefficients

The M^2S spectral measurements within the training area boundaries were edited by the computer from the CCT and processed to obtain numerical descriptors and processing coefficients for each land or water category. The descriptors (Ref 1) included the mean signal and its standard deviation for each M^2S band (the covariance matrix is stored in M-DAS for each training set). These data are then used to generate a set of processing coefficients for each category. In the M-DAS's multivariate categorized processing coefficients are used by the computer to form linear combinations of the M^2S measurements for each pixel, e.g., a set of transformed variables. Each variable produced has an amplitude associated with the probability that the unknown pixel measurements belong to the particular category sought. In categorical processing, the probability of a pixel arising from each one of the different target categories of interest is computed for each pixel, and a decision, based on these computations, is reached. If all the probabilities are below a threshold level specified by the operator, the computer will decide that the category viewed is unknown (uncategorized).

2.5.3 Evaluating Selection of Training Areas and Processing Coefficients

Before producing categorized data for the entire test area, a number of tests were applied to evaluate the computer's ability to perform the desired interpretation. The tests included generating categorization-accuracy tables and viewing the categorized imagery on the M-DAS display. Selection of training areas, generation of accuracy tables, and evaluation of processing results through use of computer printouts and the display were iterative operations.

2.5.4 Generating Categorized Tapes

When we were satisfied with the categorization accuracy achieved on the land-water categories, we placed the processing coefficients into the computer disk file and used the coefficients to process that portion of the CCTs that covered the test area. This step in the categorization processing resulted in new or categorized CCTs in which each M^2S pixel was represented by a code designating one of the 21 land-water categories. Computer tabulations were also extracted from the categorized tapes to obtain a quantitative measure of land use within the test area.

Machine-assisted processing of M^2S and simulated Thematic Mapper tapes was found to be very fast. The analysis phase required about a day for all cases. Once the analysis had been completed and the processing coefficients had been computed, the categorized tape was produced for the full M^2S CCT in less than 30 min.

2.6 M-DAS PROCESSING OF SIMULATED THEMATIC MAPPER DATA

The compilation of the three previous tasks are three sets of simulated Thematic Mapper-raw data CCTs. Generation of the CCTs included geometric synthesis of Thematic Mapper pixels to correspond to the three scanning parameter cases and addition of a predetermined noise signal in agreement with the scanner model. The simulated Thematic Mapper raw data were generated in the M^2S format to enable coherent substitution of training sets and the same scaling for direct comparison of analysis results.

The simulated Thematic Mapper CCTs were processed on the M-DAS System using the same training set coordinates and processing techniques that were applied to the M^2S original data. In addition, the M^2S original data were injected with noise corresponding to the Thematic Mapper model, as shown in Table 2-4. This

M^2S noise-injected data were also processed (Case 2) to provide an additional evaluation of the noise injection.

Categorical analysis was performed on the new simulated data in which new categorical coefficients were established from the training sets with previously defined locations.

2.7 REFERENCES

1. R.H. Dye and C.S. Chen, "Divergence Analysis of Bendix Feature Extraction and Classification System," Proceedings of LARS Symposium on Machine Processing of Remotely Sensed Data, IEEE Catalog No. 75 CH 1009-0-C, 3-5 June 1975.

2. R.H. Rogers, "Environmental Monitoring from Spacecraft Data," Proceedings of LARS Symposium on Machine Processing of Remotely Sensed Data, IEEE Catalog No. 75 CH 1009-0-C, 3-5 June 1975.

3. R.H. Johnson, "M-DAS Multispectral Data Analysis System," Bendix Report BSR 4146B, September 1974.

SECTION 3

SIMULATION RESULTS

This section presents the data derived from the Thematic Mapper simulation project. These results are color-coded categorized (or thematic) images of the same areas corresponding to each of the five test cases and data from the statistical analysis performed by M-DAS of each case. The five cases are

1. M^2S original data.
2. M^2S noise injected data.
3. Thematic Mapper simulation 1.00 IFOV sampling period, 0.0 scan overlap.
4. Thematic Mapper simulation 0.67 IFOV sampling period, 0.0 scan overlap.
5. Thematic Mapper simulation 0.67 IFOV sampling period, 0.33 scan overlap.

3.1 CATEGORIZED DATA - IMAGE RESULTS

A synoptic comparison of all aspects of the categorization performance of the study cases was difficult to summarize in tabular form. Visual evaluation of the categorized images provides the best comprehensive comparison of categorization performance. Figure 3-1 is a color infrared image of the top portion of the image and may be helpful for ground truth orientation. As previously described, the

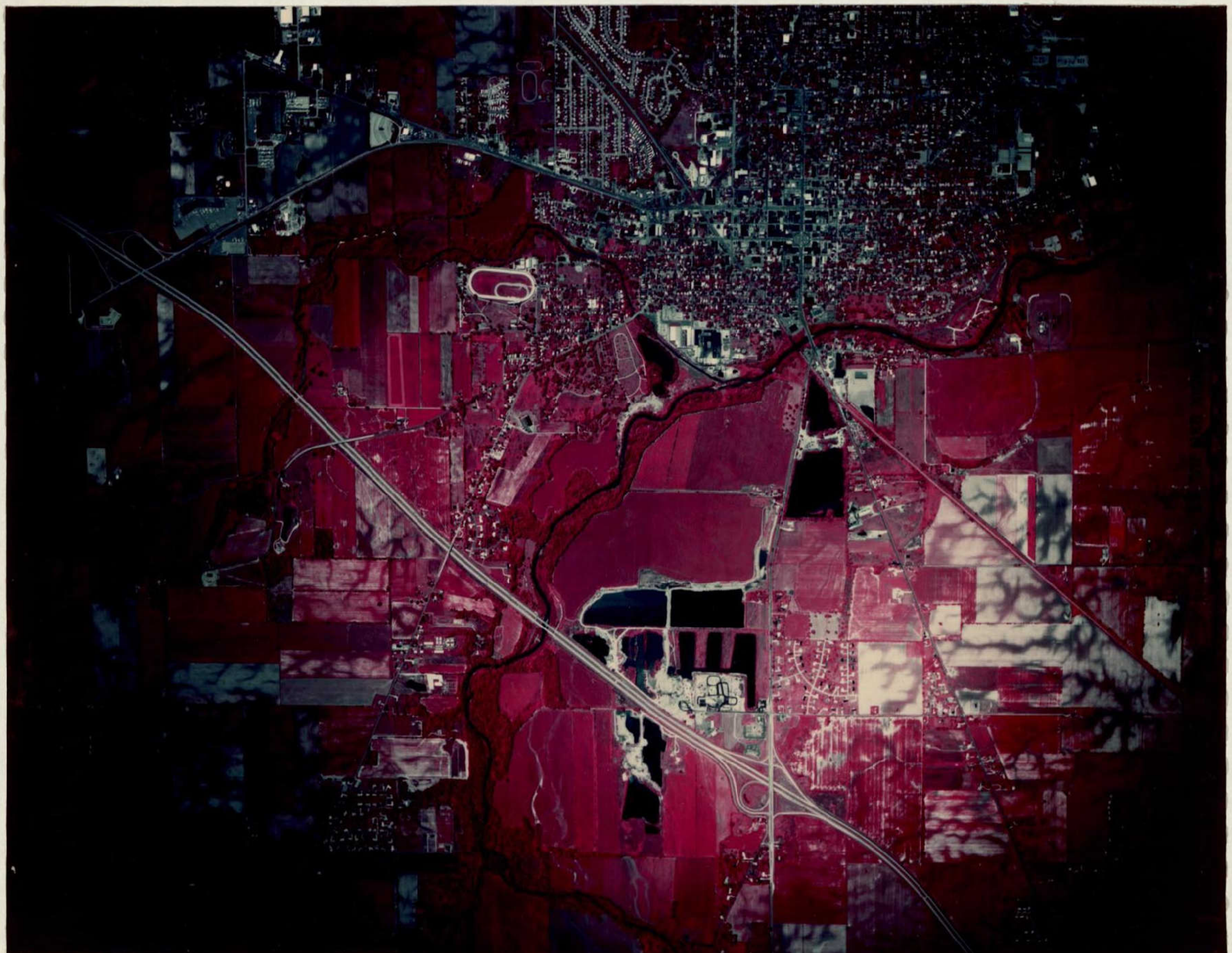

Figure 3-1 Color Infrared Image of a Portion of the Test Area

Thematic Mapper data were revised to the M^2S format in order to allow coherent analysis and appropriate scaling for feature-by-feature comparison of the categorized data.

Prints of the categorized images for the data on the entire CCT (2090 scan lines) are presented in Figure 3-2 for each respective case. In addition, Figure 3-3 shows an enlargement of a 3,200-m-wide section from the top-center of the respective images. This figure, as seen on the M-DAS display, should better illustrate the simulated geometries. Generally, comparison of the images indicates that the noise injection removes the homogeneous classification of the category areas and removes some definition of boundaries. The extent of definition loss for the river category near the center of the image should be noted for each of the overlap cases. In several areas, noise injection produced a categorization shift between several groups with different coverage density but the same agricultural crop type. This shift is illustrated by identification of two shades of red for groups 1 and 8.

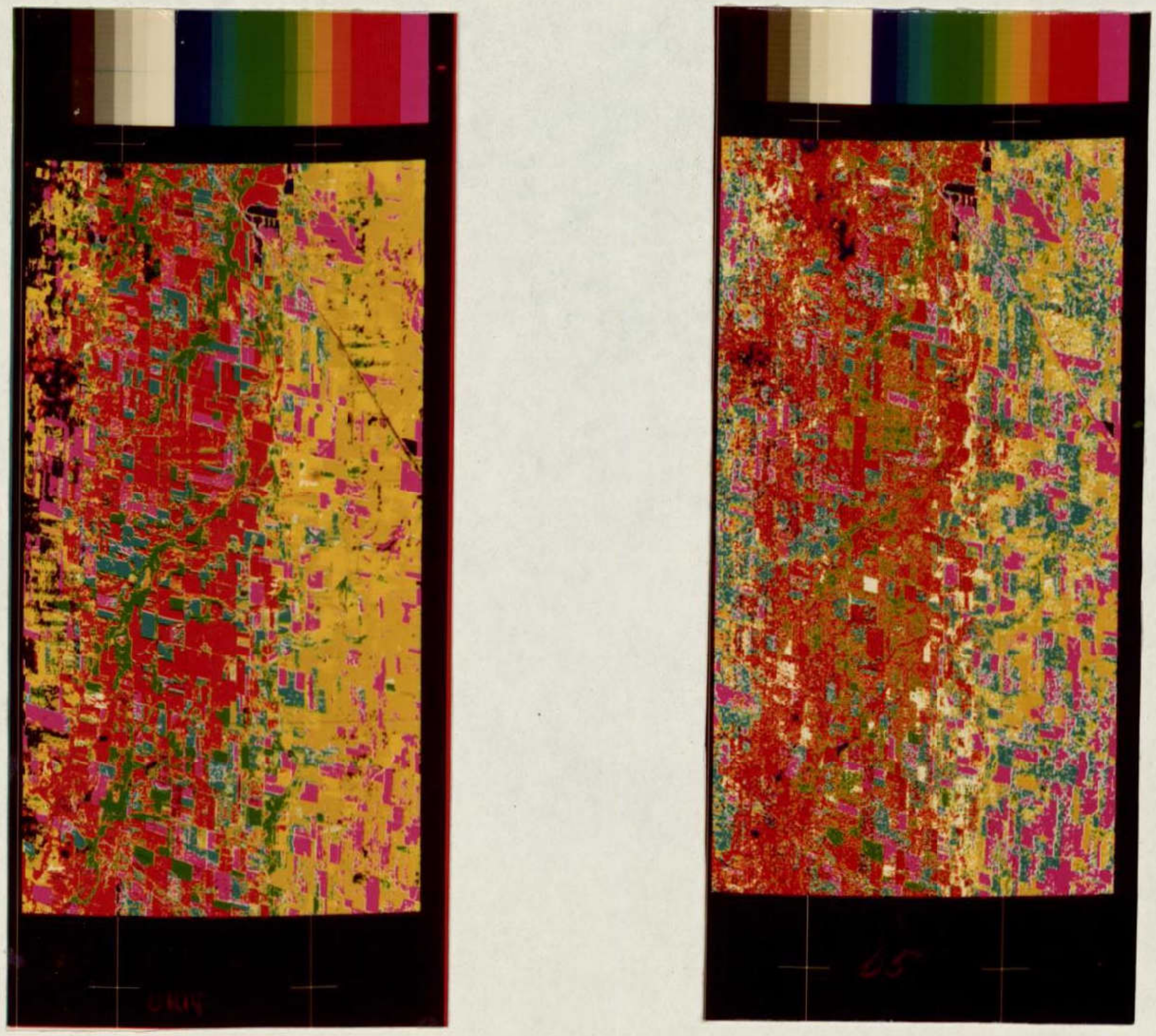

Figure 3-2 Categorized Images of the Study Data

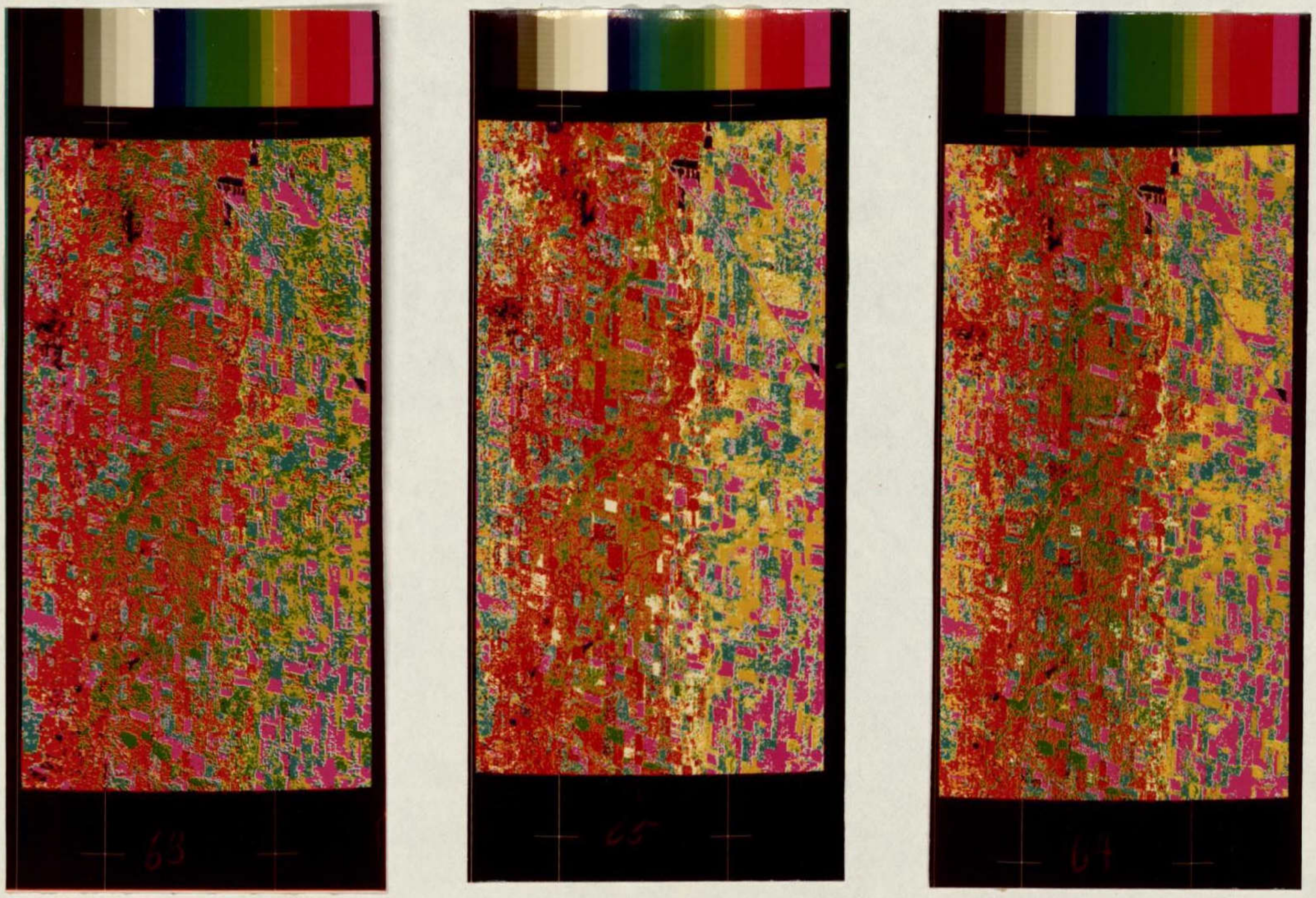

Figure 3-2 Categorized Images of the Study Data (Cont.)

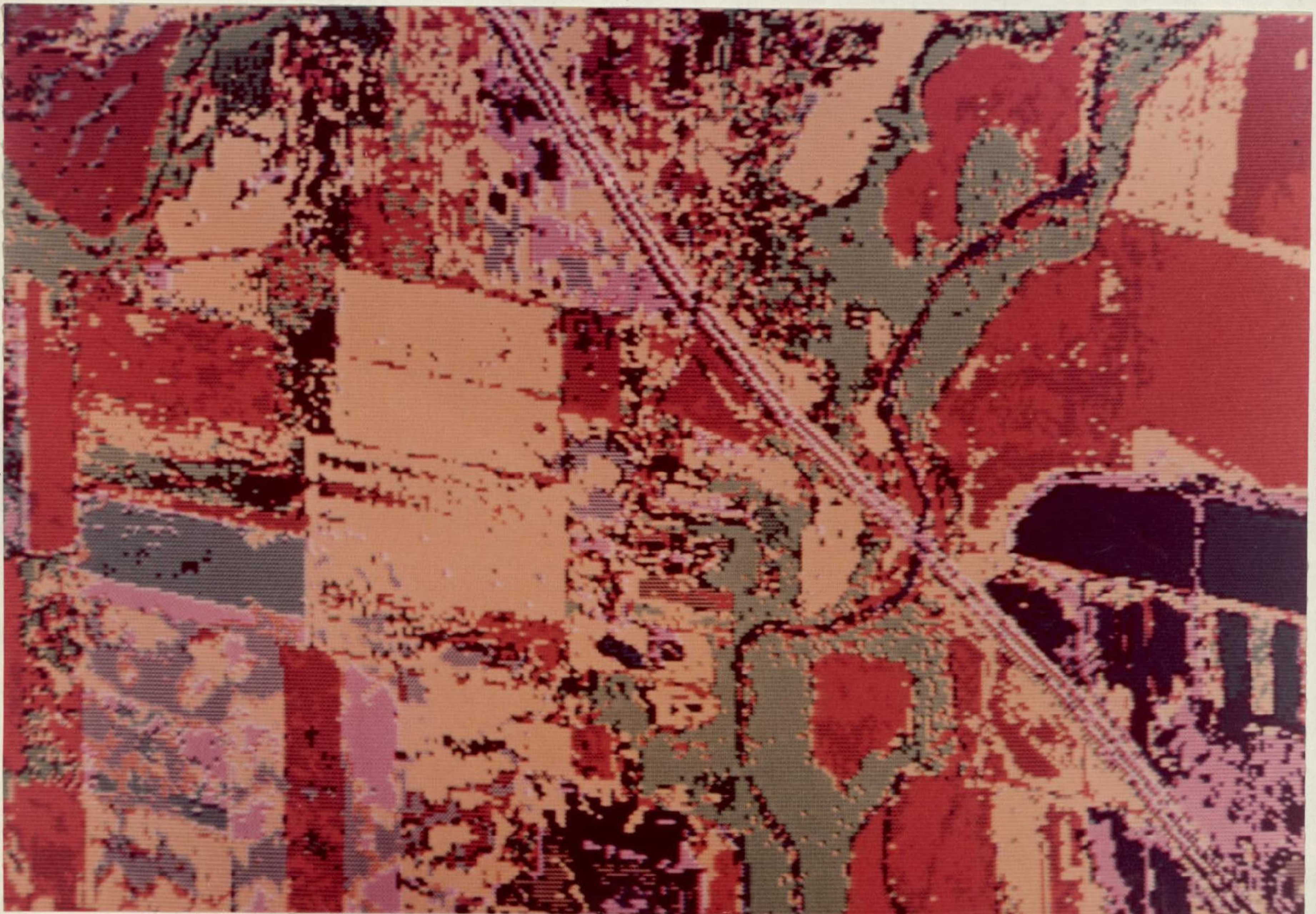

Figure 3-3 Enlarged Section of Categorized Data

Figure 3-3 Enlarged Section of Categorized Data (Cont.)

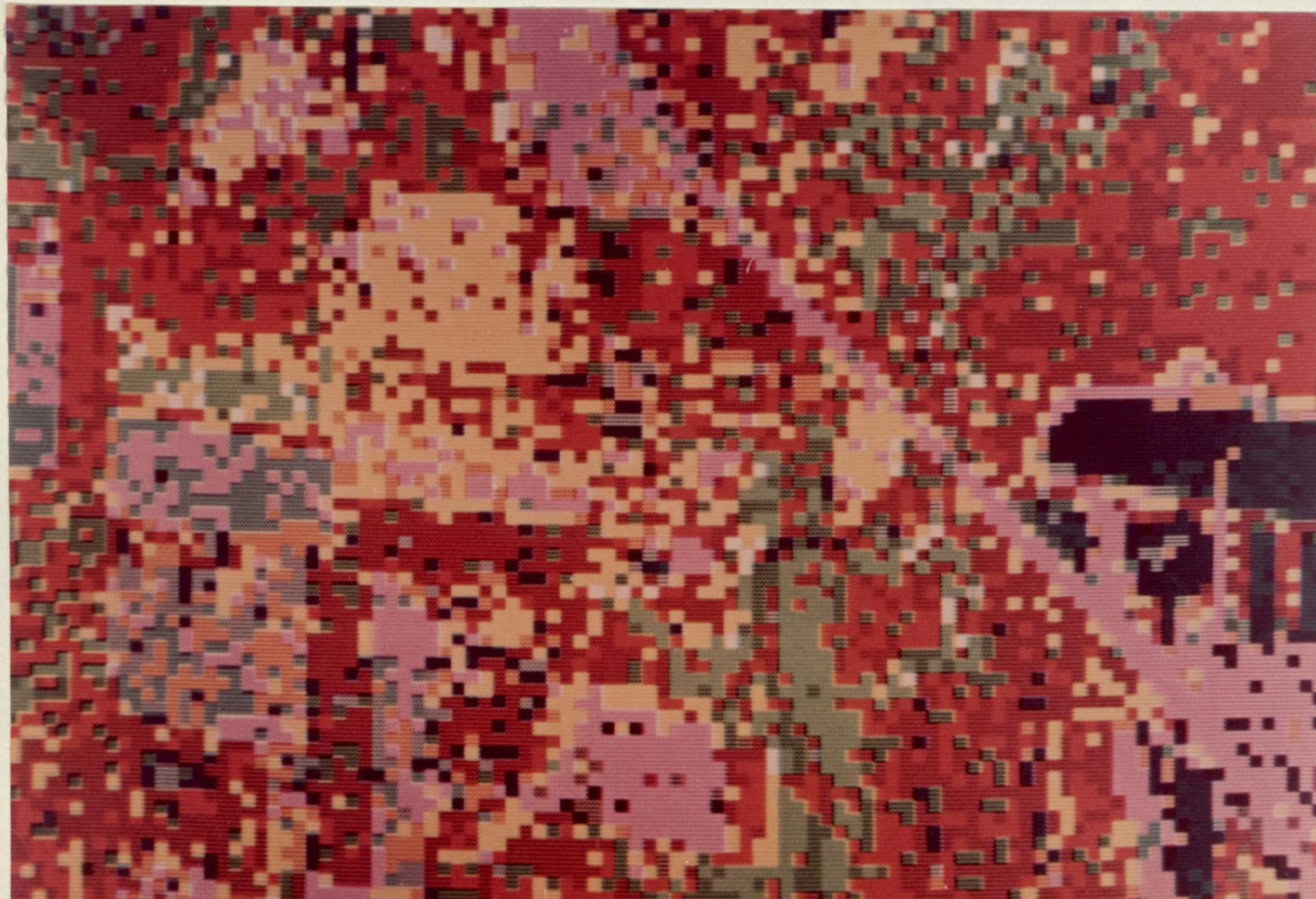

Figure 3-3 Enlarged Section of Categorized Data (Cont.)

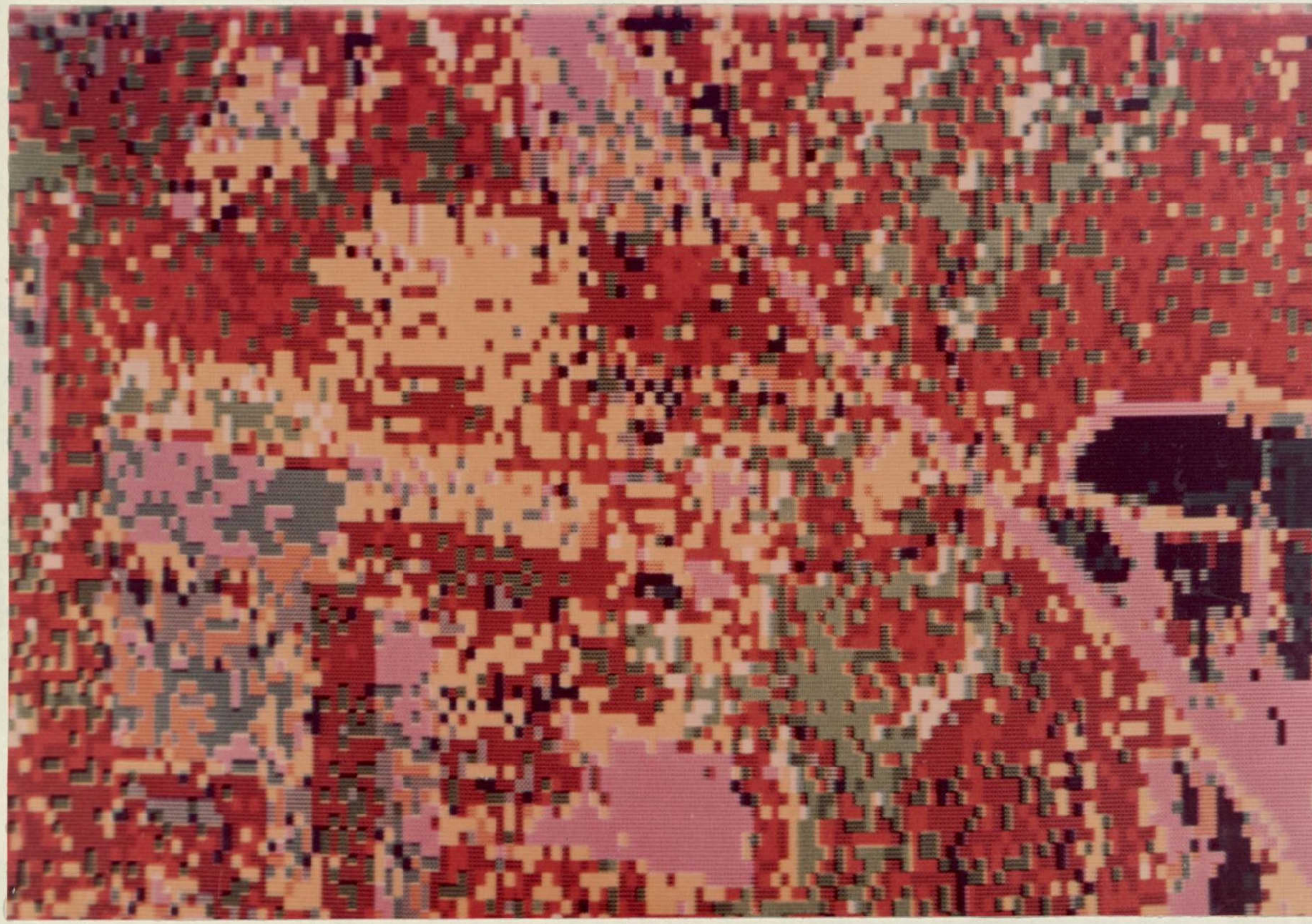

Figure 3-3 Enlarged Section of Categorized Data (Cont.)

BSR 4202

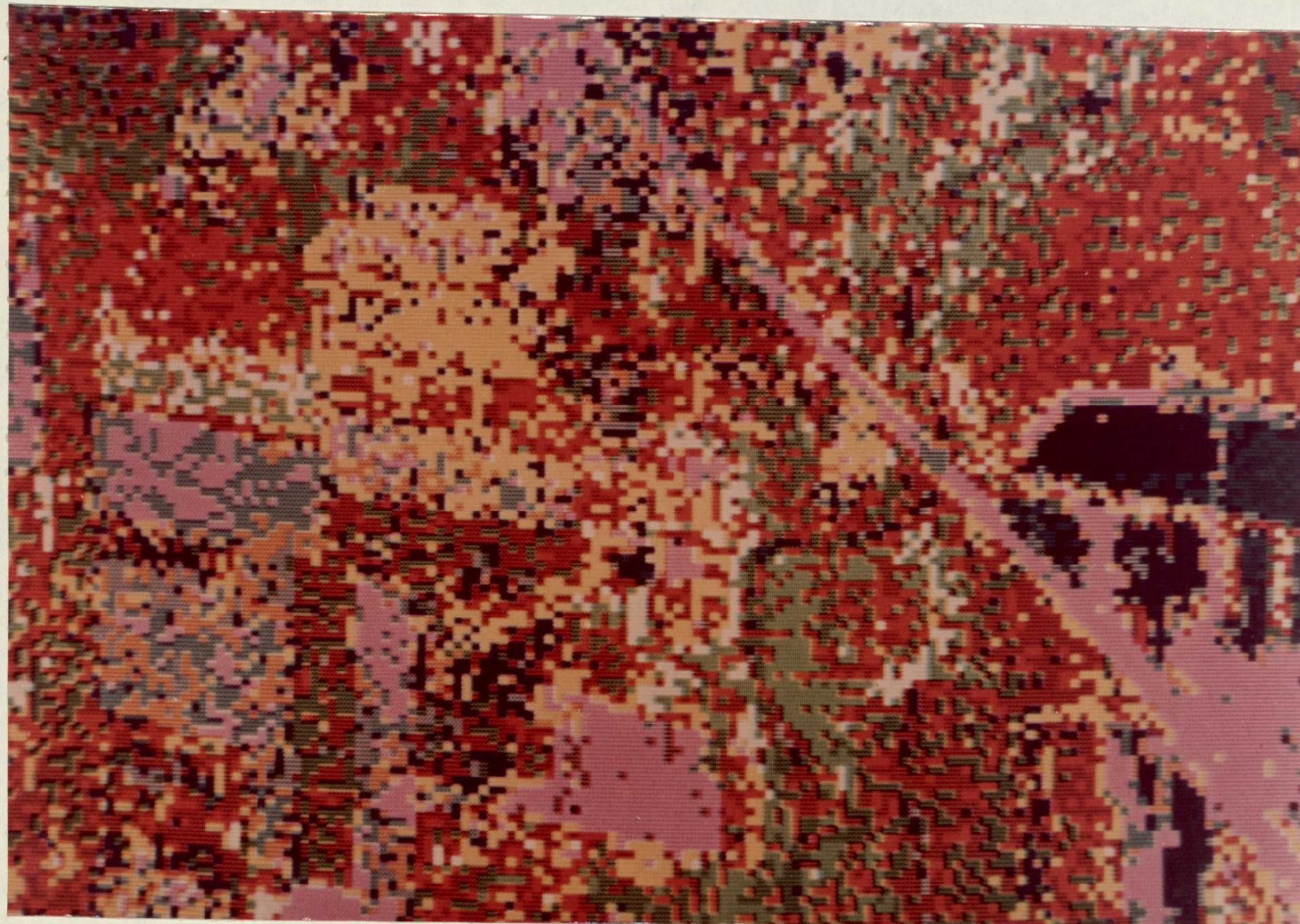

Figure 3-3 Enlarged Section of Categorized Data (Cont.)

3.2 STATISTICAL DATA

As the training data from each case are analyzed, printouts may be obtained. The printouts provide, among other data, the eigenvalues for each category and the categorization truth table. Also, as the scene data are processed to produce a categorized image, a tabulation of the area within that scene (or a selected portion of the scene) covered by each category is printed out. The following sections present the results of the simulation in terms of these data

3.2.1 Eigenvalue Analysis

The eigenvalues printed out for each category are a measure of the average separation of that category from all other categories. The first eigenvalue represents the variance of all of the other groups in the direction chosen to maximize that variance. The second eigenvalue is the variance in the direction orthogonal to the first having the largest variance.

The eigenvalues, therefore, show the separability of the selected group from all others. The square root of the eigenvalue is the average number of standard deviations of all of these other groups in that direction.

Categorical analysis was performed separately on the data from each of the study cases. The analysis results are shown in Table 3-1. The table contains the data mean, standard deviation, and first two eigenvalues obtained in the categorization of each target group. From inspection of the table, one can see that the standard deviations of the clusters for each group increase with added noise, but

Table 3-1

Categorization Analysis Summary Tabulation

Group	Case 1				Case 2				Case 3				Case 4				Case 5			
	Band 7		Eigenvalue		Band 7		Eigenvalue		Band 7		Eigenvalue		Band 7		Eigenvalue		Band 7		Eigenvalue	
	Mean	Std Dev	1st	2nd	Mean	Std Dev	1st	2nd	Mean	Std Dev	1st	2nd	Mean	Std Dev	1st	2nd	Mean	Std Dev	1st	2nd
1	63 9	4 0	181 4	67 1	64 0	6 8	42 9	29 6	63 3	5 3	68 6	36 6	63 8	8 2	42 7	29 7	63 3	9 0	36 4	25 9
2	54 2	2 0	1060 4	111 6	54 2	5 3	218 5	13 6	55 4	5 3	280 3	92 0	55 2	6 5	145 6	63 1	53 9	8 0	119 8	91.5
3	57.5	2 7	3985 0	1025 0	57 5	5 6	579 5	87 2	56 5	5.4	624 9	150 2	55 8	7 2	626 2	63 5	56 8	8 3	327 0	48 0
4	58 7	2 1	897 6	182 9	58 3	6 1	118 7	30 7	58.9	6 9	109 9	11 2	60 6	6 7	99 7	10 2	59.2	8 2	82 9	16 9
5	75 8	2 7	370.2	214 1	75 3	5 8	134 7	71 0	76 3	5 9	369 7	87 2	73 9	5 0	248 1	58 4	74 8	7 3	215 4	51.5
7	104 7	5 3	3287 6	95 4	105.2	8 4	303 2	23 0	101 7	7.4	318 3	44 7	104 8	7 1	205 2	42 7	106.3	8 8	112 9	36 1
8	59 1	2 0	786 1	485 8	58 7	5 1	143 2	112 9	58 7	4 4	325 3	251 1	58 1	4 9	183 4	108 7	59.8	6 7	137 7	67.3
9	53 5	2 4	4539.6	803 6	53 5	5 6	595 6	82.8	53 6	4 9	769 3	93 7	52 6	7 5	527 1	55 8	53 0	8.2	322 8	36 8
11	71 9	3 3	1644.6	366 5	73 1	6 7	357 0	55 5	75 0	6.8	438 3	27 9	73 1	8 1	256 4	23 2	71 2	8 7	188 0	18.7
12	63 9	2 7	348.2	240 2	64 3	5 7	133 8	65 6	64 2	4 6	194 7	74 4	63 3	7 6	89 5	72 7	63 6	8 0	102 2	48 1
15	127 5	11 5	1509 8	99 0	127 4	12 7	192 7	16 9	127 5	10 7	194 0	25 4	128 2	11 7	136 0	37 5	130 7	13 3	85 8	33.4
16	71 8	2 5	465 5	243 7	71 1	5 3	153 2	89 1	69 8	4 7	430 3	145 4	71 9	7 4	832 1	82 1	70 5	6 9	214 6	91 0
17	162 0	20 2	857.8	51 0	161 2	21 2	97 3	16 6	158 3	18 6	205 5	29 2	160 3	20 0	94 2	21 4	159 5	19 4	67 0	19 1
18	70 4	7 8	212.4	67 4	70 4	8 4	67 9	12 9	69 8	9 4	150 7	16 3	70 4	7 8	45 3	12 5	67 0	11 5	70 4	10 2
19	76 6	2 9	498 3	138 3	77 6	6 2	109 7	73 0	75 8	6 9	206 3	52 8	76 5	7 1	101 0	52 1	77 2	7 0	141 7	54 9
20	141 4	12 8	1330 2	61 3	141 9	13 6	185 7	21 1	141 7	10 0	188 9	47 1	143 2	12 5	97 3	55 3	141 4	12 9	78 2	36 6
21	61 7	2 3	464 3	109 0	62 0	5 0	107 7	55 0	63 8	7 6	157 1	39 2	63 0	6 6	134 8	70 2	62 0	5 9	95 3	58 7
22	102 6	8 2	123 2	32 7	102 7	9 7	66 3	16 3	101 0	6 9	158 2	35 9	102 5	9 1	190 6	21 5	104 6	10 5	117 2	19 5
23	90 4	2 8	1461 8	204 2	90 0	5 0	137 7	71 6	88 7	4 8	131 0	73 2	87 6	7 1	128 7	31 9	88 5	8 8	63 1	42.7
24	61 4	2 3	676 5	171 8	61 1	5 4	131 7	100 5	61 2	5 1	371 7	109 2	60 2	6 1	172 7	68 6	62 3	10 2	97 1	39 3
25	86 0	3 6	236 9	135 5	87 1	6 2	98 8	56 9	82 8	7 0	285 2	13 3	85 0	9 4	83 5	14 0	82 9	8 1	46 0	12 9

larger resolution (i.e., 30-m) reduces this effect. This is expected because the addition of nine M^2S pixels to synthesize a simulated Thematic Mapper pixel reduces the noise component of the cluster.

A comparison of the average separability of each group for each study case may be obtained by evaluating the square root of the sum of the first two eigenvalues, as shown in Table 3-2. This is the approximate average number of standard deviations from that group to all other groups, in the direction most pertinent to the decision. The bottom line of each column shows an average of these values for all the groups. These averages for each case show the relative degree of group separation. The results indicate that for the Thematic Mapper, the case of a 1.00 IFOV sampling rate - 0.0 scan overlap provides the best separation. The original M^2S data, without noise degradation, is clearly the best overall.

There is some question concerning the purity of the training sets used in the simulated Thematic Mapper cases. If, when the pixels are enlarged, they include boundary pixels from M^2S data in the pixels of the new training sets, this could increase the variance of that group and decrease its eigenvalues. Generally, in selecting the M^2S training sets, care was taken to place the borders of these sets so that the borders were not within one or two pixels of a boundary.

Table 3-2

Eigenvalue Comparison of Study Cases
(Calculated * from first two eigenvalues)

Group	Case 1 E	Case 2 E	Case 3 E	Case 4 E	Case 5 E
1	19	9.3	11.7	9.2	8.5
2	46.1	20.9	23.7	17.1	15.5
3	89.3	34	35.4	35.4	25.6
4	42.4	15.4	14.8	14.1	12.9
5	27.2	16.4	27.2	22.3	20.8
7	81.1	24.6	25.2	20.3	15
8	39.7	16.9	25.5	19.2	16.6
9	95.3	34.5	39.2	32.5	25.4
11	57.4	26.7	29.6	22.6	19.4
12	26.4	16.4	19.7	13.4	14.3
15	55	19.6	19.7	16.5	13.1
16	30.5	17.5	29.3	40.8	20.7
17	41.4	13.7	20.3	13.7	11.6
18	20.6	11.7	17.4	9.5	11.9
19	31.6	14.8	20.3	14.2	16.8
20	51.6	19.3	19.4	13.9	12.5
21	30.5	14.7	17.7	16.4	13.8
22	15.7	11.5	17.8	19.5	15.3
23	54.1	16.6	16.2	16	11.2
24	36.8	16.2	27.3	18.6	13.9
25	21.8	14.1	23.9	12.9	9.6
Average of All	43.5	18.3	22.9	19	15.4

Note * $E = \sqrt{V_1 + V_2}$

3.2.2 Band Contribution

One of the by-products of the categorical analysis program is a figure-of-merit called the band contribution coefficient. The coefficient specifies the relative importance of each band in the analysis, i.e., it's contribution in separating each category from all other categories. Figure 3-4 shows, graphically, the contribution of each band in the categorization analysis for each of the study cases. Comparison of contribution coefficients shows the relative effects of noise content and scanning geometries for the first five distinct categories. These plots were made because of the interest in the importance of each Thematic Mapper band to various Landsat applications. The results shown in the figure do not show a predominately weak or strong band in the simulated Thematic Mapper cases, but do show that the addition of noise tends to equalize the contribution of each band.

3.2.3 Categorization Accuracy Tables

The desired output of the processing is categorization of the data into the selected groups. The categorization accuracy table predicts the performance of the categorization process when applied to the training set data. Table 3-3 is a summary of the categorization tables produced for each study case. The entries of the table are the percents of the training sets which were initially selected to define the particular group that the analysis actually categorized into the group. The percentages were weighted by the number of observations in each training set, and best performance would be indicated by 100% for each entry in the table.

12747-4

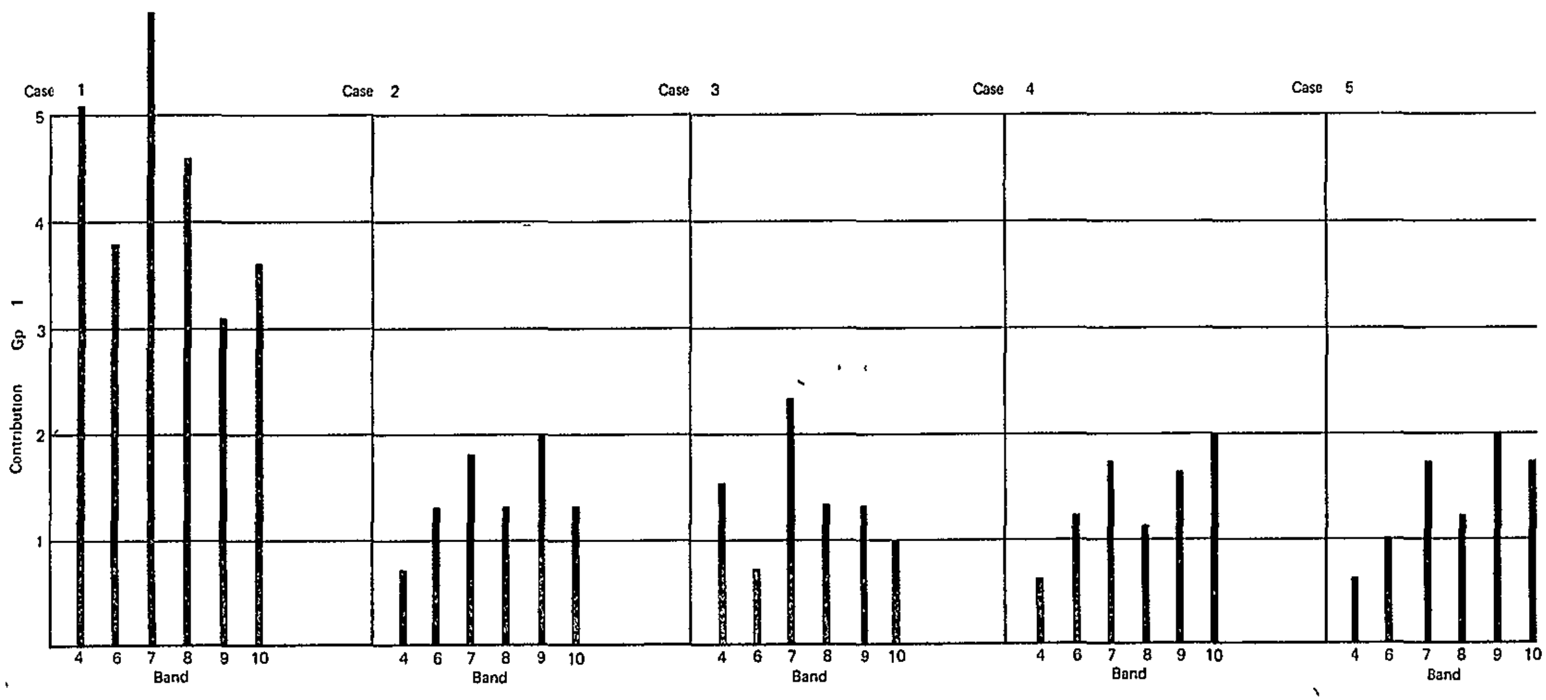

Figure 3-4 Contribution Coefficient Graph (Sheet 1 of 5)

12747-4

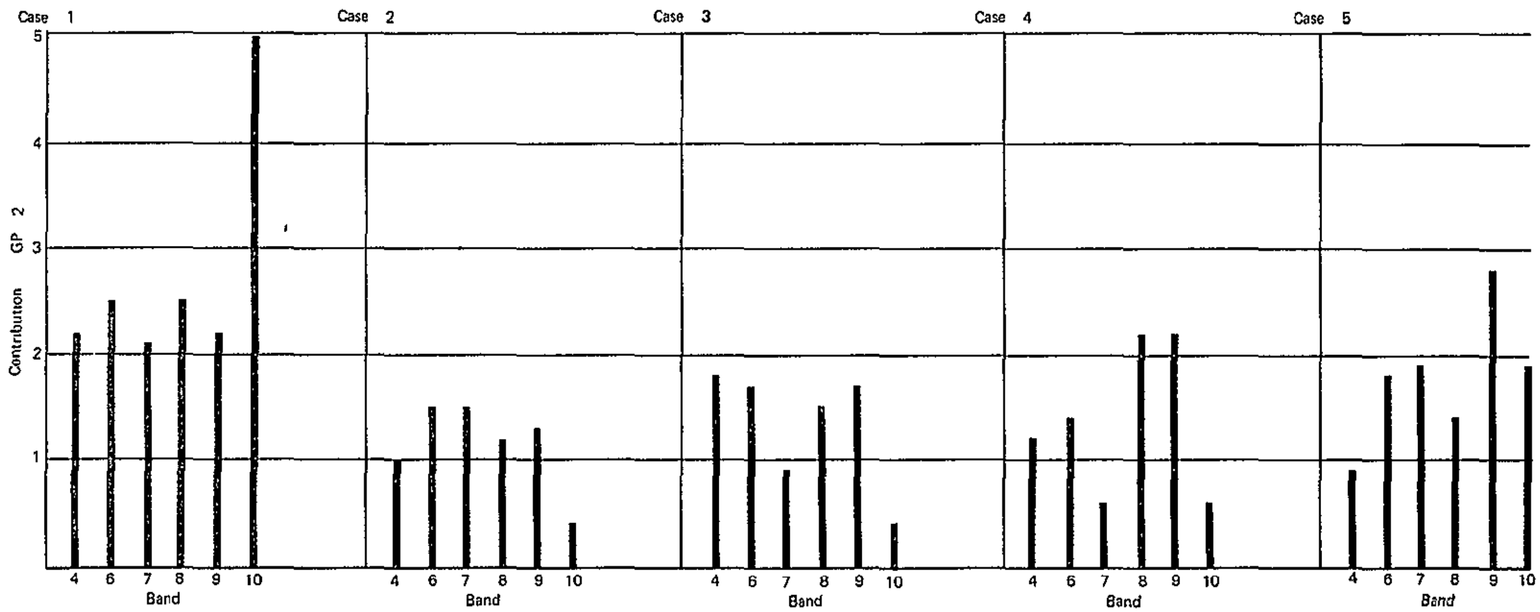

Figure 3-4 Contribution Coefficient Graph (Sheet 2 of 5)

12747-4

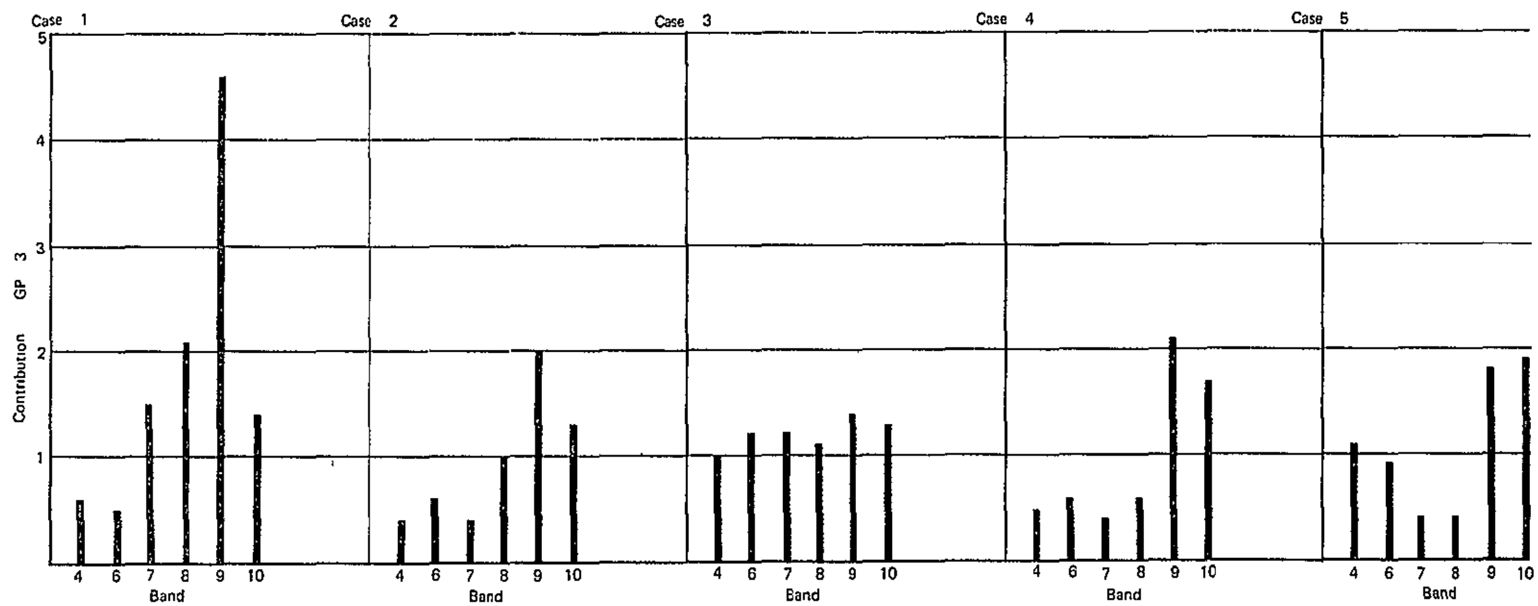

Figure 3-4 Contribution Coefficient Graph (Sheet 3 of 5)

12747-4

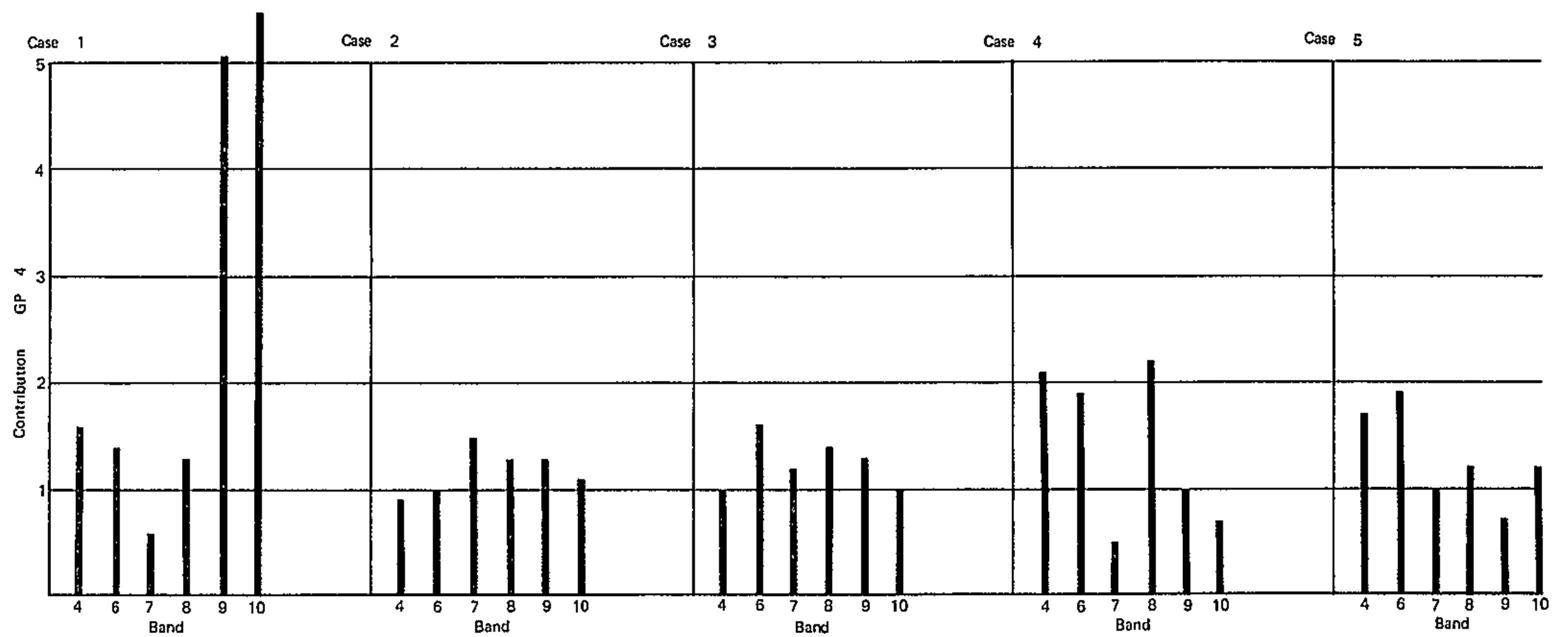

Figure 3-4 Contribution Coefficient Graph (Sheet 4 of 5)

12747-4

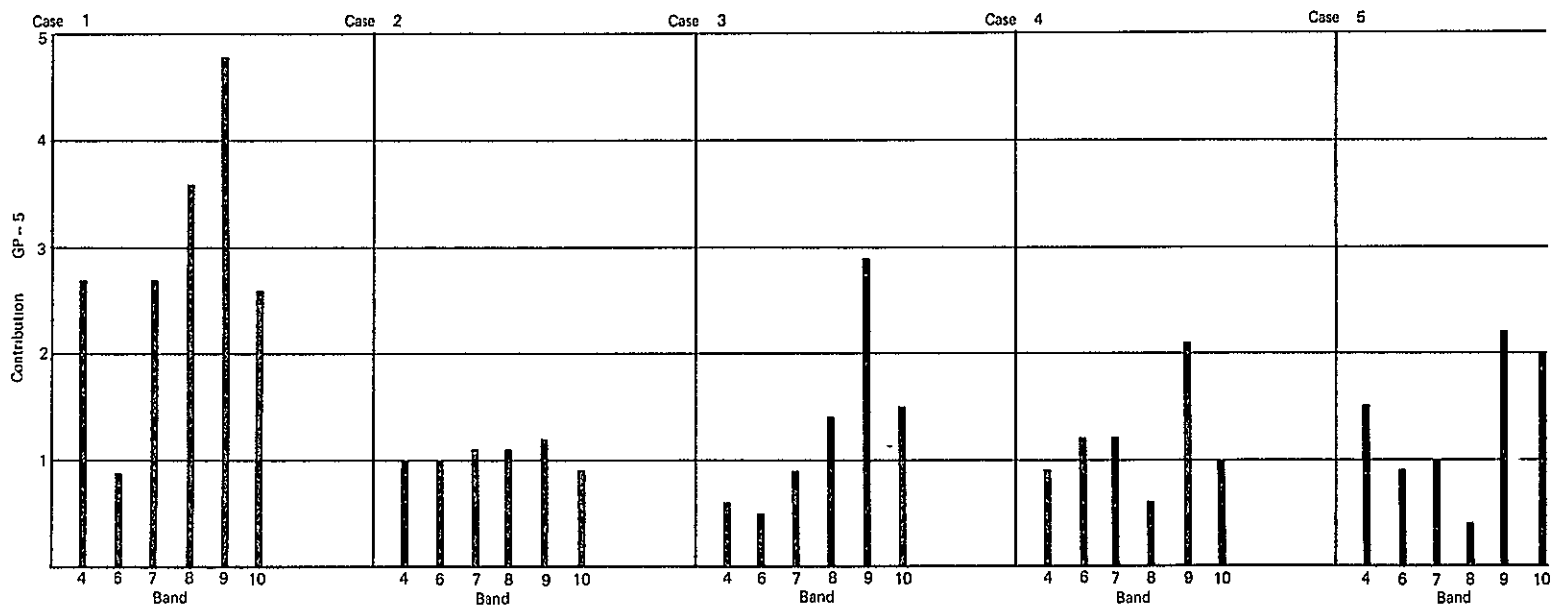

Figure 3-4 Contribution Coefficient Graph (Sheet 5 of 5)

Table 3-3

Categorization Table Summary

Group	Case 1 Percent Accurate	Case 2 Percent Accurate	Case 3 Percent Accurate	Case 4 Percent Accurate	Case 5 Percent Accurate
1	100	65	84	59	50
2	98	84	93	83	85
3	100	81	84	75	57
4	100	93	90	69	87
5	98	99	100	96	89
7	100	84	98	94	88
8	97	84	90	89	78
9	100	74	84	88	70
11	100	99	98	99	96
12	99	92	100	94	92
15	100	82	82	87	84
16	100	93	100	98	98
17	100	87	94	92	81
18	98	56	64	30	46
19	100	90	90	90	88
20	100	85	84	85	76
21	98	80	69	86	81
22	100	100	100	100	100
23	98	87	89	88	58
24	95	81	93	76	76
25	98	95	86	80	78
Total Average =	99	85	89	84	79

Note Threshold equals 6.0 standard deviations.

The average for all of the groups is shown at the bottom of the table. The average indicates that the Thematic Mapper (Case 3) 1.00 IFOV sampling rate - 0.0 scan overlap gives the best categorization results. Identification of mis-categorized elements can be made from an inspection of the categorization table of Table 3-3.

Table 3-3 shows the accuracy of each decision, assuming that the training set populations are an exact model of their parent populations and have a rejection threshold of six standard deviations. This threshold means that any pixel for which the measurement does not come within six standard deviations of one of the groups (in the first four components of the feature space) will be assigned as uncategorized.

3.2.4 Area Printouts

Tabulations of the area categorized for each group can be produced on M-DAS. For M^2S data, these tabulations represent the percentage of the designated area covered by each group, including the uncategorized areas.

Table 3-4 shows the results by tabulation of the areas for each group for the entire test site strip. For Cases 2 through 5, the absolute change in the percentages of areas covered are shown and the absolute value of these changes are summed.

This figure-of-merit is the total area in error, in comparison with the original categorized M^2S data as ground truth. Its magnitude may be misleading because the magnitude does not show that some of the positive and negative changes

Table 3-4

Categorized Area Measurement Table Summary

Group	Original Data	Case 2....	Change	Case 3...	Change	Case 4....	Change	Case 5...	Change
1	19.75	11.79	7.96	15.06	4.69	13.65	6.1	12.69	7.06
2	3.65	4.42	-0.77	1.89	1.76	2.07	1.58	2.34	1.31
3	0.1	0.2	-0.1	-0.15	-0.05	-0.1	0	-0.02	-0.08
4	0.75	4.49	-3.74	7.26	-6.51	6.27	-5.52	7.85	-7.1
5	3.06	5.69	-2.63	3.02	-0.04	2.99	0.07	2.84	-0.22
7	0.88	2.4	-1.52	1.98	-1.1	2.68	-1.8	3.19	-2.31
8	0.56	3.27	-2.71	1.52	-0.96	2.33	-1.77	2.95	-2.39
9	0.05	0.15	-0.1	-0.06	-0 01	-0.09	-0.04	-0.09	-0 04
11	0.15	0.23	-0.08	0.19	-0.04	0.32	-0.17	0.31	-0.16
12	5.5	9.22	-3.72	10.23	-4.73	10.91	-5.41	8.81	-3.31
15	2.88	4.89	2.01	5.66	-2.78	5.16	-2.28	9.41	-6.53
16	1.76	2.89	1.13	1.83	-0.07	1.05	0.71	2.64	-0 88
17	3.13	3	0.13	5.52	-2.39	3.22	-0.09	1.74	1.39
18	18.37	17.01	1.36	14.67	3.7	22.13	-3.76	16.03	2.34
19	1.95	7.02	-5.07	9.34	-7.39	8.93	-6.98	7.42	-5.47
20	3.65	6.43	-2.78	3.01	0.64	5.57	-1.92	3.76	-0.11
21	2.02	1.72	0.3	2.85	-0.83	1.21	0.81	1.15	0.87
22	9.29	9.22	0.07	5.73	3.56	2.82	6.47	4.64	4.65
23	1.25	3.61	-2.36	4.5	-3.25	3.97	-2.72	3.72	-2.47
24	0.16	1.76	-1.6	1.02	-0.86	1.75	-1.59	2.59	-2.43
25	0.27	2.9	0.02	2.42	-2.15	2.37	-2.1	5.54	-5.27
Figure of Merit			40.16		47.51		51.89		56.39

occur between similar categories and do not represent as serious errors as other changes do. The figure-of-merit does show that Case 3 provides the most accurate answers of the three Thematic Mapper cases.

Because of the uncertainty of the role of scan angle effects, area tables were also produced for a smaller section near the center of the test area. This is the area previously shown in Section 3.1. These results are shown in digital form in Table 3-5. Table 3-6 summarizes and compares these data from the selected 1-km-wide area at the center of the swath with the area data covering the full scene.

It is surprising that the areas from the small center section for Cases 2, 3, 4, and 5 do not track the categorized M^2S data as well as that for the full strip. The explanation for this may be that the areas at large scan angles on either side of the nadir are much less sensitive to degraded resolution. This would be because there is a high correlation of data between pixels at these larger scan angles because of the spreading of the ground foot-print of the IFOV.

In the selected center area, however, the trend still favors Case 3, 30-m samples and no overlap for the Thematic Mapper.

Table 3-5

Bendix Processor Results

NO. OF ORIGINAL VARIABLES = 11
DELETED VARIABLES = 1 2 3 5 11
NO. OF GROUPS = 21
REJECTION LEVEL = 6.0

GROUP	CATEGORY	CASE 1 PERCENT OF TOTAL	CASE 2 PERCENT OF TOTAL	CASE 3 PERCENT OF TOTAL	CASE 4 PERCENT OF TOTAL	CASE 5 PERCENT OF TOTAL
0	UNCATEGORIZED	20.81	0.31	2.10	0.41	0.05
1	AGRICULTURE 1	19.75	11.79	15.06	13.65	12.69
2	DECIDUOUS VEGETATION	3.65	4.42	1 89	2.07	2.34
3	WATER 1	0.10	0.20	0.15	0.10	0.20
4	AGRICULTURE 2	0.75	4.49	7.26	6.27	7.85
5	SPARSE GROWTH 1	3.06	5.69	3.02	2.99	2.84
7	BARE SOIL 1	0.88	2.40	1.98	2.68	3.19
8	AGRICULTURE 1	0.56	3.27	1.52	2.33	2.95
9	WATER 2	0.05	0.15	0.06	0.09	0.09
11	WATER 3	0.15	0.23	0.19	0.32	0.31
12	AGRICULTURE 1	5.50	9.22	10.23	10.91	8.81
15	SPARSE GROWTH 2	2.88	4.89	5.66	5.16	9.41
16	AGRICULTURE 3	1.76	2.89	1.83	1.05	2.64
17	SPARSE GROWTH 2	3.13	3.00	5.52	3.22	1.74
18	SPARSE GROWTH 3	18.37	17.01	14.67	22.13	16.03
19	AGRICULTURE 1	1.95	7.02	9.34	8 93	7.42
20	SPARSE GROWTH 2	3.65	6.43	3.01	5.57	3.76
21	DECIDUOUS VEGETATION	2 02	1.72	2.85	1.21	1.15
22	GRASSLAND	9.29	9.22	5.73	2.82	4.64
23	BARE WET SOIL	1.25	3.61	4.50	3.97	3.72
24	AGRICULTURE 1 (THICK GROWTH)	0.16	1.76	1.02	1.75	2.59
25	RIVER WATER	0.27	0 29	2.42	2.37	5.54
TOTAL		100.00	100.00	100.00	100.00	100.00

Table 3-6

Categorized Area Tabulation Comparison

	Full Scene (176.6 sq km) Study Case					Center Swath Area (1.0 km) Study Case				
	1	2	3	4	5	1	2	3	4	5
Uncategorized	20.81	0.31	2.10	0.41	0.08	13.57	0.14	0.84	0.04	0.20
Uncategorized Difference	-	20.50	18.71	20.40	20.73	-	13.43	12.73	13.53	13.37
Group Change	-	40.16	47.51	51.89	56.39	-	47.58	53.04	53.90	64.64
Group Change Less Uncategorized Difference	-	19.66	28.80	31.49	35.66	-	34.15	40.31	40.37	51.29