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A STUDY OF THE UTILIZATION OF EREP DATA FROM THE WABASH RIVER BASIN

Project #SR397

FINAL REPORT

NASA Contract NAS9-13301

April 1, 1975 - December 8, 1975

L. F. Silva, Principal Investigator

L. L. Biehl, Project Manager

THE LABORATORY FOR APPLICATIONS OF REMOTE SENSING

Purdue University, West Lafayette, Indiana

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THE LABORATORY FOR APPLICATIONS OF REMOTE SENSING
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PREFACE

In April of 1971 the proposal for the subject Skylab investigation was submitted to NASA for consideration. The proposal was modified and funded. The modified proposal described three basic experiments to take place during the SL-2, SL-3, and SL-4 missions respectively. The experiments were:

SL-2 Mission

- Classification of Cultural Vegetation
- Land Use Classification of Urban Areas

SL-3 Mission

- Classification of Cultural Vegetation
- Classification of Natural Vegetation
- Water Resource Evaluation
- Land Use Classification of Urban Areas (Change Detection)

SL-4 Mission

- Classification of Natural Vegetation
- Water Resource Evaluation
- Soil Classification

The test sites ultimately chosen for the investigations were:

Test Site	Experiments
Ribeyre Island (Posey Co, IN)	Cultivated Vegetation Classification
Lake Monroe, IN	Natural Vegetation Classification Land Use Classification Water Resource Evaluation
Hoosier National Forest	Natural Vegetation Classification
Marion Co, IN	Urban Land Use Classification

The EREP Sensors to be employed were the S-190A multispectral photographic system, the S-191 spectroradiometer, and the S-192 multispectral scanner. The intent was to use the S-190A photography as a general analysis aid as well as a multispectral data source through digitization. The S-191 sensor was to be used in conjunction with the LARS field spectroradiometer system for atmospheric transmission and correction studies. Finally, the data from the S-192 scanner was to be processed through the LARS software system (LARSYS). Later on in the pre-launch phase the S-190B earth terrain camera was added to the sensor complement and this project elected to use the sensor as an analytical aid. Much of the data were to be analyzed in cooperation with several user agencies tentatively identified as the Marion County Planning Commission, the City of Bloomington, IN. planning department, and the Indiana Department of Natural Resources.

The realities of the Skylab missions after launch forced a significant revision in the original project plan. The delay in the start of the SL-2 mission with the corresponding change in orbit timing necessitated a change in test sites from Ribeyre Island to Lake Monroe. No data over preplanned test sites were acquired during the SL-3 and SL-4 missions due to weather and orbit change problems. Data from another investigation over the Ft. Wayne, IN region were delivered for SL-4 mission analysis. Consequently some of the original proposal objectives were modified in keeping with the data sets that ultimately became available.

However, a coherent set of analyses were prepared with the available data that certainly fulfills the intent of the objectives in the original proposal. The following introduction describes the framework of the analyses.

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1. INTRODUCTION

This report describes the research performed during the total contract period (April 1, 1973 - December 8, 1975) of Skylab EREP Investigation 397, Study of the Utilization of EREP Data from the Wabash River Basin, contract number NAS 9-13301.

Section 2 describes the results of the comparisons of data sets obtained from different sensors including the Skylab Multispectral Scanner (MSS), Landsat 1 MSS, S190A color IR camera, and S190A black and white cameras during the SL/2 and SL/4 missions. Section 3 discusses the evaluation of the filtered and interim (nonfiltered) Skylab MSS, S192, data obtained over the Lake Monroe, Indiana, area during the SL/2 mission. Section 4 describes the analysis of the Skylab MSS, S192, data from the X-5 detector array over Allen County, Indiana. Section 5 discusses the analysis of the Skylab spectroradiometer, S191, data and the Exotech Model 20C field spectroradiometer data obtained during the SL/2 mission over Lake Monroe, Indiana. Section 6 presents an overall survey of the significance of particular spectral regions in the studies presented in sections 2, 3, and 4. Section 7 includes the overall conclusions of the study and the recommendations for future operational earth resource systems.

The data received for this project is listed in Tables 1.1, 1.2, and 1.3. The Skylab SL/3 data was not studied because clouds obscured the Wabash River Basin. The Skylab S192 data set, 51-3, was not used since SDO's (scientific data output) #7 and #8 were useless, as described in the S192 Final Quality Assessment Report for DPAR number 111-02-07. Also, some loss of synchronization (sync) was present in SDO #19 and the data did not cover the same area as the interim S192 data. These problems were

TABLE 1.1

Skylab Data Received for Project

Data Set - DPAR NO	Time Data Collected	Location	EREP Pass	Data Included	Date Received
		SL/2 MISSION			
S190A	161/14:25:04-26:56	Southern IN	7	6-Stations	8/6/73
S190B	161/14:25:02-27:01	Southern IN	7	Color	11/12/73
S191-23-2-7-42-3-R4	161/14:25:04-26:17	Southern IN	7	4-15μm	11/8/74
S192-111-01-07	161/14:26:01-26:05	Southern IN	7	SDO's 1-14, 19-20, 22	10/25/73
S192-111-02-07-51-3	161/14:25:56-16:02	Southern IN	7	SDO's 1-22	9/3/74
S192-111-02-07-51-3R1	161/14:25:56-16:02	Southern IN	7	SDO's 1-22	1/20/75
S192-111-02-07-51-3R2	161/14:25:59-26:10	Southern IN	7	SDO's 1-2, 9-12, 15-22	2/3/75
S192-111-02-07-51-3R3	161/14:25:56-26:06	Southern IN	7	SDO's 19	3/27/75
		SL/3 MISSION			
S190A	258/16:33:10-34:50	Kentucky	42	6-Stations	1/14/74
S190B	258/16:33:08-34:49	Kentucky	42	Color IR	5/17/74
S190A	263/21:02:27-04:06	Southern IN	51	6-Stations	1/14/74
S190B	263/21:02:37-04:48	Southern IN	51	Color	5/17/74
		SL/4 MISSION			
S190A	025/17:14:50-17:20	Northern IN	90	6-Stations	6/27/74
S192-111-03-90-51-3	025/17:15:59-16:12	Northern IN	90	SDO's 3-4, 7-16, 19-21	11/14/74

TABLE 1.2

Underflight Data Received for Project

Platform/ Organization	Altitude (M)	Time Data Collected (GMT)	Location	Products Received
		SL/2 STUDY SITE		
WB57F/NASA	18,300	6/10/73, 14:14-15:42	Southern IN	9 in Color & Color IR 70mm B&W, Color, & Color IR
C46/ERIM*	1,520	6/10/73, 14:40-15:18	Southern IN	9.5 in B&W Prints 70mm Color & Color IR 12 Channel MSS
Cessna 310/CES+	1,000	6/22/73, 18:00-20:30	Southern IN	Color Slides Ground Truth Information
Cessna 310/CES+	2,120	10/24/73, 15:20-17:00	Monroe Co., IN	70mm Color & Color IR
WB57F/NASA	18,300	1/30/74, 17:08-17:46	Southern IN	9 in Color & Color IR 70mm B&W, Color, & Color IR
		SL/4 STUDY SITE		
C46/ERIM*	2,350	1/30/74, 16:28-18:02	Northern IN	9.5 in B&W Prints 70mm Color & Color IR 12 Channel MSS

*ERIM - Evironmental Research Institute of Michigan

+CES - Cooperative Extension Service

Table 1.3

Ground Data Collected for Project

SL/2 Mission

Instrument	Time Data Collected (GMT)		Location	Type of Data Collected
Exotech Model 20C	6/10/73	14:20 - 17:30	Lake Monroe and Purdue Farm near Bedford, IN	Solar Irradiance and Target Reflectance (.45-2.4μm)
Pyrheliometer	6/10/73	14:00 - 18:15	Lake Monroe, IN	Surface Solar Irradiation through Three Filters
PRT-5	6/10/73	14:25 - 14:40	Lake Monroe, IN	Radiometric Temperature of Water
Precision Glass Thermometer	6/10/73	14:30 - 14:40	Lake Monroe, IN	Temperature of Air and Water

discussed with the S192 personnel at the Johnson Space Center during an S192 data processing meeting in the first week of October, 1974. The S192 data set, 51-3R1, was not used since the sync loss was still present in SDO 19 and again the data didn't cover the same area as the interim S192 data. The S192 data set, 51-3R2, was used for the study described in section 3 even though the sync loss in SDO 19 was still present and not all the channels were present. It wasn't possible to obtain the complete data set because of the time constraints in the project period. Channel 8 (SDO 19) was rerun, data set 51-3R3, and sent to Purdue but the scale of the data set, 51-3R3, was different than that of the base data set, 51-3R2. Time and resources were not available to overlay the two data sets.

Many iterations of the S191 data were received. Only the final (most nearly correct) set of S191 data is listed in Table 1.1.

Data were utilized from two study sites in Indiana - the Lake Monroe, Indiana, study site for the SL/2 mission (Fig. 1.1) and Allen County, Indiana, for the SL/4 mission (Fig. 1.2).

This report represents the final results of the research activities for this project.

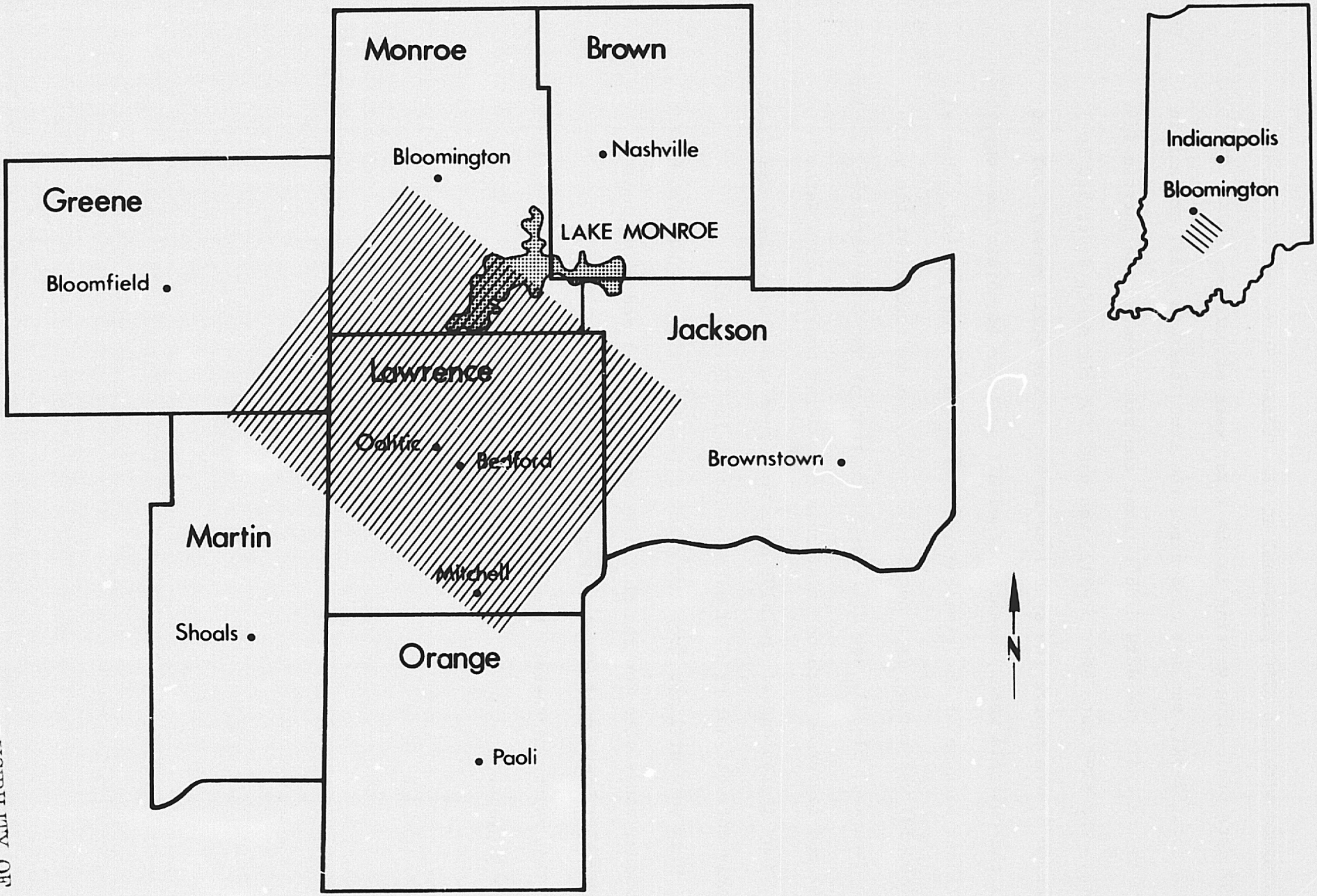


Fig. 1.1 SL/2 study site indicated by lined area.

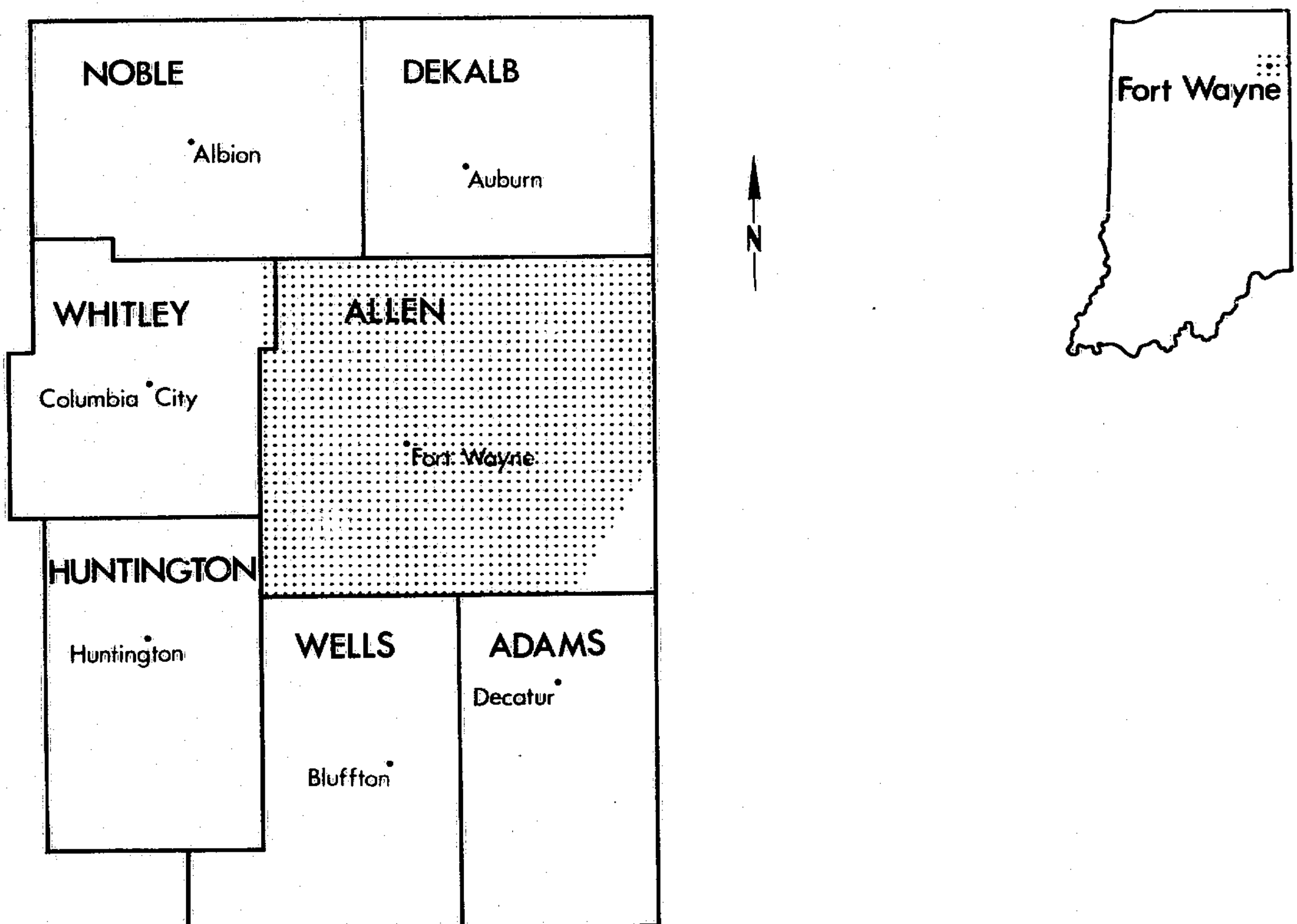


Fig. 1.2 SL/4 study site outlined is shaded area.

2. EVALUATION OF MULTISPECTRAL DATA SETS FROM SPACECRAFT PHOTOGRAPHIC AND MULTISPECTRAL SCANNER SENSORS

2.1 INTRODUCTION AND OBJECTIVES

The optical portion of the electromagnetic spectrum has been the major vehicle for remote sensing of the environment by a variety of disciplines including geology, forestry, water resources, crop studies, and land use studies. Besides the complex human nervous system, the energy reflected and emitted from the earth in the optical region is collected by two other primary techniques -- photographic emulsions and multispectral scanners. The resulting imagery can be interpreted by visual techniques or, if in a digital format, by a computer using pattern recognition techniques.

Multispectral scanners sample the energy in different regions (termed channels) of the optical spectrum as a mirror scans the scene. The optics and detectors determine the spectral windows of the individual channels. The energy levels for each channel are stored in either an analog or a digital format on a magnetic tape to form a multispectral data set. Multi-emulsion photography (e.g. color IR film) and multiband photography (i.e. combination of different cameras, films, and filters) are also used to form multispectral data sets.

The purpose of the evaluation was to study and compare different multispectral data sets obtained from spacecraft altitudes in land use studies using machine processing techniques. Multispectral scanners can acquire data from a larger portion of the optical spectrum (0.35 - 15.0μm) with better spectral resolution than can photographic cameras (0.4 - 0.9μm). Photographic camera systems on the other hand can acquire data with better spatial resolution. The evaluation basically addresses the differences in spectral range and resolution and somewhat the differences in spatial resolution. (The spatial resolution of the photographic infrared channels is nearly the same as that of the multispectral scanner channels.)

The evaluation includes two separate studies. The first includes four data sets collected in late spring during the SL/2 mission over the Lake Monroe, Indiana, area (Fig. 1.1). The second includes two data sets collected over Allen County, Indiana, during the SL/4 mission (Fig. 1.2).

2.2 LAKE MONROE, INDIANA, AREA STUDY - SL/2

2.2.1 INTRODUCTION AND PROCEDURES

This study compares four multispectral data sets acquired within a 24-hour time period on June 9, and June 10, 1973, over an area in south-central Indiana in a land use analysis of the study area (see Fig. 1.1). The data sets were acquired by the 4-channel multispectral scanner (MSS) on the Landsat 1 satellite, the Earth Resource Experiment Package (EREP) 13-channel MSS on Skylab, the color infrared photography from the EREP camera system, and the black and white multiband photography from the EREP camera system.

The study area was centered around Lawrence County and parts of the surrounding counties in south-central Indiana, an area covering approximately 147,000 hectares. The land is rolling, with around 140 m of local relief, and a variety of land use categories--a lake, a river, forests, agricultural fields, residential areas and commercial-industrial areas.

The study used the IBM 360/Model 67 computer at the Laboratory for Applications of Remote Sensing (LARS) at Purdue, the MSS data sets and the digitized photographic data sets to classify the study area into twelve land use classes which correspond to those suggested by Hardy, Anderson, and Roach {1}: new residential, old residential, commercial-industrial, extractive, light soil, dark soil, grass, sparse woods, deciduous forest, coniferous forest, river, and lake. For analyzing the results, the new and old residential classes were considered as one class, as were the light and dark soil classes and the sparse woods and deciduous forest classes. These pairs of classes were combined because of the difficulty in determining the boundary definitions of the classes.

The classification procedure employed the pattern recognition algorithms that have been implemented on the computer at LARS in a software package called LARSYS {2}. The procedure consisted of choosing fields or areas to represent each of the twelve classes listed above. These training fields, representing around 0.3% of the study area, were scattered throughout the study area. The same ones were used for each of the four data sets. The possibilities for training fields were somewhat limited by clouds in the Landsat 1 MSS data set.

The training fields were evaluated using a clustering routine to find if further division of the twelve classes was necessary so that each of the resulting spectral classes represented a unimodal distribution. Under the assumption that the spectral data of the samples for each spectral class were normally distributed (Gaussian), the n-dimensional mean vector and the n x n covariance matrix of the multispectral data sets were computed for each class where n represents the number of channels of spectral information in each data set. The mean vectors and covariance matrixes were used in the actual classification routine which uses the maximum likelihood decision rule {3} with the *a priori* probability of occurrence for each class being equal.

A modified divergence was used to select the "best" set of four out of the twelve channels in the SKYLAB MSS (S192) data set (a feature selection routine) and to obtain a measure for the separability of the classes in each of the data sets. Divergence, a measure of separability between two density functions which represent two land use classes, i and j for n spectral channels $C_1, C_2, \ldots C_n$, assuming normal variables, is given {4} by Eq. (2.1).

$$D(i,j/C_1, C_2, \ldots C_n) = \tfrac{1}{2} \, tr \, \{(K_i - K_j)\,(K_j^{-1} - K_i^{-1})\} + \tfrac{1}{2} \, tr \, \{(K_i^{-1} + K_j^{-1})\,(M_i - M_j)\,(M_i - M_j)^T\} \qquad (2.1)$$

where M and K represent the mean vector and covariance matrix respectively; tr {A} (trace A) is the sum of the diagonal elements of A. A^T is the transpose of the matrix A. A modified form of divergence D_T, termed transformed divergence, was used in this study because it behaves more like the probability of correct classification {3}. See Eq. (2.2).

$$D_T = 2000\ \{1 - \exp(-D/8)\} \qquad (2.2)$$

Transformed divergence was extended to a multiclass case to choose the "best" 4 channels in two separate ways. The average of the transformed divergence for all possible class pairs was maximized and the minimum transformed divergence of all possible class pairs was maximized. There is no guarantee, however, that either of these methods are optimal. The selection of four channels for the classification was done to reduce computer costs and to find if the channels selected included any spectral bands not available in the other data sets.

The products obtained in the study include the transformed divergence measures for the separability of each pair of classes in each data set, the classification maps, and the classification performance results. The classification performance results were obtained by selecting six test areas scattered throughout the study area representing the classes under consideration. The underflight photography was projected onto the classification map of these test areas and a point-by-point check of the classification was done. The points from all six test areas were combined to obtain performance results for each class and for the overall classification performance - total number of points classified correctly divided by total number of points in test areas. The total test area represented 3.5% of the study area or approximately 5,150 hectares. (The test areas are outlined in Fig. 2.12).

2.2.2 DESCRIPTION OF SENSORS

At 14:39 GMT (9:39 local time) on June 10, 1973, an aircraft (flown by the Environmental Research Institute of Michigan, ERIM) acquired 12-Channel MSS Data and photography over a north-south strip over Lake Monroe, 1520 m above the ground. The photography from the aircraft consisted of 24.1 cm (9.5 in) black and white transparencies and prints (see Fig. 2.1), 70 mm color and color IR positive transparencies.

At 15:30 GMT (10:30 local time) on June 10, 1973, a WB-57 high-altitude reconnaissance aircraft (flown by the National Aeronautics and Space Administration) acquired photography along the track of the Skylab pass across Indiana and a north-south strip across Bloomington, Lake Monroe, Bedford, and Mitchell at an altitude of 18,300 m (60,000 ft). The photography consisted of 24.1 cm (9.5 in) color and color IR positive transparencies (see Fig. 2.2), 70 mm color, color IR, and 4 bands of black and white positive transparencies.

On October 24, 1973, a Cessna 310 (operated by LARS) flew the portion of the study area that is in Monroe County at an altitude of 2,120 m

Fig. 2.1 Frame from the Michigan underflight photography over the Monroe Lake dam. The field spectroradiometer system (Sec. 5) was set up on the ramp going into the lake a few hundred meters upstream for the dam. Altitude - 1520 meters. Scale - 1:26,000

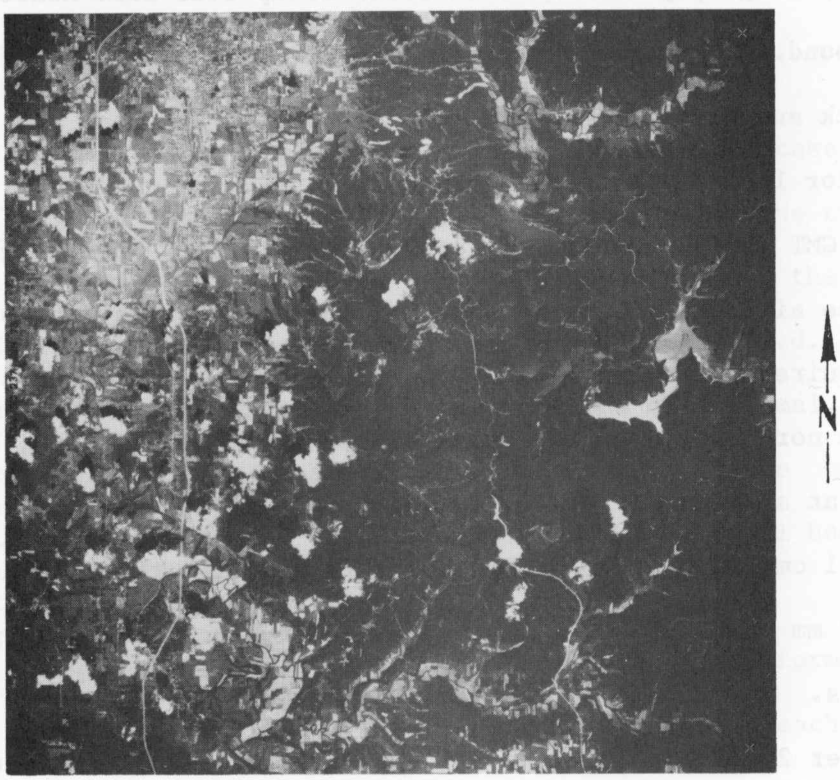


Fig. 2.2 Black and white reproduction of color IR frame from WB57 underflight photography. Lake Monroe and U.S. Highway 37 are dominant features. The city in the upper left is Bloomington, Indiana Altitude - 18,300 meters. Scale - 1:270,000

(7,000 ft) acquiring 70 mm color and color IR positive transparencies.

At 14:26 GMT (9:26 local time) on June 10, the Skylab space station flew over the test area at an altitude of 440 km (270 mi). The weather conditions were excellent; the sky was clear and the air was calm. Data were utilized from 3 of 6 sensors in the Earth Resources Experiment Package on Skylab: Photographic - S190A and S190B - and MSS data - S192 {5}.

The photography was acquired by the S190A and S190B experiments on EREP. The S190A experiment is an array of 6 cameras with high precision f/2.8, 21.2° field of view, 153 mm (6 inch) focal length lenses obtaining 1:3,000,000-scale photography. The film products include 70 mm color, color IR, and 4 spectral bands of black and white transparencies. The film types, spectral resolutions, and ground resolutions of the S190A photography used for this study are given in Table 2.1. The S190B photographic camera (Earth Terrain Camera) has an f/4 lens with a focal length of 458 mm (18 in) obtaining approximately 1:950,000-scale photography. The film products were five inch color positive transparencies.

The multispectral scanner (the S192 experiment) on Skylab has 13 channels which cover the wavelength range of 0.41 μm to 12.5 μm in five visible channels, five near infrared channels, two middle infrared channels, and one far infrared or thermal channel (see Table 2.2). The bands were sampled at high and/or low rates and stored as 22 scientific data output (SDO) channels on the EREP 28-track data tape. Two SDO channels were used for the high rate bands and one SDO channel was used for the low rate band {6}.

The incoming radiant energy is collected by a 423 mm (17 in) spherical collecting aperture. The radiation in all 13 bands are focused on to Hg:Cd:Te detectors. The multispectral scanner has a conical line scan with an instantaneous field of view (IFOV) of 0.182 milliradians or 79 m (260 ft) square ground coverage. The total field of view is 68.5 km (42.5 mi) on the ground.

At 15:59 GMT (10:59 local time) on June 9, 1973, the Landsat 1 Satellite acquired multispectral scanner (MSS) data over the test site at an altitude of 933 km (570 mi). The MSS on Landsat 1 consists of 4 channels, 2 visible and 2 near infrared, which cover a wavelength range from 0.5 to 1.1μm (Table 2.3). The Landsat 1 MSS has a rectilinear line scan with total field of view of 185 km (115 mi) and IFOV of 79 m square on the ground. The detectors for channels 1, 2, and 3 are photo-multiplier tubes (PMT) and the detectors for channel 4 are silicon photodiodes.

2.2.3 ANALYSIS OF DIGITIZED S190A PHOTOGRAPHIC DATA

The EREP's S190A film products from Skylab used for the analysis were second generation contact positive transparencies (Figs. 2.3 and 2.4) made from the 70 mm original. The original color IR transparency was duplicated onto Kodak Ektachrome Aerographic Duplicating Film SO-360 by Kodak Rainbow or Colorado Continuous Contact Printers by the Versamat 1811/EA-5 Process. The 70 mm original Kodak SO-022 and Kodak 2424 were duplicated onto Kodak Fine Grain Aerial Duplicating Film 2430 and Kodak Aerographic Duplicating Film 2420, respectively. These duplications were done on a Kodak Niagra Continuous Contact Printer by the Fultron or Versamat/MX 641 processes.

These second generation 70 mm color IR, and the four black and white positive transparencies were digitized by Mead Technology Laboratories at Dayton, Ohio. The instrument used was a modified Fairchild Scan-A-Color Model 4 drum scanner. The instrument has been modified so that its spot size could be reduced to 12.5 μm and 25 μm from the original 50 μm.

The 70 mm color IR transparency was separated and digitized using a 25 μm aperture and a 20 μm sampling interval. The method used was to scan a line with a Kodak 92 filter to separate the red layer, repeat the scan

Table 2.1

S190A Film Characteristics

Wavelength (μm)	Film	Filter*	Dynamic Resolution On the Ground (m)
0.5-0.6	PAN-X B&W (SO-022)	AA	30
0.6-0.7	PAN-X B&W (SO-022)	BB	28
0.7-0.8	IR B&W (EK 2424)	CC	68
0.8-0.9	IR B&W (EK 2424)	DD	68
0.5-0.88	IR Color (EK 2443)	EE	57

*As designated by the EREP INVESTIGATORS' INFORMATION BOOK

Table 2.2

Skylab MSS (S192) Spectral Bandwidths and Scientific Data Outputs (SDO's) Utilized in Data Set

Channel	SDO	Spectral Bandwidths (μm)
1	22	0.41-0.46
2	18	0.46-0.51
3	1	0.52-0.56
4	3	0.56-0.61
5	5	0.62-0.67
6	7	0.68-0.76
7	9	0.78-0.88
8	19	0.98-1.08
9	20	1.09-1.19
10	17	1.20-1.30
11	11	1.55-1.75
12	13	2.10-2.35
13	NA*	10.20-12.50

*Not Available

Table 2.3

Landsat 1 MSS Spectral Bandwidths

Channel	Spectral Bandwidths (μm)
1	0.5-0.6
2	0.6-0.7
3	0.7-0.8
4	0.8-1.1

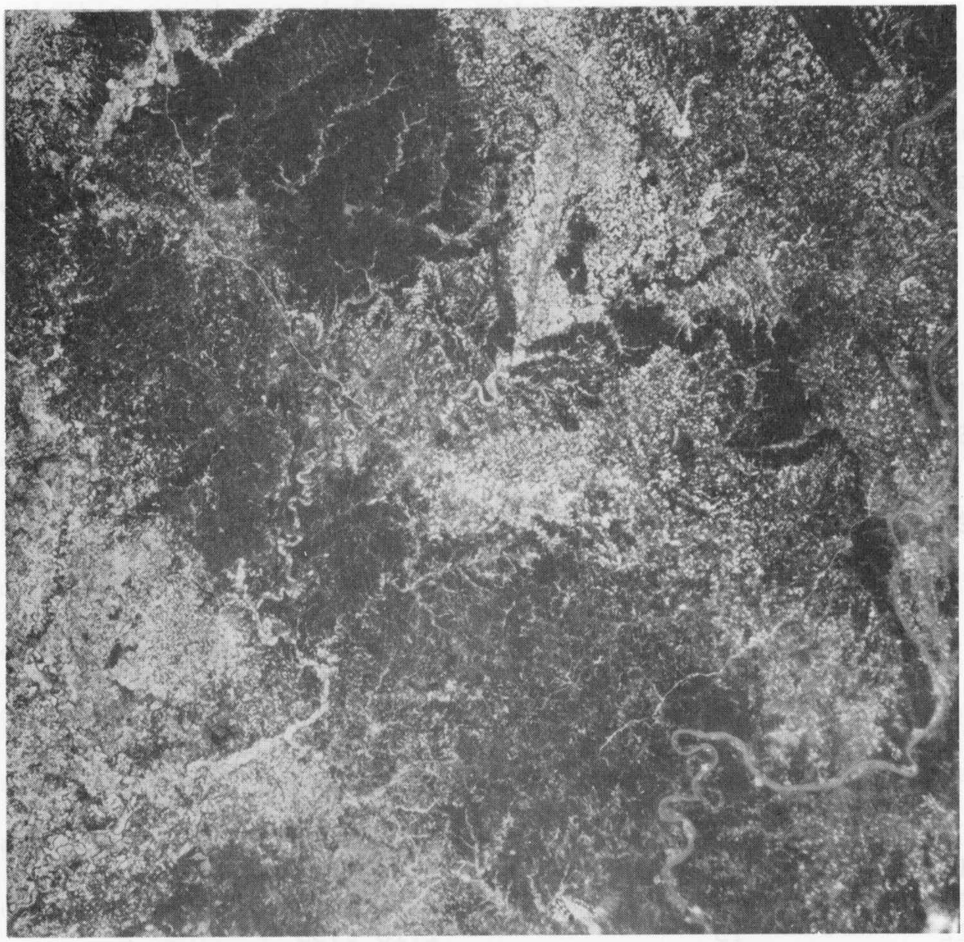


Fig. 2.3 Black and white reproduction of Skylab S190A color IR frame that was digitized. Study area is in upper left quarter of frame. The Ohio River runs along right edge of frame. Altitude -440km. Scale 1:1,280,000

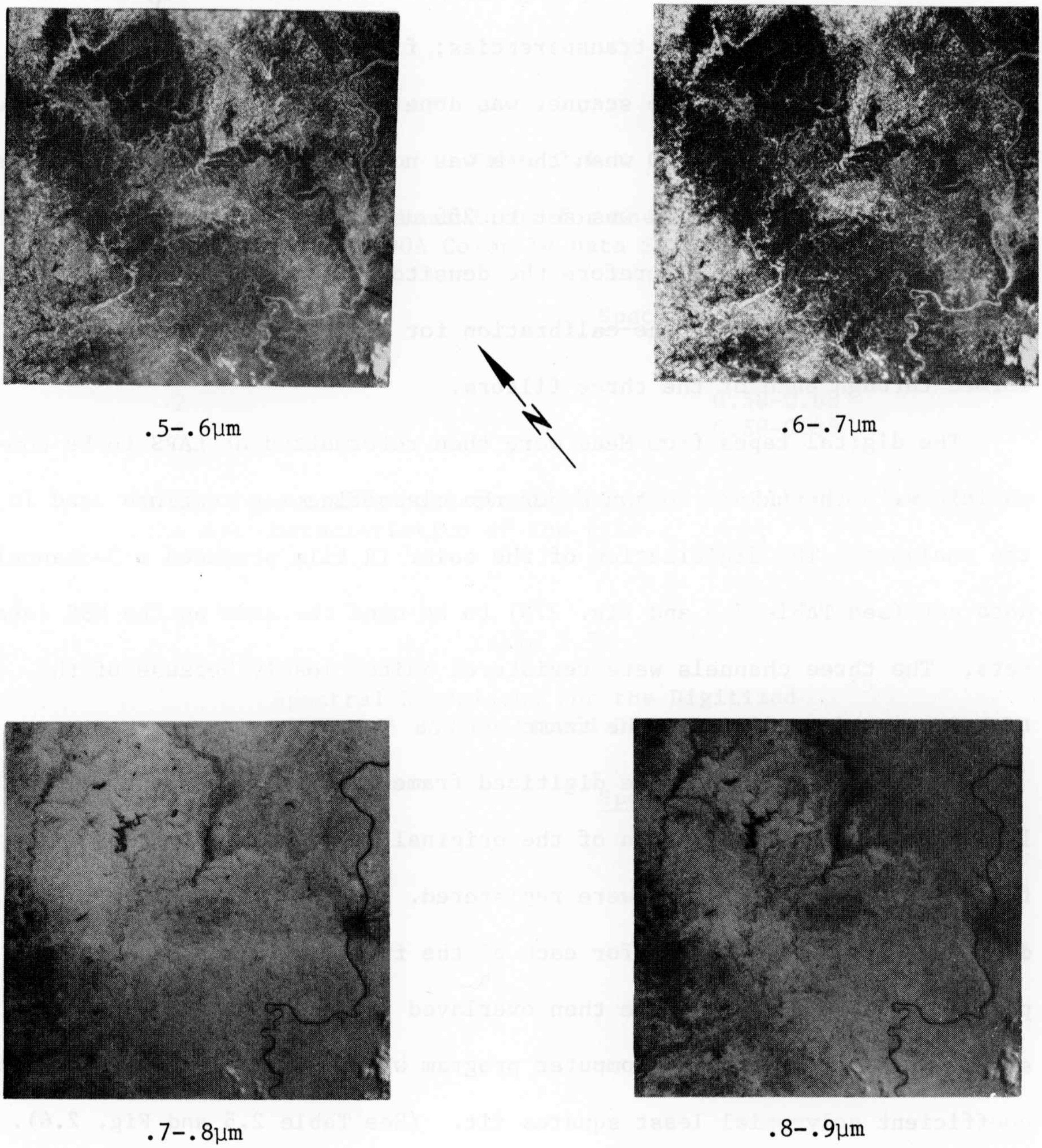


Fig. 2.4 Skylab S190A black & white multiband frames that were digitized. Study area is in upper left quarter of frame. Altitude - 440 km. Scale - 1:3,000,000

with a Kodak 93 filter for the green layer, and scan again with a Kodak 94 filter for the blue layer. The scanner was then stepped down a line and the process was repeated. The 25 μm aperture corresponds to approximately 68 m (223 ft) on the ground, the sampling interval to 55 m (180 ft). The same aperture size and sampling interval were used to digitize the four 70 mm black and white transparencies; filters were not used.

The calibration of the scanner was done such that the low end of the scanner output was set to 0 when there was no attenuation of light on the glass drum and the high end was set to 255 using the dark area between the frames of the imagery. Therefore the densitometer measured 256 different levels of film density. The calibration for the color IR image was performed through each of the three filters.

The digital tapes from Mead were then reformatted at LARS to be compatible with the LARSYS software for the classification routines used in the analysis. The digitization of the color IR film produced a 3-channel data set (see Table 2.4 and Fig. 2.5) to be used the same as the MSS data sets. The three channels were registered quite closely because of the technique used to digitize the frame.

The four black and white digitized frames had to be registered. A 1100 line by 1100 column area of the original 3,000 lines by 3,000 columns for each of the four frames were registered. Around sixty points evenly distributed across the area for each of the frames were chosen as common points. The four frames were then overlayed to produce a 4-channel data set by a LARS registration computer program which uses a second order six coefficient polynomial least squares fit. (See Table 2.5 and Fig. 2.6). The registration of the two visible channels is within a pixel, approximately 40 m on the ground. The registration of the two infrared channels is within the resolution of the film approximately 70 m on the ground. The registration

Table 2.4

Spectral Bandwidths for the Digitized
S190A Color IR Data Set

Channel	Spectral Bandwidths* (μm)
1	0.52-0.58
2	0.58-0.68
3	0.68-0.88

*There is actually some overlap between the channels because of the dye characteristics of the film.

Table 2.5

Spectral Bandwidths for the Digitized
S190A B&W Multiband Data Set

Channel	Spectral Bandwidth (μm)
1	0.5-0.6
2	0.6-0.7
3	0.7-0.8
4	0.8-0.9

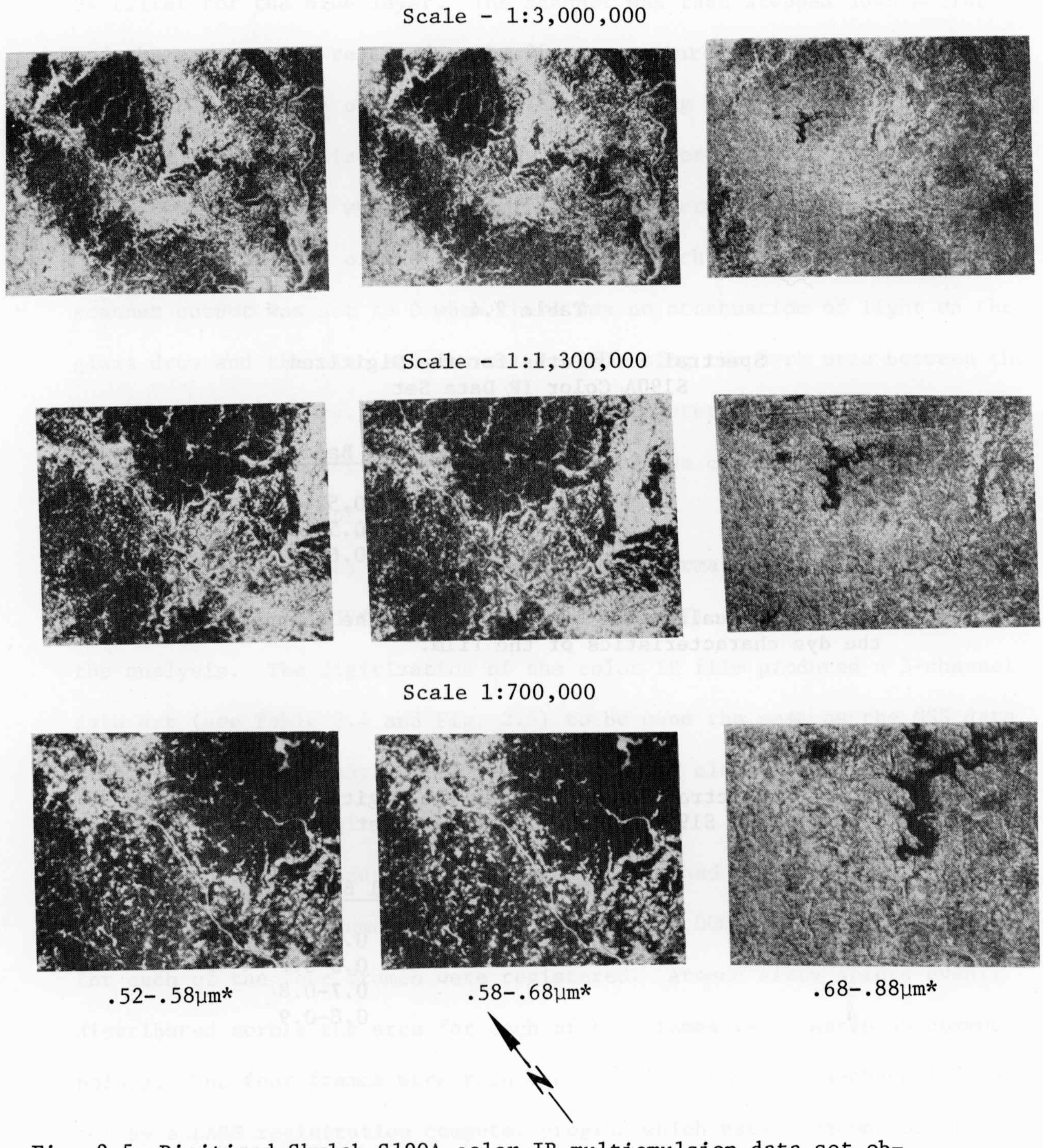


Fig. 2.5 Digitized Skylab S190A color IR multiemulsion data set obtained from digital display screen using 16 gray levels. Top row-complete digitized frame. Middle row-enlargement of study area (See Fig. 2.6 for exact boundary of study area). Bottom row-enlargements within study area.
*See note in Table 2.4.

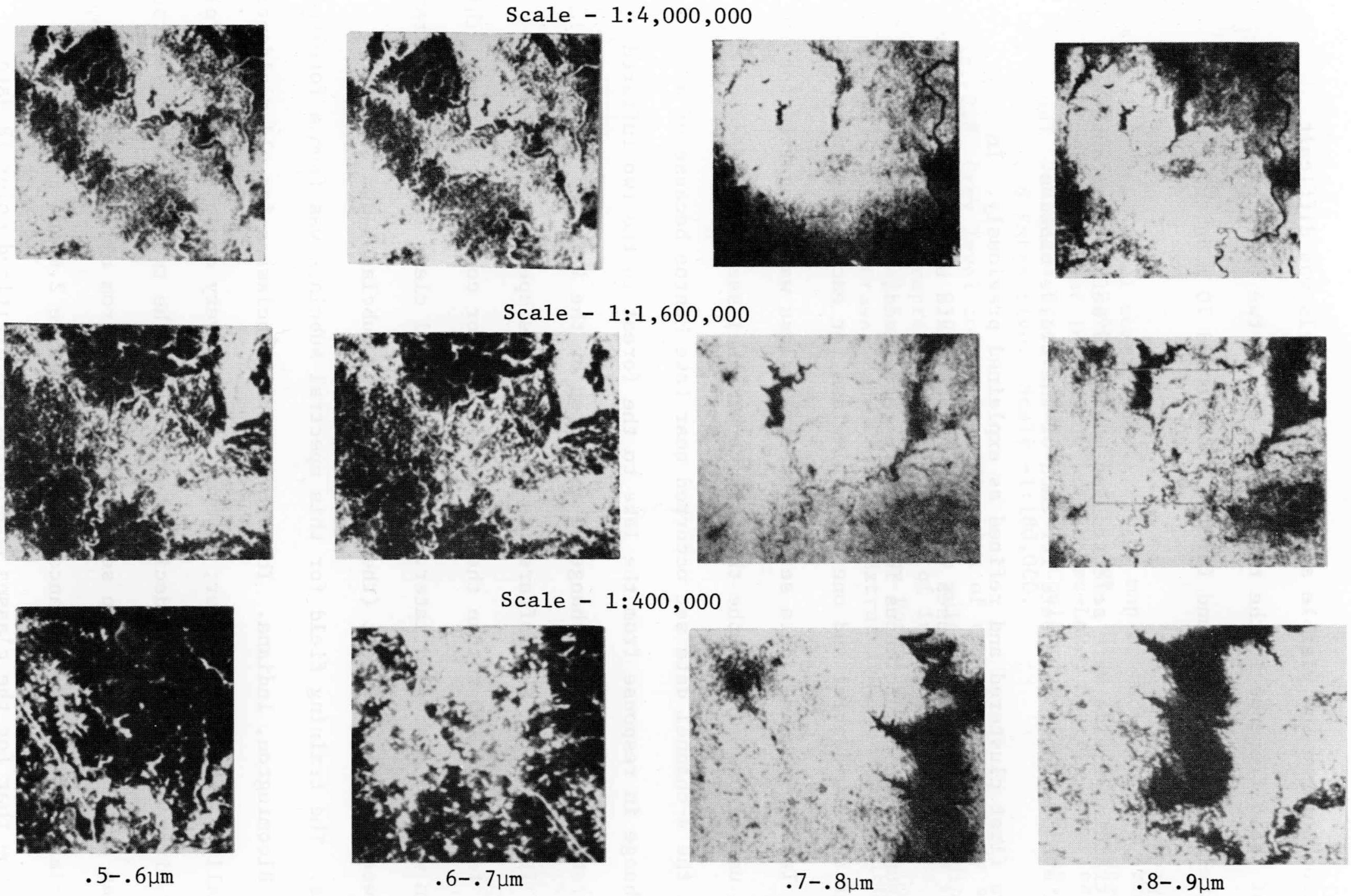


Fig. 2.6 Digitized Skylab S190A black & white multiband data set obtained from digital display screen using 16 gray levels. Top row-complete digitized frames. Middle row-enlargement of study area. Study area is outlined in the .8-.9 μm band. Bottom row-further enlargements of study area. Note difference in resolution between visible and infrared frames.

between the visible and infrared channels is within two pixels. The registration between the visible and infrared channels was difficult because of the difference in the resolutions of the two types of film--approximately 30 m on the ground for the visible and 70 m on the ground for the infrared.

The training fields were selected, as mentioned before, for both the 4-channel and 3-channel data sets for each of the twelve classes. The areas were first clustered and refined as explained previously. In clustering the individual classes of the 4-channel data set, three separate spectral subclasses of deciduous forest were recognized, two spectral subclasses of old residential and one spectral class for each of the other classes. In the 3-channel data set one spectral class was recognized for each land use class. One of the three spectral subclasses for deciduous forest in the 4-channel data set occurred near Lake Monroe because of a gradual change in response from the lake to the forest in the two infrared channels rather than a sharp change as indicated by the infrared channel in the color IR data set. The infrared response of this spectral subclass of deciduous forest was lower than the spectral class for coniferous forest. This phenomenon will be discussed later. Another spectral class represented a transition between the dense forest (the third spectral subclass) and the sparse wood class. The training field for this spectral subclass was from a forested area near Bloomington, Indiana. The two spectral subclasses for old residential were actually close to each other; however, one was very close to the spectral class for river so that it was decided best to keep the two subclasses separate rather than combine them to help separate the river from old residential.

The classification performance results (see Table 2.6 and Figs. 2.7 and 2.8) show that for the classes considered the digitized color IR data

Fig. 2.7 Color coded classification of two-thirds of study area using digitized S190A color IR data set. Nine land use classes represented: Residential-red, Commercial-Industrial-dark gray, Extractive-cream, Bare Soil-yellow, Grass-light green, Deciduous Forest-dark green, Coniferous Forest-pink, River-light blue, Lake-dark blue. Scale - 1:180,000.

Fig. 2.8 Color coded classification of two-thirds of study area using digitized S190A black and white multiband data set. Nine land use classes represented: Residential-red, Commercial-Industrial-dark gray, Extractive-cream, Bare Soil-yellow, Grass-light green, Deciduous Forest-dark green, Coniferous Forest-pink, River-light blue, Lake-dark blue. Scale - 1:180,000.

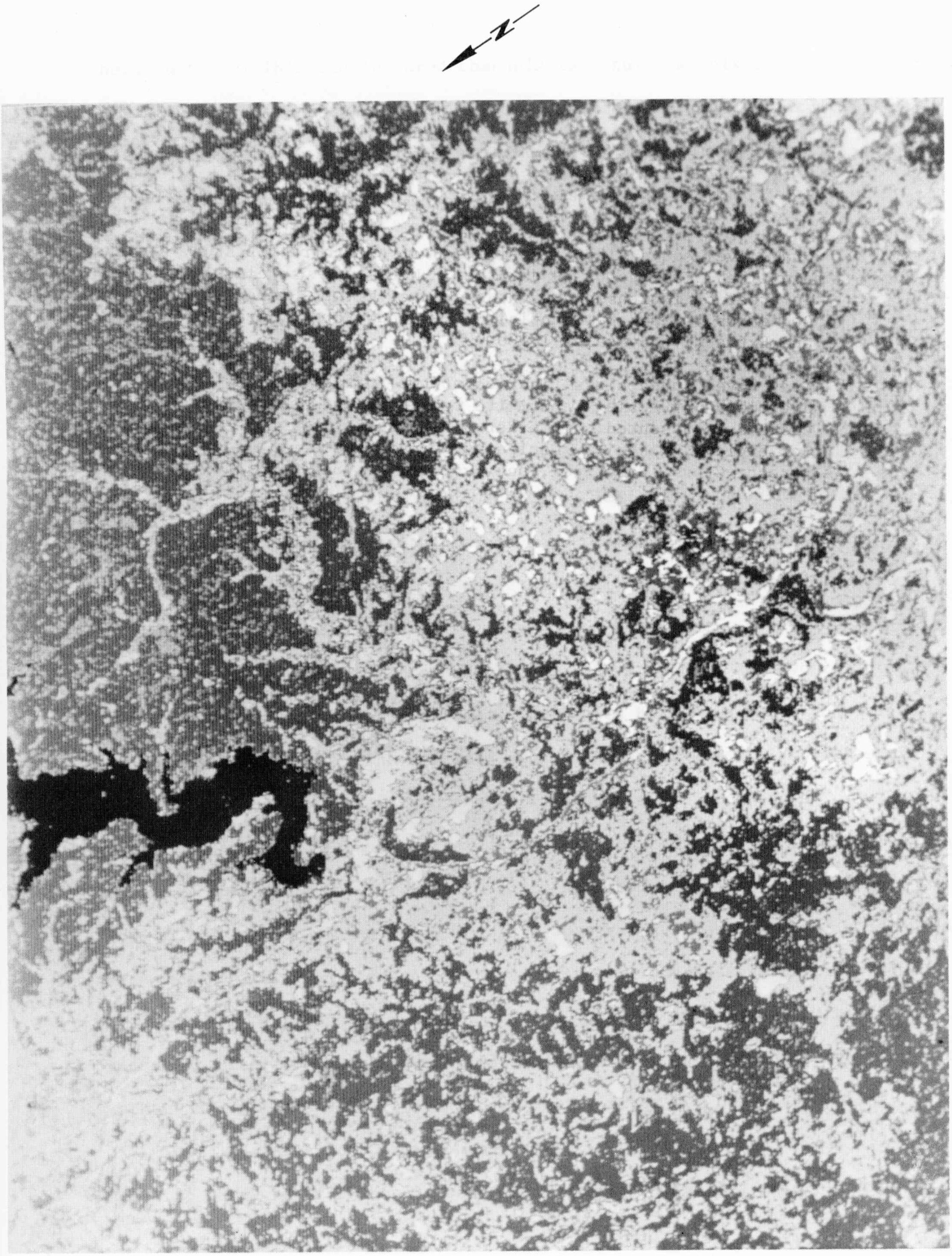


Fig. 2.7

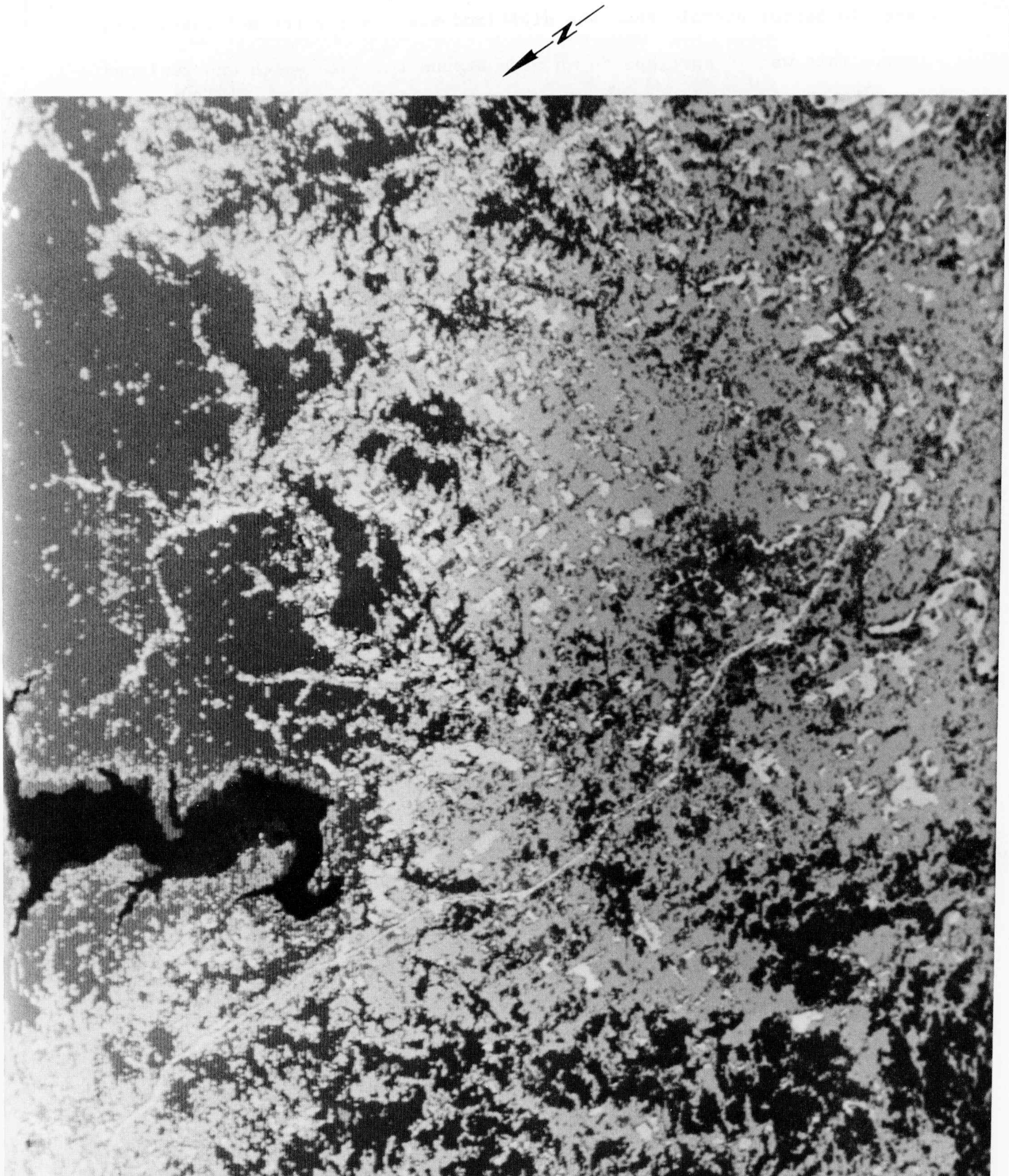


Fig. 2.8

set did better overall than the digitized black and white multiband data set. This was in part due to an area around the lake which was assigned to the coniferous class instead of the deciduous class and to some of the points around the edge of the lake which were delineated as commercial-industrial instead of lake. Also many data points in the bare soil and the residential areas were incorrectly classified as river.

The misclassifications around the lake in the multiband b&w data set were due to the indistinct boundary between the vegetative covered shore and the lake in the infrared frames as illustrated in Figure 2.9. The effect is enhanced in Figure 2.9 by using a high contrast printing process for illustration purposes. However, the anomaly is definitely present in the second generation contact positive prints used as the data source. The original negatives are not available to the investigators.

The classification results show that the above anomaly does indeed affect the b&w data processing and also that a similar effect does not exist in the infrared portions of the other data sources. In addition a close visual examination of the color IR, S-192, and Landsat 1 scanner imagery along with the supporting color IR and black and white photography taken by the WB-57 aircraft did not disclose a similar lake edge anomaly in the infrared frames of these data sources. By scaling the Skylab black and white infrared imagery it was determined that the shaded boundary was 1000 m (3300 ft) wide at points around the lake shore. In some cases over 35 m (115 ft) of relief were encountered over these distances which eliminated any lake shore moisture effect as a source of the anomaly.

Because of the small aperture used in digitizing the film (comparable to the resolution of the infrared film), the drum scanner measured this

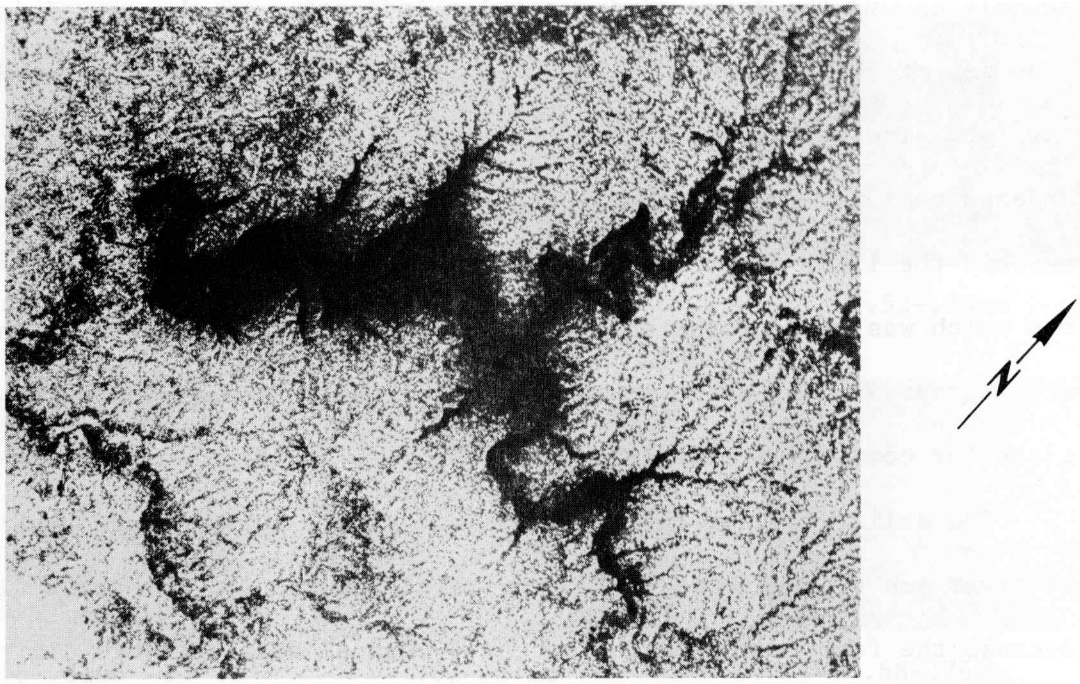


Fig. 2.9 Enlargement of the .8-.9μm black and white frame that was digitized, illustrating the anomaly around Lake Monroe. Scale - 1:230,000

Table 2.6

Classification Performance Results
(Percent Correct)

Class	SKYLAB MSS 3,7,8,11	SKYLAB MSS 3,5,6,8	ERTS MSS	Color IR	4 Band B&W
Residential	97	81	97	91	84
Commercial-Industrial	73	33	61	76	46
Extractive	51	59	61	32	34
Soil	87	78	83	67	78
Grass	95	86	93	82	69
Sparse Wds-Decid. For.	81	80	86	84	77
Coniferous Forest	99	68	95	85	43
River	87	27	77	16	64
Lake	89	86	86	98	93
Overall Performance*	87	80	88	83	76
Class Average**	84	66	82	70	65

*Total number points classified correctly/total number pts. in test areas.

**Arithmetic mean of the performance results of the nine classes.

anomaly around the lake, giving a false indication of the actual infrared response of the lake (higher) and the forest (lower) near the boundary of the two. The spectral subclass of deciduous forest which was trained from an area near the lake did represent all the deciduous forest data points nearest the lake; however, there was a band of data points outside of this one which was nearest the spectral class for coniferous forest. Those data points representing water near the edge of the lake were nearest the spectral class for commercial-industrial areas because of the higher infrared response.

The delineation of those points in the bare soil and residential areas as river was probably due to a poor training class for the river class. Because the four frames making up the 4-channel data set were digitized separately, the centers of the resolution elements are probably not the same. When registered to the nearest point, the centers may still be off a maximum of 40 m (130 ft). Since the river is rather narrow, one to two data points wide, the training class for river probably did not represent the true spectral nature of the river.

If the test area which includes the lake is left out, the overall performances of the two data sets for the five remaining test areas are much closer–77% correct classification for the digitized multiband photography and 80% correct classification for the digitized color IR photography.

2.2.4 ANALYSIS OF S192 MULTISPECTRAL SCANNER DATA

The quality of the unfiltered MSS data from Skylab by inspection of the images was good to poor (see Fig. 2.10). Channel 1, 0.41-0.44 μm was of little use. The atmospheric scattering reduced the contrast significantly and low frequency noise, banding, was serious. The noise varies from channel to channel with channels 3, 7, & 11 appearing to be the best from a visual point of view. The thermal band (channel 13) was not received in this data

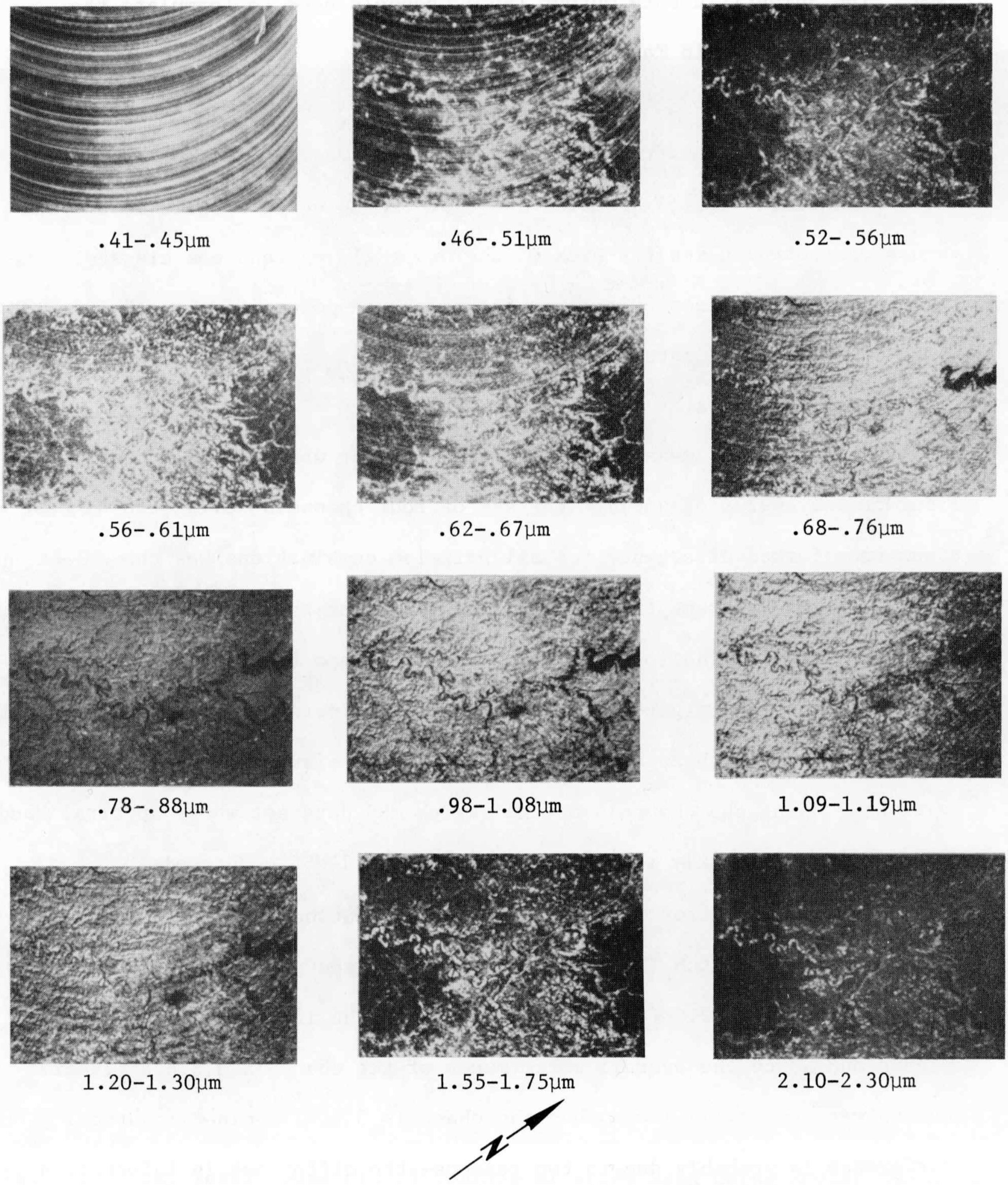


Fig. 2.10 Skylab S192 MSS 12-channel interim data set obtained from CRT digital display screen using 16 gray levels. Lake Monroe, U.S. Highway 37 and the East Fork of the White River are dominant features. Altitude - 440 km. Scale - 1:1,150,000

set. The Scientific Data Output (SDO) Channels used to formulate the data set are given in Table 2.2.

The same training fields used in the digitized photography described earlier were selected from this data set to represent the twelve classes. Clustering indicated 13 spectral classes, two spectral subclasses of lake and one spectral class for each of the other eleven land use classes. The second spectral lake subclass represented those points in channel 12 which were anomalies, saturated data values, probably occurring in the processing of the original data.

A separability measure as described earlier was used to choose the best four of the twelve channels. The set of four channels having the highest minimum transformed divergence for all pairwise combinations was chosen - channels 3,7,8,11. The average transformed divergence for this combination was only one less than the combination with the highest average transformed divergence. The optimum channels as given by the transformed divergence measure included the three channels which appear to be the cleanest, visually. A classification was also done using the channels of the Skylab MSS data set whose spectral bands correspond most nearly to those on the Landsat 1 MSS - channels 3,5,6,8

The test areas for computing the classification performance results were selected to match those used in the digitized photography. The results are given in Table 2.6 (also see Fig. 2.11). The individual class performances and hence the overall performance of the channels 3,5,6,8 classification were generally lower than the channels 3,7,8,11 classification. The difference is probably due to two reasons--the difference in information content of the channels and the difference in the noise of channels. Channels 5 and 6 appear visually to be noisier than channels 7 and 11. In the 3,7,8,11 classification all classes except the extractive and the commercial-industrial

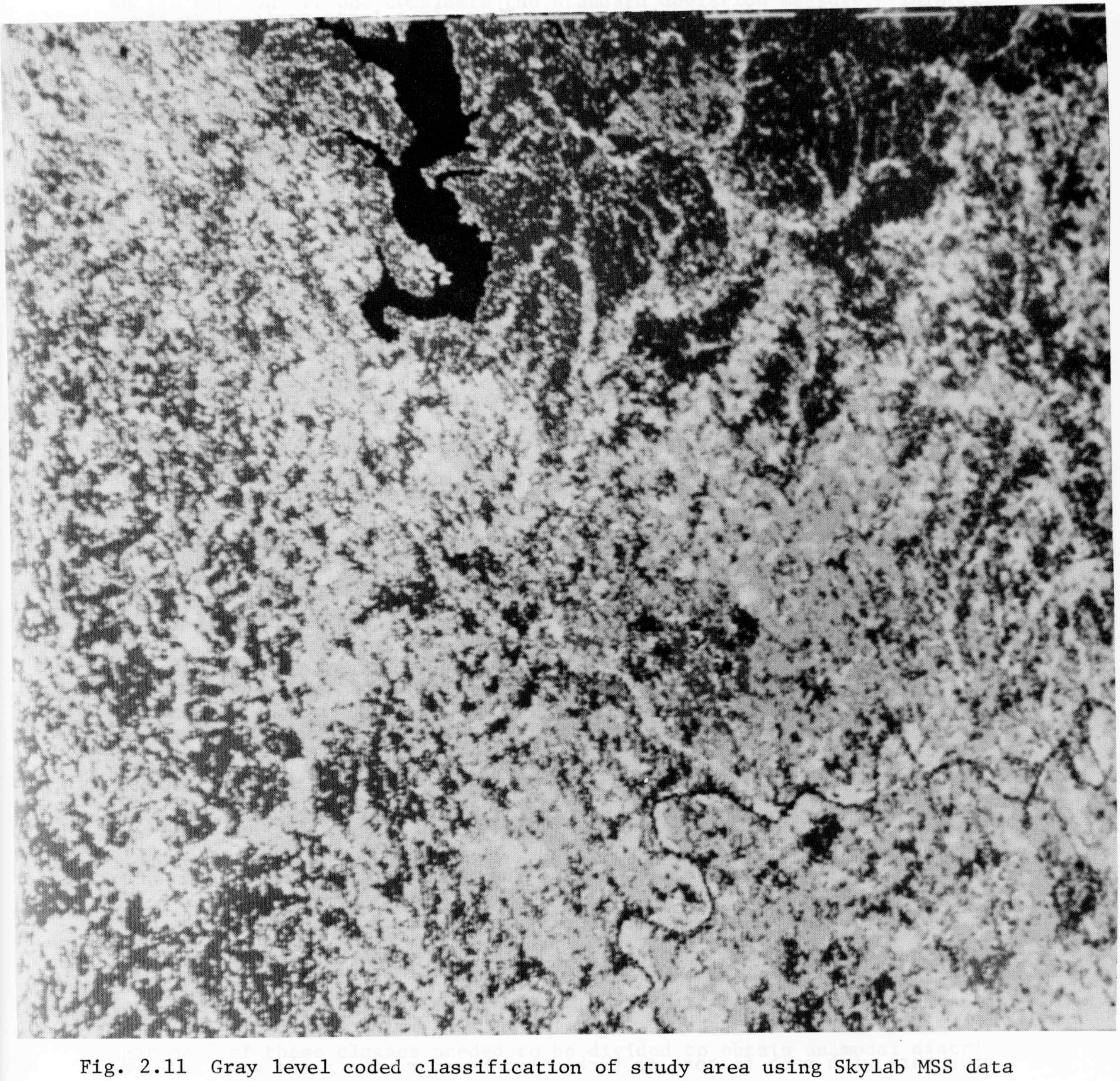


Fig. 2.11 Gray level coded classification of study area using Skylab MSS data set. Nine land use classes represented: in order of increasing brightness-Lake, River, Commercial-Industrial, Deciduous Forest, Residential, Coniferous Forest, Grass, Bare Soil, and Extractive. This is the channels 3,7,8,11 classification. Scale - 1:240,000

classes were separated quite well. The extractive class includes the limestone quarries in the study area. There is a large variance in the quarries, including some with no vegetation and some older ones with trees scattered around the water in the pits. The trees and water made some of the quarries hard to delineate with the training fields that were used. The commercial-industrial class was confused with the dark soil class. This pair of classes had the lowest transformed divergence measure separating them.

In the 3,5,6,8 classification, the commercial-industrial and the extractive classes were again not well separated. In addition to those classes, the river class was confused with the residential, commercial-industrial, and the dark soil classes. The coniferous class was confused with the sparse woods class. In all of the cases, the transformed divergence measurements between the confused classes were significantly less than in the 3,7,8,11 combination (see Tables 2.9 and 2.10).

To obtain a measure of the noise in the data, the mean and standard deviation of the data values for each of the twelve channels were computed for four separate areas and the total of the four areas (189 data points) in the deepest part of Lake Monroe (greater than six meters) and well away from the shore (at least 150 meters). The means and standard deviations of the four separate areas were in close agreement. The lake was chosen because it would have the most uniform spectral response of any scene in the study area. It should be noted that the spectral response of water does vary with such factors as turbidity; however, the areas were selected to minimize these effects. The measure used to obtain a representation of the noise level in the individual channels was the standard deviation (see Table 2.7). Three (3,7,11) of the four channels (3,7,8,11) selected as the optimum set of four by the transformed divergence measure were ranked in the top four if one considers the standard deviation measure. This indicated that the noise level of the data may have had a bearing on the channels selected for the optimum classification performance.

Also, the "quality" measure, the standard deviation, seems to indicate that channel 8 is an important spectral band to complement channels 3,7, and 11 for this set of data and classes. Even though channel 8 ranks 6th according to the quality measures, the channel is still chosen to be included in the "best four" channels to use. The transformed divergence measure of the separability of classes using just one channel also indicates that channel 8 is important. (See Table 2.8). Channel 8 ranks third after channels 11 and 10 for the highest average transformed divergence of all class combinations.

2.2.5 ANALYSIS OF LANDSAT MULTISPECTRAL SCANNER DATA

The Landsat 1 MSS data collected the day before were also classified using the same training areas to represent the classes used. The quality of the data for the study area was good except for one bad data line and clouds in the southeastern part of the area (see Fig. 2.12). Because of the clouds, it was not possible to obtain a good representative commercial-industrial class from Bedford, so the training field for this class was taken from Bloomington, 45 km to the north. A class for clouds and a class for cloud shadows were used in this classification; however, these classes were not considered in the evaluation. The clustering procedure indicated that none of these classes needed to be divided to obtain unimodal distributions for each spectral class. All four channels were used for this classification.

Table 2.7

Data Quality Measures
Obtained from a Portion of Lake Monroe
Skylab MSS (S192)

Channel	Mean	Std.Dev.
1	137.73	14.09
2	98.93	6.41
3	53.34	3.39
4	44.85	3.95
5	36.35	3.47
6	34.73	4.63
7	42.86	1.90
8	38.68	3.64
9	33.21	2.79
10	49.43	4.11
11	44.57	1.84
12	3.48	3.92
	Landsat 1 MSS	
1	66.00	1.58
2	43.26	1.54
3	32.16	2.58
4	19.80	2.56

Table 2.8

Separability of Classes
Using One Channel

Channel	Transformed Divergence Average of 77 Class Combinations*
11	1588
10	1476
8	1441
9	1394
7	1375
6	1344
12	1289
3	1273
5	990
4	947
2	868
1	284

*2000 is maximum value of separability.

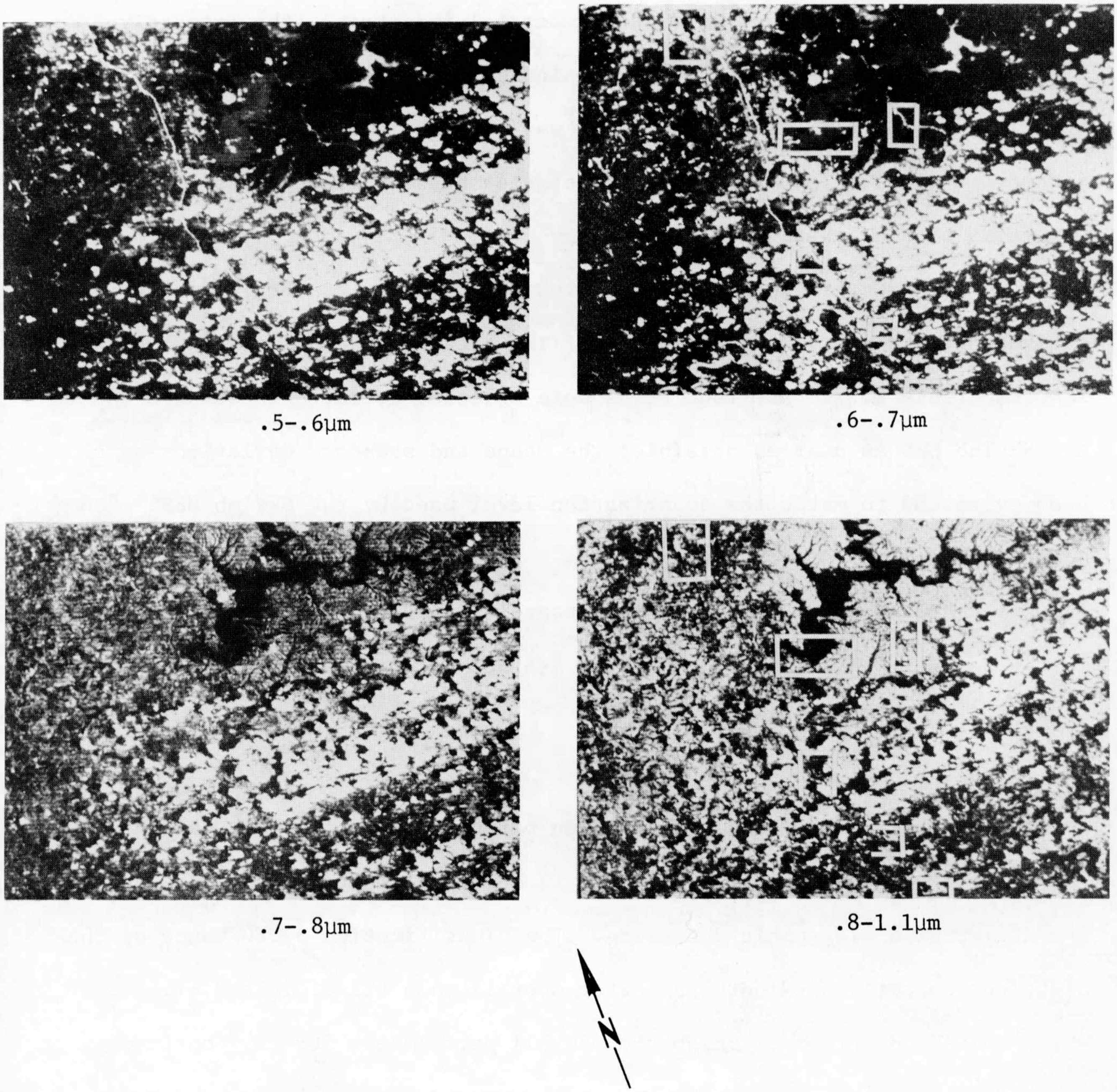


Fig. 2.12 Landsat 1 MSS 4 channel data set obtained from digital display screen using 16 gray levels. The six test areas used to obtain the classification performance results are outlined in the .6-.7µm and .8-1.1µm bands. Altitude - 933 km. Scale - 1:800,000

The same six test areas were selected again and the same procedure as stated before was used to obtain the classification performance results (see Table 2.6 and Fig. 2.13). The overall classification performance was good-88%. The worst cases were the commercial-industrial, the extractive, and the river classes. The commercial-industrial class was confused with the light soil class. The river class was confused with the commercial-industrial class. The transformed divergence between these pairs of classes were some of the lower ones in the set.

The same measure used for the Skylab MSS data set to obtain a quantitative estimate of the noise quality of the data were used for the Landsat MSS (see Table 2.7). The four areas were selected to match those used in the Skylab MSS as near as possible; the means and standard deviations have been corrected to match the quantization level used by the Skylab MSS. (The quantization level of the Skylab MSS is 256, while that of the Landsat 1 is 128 for channels 1,2, & 3 and 64 for channel 4). The two visible channels in the Landsat 1 MSS by these measures are not as noisy as the near infrared channels.

2.2.6 SUMMARY AND CONCLUSIONS

In comparison of the classification performance of the four data sets, the overall performances for the MSS data sets were better than those for the digitized photographic data sets. The classification performance of the digitized color IR data set was better overall than the digitized black and white multiband data set. Also the overall performance for the "optimum" four channels in the Skylab MSS data set (3,7,8,11) was essentially the same as that for the Landsat 1 MSS data set. However, when the four channels in the Skylab MSS (3,5,6,8) which most nearly correspond to those in the Landsat 1 MSS were used to classify the study area, the overall performance for the Skylab MSS

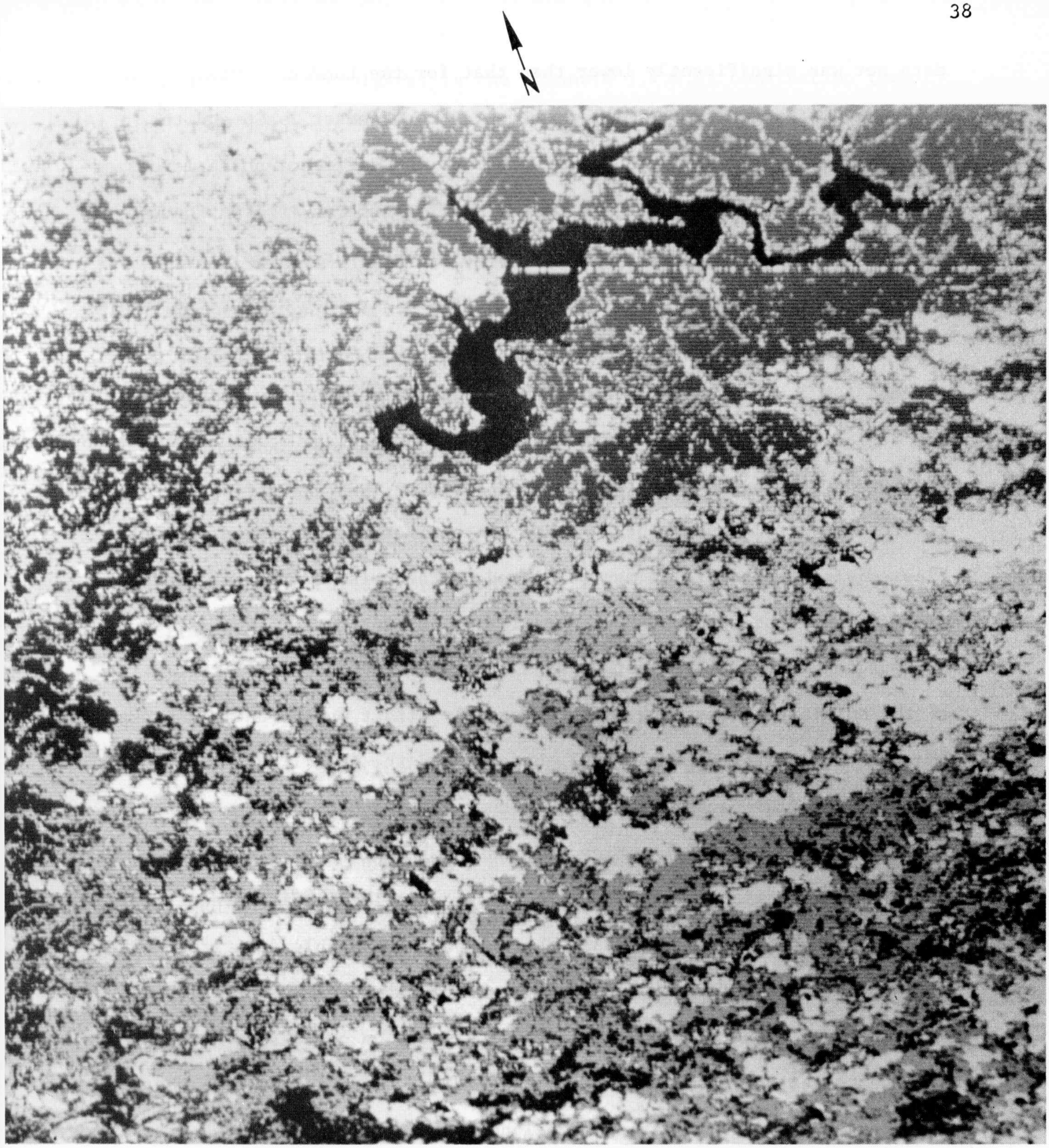


Fig. 2.13 Gray level coded classification of study area using Landsat I MSS sata set. Nine land use classes plus a cloud and cloud shadow class represented: in order of increasing brightness-Lake, River, Commercial-Industrial, Deciduous Forest, Residential, Coniferous Forest, Grass Bare Soil, Cloud and Cloud Shadow, and Extractive. Horizontal line near top was caused by a bad data line in the original Landsat data. Scale - 1:300,000.

data set was significantly lower than that for the Landsat 1 MSS.

The difference in the performances for the Landsat 1 MSS and the Landsat 1 simulated Skylab MSS may be due to the different noise levels of the two MSS sets, as well as the possible difference in information content of the two sets since the spectral windows of the four channels do not match precisely. In comparison of the data quality measure for the two MSS sets (see Table 2.7), the standard deviations for each of the channels in the Landsat 1 MSS are lower than those for the corresponding channels in the Skylab MSS. This measure indicates that the Skylab MSS is noisier than the Landsat 1 MSS and they also suggest that one must be careful in concluding that one spectral band is better than another for delineating different classes since the decision may be biased by the noise content of channels introduced by the optics and electronics of the scanner.

For this study the expected gains from the better spectral resolution of the multiband photography were apparently offset by the anomaly around the lake in the infrared spectral channels and the inability to spatially register the four bands exactly. In other areas and/or different uses of multispectral data these problems may not be significant. As has been reported in other studies {7,8}, there seems to be little difference in digitized multiemulsion and multiband photography. A useable digitized multiemulsion photographic data set, however, is much easier to obtain than a digitized multiband data set since the registration process is not needed.

In comparing the individual class results, there is one case where the addition of a middle infrared channel helped significantly in the classification, in delineating river from commercial-industrial and dark soil. The classification results for the river class were significantly higher in the channels 3,7,8,11 combination than for any other data set. The interclass transformed divergence measures for the separability of these two combinations were the highest in the channels 3,7,8,11 combination (see Tables 2.9-2.13). In the Landsat 1 and Skylab MSS data sets, the transformed divergence measurements using just one channel indicate that the middle infrared spectral bands (channels 11 & 12) for the Skylab MSS are the only channels to give a separation better than 1552 for the two combinations being considered. This was borne out by the classifications; if a middle infrared channel was not used, there was much confusion separating river from commercial-industrial and dark soils.

Caution must be taken when comparing the MSS data sets with the digitized photographic data sets because of the difference in the ground resolution of the two and the effect of the rather narrow river. The digitized color infrared photography separated the river from commercial-industrial and dark soil better than the Landsat MSS and the digitized multiband photography, but did a much poorer job separating river and old residential.

Many of the classification errors in all the data sets are due to boundaries where the resolution elements consisted of the energy from two different classes. Around Lake Monroe the averaging of the water and the forest results in a resolution element most similar to the coniferous forest or the commercial-industrial classes. Also, around the light soil areas adjacent to grass, the averaging of the two classes results in resolution elements most similar to the new residential class, and light soil areas adjacent to forest cover result in resolution elements most similar to the old residential class. The boundary classes may be separable from the classes to which they were assigned; however, this point was not examined in this study.

It is also believed that the difference in the size of the resolution

Table 2.9

INTERCLASS TRANSFORMED DIVERGENCE MATRIX
SKYLAB MSS (S192)
Channels 3,7,8,11

Average Transformed Divergence-1984

Minimum Transformed Divergence-1776

	Old Res	New Res	Com Ind	Extrac	Lt Soil	Dk Soil	Grass	Sprs Wd	Decid.	Conif.	River
New Res	1831										
Com Ind	1982	1999									
Extrac	2000	2000	2000								
Lt Soil	1999	1966	1983	1997							
Dk Soil	1916	1997	1776	2000	2000						
Grass	1927	1999	2000	2000	1995	2000					
Sprs Wd	1820	2000	2000	2000	2000	2000	1929				
Decid	1999	2000	2000	2000	2000	2000	1867	1995			
Conif	1976	2000	2000	2000	2000	2000	1987	1978	1849		
River	1998	2000	1998	2000	2000	2000	2000	2000	2000	1982	
Lake	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000

Table 2.10

INTERCLASS TRANSFORMED DIVERGENCE MATRIX
SKYLAB MSS (S192)
Channels 3,5,6,8

Average Transformed Divergence-1937 Minimum Transformed Divergence-1160

	Old Res	New Res	Com Ind	Extrac	Lt Soil	Dk Soil	Grass	Sprs Wd	Decid	Conif	River
New Res	1921										
Com Ind	1961	1998									
Extrac	2000	2000	2000								
Lt Soil	1880	1160	1839	1989							
Dk Soil	1780	1996	1309	2000	1978						
Grass	1893	1997	2000	2000	1930	2000					
Sprs Wd	1913	2000	2000	2000	2000	1999	1894				
Decid	1987	2000	2000	2000	1999	2000	1264	1865			
Conif	1985	2000	1999	2000	1998	1986	1974	1746	1759		
River	1984	2000	1367	2000	2000	1779	2000	2000	2000	1999	
Lake	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000

Table 2.11

INTERCLASS TRANSFORMED DIVERGENCE MATRIX
ERTS MSS
Channels 1,2,3,4

Average Transformed Divergence-1989 Minimum Transformed Divergence-1759

	Old Res	New Res	Com Ind	Extrac	Lt Soil	Dk Soil	Grass	Sprs Wd	Decid	Conif	River
New Res	1759										
Com Ind	2000	2000									
Extrac	2000	2000	2000								
Lt Soil	2000	2000	1997	1911							
Dk Soil	2000	1999	1788	2000	1992						
Grass	1999	2000	2000	2000	2000	2000					
Sprs Wd	2000	2000	2000	2000	2000	2000	1826				
Decid	2000	2000	2000	2000	2000	2000	2000	2000			
Conif	2000	2000	2000	2000	2000	2000	2000	1999	1896		
River	2000	2000	1868	2000	2000	1977	2000	2000	2000	2000	
Lake	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000

Table 2.12

INTERCLASS TRANSFORMED DIVERGENCE MATRIX
SKYLAB DIGITIZED COLOR IR (S190A)
Channels 1,2,3

Average Transformed Divergence-1924

Minimum Transformed Divergence-352

	Old Res	New Res	Com Ind	Extrac	Lt Soil	Dk Soil	Grass	Sprs Wd	Decid	Conif	River
New Res	1663										
Com Ind	1916	1843									
Extrac	2000	2000	2000								
Lt Soil	1997	1837	1781	1867							
Dk Soil	1797	1498	352	2000	1910						
Grass	1746	1962	2000	2000	2000	1997					
Sprs Wd	2000	2000	2000	2000	2000	2000	1699				
Decid	2000	2000	2000	2000	2000	2000	1986	1870			
Conif	2000	2000	2000	2000	2000	2000	2000	1989	1871		
River	1461	1999	1972	2000	1800	1985	1985	2000	2000	2000	
Lake	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000

Table 2.13

INTERCLASS TRANSFORMED DIVERGENCE
SKYLAB DIGITIZED MULTIBAND PHOTOGRAPHY (S190A)

Channels 1,2,3,4

Average Transformed Divergence-1972 Minimum Transformed Divergence-1028

	Old Res		NewRes	ComInd	Extrac	LtSoil	DkSoil	Grass	SprsWd	Decid			Conif	River
	1	2								1	2	3		
NewRes	1881	1998												
ComInd	2000	1948	1998											
Extrac	2000	2000	2000	2000										
LtSoil	2000	2000	1958	1982	1974									
DkSoil	2000	1993	1999	1028	2000	1853								
Grass	2000	2000	1971	2000	2000	2000	2000							
SprsWd	2000	2000	2000	2000	2000	2000	2000	1858						
Decid 1	2000	2000	2000	2000	2000	2000	2000	2000	1935					
2	2000	2000	2000	2000	2000	2000	2000	2000	2000					
3	2000	2000	2000	2000	2000	2000	2000	2000	2000					
Conif	2000	2000	2000	2000	2000	2000	2000	2000	1988	2000	2000	1392		
River	2000	1891	1995	1388	2000	1998	1556	1999	2000	2000	2000	2000	2000	
Lake	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000

element for the MSS's on Landsat 1 and Skylab and the digitized photography had a bearing on the classification performances. Because of the smaller resolution element for the digitized photography (see Table 2.14) each field is represented by more data points. The ratio of the number of interior data points to the number of boundary points is greater for the digitized photography than for the MSS data. This may have been a help in the overall classification performance for the digitized photographic data sets. As an example, the lake class was delineated better by the digitized photography than by the MSS data sets according to the classification performance results. This indication is misleading because the reason for the difference in performance is the greater number of interior points compared to the number of boundary points. To put this point in another perspective, it is felt that if the photography had been digitized for the same ground resolution as that of the MSS's on Landsat 1 and Skylab, there would be a larger difference in the classification performances. This conjecture was not examined however.

This study was not optimum in the sense that the best classification performances were obtained. By using more of the nonsupervised classification approach {3} and analyzing each set separately (not using the same training areas from set to set), better performances may be obtained for some or all of the multispectral data sets. Other spectral classes probably may be recognized that were not in the training areas used in this study.

Table 2.14

Ground Representation of Sample Elements

Data Set	Sample Size (m)	Area (hectares)
Skylab MSS (S192)	68x72	0.49
Landsat 1 MSS	59x79	0.47
Color IR	57x57	0.32
B&W Multiband	57x57	0.32

2.3 ALLEN COUNTY, INDIANA STUDY - SL/4

2.3.1 INTRODUCTION

This study was an attempt to compare two multispectral data sets obtained on January 25, 1974, in a machine aided land use analysis of a portion of Allen County, Indiana, (see Fig. 2.14). The study was over an area which had been glaciated (as opposed to Lake Monroe study area). The county includes part of the old Maumee Lake plain (western part of Allen County) and the Wabash and Eel River Sluiceways. The county is slightly rolling with approximately 40 meters of relief. It is relatively flat as compared with the area around Lake Monroe. The county includes the city of Fort Wayne with a population of around 180,000.

The area includes a variety of land uses - as commercial and industrial areas, parks and golf courses, residential areas, rivers, and farm land. Because of the time of the year (winter) most of the farm land did not have a crop cover. The farm land was of two general types, however, the flat lake plain west of Ft. Wayne and the slightly to moderate rolling farm ground over the remaining portion of the county. The land use classes in the study area that the analysis attempted to delineate and the corresponding number of spectral classes are given in Table 2.15. The land use classes were selected to correspond with the system suggested by Anderson, et. al. (1).

The two multispectral data sets included the SL/4 S192 MSS data obtained from the X-5 detector array and the S190A color IR photography. The color IR frame, roll 75 - frame 012, (Fig. 2.15) was digitized at Mead Technology Laboratories in the same manner as the photography described in section 2.2. A false color IR representation of the digitized color IR data set is shown in Figure 2.16. The SL/4 S192 MSS data set included eight channels of data (see Fig. 4.1 and Table 4.1).

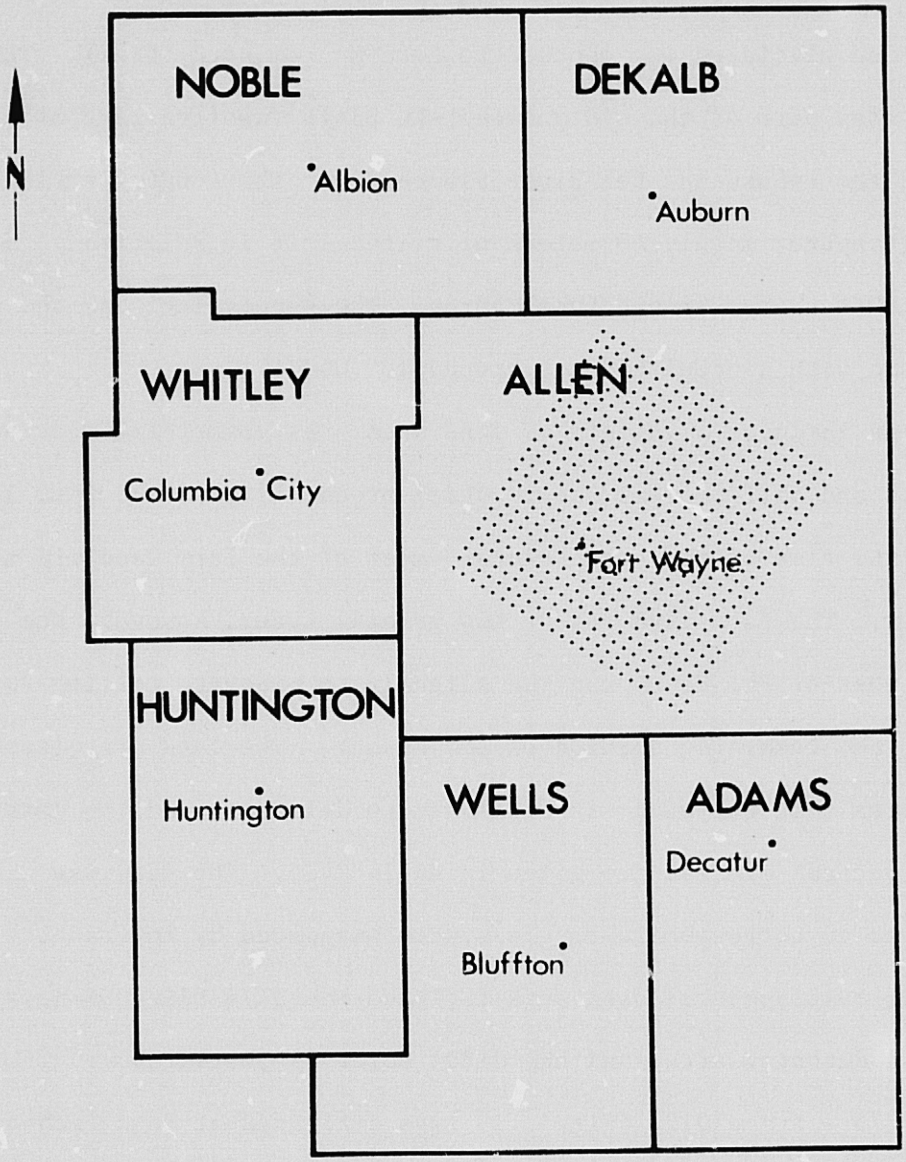


Fig. 2.14 Position of the SL/4 S190A color IR study area in Allen County, Indiana. Study area is shaded area. Scale - 3 cm = 20 km.

Table 2.15

Land Use Classes and Corresponding
Number of Spectral Classes

Land Use Classes Level 1	Level 2	Number of Spectral Classes
Urban		
	Residential	4
	Com-Ind	3
	Hard Surface	2
Agriculture		
	Bare Land	7
	Grass	2
Forest		1
Other		
	Snow	1

The results of the machine analysis of the S190A color IR photography were so negative in light of the results of the S192 analysis given in section 4. that it was decided it would be of dubious value to repeat the analysis of the S192 MSS data using the same training areas and analysis procedure as that used in the color IR photography analysis. The results of analysis of the digitized S190A color IR photography follows. General comparisons with the S192 MSS data are done using the results reported in section 4.

2.3.2 ANALYSIS OF DIGITIZED S190A COLOR IR PHOTOGRAPHIC DATA

The analysis procedure consisted of the selection of eight areas scattered within the study area. (See Fig. 2.16). Each of these eight areas were clustered into fifteen classes using all three channels. Using the underflight photography, S190A photography, and the Soil Survey of Allen County, Indiana {9}, the clusters were identified as to land use type. Data points representing the clusters (training points) were then

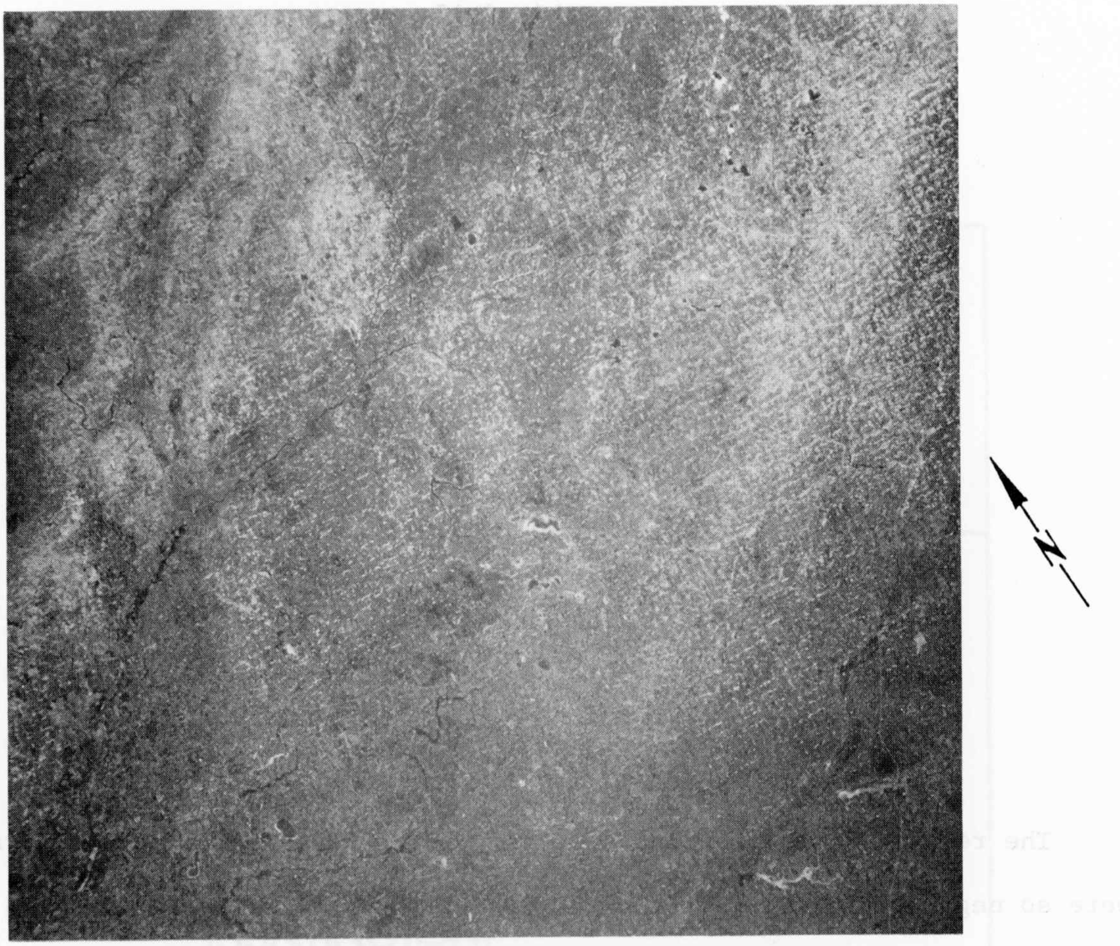


Fig. 2.15 Black and white reproduction of SL/4 S190A color IR frame over northwestern Indiana that was digitized. The study area is below the right center of frame. Altitude - 44km. Scale - 1:1,280,000.

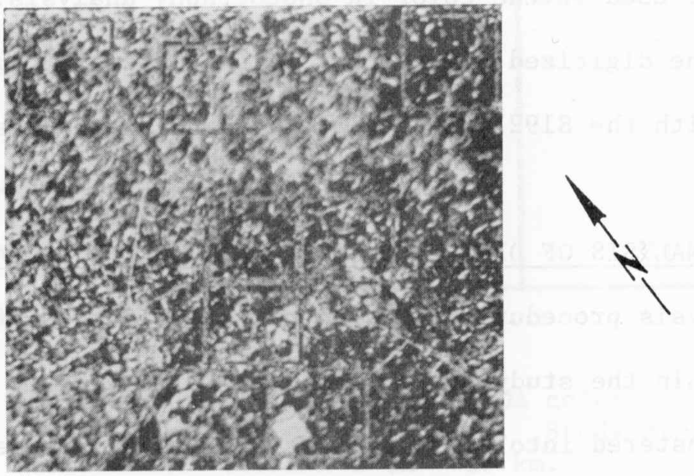


Fig. 2.16 Black and white reproduction of false-color IR representation of study area using digitized S190A color IR photography. This was obtained from a CRT digital display screen. The training areas are outlined. Scale - 1:480,000.

selected and the estimates of the three dimensional Gaussian statistics (mean vectors and covariance matrices) were calculated. The original 73 spectral classes were combined or discarded using the results of the separability processor (transformed divergence). The final set of classes included 20 different spectral classes representing six different land uses and snow (see Table 2.15). The river was not separable from the bare land surrounding it. The average transformed divergence value for the 20 spectral classes and those spectral classes with a separability measure less than 1300 are given in Table 2.16. Generally there is significant confusion between spectral class pairs with a transformed divergence separability measure less than 1300.

Table 2.16

Separability Measures for Confusional Spectral Class Pairs

Ave. Transformed Divergence for 159 pairwise combinations - 1834

Class Pail with Transformed Divergence Less Than 1300	Transformed Divergence Value* Using All Three Channels
Resid 1 - ComInd 2	675
Resid 1 - B. Land 3	1061
Resid 1 - B. Land 4	1031
Resid 2 - B. Land 3	1131
Resid 2 - B. Land 5	1116
Resid 3 - H. Surf 1	759
Resid 3 - B. Land 3	681
Resid 4 - B. Land 4	786
Resid 4 - B. Land 6	858
ComInd 1 - B. Land 6	757
H. Surf 1 - B. Land 2	883
H. Surf 1 - Snow/wood	627
H. Surf 1 - Snow	962
Grass 1 - B. Land 4	904

* Maximum value is 2000

The study area was classified using the maximum likelihood decision rule using both equal and weighted a priori probabilities. The weighted a priori probabilities were selected for the land use classes using the data from the 1968 Soil and Water Conservation Needs Inventory {10}. The weights for the spectral classes representing the same land use class were assigned in proportion to the number of training points representing each of the spectral classes. The resulting classification maps are shown in Figures 2.17 and 2.18.

The classification maps indicate that there was much confusion among the land use classes. The urban classes weren't concentrated in urban areas but scattered throughout the study area. The classification of the study area using the "best" four channels of the S192 data set is shown in Figure 4.5. The procedure used to obtain this classification map is given in section 4. No test areas were selected to determine the classification performance. However, one can obtain an indication of the performance by examining the classification accuracy of the pixels used for training. In general the training pixel performance is an upwards biased estimate of true classification performance. For this case, therefore, the training pixel performance (Table 2.17) can be regarded as a top limit, i.e. the true classification performance was probably less.

2.3.3 SUMMARY AND CONCLUSIONS

The results of the analysis of the digitized S190A color IR photography indicate that it is very difficult to separate land use classes using data acquired during the winter time over areas of dormant vegetation. The spectral range included in the photography did not contain enough information to separate the land use classes. Using photo interpretive techniques to distinguish classes in the S190A photography was also difficult. Determining

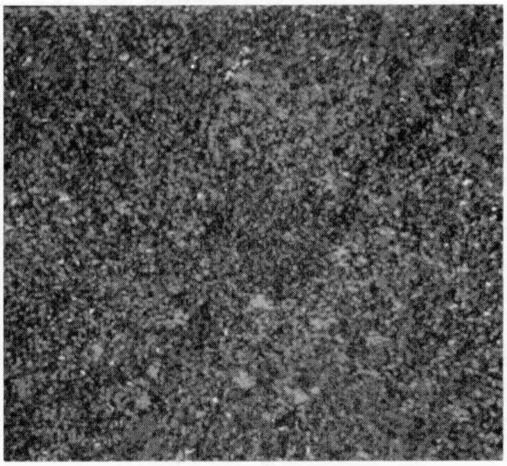


Fig. 2.17 Black and white reproduction of color coded classification of study area using digitized S190A color IR photography. Equal a priori probabilities used in classification. Five land use classes represented plus snow: Residential-red, Commercial/Industrial/ Hard Surface - black, Bare Land-light brown, Grasses-light green, Forest/Snow mix-dark green, Snow-white. Scale - 1:140,000.

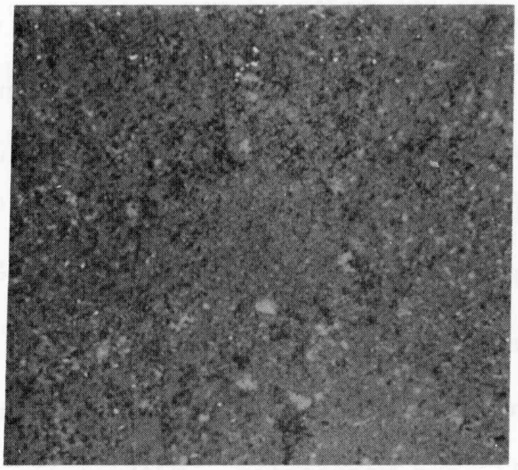


Fig. 2.18 Black and white reproduction of color coded classification of study area using digitized S190A color IR photography. Weighted a priori probabilities used in classification. Five land use classes represented plus snow: Residential-red, Commercial/ Industrial/Hard Surface-black, Bare Land-light brown, Grass-light green, Forest/Snow mix-dark green, Snow-shite. Scale - 1:140,000.

Table 2.17

Digitized SL/4 S190A Color IR
Classification Performance of Training Pixels

Land Use Class	No. of Pixels	Classification Performance: Equal *A Priori* Probabilities	Weighted *A Priori* Probabilities
Residential	579	56.5	38.9
Com-Ind	53	75.5	32.1
Hard Surface	58	58.0	81.8
Grass	114	87.7	64.0
Bare Land	933	72.7	85.2
Forest/Snow	18	83.3	5.6
Snow	112	80.4	67.9
Overall	1990	68.1	67.1

objects, as buildings, in the S190A color IR frame positively, were sometimes possible only because of having prior information from other sources.

The same problems were found in the analysis of the S192 MSS data when no far infrared (FIR) channels were used. A very significant improvement in distinguishing land uses was achieved, however, when a FIR or thermal channel was used in the analysis.

The main reason for the inability to distinguish land uses using wintertime data without thermal information is perceived to be the lack of live green vegetation. Land uses are characterized by different combinations of man made features, soil, and vegetation. Without the green vegetation, the Ft. Wayne scene contained very little contrast in the reflective channels. (See Fig. 2.15).

2.4 CONCLUSIONS FOR SENSOR EVALUATION STUDY

Better separation of land use features using machine processing techniques was obtained using multispectral data collected by scanners than by digitizing S190A photographic data. The increased accuracy was much more significant for the wintertime scene than the late spring scene. The primary reason for the increased accuracy was the increased spectral range of the multispectral scanners. The far infrared channel was very important for the land use study of Allen County with wintertime data. A middle infrared channel was important in both the late spring and winter scenes. These two regions are not available in the present two Landsat systems.

Slightly better results were obtained with the digitized multiemulsion photography than the digitized multiband photography. The multiemulsion multispectral data set was much easier and less expensive to assemble since the registration process was not needed.

The results of the Landsat 1 data and the best four channels of the interim Skylab S192 data were comparable. The noise in the S192 data probably offset the expected gains of the better spectral resolution and range. The Landsat-Skylab comparison may be scene and problem dependent. This study dealt primarily with land use; more may be gained with better spectral resolution for crop identification. The Lake Monroe area data set was not over an intensive agricultural area and also the data was obtained before many of the crops had emerged from the soil.

3. EVALUATION OF INTERIM (NON-FILTERED) AND FILTERED S192 DATA USING MACHINE PROCESSING ANALYSIS TECHNIQUES

3.1 OBJECTIVES

The results of the analysis of the twelve channel S192 interim (non-filtered) multispectral scanner data collected on June 10, 1973, over the area near Lake Monroe in south-central Indiana and other studies {11, 12} indicated that some of the channels may have been degraded by noise. The noise in the S192 data has been studied by groups at the Johnson Space Center {5, 13} and filters were designed to remove the major portion of the noise. {14, 15} The S192 data was then reprocessed using these filters.

The purpose of this study was to compare the interim (non-filtered) (Fig. 2.10) and filtered S192 data (Fig. 3.1) in a machine aided land use analysis of the area in south-central Indiana that had been studied and reported in section 2.2. Multispectral scanner data can appear noisy and degraded to the human eye with very little affect on the results of machine aided analysis if the noise is correlated {16} from channel to channel. The study area of 108,000 hectares included the cities of Bedford and Mitchell, a portion of Lake Monroe, agricultural areas along the East Fork of the White River, forests, and grasslands.

Unfortunately, the study is not complete since not all of the thirteen channels were available in the interim and filtered data sets. The channels available and scientific data output channels utilized in the two data sets are given in Table 3.1.

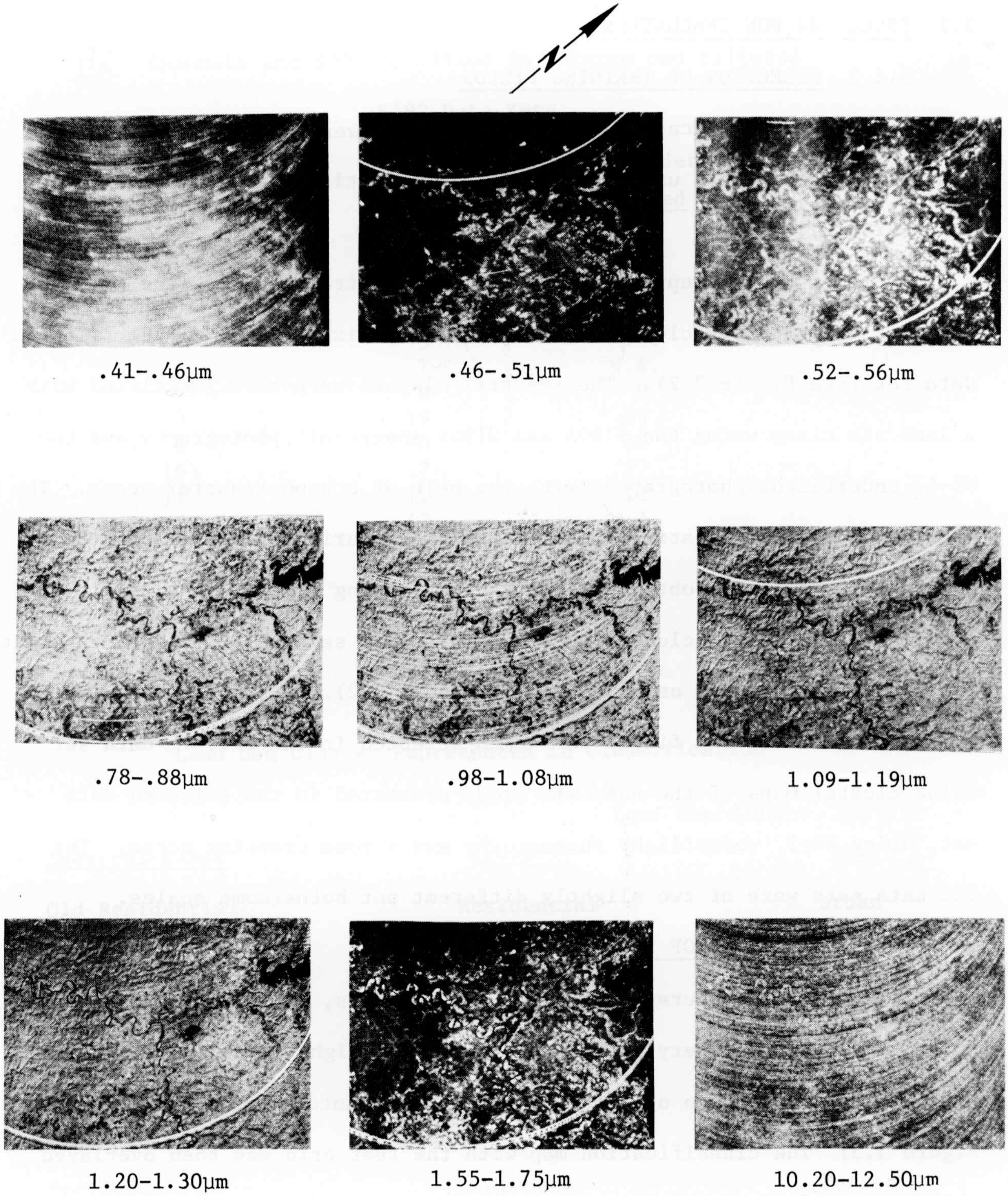


Fig. 3.1 Skylab SL/2 MSS (S192) 9-channel filtered data set obtained from CRT digital display screen using 16 gray levels. Scale 1:1,000,000

3.2 PROCEDURE FOR EVALUATION

3.2.1 SELECTION OF TRAINING FIELDS

Land use classifications of the study area were done with the interim and filtered data sets using the pattern recognition techniques included in LARSYS {2}.

Training fields representing different spectral classes were selected from six individually clustered 1,000 to 2,000 pixel blocks in the filtered data set (see Figure 3.2). The spectral classes were then identified with a land use class using the S190A and S190B spacecraft photography and the WB-57 underflight photography, with the help of a zoom transfer scope. The multivariate Gaussian statistics (mean vector and covariance matrix) for the spectral classes were obtained from these training fields. The resulting training statistics included fourteen spectrally separable classes representing ten different land use classes (see Table 3.2).

The same training fields were then selected in the interim data set using cluster maps of the same six areas clustered in the filtered data set, using WB-57 underflight photography and a zoom transfer scope. The two data sets were of two slightly different but bothersome scales.

3.2.2 SELECTION OF TEST BLOCKS

To assess the accuracy of the classifications, a grid of two pixel by two pixel blocks every eight lines and every eight columns were outlined on a classification map of the study area using interim data. (See Figure 3.3) The classification map with the test grid was then overlayed with the WB-57 underflight photography using the zoom transfer scope and each test block was evaluated as to whether it represented a single land use class. If the test block did represent a single class then the block was annotated as to type of land use class; if the block contained more than one land use class then it was discarded.

Table 3.1

Channels and SDO's Utilized in Interim and Filtered

S192 Data Sets

	SDO's Utilized in Data Sets	
Channel	Interim	Filtered
1	22	22
2	18	18
3	1	1
4	3	N.A.
5	5	N.A.
6	7	N.A.
7	9	9
8	19	19
9	20	20
10	17	17
11	11	11
12	13	N.A.
13	N.A.	21

* Not Available

Table 3.2

Land Use Classes Represented in Classification

	Land Use Class	
Spectral Class	Level II	Level I
Old Residential	Residential	Urban
New Residential	Residential	Urban
Com-Ind	Com-Ind	Urban
Extractive	Extractive	Urban
Soil 1	Soil	Agriculture
Soil 2	Soil	Agriculture
Agriculture Crop		Agriculture
Grass 1	Grass	Agriculture
Grass 2	Grass	Agriculture
Deciduous 1	Deciduous	Forest
Deciduous 2	Deciduous	Forest
Coniferous	Coniferous	Forest
River	River	Water
Lake	Lake	Water

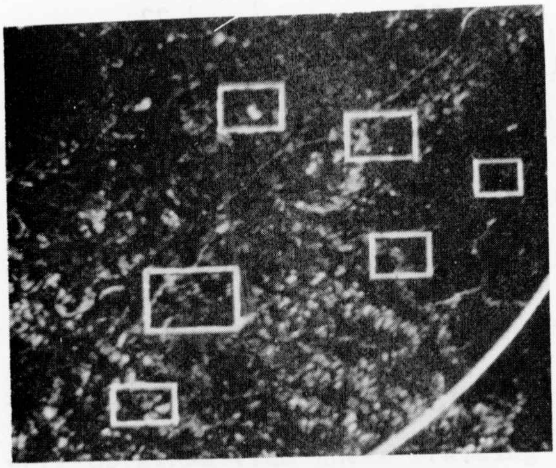


Fig. 3.2 Black and white reproduction of color enhancement of study area using channels 3,7, and 11 of the filtered data set showing location of six training blocks. Scale - 1:500,000.

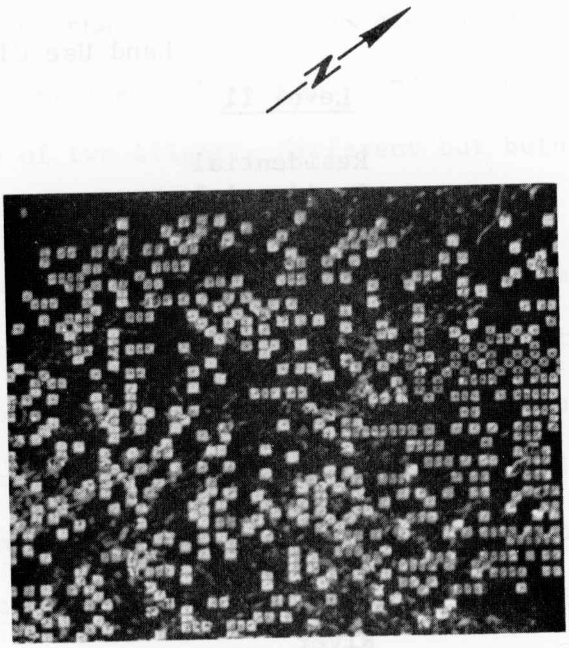


Fig. 3.3 Black and white reproduction of color enhancement of study area using channels 3,7 and 11 of the interim data set showing forty percent of the test blocks. Scale - 1:500,000

The resulting test blocks were then outlined on a classification map obtained using the filtered data. The uniformity of the test blocks was checked again using the filtered data classification map and underflight photography as described previously. If a test block in the filtered data was not uniform that test block was discarded from both sets.

The grid of test blocks was originally outlined on a gray level map with sixteen different levels of channel 11 of the data. However, for this data set, a single channel of data was not enough information to accurately overlay the underflight photography and the gray level map with the zoom transfer scope to check the uniformity of the test blocks.

The classification maps discussed above delineated five major classes - soil, grass, forest, river, and lake. The statistics used to obtain the interim data classification map were from a previous study. The statistics used to obtain the filtered data classification map were a subset of those utilized in this study. Only five of the fourteen spectral classes were used. This procedure was followed to minimize the bias of the analyst yet retain enough information to accurately determine the uniformity of the test blocks.

Because of the small representation of the urban, river, and coniferous classes, more test areas were chosen so that there would be enough points to obtain a reasonable estimate of the classification performance for these classes. (This was in addition to those obtained in the grid selection.) The final set of test blocks represented around 2.1 percent of the study area (see Table 3.3)

3.2.3 SELECTION OF CHANNEL COMBINATIONS

The best sets of 1, 2, 3, 4, 5, and 6 channels were obtained using the highest average transformed divergence measure of all pairwise combinations of the fourteen spectral classes ignoring the separability measure between the two soil classes, the grass classes and the two deciduous classes. See section 2.2.1 for a discussion of average and minimum transformed divergence. The channel combinations used for the classifications are given in Table 3.4. and the average and minimum transformed divergence values for the interim and filtered data sets are given in Tables 3.5 and 3.6 respectively. The average transformed divergence values for the two data sets are plotted in Figure 3.4.

Since the results of interest were the classification performance of the test pixels, only the test blocks were classified. They were classified using the maximum likelihood classification rule with both equal a priori probabilities and weighted a priori probabilities obtained from the data in the 1968 Soil and Water Conservation Needs Inventory for Lawrence County, Indiana. Lawrence County was the major portion of the study area. The classification performance results for the twelve different channel combinations are given in Tables 3.6 thru 3.18. The overall classification performance results along with their 95% confidence internal for the level one and level two classifications using both equal and weighted a priori probabilities are illustrated in Figures 3.5, and 3.6. The 95% confidence internal (C.I.) was calculated according to the formula given in equation 3.1 {17}.

$$C.I. = \pm (1.96\sqrt{p(100-p)/n}+50/n) \qquad (3.1)$$

where C.I. is the 95% confidence interval, p is the classification performance results (percent correctly classified), and n is the number of pixels. The overall number of test pixels was 4,896.

3.2.4 NOISE EVALUATION

The standard deviations of the data values for portions of Lake Monroe were computed to compare the relative noise in each channel of the

Table 3.3

Number of Test Pixels for Land Use Classes

Class	No. of Test Points
Residential	91
Commercial-Industrial	32
Extractive	26
Soil	264
Grass	1400
Deciduous	2696
Coniferous	78
River	37
Lake	272
Total	4896

Table 3.4

Channel Combinations Used for Classifications
Using D_T(ave) as Measure of Separability
and
The Feature Attributes

Channel Combinations	Combinations Attribute
11	Best 1 channel interim and filtered
1,2,11	Best 3 channels filtered including channels 1&2
2,7,8,11	Best 4 channels filtered
2,7,9,11	Best 4 channels filtered without channel 8
3,7,9,11	Best 4 channels interim
1,2,7,11	Best 4 channels filtered including channel 1
3,7,8,10	Best 4 channels filtered without channel 11
2,7,8,9,11	Best 5 channels filtered
2,3,7,9,11	Best 5 channel interim
3,7,9,10,11	2nd Best 5 channels interim
2,3,7,9,10,11	Best 6 channels interim
2,7,8,9,10,11	2nd Best 6 channels filtered

Table 3.5

Separability Measures for Interim Data Feature Sets

Channel Combinations	*Average Transformed Divergence Value	*Minimum Transformed Divergence Value	Class Pair with Minimum Value
11	1474	25	Commercial and Industrial-Grass 1
1,2,11	1722	417	New Residential-Ag Crop
2,7,8,11	1943	1058	Old residential - New residential
2,7,9,11	1952	1159	Old residential - New residential
3,7,9,11	1958	1304	Old residential - New residential
1,2,7,11	1925	895	Old residential - New residential
3,7,8,10	1891	1066	Grass 1 - Deciduous 1
2,7,8,9,11	1967	1374	Old residential - New residential
2,3,7,9,11	1972	1410	Old residential - New residential
3,7,9,10,11	1972	1467	Grass 1 - Deciduous 1
2,3,7,9,10,11	1982	1537	Grass 1 - Deciduous 1
2,7,8,9,10,11	1977	1546	Grass 1 - Deciduous 1

* 2000 is the maximum value

Table 3.6

Separability Measures for Filtered Data Feature Sets

Channel Combinations	*Average Transformed Divergence Value	*Minimum Transformed Divergence Value	Class Pair with Minimum Value
11	1490	64	New residential - Grass 2
1,2,11	1869	853	Deciduous 2 - Coniferous
2,7,8,11	1977	1359	Deciduous 2 - Coniferous
2,7,9,11	1967	1179	Old residential - New residential
3,7,9,11	1958	1236	Deciduous 2 - Coniferous
1,2,7,11	1960	1096	Old residential - New residential
3,7,8,10	1923	1071	Old residential - New residential
2,7,8,9,11	1984	1535	Deciduous 2 - Coniferous
2,3,7,9,11	1974	1293	Old residential - New residential
3,7,9,10,11	1967	1357	Deciduous 2 - Coniferous
2,3,7,9,10,11	1981	1558	Old residential - New residential
2,7,8,9,10,11	1988	1609	Deciduous 2 - Coniferous

* 2000 is the maximum value

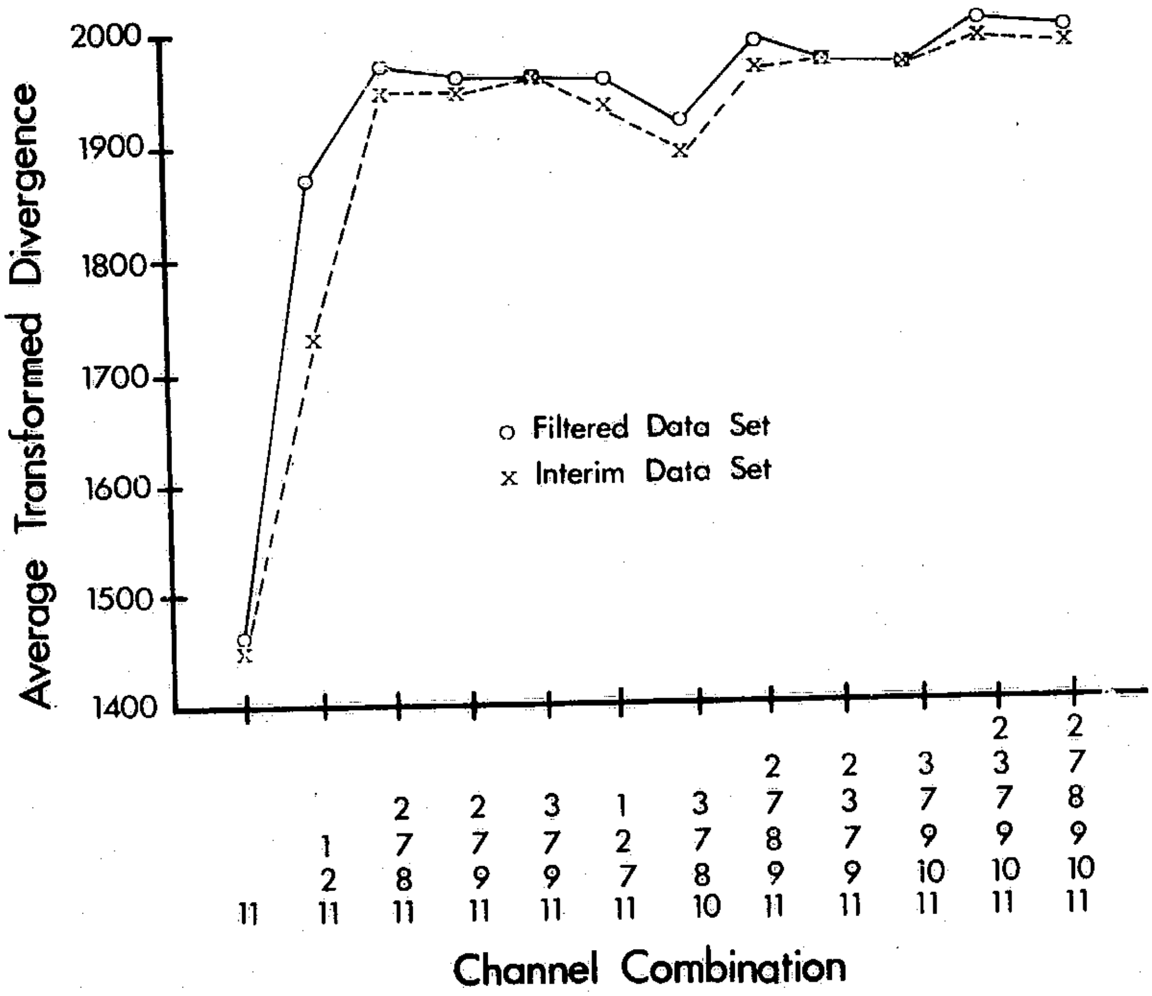


Fig. 3.4 Interim and filtered average transformed divergence separability measures of channel combinations.

Table 3.7

Classification Results using Channel 11

Land Use Class	Equal *A Priori* Probabilities Interim*	Equal *A Priori* Probabilities Filtered*	Weighted *A Priori* Probabilities Interim*	Weighted *A Priori* Probabilities Filtered*
Urban	73.2	65.1	4.7	4.0
Res	79.1	63.7	0.0	0.0
Com Ind	0.0	6.3	0.0	0.0
Extrac	46.2	46.2	26.9	23.1
Agriculture	34.5	45.1	87.2	80.7
Soil	81.4	89.4	87.1	92.7
Grass	0.0	10.5	82.4	73.4
Forest	74.4	72.9	92.1	94.5
Decid	67.5	60.5	89.2	90.2
Conif	43.6	65.4	37.2	51.3
Water	93.9	95.8	90.6	90.0
River	51.4	64.9	0.0	0.0
Lake	84.9	94.5	98.4	97.4
Overall				
Level 1	60.8	63.8	87.7	86.5
Level 2	49.1	49.3	83.6	82.0

*per cent correct

Table 3.8

Classification Results using Channels 1,2,11

Land Use Class	Equal *A Priori* Probabilities Interim*	Equal *A Priori* Probabilities Filtered*	Weighted *A Prioiri* Probabilities Interim*	Weighted *A Prioiri* Probabilities Filtered*
Urban	70.5	75.2	42.3	68.5
Res	53.8	59.3	25.3	56.0
Com Ind	50.0	68.8	28.1	59.4
Extrac	57.7	65.4	42.3	50.0
Agriculture	75.5	81.2	86.0	80.9
Soil	87.5	92.7	90.9	94.2
Grass	62.1	68.5	80.9	73.6
Forest	77.8	91.0	90.9	95.4
Decid	70.0	79.4	88.5	90.5
Conif	43.6	55.1	32.1	39.7
Water	97.4	97.4	94.2	96.1
River	73.0	93.8	10.8	70.3
Lake	77.2	96.0	99.3	97.8
Overall				
Level 1	77.9	87.3	87.9	89.3
Level 2	68.2	77.0	84.0	88.4

*per cent correct

Table 3.9

Classification Results using Channels 2,7,8,11

Land Use Class	Equal *A Priori* Probabilities Interim*		Filtered*		Weighted *A Priori* Probabilities Interim*		Filtered*	
Urban	72.5		77.9		54.4		71.8	
Res		82.4		78.0		58.2		82.4
Com Ind		62.5		78.1		56.3		75.0
Extrac		46.2		53.8		34.6		46.2
Agriculture	84.6		83.7		89.3		86.1	
Soil		86.0		93.8		90.2		94.6
Grass		82.4		80.1		85.7		82.0
Forest	85.6		91.1		89.6		93.4	
Decid		83.2		88.8		87.9		91.4
Conif		69.2		61.5		66.7		61.5
Water	97.7		96.8		96.4		95.5	
River		86.5		81.1		75.7		70.3
Lake		97.4		98.2		98.2		98.2
Overall								
Level 1	85.6		88.3		88.9		90.2	
Level 2		83.4		86.2		86.5		87.9

*per cent correct

Table 3.10

Classification Results using Channels 2,7,9,11

Land Use Class	Equal *A Priori* Probabilities Interim*		Filtered		Weighted *A Priori* Probabilities Interim*		Filtered*	
Urban	73.8		79.6		55.0		73.8	
Res		84.6		83.5		57.1		78.0
Com Ind		65.0		75.0		62.5		68.8
Extrac		38.5		53.8		30.8		46.2
Agriculture	86.2		85.1		89.0		86.6	
Soil		87.5		93.6		89.0		95.4
Grass		84.4		82.0		85.9		82.8
Forest	84.3		92.8		89.5		94.2	
Decid		82.8		89.4		88.1		92.3
Conif		61.5		53.8		62.8		53.8
Water	98.1		97.7		96.4		96.1	
River		86.5		83.8		73.0		70.3
Lake		97.1		98.5		97.1		98.5
Overall								
Level 1	85.5		90.0		88.7		90.9	
Level 2		83.7		87.9		86.5		88.6

*per cent correct

Table 3.11

Classification Results using Channels 3,7,9,11

Land Use Class	Equal *A Priori* Probabilities Interim*		Equal *A Priori* Probabilities Filtered*		Weighted *A Priori* Probabilities Interim*		Weighted *A Priori* Probabilities Filtered*	
Urban	75.2		83.9		57.7		78.5	
Res		82.4		85.7		59.3		79.1
Com Ind		75.0		75.0		68.8		75.0
Extrac		34.6		65.4		26.9		65.4
Agriculture	89.6		85.4		90.9		88.9	
Soil		87.9		93.8		88.6		95.3
Grass		88.4		82.2		88.6		86.2
Forest	85.0		90.6		89.3		92.7	
Decid		82.9		88.2		87.1		90.4
Conif		65.4		59.0		70.5		59.0
Water	98.4		97.7		97.4		96.1	
River		91.9		86.5		83.8		[illegible]
Lake		98.2		98.5		98.2		[illegible]
Overall								
Level 1	87.2		88.9		89.5		91.[illegible]	
Level 2		85.4		86.5		87.0		[illegible]

Table 3.12

Classification Results using Channels 1,2,7,11

Land Use Class	Equal *A Priori* Probabilities Interim*		Equal *A Priori* Probabilities Filtered*		Weighted *A Priori* Probabilities Interim*		Weighted *A Priori* Probabilities Filtered*	
Urban	71.1		77.9		47.7		70.5	
Res		72.5		81.3		44.0		72.5
Com Ind		78.1		81.3		65.0		78.1
Extrac		46.2		46.2		30.8		38.5
Agriculture	82.6		83.9		88.6		85.5	
Soil		83.7		92.8		87.9		95.0
Grass		79.6		80.5		85.2		81.4
Forest	82.8		91.9		89.0		94.3	
Decid		80.4		89.5		87.1		92.0
Conif		56.4		59.0		62.8		59.0
Water	97.7		97.4		95.8		96.1	
River		83.8		86.5		67.6		75.7
Lake		97.8		98.5		97.8		98.5
Overall								
Level 1	83.2		88.9		88.0		90.4	
Level 2		80.6		86.7		85.4		88.1

*per cent correct

Table 3.13

Classification Results using Channels 3,7,8,10

Land Use Class	Equal *A Priori* Probabilities				Weighted *A Priori* Probabilities			
	Interim*		Filtered*		Interim*		Filtered*	
Urban	72.5		63.8		58.4		53.0	
Res		81.3		67.0		63.7		53.8
Com Ind		59.4		53.1		50.0		50.0
Extrac		50.0		61.5		38.5		50.0
Agriculture	80.3		82.0		82.8		86.3	
Soil		76.5		80.3		85.2		84.8
Grass		82.1		83.7		81.1		85.5
Forest	83.0		78.6		87.7		82.8	
Decid		80.3		75.5		85.4		80.3
Conif		74.4		62.8		73.1		62.8
Water	92.6		90.9		89.0		89.3	
River		43.2		35.1		16.2		21.6
Lake		98.5		97.8		98.5		97.5
Overall								
Level 1	82.3		80.2		85.1		83.6	
Level 2		81.0		78.5		83.3		81.4

*per cent correct

Table 3.14

Classification Results using Channels 2,7,8,9,11

Land Use Class	Equal *A Priori* Probabilities				Weighted *A Priori* Probabilities			
	Interim*		Filtered*		Interim*		Filtered*	
Urban	71.1		78.5		56.4		71.8	
Res		81.3		80.2		60.4		72.5
Com Ind		62.5		75.0		59.4		75.0
Extrac		42.3		53.8		34.6		42.3
Agriculture	86.8		84.5		88.8		86.4	
Soil		86.4		94.2		89.4		94.2
Grass		89.1		80.7		85.8		82.5
Forest	84.5		91.1		89.1		93.2	
Decid		83.0		89.3		87.7		91.6
Conif		60.3		53.8		62.8		51.3
Water	98.4		96.8		96.4		95.5	
River		89.2		81.1		73.0		70.3
Lake		97.1		98.2		97.1		98.2
Overall								
Level 1	85.8		88.6		88.5		90.2	
Level 2		83.9		86.5		86.3		87.9

*per cent correct

Table 3.15

Classification Results using Channels 2,3,7,9,11

Land Use Class	Equal A Priori Probabilities Interim*		Equal A Priori Probabilities Filtered*		Weighted A Priori Probabilities Interim*		Weighted A Priori Probabilities Filtered*	
Urban	74.5		82.6		61.1		75.0	
Res		81.3		83.5		63.7		79.0
Com Ind		68.8		75.0		65.6		71.9
Extrac		42.3		69.2		30.8		50.0
Agriculture	90.2		88.2		90.8		89.1	
Soil		87.9		95.0		89.4		95.0
Grass		89.3		85.6		88.5		86.2
Forest	85.7		92.1		89.6		93.6	
Decid		84.2		89.9		88.2		91.6
Conif		60.3		55.1		61.5		53.1
Water	99.4		98.1		98.1		97.4	
River		97.3		89.2		86.5		83.8
Lake		97.8		98.5		98.2		98.2
Overall								
Level 1	87.9		90.7		89.7		91.6	
Level 2		85.9		88.6		87.7		89.4

*per cent correct

Table 3.16

Classification Results using Channels 3,7,9,10,11

Land Use Class	Equal A Priori Probabilities Interim*		Equal A Priori Probabilities Filtered*		Weighted A Priori Probabilities Interim*		Weighted A Priori Probabilities Filtered*	
Urban	73.2		82.6		64.4		78.5	
Res		78.0		85.7		69.2		80.2
Com Ind		75.0		71.9		68.8		71.9
Extrac		38.5		65.4		26.9		61.5
Agriculture	88.6		86.0		90.0		88.3	
Soil		88.6		91.3		89.4		88.3
Grass		87.4		83.2		87.9		85.6
Forest	86.8		90.3		91.2		92.5	
Decid		85.0		88.3		89.5		90.5
Conif		62.8		53.8		64.1		53.8
Water	98.7		98.1		97.7		96.8	
River		91.9		89.2		86.5		78.4
Lake		97.8		98.5		98.2		98.5
Overall								
Level 1	87.8		88.8		90.4		90.8	
Level 2		85.8		86.7		88.2		88.6

*per cent correct

Table 3.17

Classification Results using Channels 2,3,7,9,10,11

Land Use Class	Equal *A Priori* Probabilities Interim*		Filtered*		Weighted *A Priori* Probabilities Interim*		Filtered*	
Urban	74.5		82.6		63.8		77.2	
Res		81.3		84.6		67.0		80.2
Com Ind		68.8		71.9		62.5		71.9
Extrac		42.3		65.4		38.5		50.0
Agriculture	89.3		88.0		90.1		88.7	
Soil		88.6		93.5		90.2		93.5
Grass		88.2		85.6		87.6		86.0
Forest	87.0		92.0		91.0		93.7	
Decid		85.9		90.2		90.0		92.2
Conif		53.8		56.4		52.6		56.4
Water	99.0		98.4		99.0		98.1	
River		94.6		91.9		94.6		89.2
Lake		97.8		98.5		98.5		98.9
Overall								
Level 1	88.2	8	89.7		90.4		91.6	
Level 2		86.5		88.6		88.4		89.7

*per cent correct

Table 3.18

Classification Results using Channel 2,7,8,9,10,11

Land Use Class	Equal *A Priori* Probabilities Interim*		Filtered*		Weighted *A Priori* Probabilities Interim*		Filtered*	
Urban	69.8		78.5		63.8		74.5	
Res		80.2		80.2		71.4		78.0
Com Ind		59.4		75.0		59.4		71.9
Extrac		38.5		53.8		34.6		42.3
Agriculture	86.6		85.3		88.6		86.4	
Soil		88.3		93.8		89.4		93.8
Grass		84.8		81.7		83.4		82.4
Forest	86.2		89.9		91.0		93.0	
Decid		84.8		88.1		89.7		91.5
Conif		51.3		53.8		53.8		50.0
Water	98.1		97.1		96.4		95.5	
River		89.2		83.8		78.4		70.3
Lake		97.1		98.2		97.1		98.2
Overall								
Level 1	86.5		88.3		89.6		90.2	
Level 2		84.7		86.1		87.4		87.9

*per cent correct

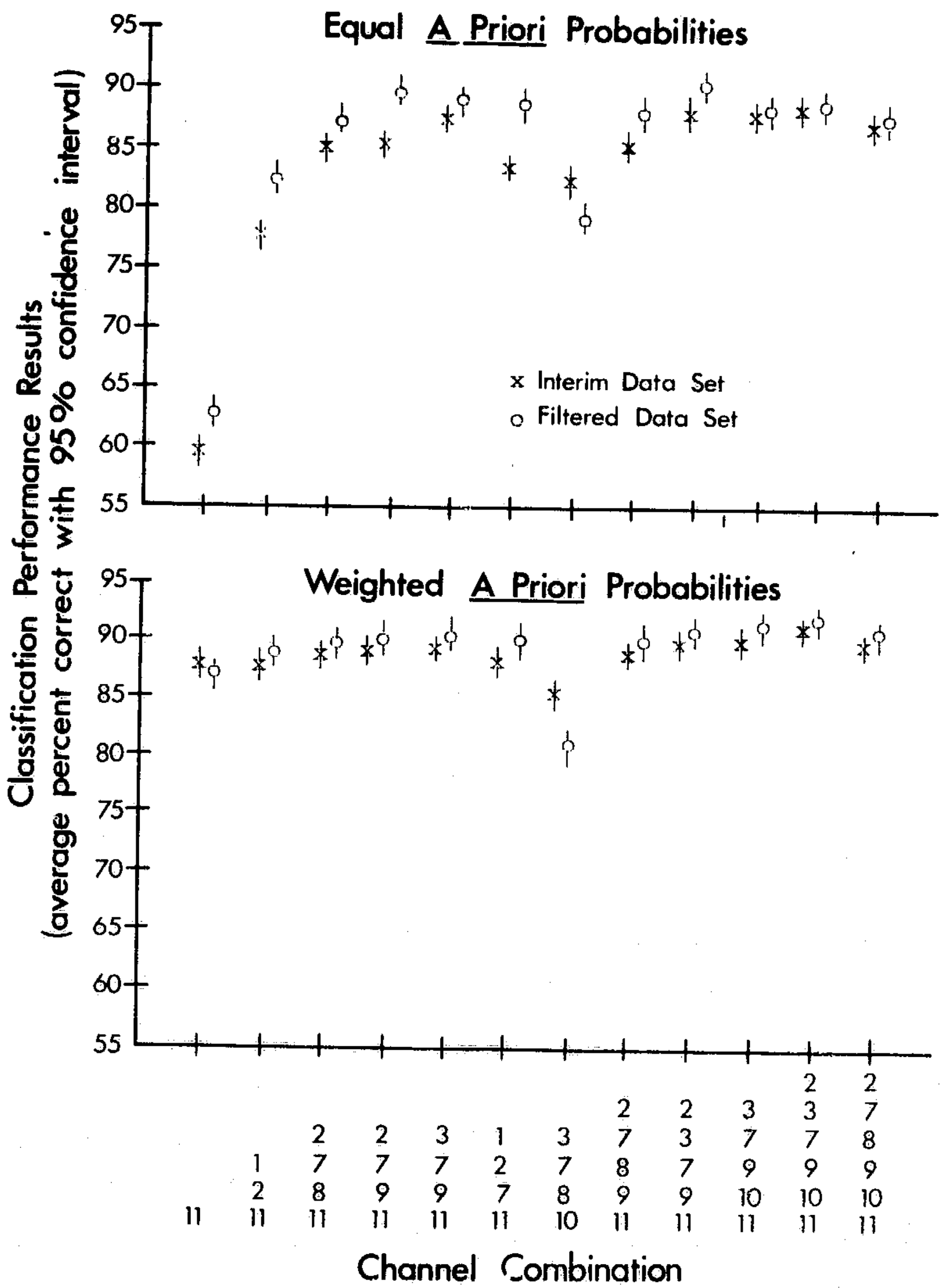


Fig. 3.5 Interim and filtered overall classification performance results for level 1 classifications with both equal and weighted a priori probabilities.

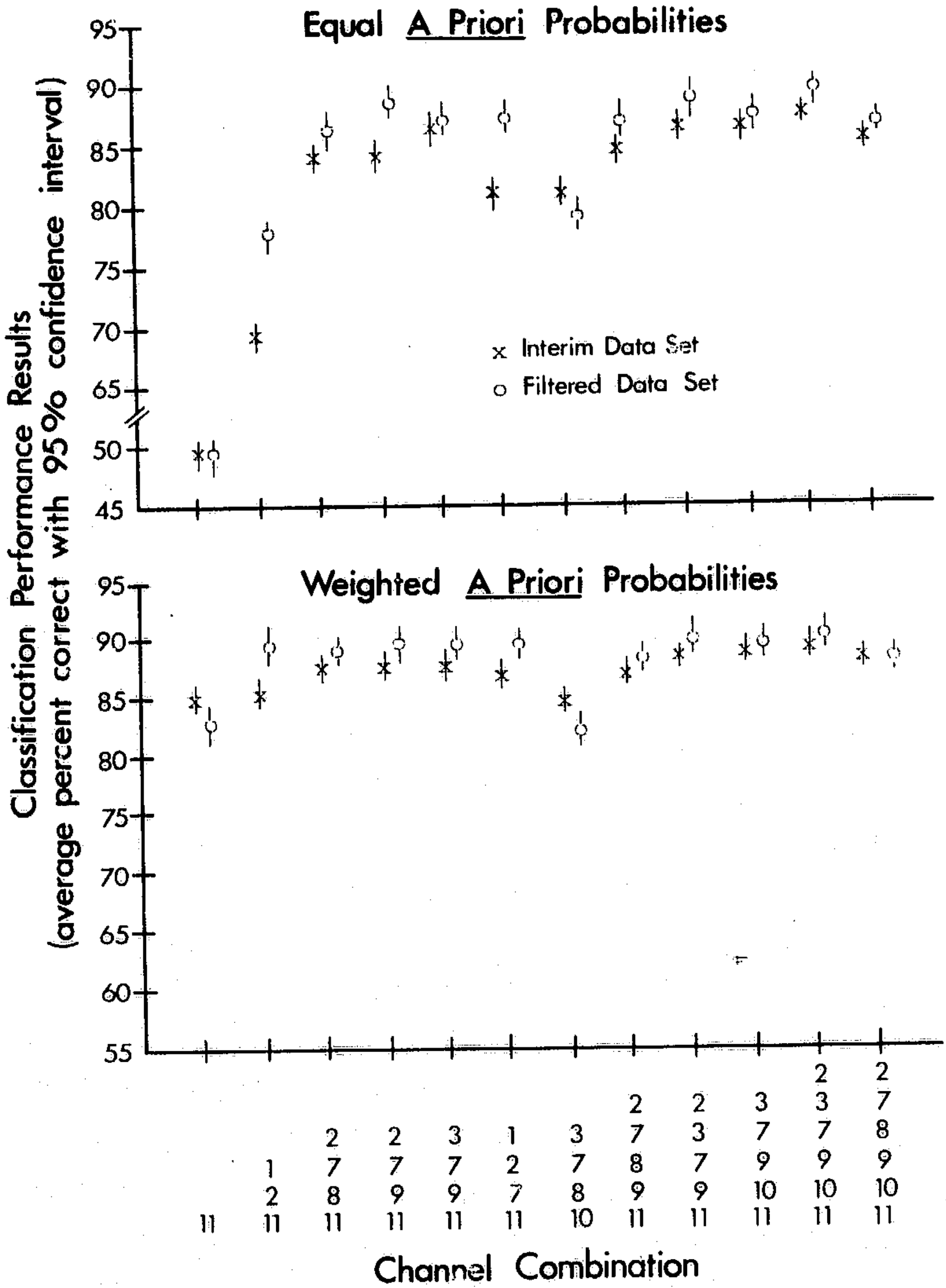


Fig. 3.6 Interim and filtered overall classification performance results for level 2 classifications with both equal and weighted a priori probabilities.

two data sets similar to the method described in section 2.2.4. The values are given in Table 3.19.

3.3 RESULTS OF ANALYSIS

The results in Table 3.19 indicate that overall there was significantly less noise in the visible channels and slightly more noise in the infrared channels. There was little change in channel 3. Channel 3 was the best visible channel from a noise viewpoint in the interim data set. The greater noise in channel 8 was caused by subframe dropouts in the filtered data set which were not present in the interim data set.

The separability measures illustrated in Figure 3.4 indicate that the classes of interest are more separable in the filtered data set for those channel combinations with four or fewer channels and which include channels one and/or two. Apparently when five or more channels are used, enough information is present to compensate for the lack of information in channel two. There was a significant increase in separability from interim to filtered data for channel combinations which include both channels one and two.

The classifications performance results (Figures 3.5 and 3.6) follow closely to what the separability measures in Figure 3.4 indicated. The classification performance results of the filtered data set increased the most for those channel combinations that used both channels 1 and 2. The results increased only sightly for those channel combinations which did not include either channel 1 or 2. Also, the results increased only slightly for those channel combinations which include five or six channels even though channel 2 was present.

3.4 CONCLUSIONS

The filtering process for the Skylab S192 data did improve the data, at least channels 1 and 2, for machine processing. Unfortunately, no direct statement can be made about channels 4, 5, and 6 since they weren't

Table 3.19

Standard Deviations of Channels for Similar Areas of Lake Monroe

Channel	Interim Mean	Interim Std Dev.	Filtered Mean	Filtered Std Dev.
1	137.64	14.08	107.05	5.30
2	99.01	6.25	93.39	3.39
3	53.31	3.26	50.38	3.08
4	44.80	3.96	N.A.	N.A.
5	36.34	3.49	N.A.	N.A.
6	34.62	4.53	N.A.	N.A.
7	42.83	1.90	18.87	2.95
8	38.88	3.69	18.92	5.24
9	33.20	2.74	20.80	3.29
10	49.45	4.17	13.21	4.38
11	44.59	1.55	6.82	2.89
12	3.49	2.50	N.A.	N.A.
13 (SDO 15)	N.A.	N.A.	124.78	11.29
13 (SDO 21)	N.A.	N.A.	146.34	7.62

*N.A. - Not Available

available to the investigators. One can probably safely infer, though, that those channels were improved for machine processing since the same techniques were used and since they contained noise of the same order as channel 2. No significant change in the reflective infrared channels (7-11) was apparent. The results of the classifications (Fig. 3.5) didn't suggest any momentous differences, even though the noise data (Table 3.19) indicated that the filtered reflective infrared channels were noisier than the respective interim channels.

Assessing the value of filtering multispectral scanner data or determining the correct filtering process is difficult. Sometimes the data is improved; other times filtering can degrade the data. For this data set channels one and two were greatly improved from a pictorial viewpoint; however, from a machine processing viewpoint there was little change. The primary reason for these results is probably the fact that only two of the eight channels common in both data sets were seriously degraded. Information in three or more of the other six channels offset the degradation in the noisiest two channels.

4. A LAND USE ANALYSIS UTILIZING THE SKYLAB S192 DATA FROM THE X-5 DETECTOR ARRAY

4.1 INTRODUCTION AND OBJECTIVES

Land use studies using wintertime spacecraft multispectral scanner (MSS) data with only reflective channels {visible (VIS), near infrared (NIR), and middle infrared (MIR)} available, .4μm to 2.5μm, have been difficult because of the lack of contrast between land use classes. Residential housing, commercial areas, bare or fallow agricultural land, and deciduous wooded areas, are more easily separated during the summer months because each use is characterized by varying combinations of green vegetation and man made features. During the winter months, the reflected energy from .6 hectare (1.5 acres) of residential areas, agricultural areas, and commercial-industrial areas is very similar in the reflective portion of the electromagnetic spectrum, since little green vegetation is present (i.e. dormant vegetation predominates). (The resolution of the present Landsat and Skylab scanners is approximately 0.6 hectare).

The purpose of this study was to investigate the usefulness of a spacecraft MSS data set which included a thermal (far infrared) channel in addition to reflective channels in a land use analysis of a scene obtained during January, 1974. The specific test site was a rectangular area in Indiana which includes Allen County and a small portion of Whitley County. (Fig. 1.2) This includes the city of Fort Wayne with a population of around 180,000. Unfortunately, no data were available for approximately 8,900 hectares (22,000 acres) in the southeast portion of Allen County.

Eight channel multispectral scanner data, S-192 experiment, (Fig. 4.1) and photography, S-190A experiment, (Fig. 2.15) from the Skylab Earth Resources Experiment Package (EREP) were obtained over northeastern Indiana from Lake

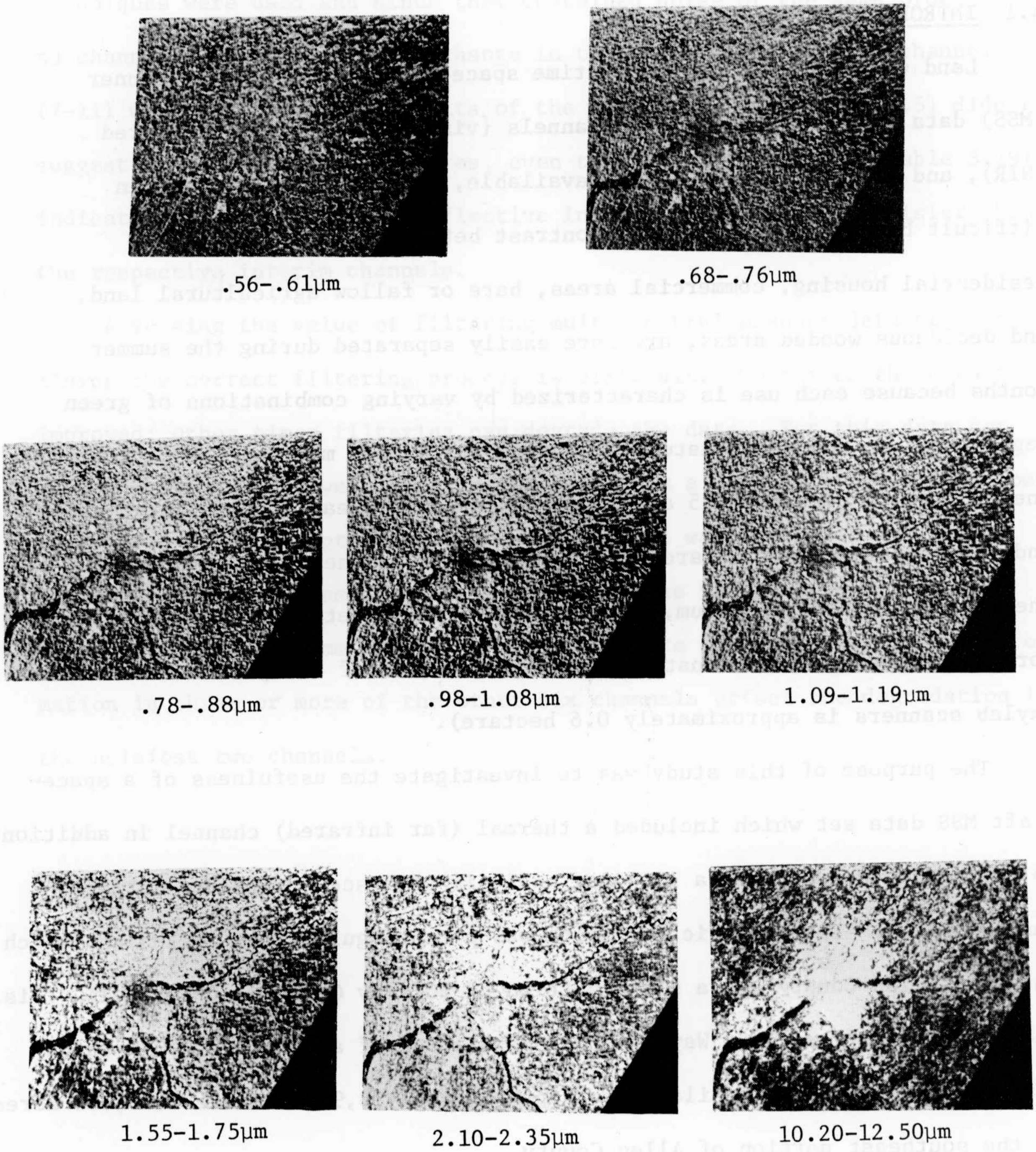


Fig. 4.1 Skylab SL/4 MSS (S192) 8 channel data set obtained from digital display screen using 16 gray levels. The data has been rotated so that North is at top. Scale - 1:900,000

Michigan to the Ohio-Indiana border on January 25, 1974 at approximately 17:00 GMT (12:00 noon local time). The spacecraft was at an altitude of 440 km (270 statute miles). The multispectral scanner data included one VIS channel, four NIR channels, two MIR channels and one FIR or thermal (T) channel. The specifications of the S-190A and S-192 experiments have been reported previously {5} and discussed briefly in section 2.2.2.

This detector arrangement for the Skylab MSS is termed the X-5 detector array. A new FIR detector was installed midway through the Skylab IV (SL-4) mission. When the new detector was installed, the number of spectral channels was reduced from the original thirteen to eight. (See Tables 4.1 and 2.2). The new FIR detector, however, had a noise equivalent temperature (NEΔT) of approximately .9°C compared with that of the previous detector of 2.2°C-4.5°C {13}.

Supporting underflight MSS data and photography were obtained five days later over Fort Wayne on January 30, 1974, by an aircraft operated by the Environmental Research Institute of Michigan (ERIM) from an altitude of 2,300 m. These data were used for ground reference during the analysis of the Skylab MSS data.

At the time of the Skylab overpass there was some snow on the ground in the northern part of the county--mainly along fence rows and woods. During the week before the overpass, 1.4 inches of rain was reported at the Fort Wayne Disposal Plant {18}. There was some lowland flooding along the Maumee and St. Mary's Rivers at the time of the overpass. The high and low temperatures reported by the National Weather Service at Baer Field for the day of the overpass was 6.7°C (44°F) and -2.8°C (27°F) respectively {18}. The sun angle at the time of the overpass was 30 degrees.

4.2 ANALYSIS PROCEDURE

During the early analysis of the MSS data, it was discovered that channels eight and thirteen were misregistered by one pixel. The misregistration was corrected by the Data Processing Group at LARS, but it is not known how the misregistration occurred. After the MSS data was registered, the Data Processing Group, using programs they have developed, rotated the data so that the top of the MSS data is due north. The top of the original data was northwest because of the orbital inclination angle of the Skylab space station.

A measure of the noise in each channel of the MSS data was obtained by computing the mean and standard deviation of five areas of Lake Michigan each totaling 250 points, similar to the method described in section 2.2.4. Lake Michigan was chosen because it was the most uniform spectral scene in the data set. The results are given in Table 4.2 along with the standard deviations of the high and low calibration values from a portion of EREP pass #90 obtained from the EREP Sensor Performance Report {13}. The detailed description of the procedure used to obtain the means and standard deviations of the calibration values are given on page 3-2 of the EREP Sensor Performance Report {13}. As discussed in the above report, the standard deviations are too small because of the possible clipping in conversion from analog to digital signals.

An attempt was made to "calibrate" the FIR channel by converting the data counts of the FIR channel to equivalent black body temperature. The procedure consisted of converting the data count to radiance (R), using A_0, E_0, A_1, and E_1 given in the original tape header record and equation 4.1 {18}.

$$R=A_0\cdot 10\exp(E_0)+A_1\cdot 10\exp(E_1)\cdot(\text{data count}) \qquad (4.1)$$

The radiance (R) was then converted to equivalent black body temperature in degrees Kelvin using the table given in the Skylab S-192 data calibration documentation {20}. The table was produced by integrating over the actual bandpass of the FIR detector. A weak point in this procedure is that the table for converting radiance to degrees Kelvin was developed using the bandpass of the original FIR detector, not the new detector for the X-5 array that was installed midway through the SL-4 mission. The actual bandpass information for the new detector was not available. The detectors are supposed to be similar so that any difference should not affect the table significantly. The resulting equivalent black body temperatures in degrees centigrade for the training statistics used to represent the twelve spectral classes are given in Fig. 4.2. It should be noted that no correction has been made for atmospheric effects.

The pattern recognition programs that have been implemented on the computer at LARS in a software package called LARSYS {2} were used in a level two classification of the test area. The level two classification corresponded to the land use classes suggested by Anderson et al. {1}.

Areas of the test site were clustered and then, using the support photography from the Michigan aircraft, training areas were selected for residential, commercial, industrial, hard surface (parking lots and runways), grass covered areas, bare land, forest, water, and snow classes. See Table 4.3 for the level one and level two break down of the land use classes. Grass includes some pastures, wheat, and golf courses. There were three spectral classes of bare land, probably due to tilled land, different soil types, and/or land with crop stubble. There were two spectral classes for forest, that with snow among the trees and that without snow. The wooded areas without snow, however, were not separable from the dark bare land.

After the eight dimensional Gaussian statistics (mean vectors and covariance matrices) were obtained for the twelve spectral classes, the transformed divergence distance measure {3} was used to obtain a measure of separability of the land use classes using different combinations of spectral channels.

Tables 4.4, 4.5, and 4.6 contain the separability information for the best ten combinations of three, four, and five channel combinations, respectively, ranked according to D_T(ave) - the average of 62 pairwise class combinations. D_T(min) is the minimum separability of the 62 pairwise combinations.

Three different combinations of four channels were used to classify the test area--the best four channels (4,8,11,13), the best four without the FIR channel (4,7,8,11) and the best four without a MIR channel (4,8,9,13). The "best" mentioned above was selected according to highest D_T(ave). The maximum likelihood decision rule was used in the classification process. Weights or a priori probabilities of occurrence for each class were calculated using the statistics given in the 1968 Indiana Soil and Water Conservation Needs Inventory {10}. These statistics were gathered in 1967. The classifications are shown in Figures 4.3, 4.4, and 4.5.

The classification performance of the training pixels is given in Table 4.7. As mentioned in section 2.3.2, the training pixel performance is an upwards biased estimate of the classification performance since only the pixels used to estimate the multidimensional Gaussian statistics were used for the test. The training pixel performance, however, does give an indication of the relative performance of the three classifications.

The area estimates of the land use classes for the three classification sets are given in Table 4.8. The estimates obtained during a meeting with the Allen County Plan Commission (ACPC) and the Ft. Wayne Department of Community Development and Planning (Ft. Wayne) on April 16, 1975, are given in Table 4.9. The land use area percentage estimates of the planning commissions and the classification sets are given in Table 4.10 for those land use classes which have nearly the same definitions for the two different approaches. The commercial and industrial classes were combined because the type of structures attributed to them are very similar.

The area estimates in Table 4.8 include only Allen County (i.e. that portion of the test site that was in Whitley County was deleted). Also the ACPC estimate for Monroe Township has been deleted from the planning commission totals in Table 4.9 since this township is the major portion of the county for which no S192 data were available. Also see Figure 4.6.

The area estimates were found using a conversion factor of one pixel equaling .5 hectares (1.245 acres). The conversion factor was found by scaling the data with the actual distance represented. Each pixel represents approximately 69 m (227 ft.) by 73 m (238 ft.) north-south by east-west.

4.3 DISCUSSION OF RESULTS

The data quality measures (Table 4.2) indicate that the MIR and FIR channels are the best, the NIR channels next best and the VIS channel the worst, considering the smallest standard deviation to represent least noise in the data. The large standard deviation for data values from Lake Michigan for channel four indicate that the standard deviation of the calibration values may be valid (see Table 4.2). The standard deviation for the FIR channel (2.5) represents approximately 1.2^{o}C. The best three, four, or five channels considering data quality were not selected as the best three, four, or five channels considering information content (Tables 4.4-4.6). However, within the MIR region, the channel with the least noise, channel 11, tended to be selected over the "noisier" channel 12.

The FIR channel could distinguish the areas with buildings from the cooler undeveloped land, as indicated in Figures 4.2 and 4.7. The black body equivalent temperatures of the grass and residential areas overlapped some but the grass exhibited much higher reflectance in the NIR channels than did the residential areas. The industrial centers in Allen County were very distinguishable from their surroundings in the FIR channel; they were much warmer. In the channels 4,8,11,13 classification, school buildings (such as Ft. Wayne Northrop) were classified as industrial. The school buildings are built similar to the factories with large areas of flat tarred roofs. The higher

Table 4.1

Channels Available on Skylab
SL/4 S192 Data Set*

Channel	SDO**
4	3
6	7
7	9
8	19
9	20
11	11
12	13
13	21

* See Table 2.2 for Spectral Resolution of Channels

** Scientific Data Output Channel

Table 4.2

"Data Quality" Measure

Channel	Average Standard Deviation of Five 250 pixel Areas of Lake Michigan	Standard Deviations* of Calibration Values from a Portion of EREP Pass #90 from 025:17:16:14 to 16:17 GMT	
		High Calibration	Low Calibration
4	24.9	+11.2+	+12.1+
6	10.9	4.7	3.0
7	6.8	3.8	1.3
8	8.5	1.2	3.5
9	9.6	15.0	3.0
11	4.1	2.3	1.3
12	5.6	9.3	1.4
13	2.5	2.2	2.0

* Obtained from MSC-05528, EREP Sensor Performance Report Vol. III (S192), page 3-285.

\+ According to MSC-05528, data is of doubtful validity.

Table 4.3

Classes Used in Landuse Classification of Allen County

Level 1	Level 2
Urban	Residential Commercial Industrial Hard Surface
Agriculture	Grass Bare Land
Forest	Forest
Water	Water
Other	Snow

Table 4.4

Separability of Classes Using Three Channels*

Channels	D_T(Ave)	D_T(Min)
4,11,13	1911	535
4, 8,13	1905	941
8,11,13	1904	385
7,11,13	1903	578
4, 8,11	1895	705
6,11,13	1890	1000
4, 9,13	1888	891
8,12,13	1870	340
4, 7,11	1864	527
9,11,13	1863	321

* Separability measure is transformed divergence; maximum value is 2000.

Table 4.5

Separability of Classes Using Four Channels*

Channels	D_T(Ave)	D_T(Min)
4,8,11,13	1963	1620
4,7,11,13	1954	1533
4,9,11,13	1946	1563
4,8,12,13	1937	1331
4,6,11,13	1930	1263
6,8,11,13	1930	1221
6,7,11,13	1919	1271
4,7,12,13	1919	1234
4,9,12,13	1918	1307
4,8,11,13	1914	589

* Separability measure is transformed divergence; maximum value is 2000.

Table 4.6

Separability of Classes Using Five Channels*

Channels	D_T(Ave)	D_T(Min)
4,7, 8,11,13	1977	1667
4,6, 8,11,13	1974	1652
4,8,11,12,13	1974	1646
4,8, 9,11,13	1974	1636
4,7, 9,11,13	1971	1623
4,7,11,12,13	1966	1546
4,6, 9,11,13	1965	1600
4,6, 7,11,13	1965	1568
4,8,11,12,13	1962	1616
4,8, 9,12,13	1956	1439

* Separability measure is transformed divergence; maximum value is 2000.

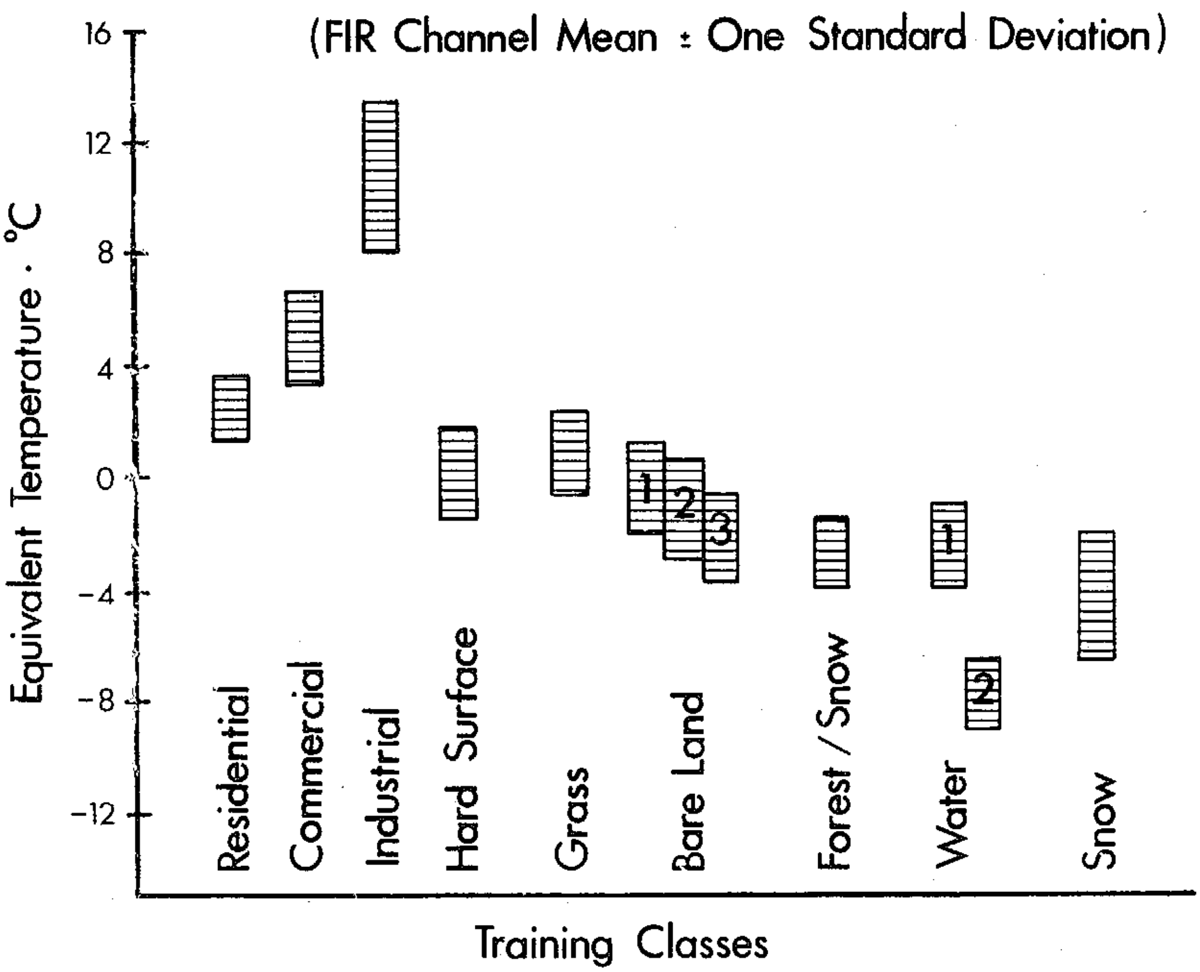


Fig. 4.2 Equivalent Black Body Temperatures Computed From FIR Channel for Training Classes

Table 4.7

Training Pixel Classification Performance

Land Use Class	Number of Training Pixels	Classification Performance (percent correct) Channel Combination 4,8,11,13	4,7,8,11	4,8,9,13
Residential	175	92	65	82
Com-Ind	61	95	18	90
H. Surface	52	73	71	52
Grass	141	90	89	81
B. Land	459	95	93	89
Forest/Snow	81	79	86	54
Water	152	80	77	58
Snow	25	96	92	92
Overall	1146	90	80	79

Table 4.8

Land Use Area Estimates for Major Portion of Allen County Using SL/4 S192 MSS Data

Land Use Class	Land Use Area Estimates (In Hectares) Channel Combination 4,8,11,13	4,7,8,11	4,8,9,13
URBAN	16,300	45,540	12,090
Residential	15,000	43,850	11,200
Com-Ind	340	900	350
H. Surface	960	790	540
AGRICULTURE	131,490	102,200	137,120
Grass	11,590	11,270	5,230
Bare Land	119,900	90,930	131,890
FOREST	9,340	9,860	6,470
WATER	2,380	2,250	2,580
SNOW	5,040	4,680	6,300
TOTAL	164,550	164,530	164,560

Table 4.9

Land Use Area Estimates of Allen County
(Minus Monroe Township)
Using ACPC* & Ft. Wayne Dept. CD&P+ Data

Land Use Class	Land Use Area Estimates (in Hectares)
URBAN	21,090
Residential	16,900
Com-Ind	4,190
AGRICULTURE/ FOREST	143,130
OTHER LAND	2,940
TOTAL	167,160

* Allen County Plan Commission

+ Ft. Wayne Department of Community Development and Planning

Table 4.10

Land Use Area Percentage Estimates of
Major Portion of Allen County

	Land Use Area Percentage			
		Channel Combination		
Land Use Class	ACPC & Ft. Wayne	4,8,11,13	4,7,8,11	4,8,9,13
URBAN	12.6	9.9	27.7	7.3
Residential	10.1	9.1	26.7	6.8
Com-Ind-H. Surface	2.5	.8	1.0	.5
AGRICULTURE/FOREST	85.6	85.6	68.1	87.3
WATER		1.4	1.4	1.6
OTHER LAND	1.8			
SNOW		3.1	2.8	3.8

thermal energy being radiated from these buildings is probably due to a combination of the building heat loss and the high solar absorption of the black tar roofs. This is speculated to be the same reason for the residentials areas being warmer than the undeveloped land. However, since the houses are smaller than the factories and school buildings, residential areas are cooler than the industrial centers and schools.

The surface of grass covered areas is generally warmer than bare land. The grass blades act similar to a black body, absorbing the solar energy from the sun. The grass blades insulate the ground beneath which acts similar to a large heat sink in areas with no cover. Therefore, the surface of the grass is warmer than bare land.

The different black body equivalent temperatures for the three bare land classes is probably due to the differing soil types and crop stubble cover. The dark ground in the Lake Maumee Plain west of Fort Wayne and the old glacial river bed (Little River) east of Fort Wayne was the coolest.

The separability information given in Table 4.5 for the best for channel combinations indicate that the FIR channel is relatively important for separating the spectral classes being used for this study. The FIR channel is selected in every one of the top ten combinations; in fact, it was selected in the top 21 combinations. Channels 4,7,8,11 were the 22nd combination with a D_T(ave) of 1895 and D_T(min) of 772. The lowest separability combination was industrial and bare land. Other class combinations with a separability less than 1500 were residential - bare land and commerical-industrial.

The FIR channel is selected eight times in the top ten combinations of three channels. (See Table 4.4). However, there is always at least one pair of classes that will be hard to separate with any combination of three channels. Generally, any class combination with a separability measure less than 1500 will be hard to separate. According to the separability measures, at least four channels are needed to obtain a good class separation in a classification of the study site.

The FIR channel is selected in all of the top ten combinations of five channels (Table 4.6). It is actually chosen in the top 29 combinations of five channels. (32 possible combinations of channels exist that include the FIR channel).

The MIR region of the spectrum also appears to be important in the separation of the classes for this study in that a channel from that region is selected in the top ten separability combinations using both four channels and five channels. The highest four channel combination that does not include a MIR channel (4,8,9,13) is ranked 14th. The 4,8,9,13 combination has a D_T(ave) of 1907 and a D_T(min) of 744. The pair of classes having the minimum separability is grass and one of the bare land classes.

Another observation from Table 4.5 is that a VIS, NIR, MIR, FIR combination occurs seven times in the top ten combinations. There are eight possible combinations of VIS, NIR, MIR, FIR. This same phenomenon also occurs in tables 4.4 and 4.6. The channel combinations which give the best separability for the classes considered tend to be those that have as many of the four spectral regions as possible represented. In the top ten combinations of the three channels, none of the four spectral regions is represented twice. In the top ten combinations of five channels every region is represented at least once.

The urban and agriculture classes were much more mixed and scattered in the 4,7,8,11 classification (no FIR) than in the 4,8,11,13 classification (with FIR). Some of the rivers and bare land were classified as residential in the 4,7,8,11 classification (no FIR). See Figures 4.3, 4.4, and 4.5.

The differences in the 4,8,11,13 classification and the 4,8,9,13 classification (no MIR) are not as great as those between the FIR and no FIR

Fig. 4.3 Color coded classification of Allen County using channels 4,8,11,13. Five land use classes represented plus snow: Residential-red, Commercial/Industrial/Hard Surface-black, Bare Land/Forest-light brown, Grass-green, River-blue, Snow-white. Scale 1:200,000.

Fig. 4.4 Color coded classification of Allen County using channels 4,7,8,11 (no FIR). Five land use classes represented plus snow: Residential-red, Commercial/Industrial/Hard Surface-black, Bare Land/Forest-light brown, Grass-green, River-blue, Snow-white. Scale 1:200,000.

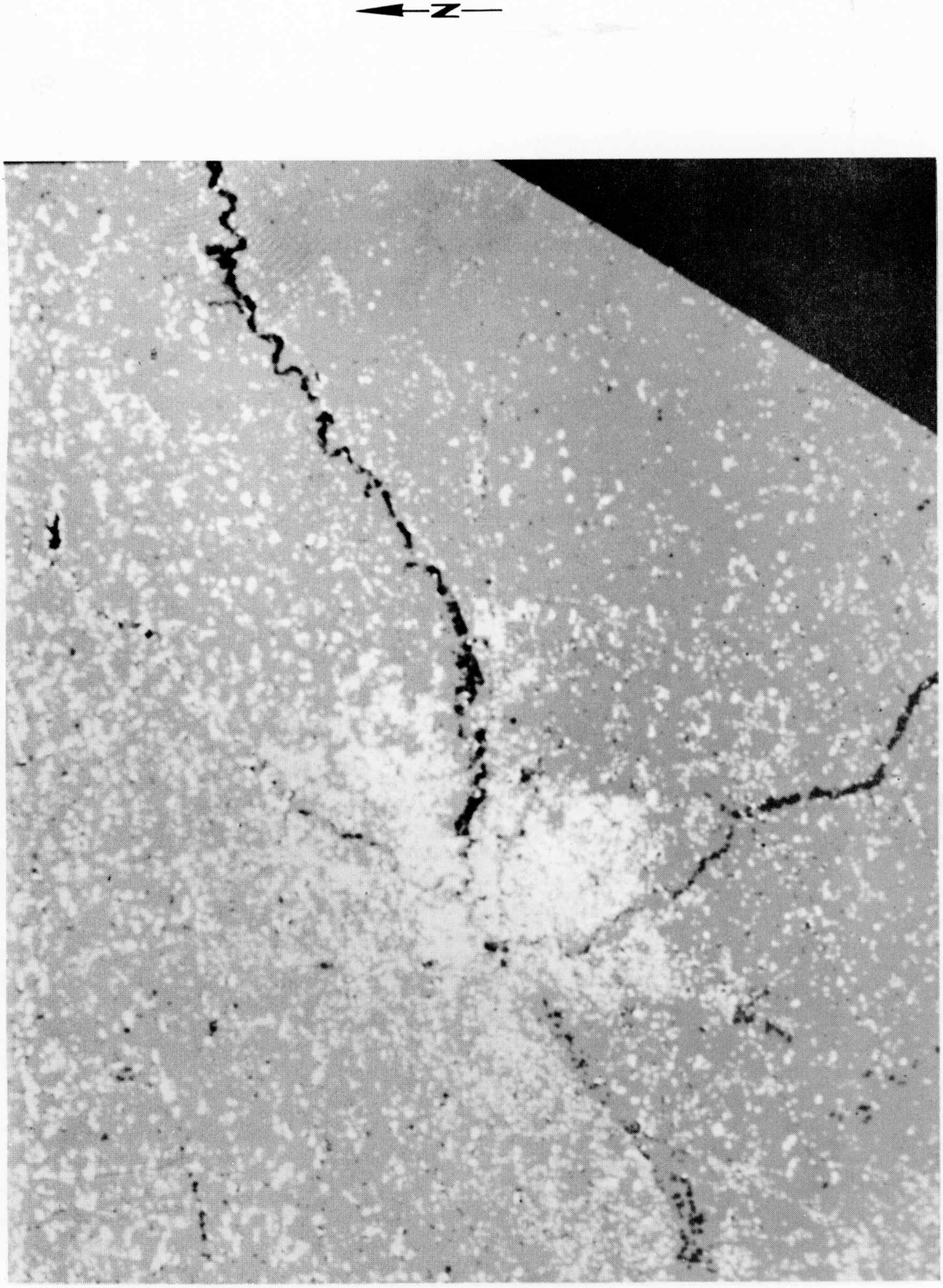


Fig. 4.3

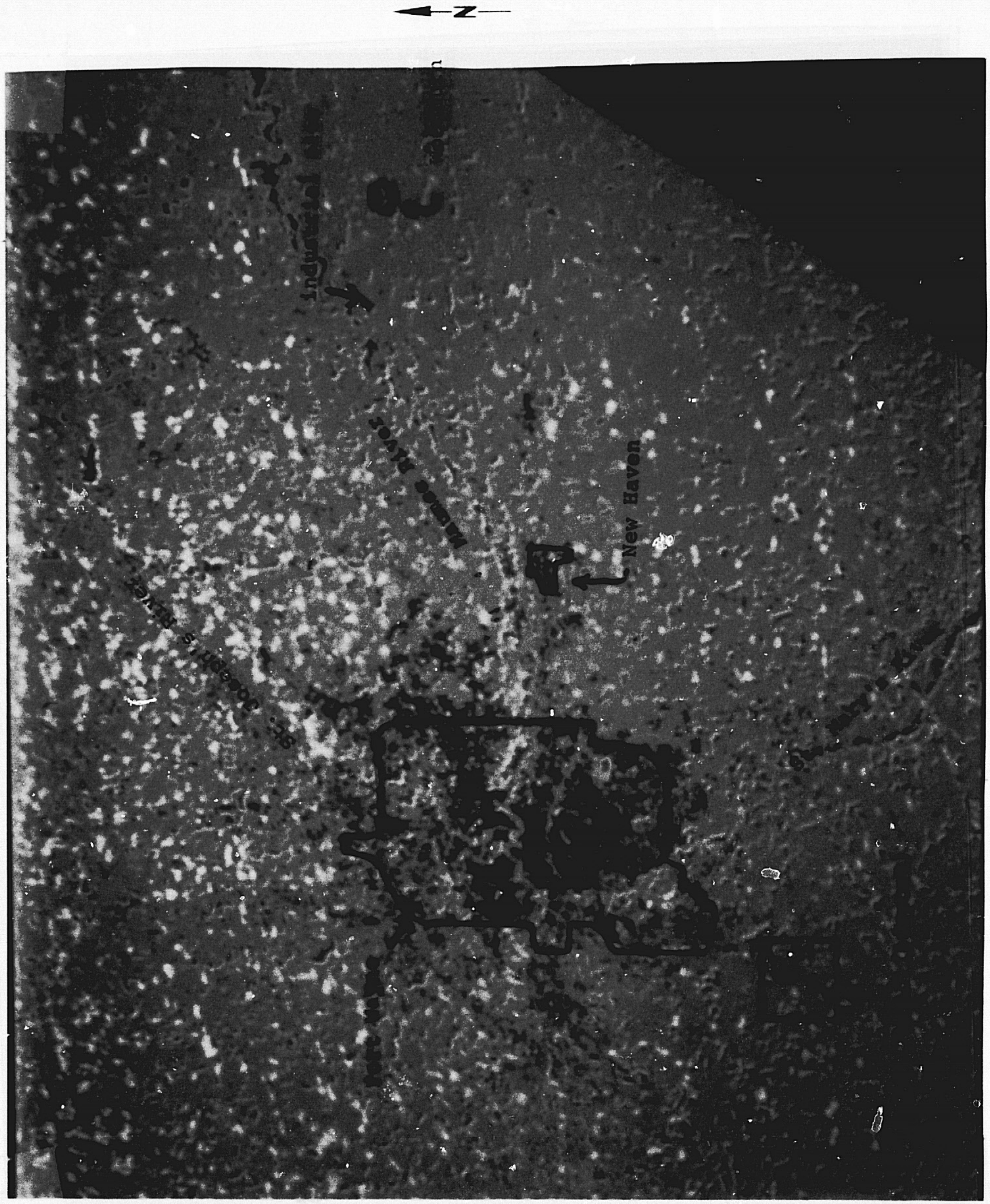


Fig. 4.3

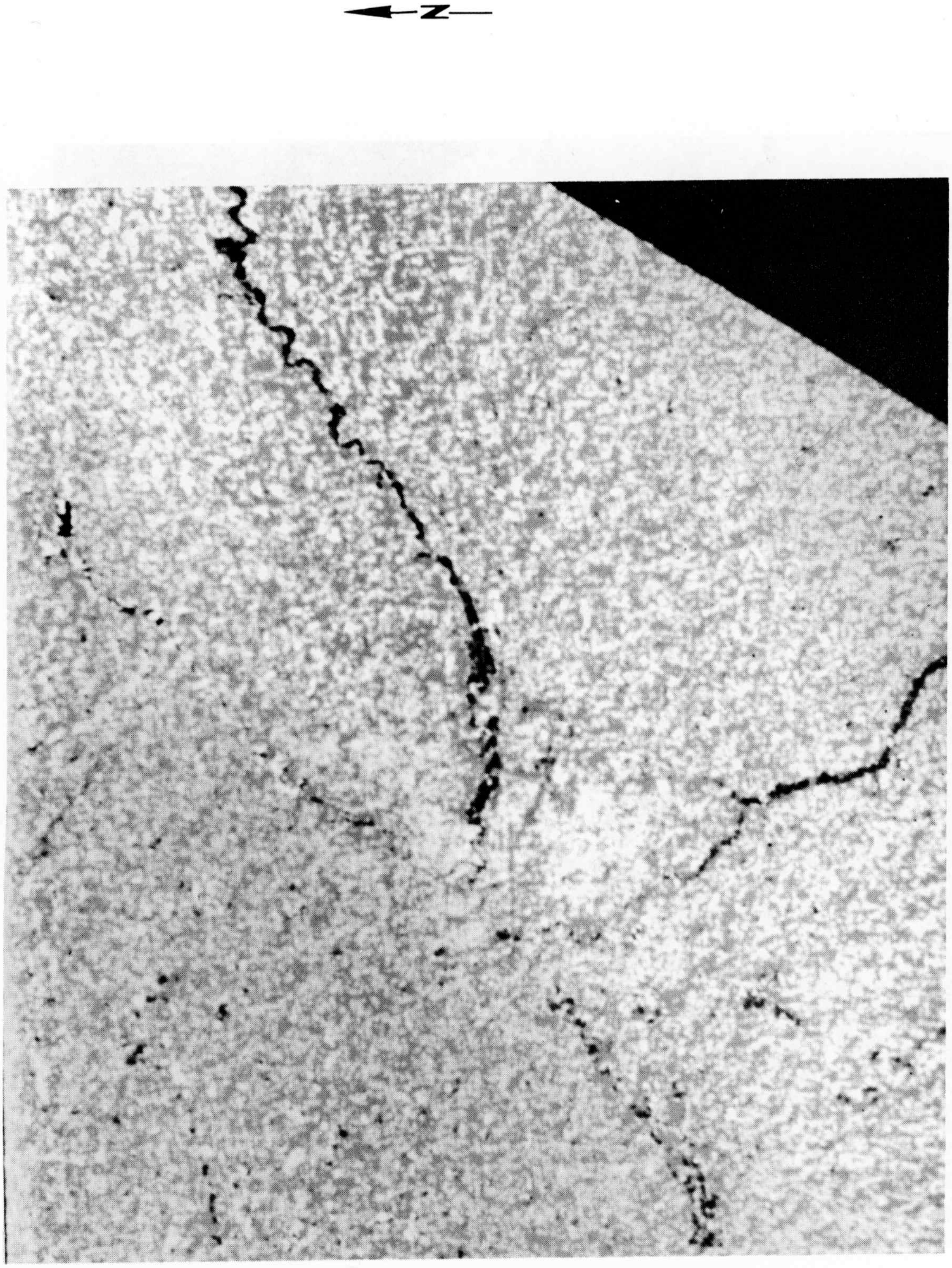


Fig. 4.4

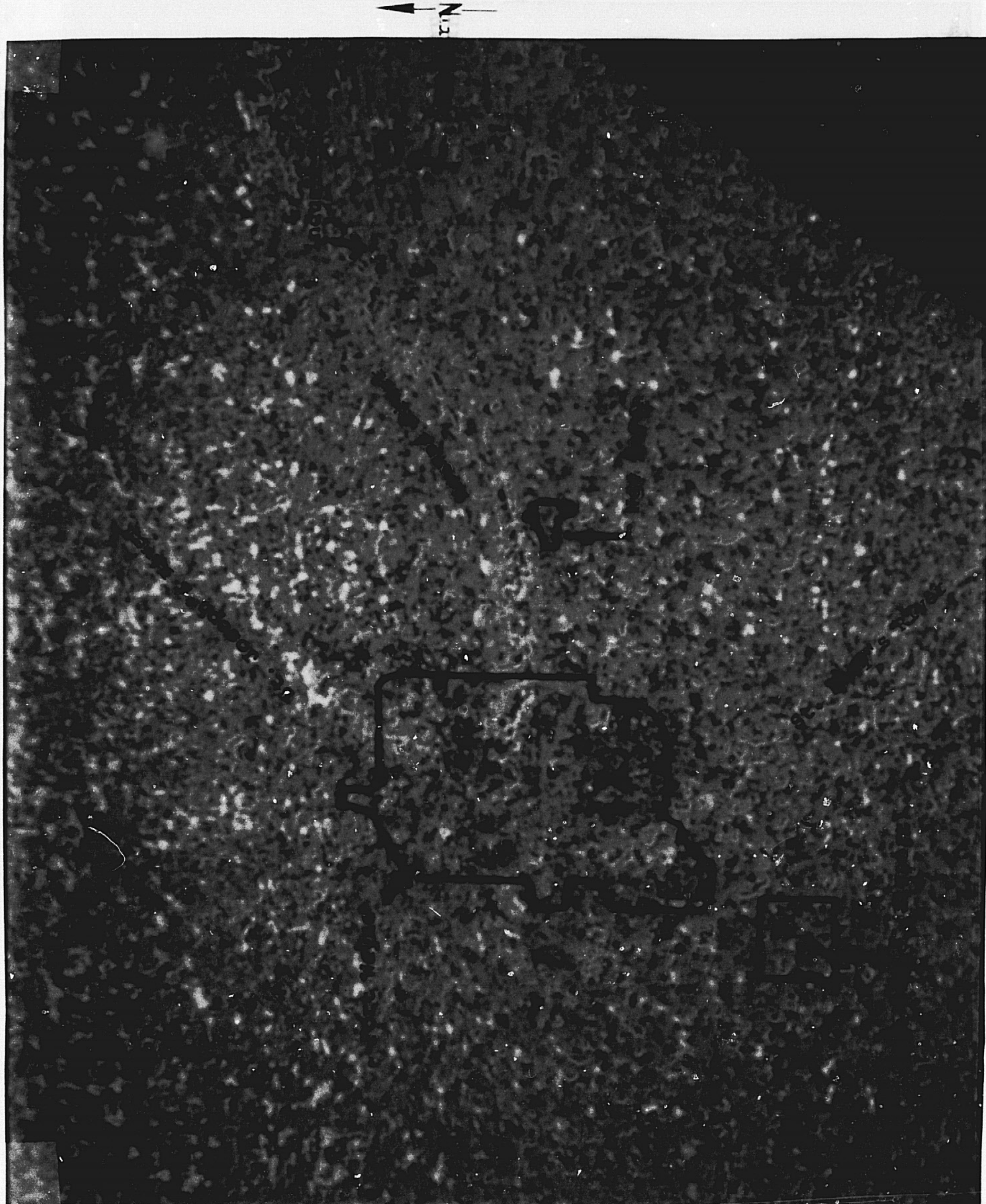


Fig. 4.4

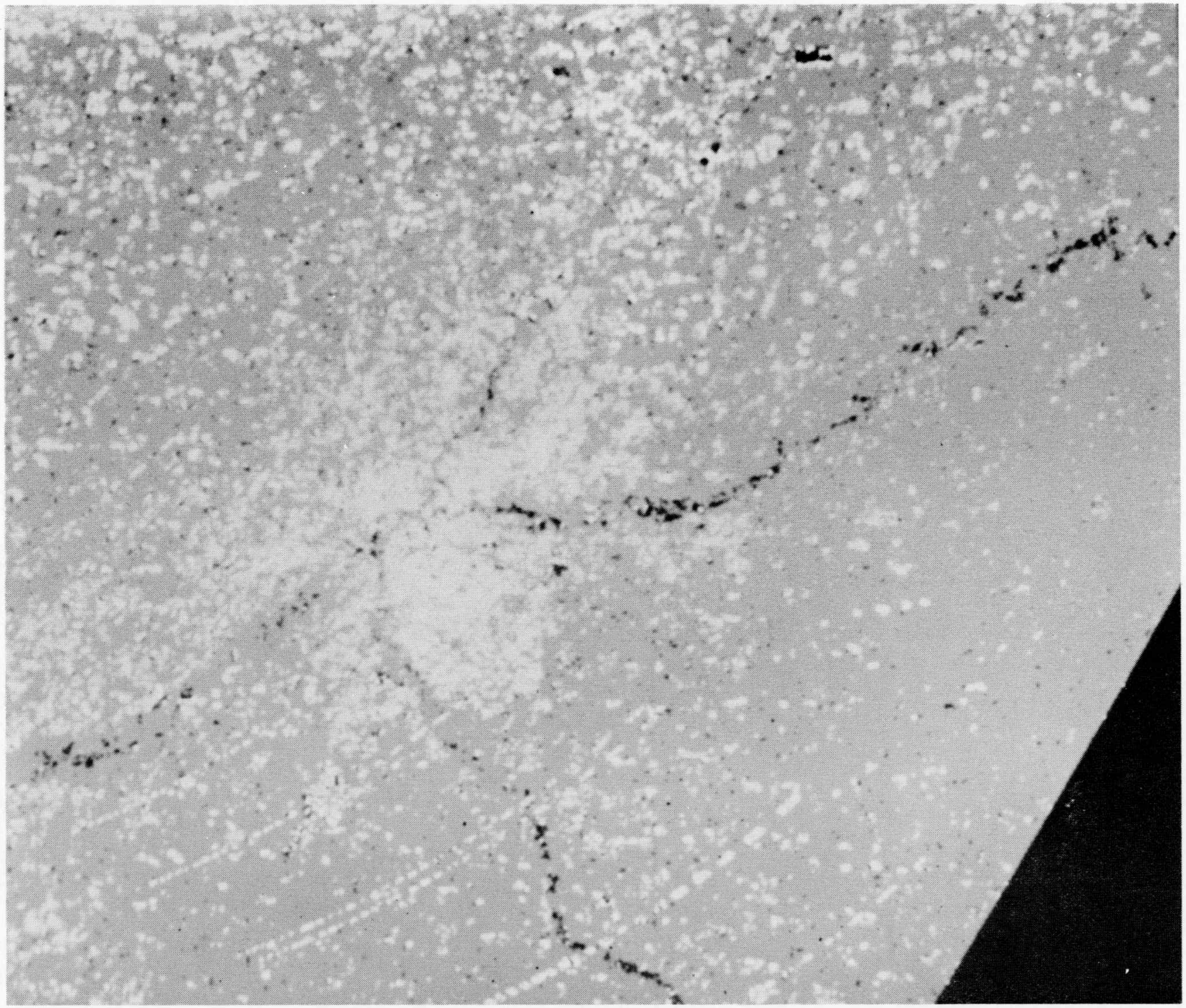


Fig. 4.5 Gray level coded classification of Allen County using channels 4,8,9,13 (no MIR). Five land use classes represented plus snow. In order of increasing brightness: Water, Commercial/Industrial/Hard Suface, Grass, Bare Land/Forest, Residential, Snow.

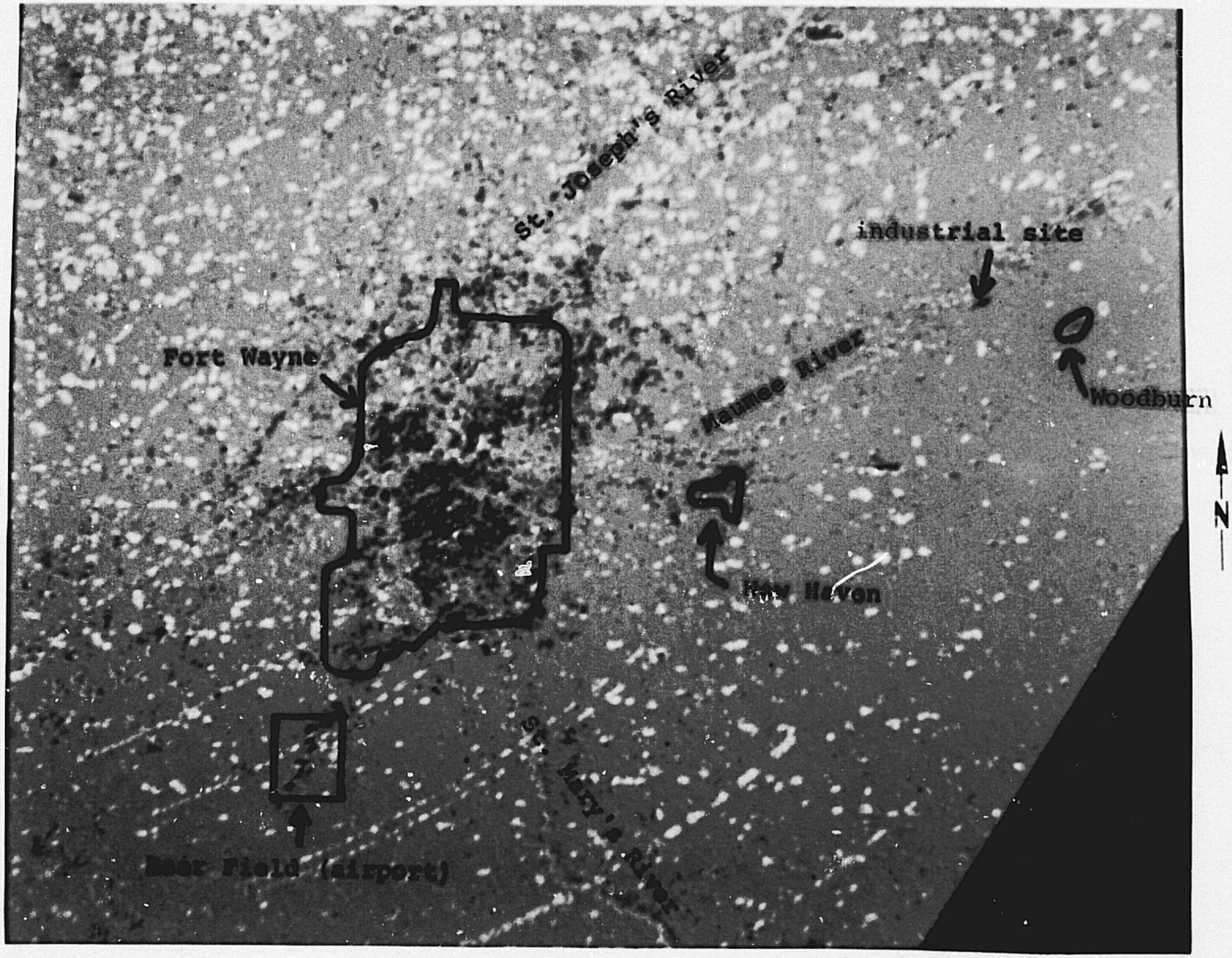
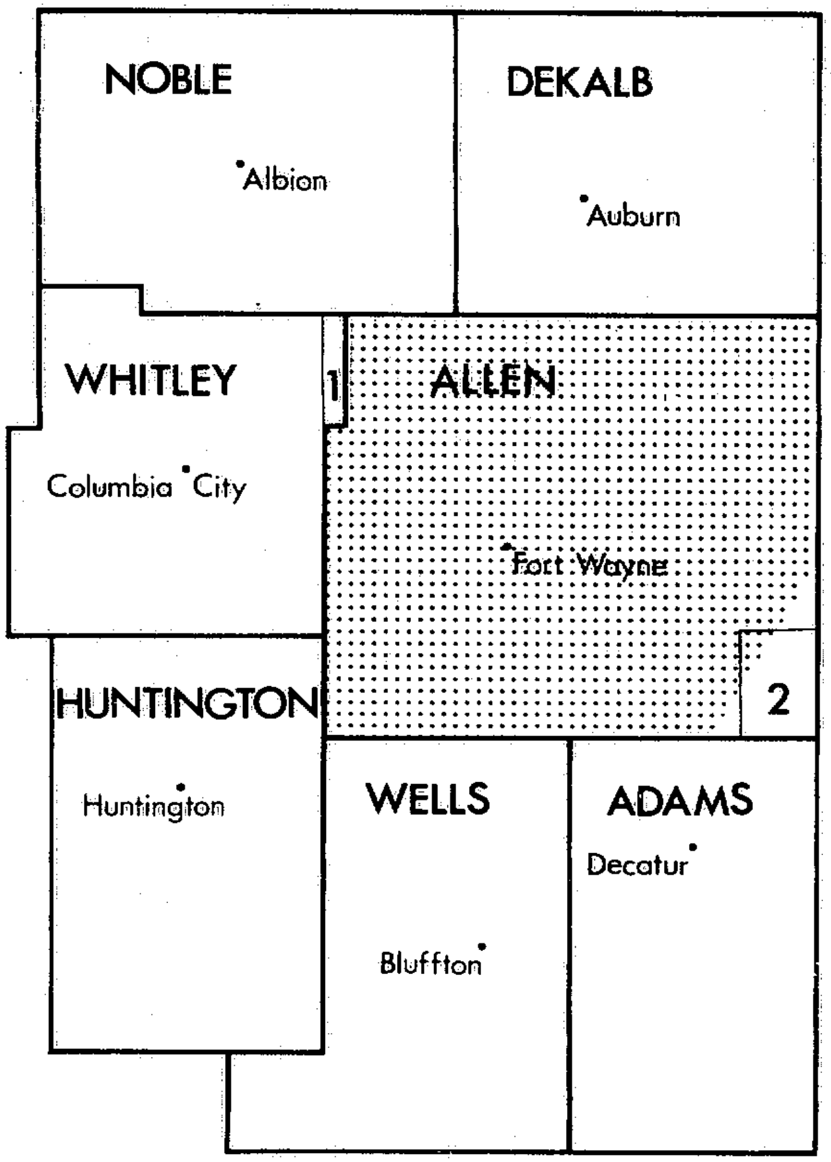
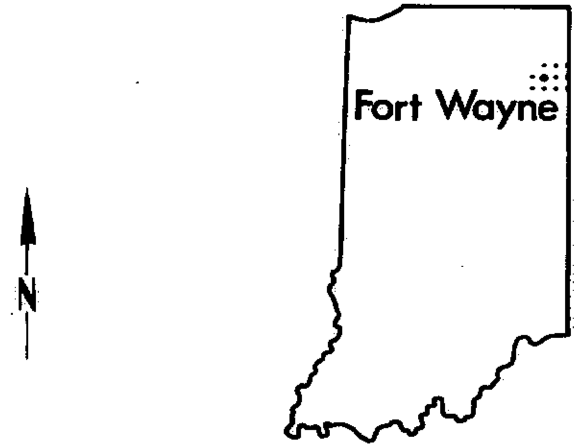


Fig. 4.5 Color coded classification of Allen County using channels 4,8,9,13 (no MIR). Five land use classes represented plus snow: Residential-red, Commercial/ Industrial/Hard Surface-black, Bare Land/Forest-light brown, Grass-green, River-blue, Snow-white. Scale - 1:230,000





1. Portion of Whitley County that was deleted from classification area estimates.

2. Monroe Township - deleted from ACPC and Fort Wayne area estimates.

Fig. 4.6 Portions of test site deleted from area estimates.

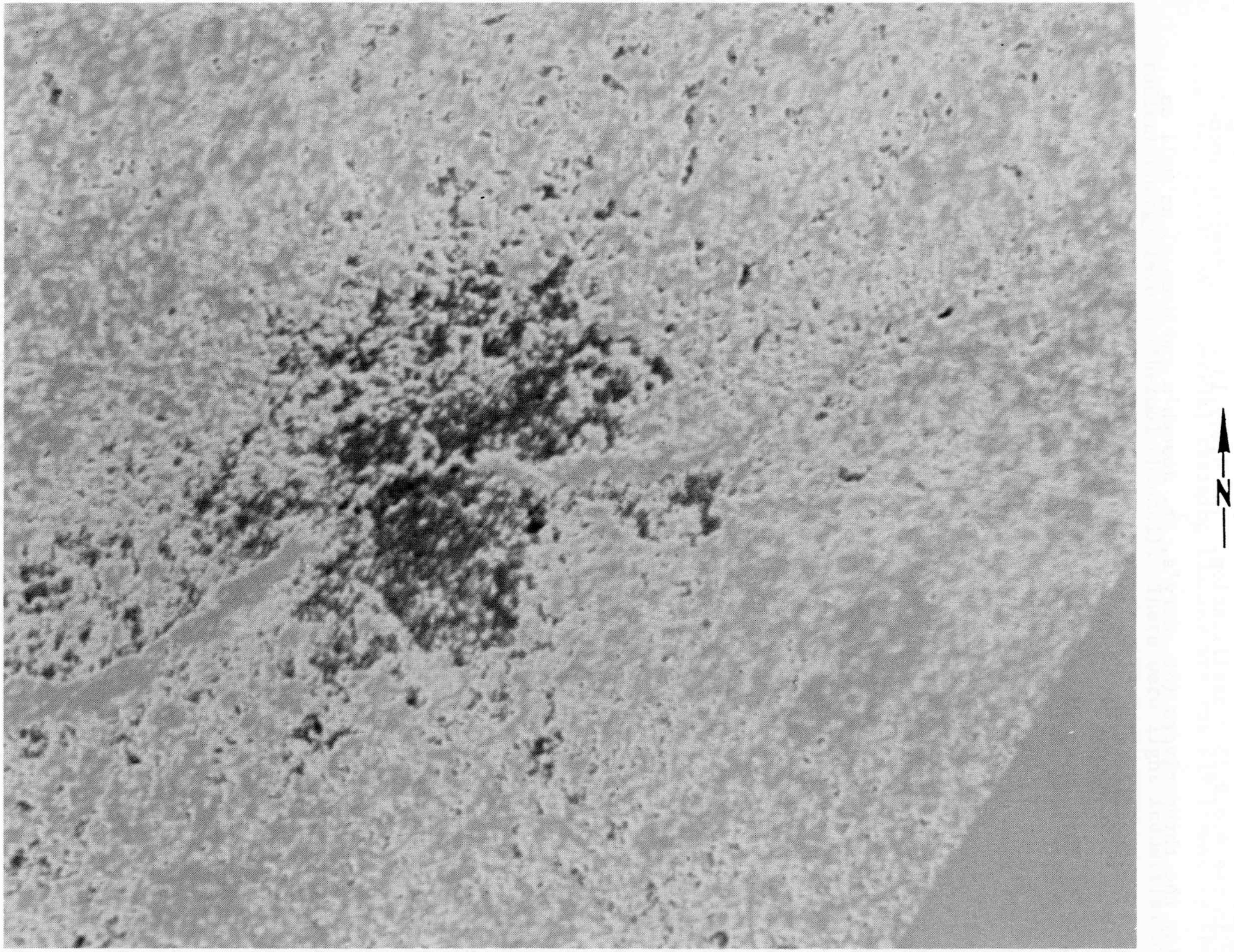


Fig. 4.7 Black and white reproduction of FIR (thermal) channel imagery of Allen County. Red, brown, light blue, dark blue represents warmest to coolest. Scale - 1:230,000

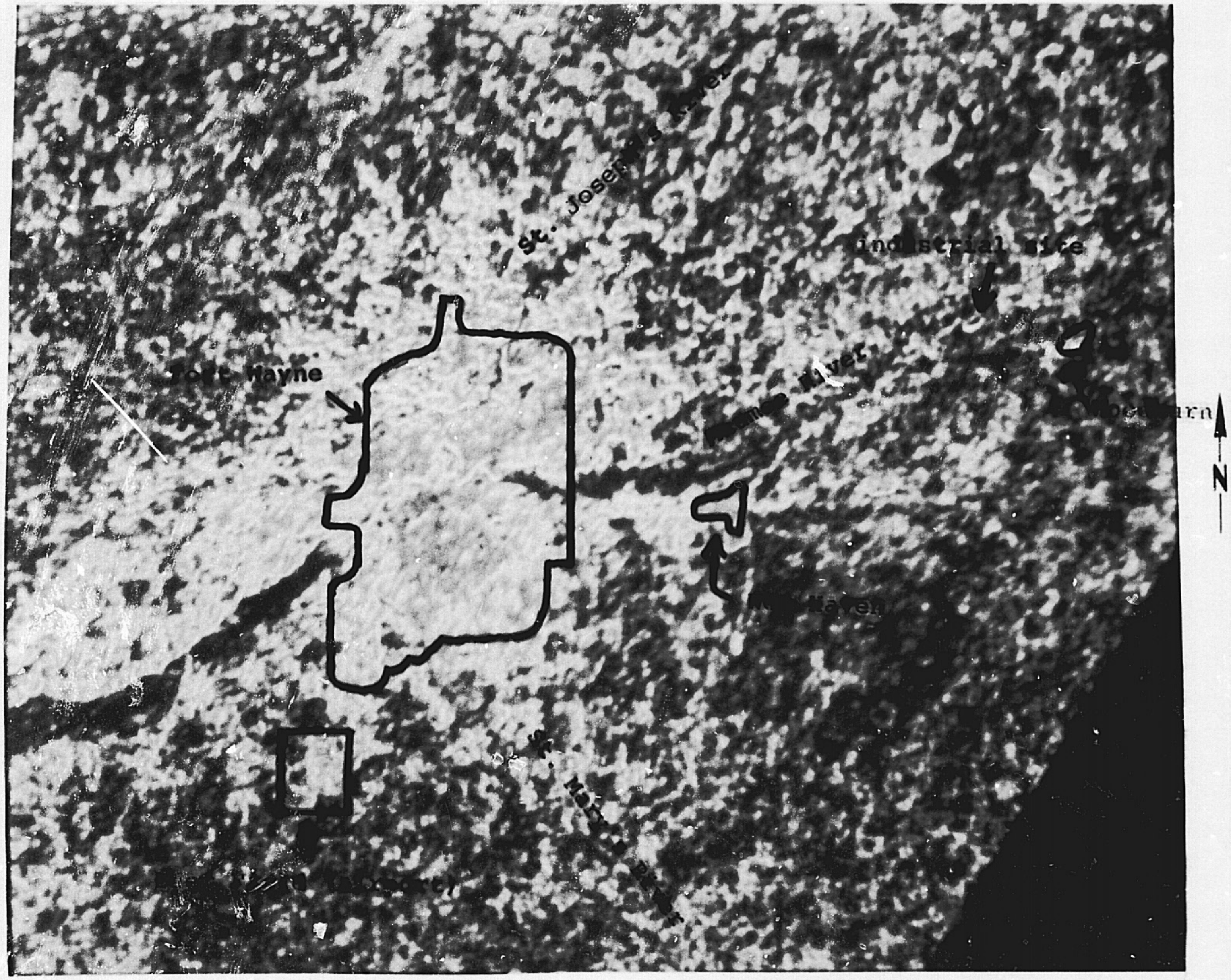


Fig. 4.7 FIR (thermal) channel imagery of Allen County. Red, brown, light blue, dark blue represents warmest to coolest. Scale - 1:230,000

classifications. The 4,8,9,13 classification didn't delineate the grassy areas as well as 4,8,11,13. There was also more confusion between bare land and water in the 4,8,9,13 classification. The 4,8,9,13 classification doesn't display the three rivers (St. Mary's, St. Joseph's and Maumee) as well as 4,8,11,13 classification. Also there appears to be more agriculture land in the city of Fort Wayne in the 4,8,9,13 classification.

The 4,8,11,13 classification is probably the most representative of the area with approximately ten percent classified as urban. This urban figure doesn't include the areas in Allen County which are usually considered part of the urban area but are not represented by buildings as parks, golf courses, and railroads. These areas were either classified as grass or bare land. The Allen County Plan Commission and Ft. Wayne estimates for residential includes those areas which are golf courses and parks which account for a major share of the difference in the best four channel classification (4,8,11,13) and the planning commissions' estimates. Golf courses and parks were delineated as grass in the classifications.

The major concern is the underestimate of commercial and industrial. The commissions' estimates for industrial and commercial include the area owned by the businesses or industries - i.e. buildings, parking lots, and landscaped property. In the classifications, the buildings themselves were delineated as commercial or industrial and the stoned parking lots as hard surface but the asphalt parking lots many times were delineated as residential. Also a portion of downtown Ft. Wayne (commercial) was delineated as residential. The railroad right-of-way through Ft. Wayne is considered as commercial in the Ft. Wayne estimates, while in the classification it was delineated as bare land. These are probably the major sources of error in the classification estimates for commercial and industrial.

The separation of commercial and industrial was difficult because the types of buildings for the two are very similar. The only difference between the commercial and industrial training classes was the difference in the radient energy levels (thermal channel). There were light industrial areas however which have the same radiant energy levels as the commercial areas.

Other land under the commissions' estimates include that area of the county which the planning commissions haven't accounted for. The rivers in the county are included in other land.

The total agriculture and forest and snow area estimates (major part of snow is over agriculture land) for the 4,8,11,13 classification is in close agreement with that of the planning commissions.

4.4 CONCLUSIONS

The study indicates that a FIR channel with a detectivity and a responsivity of that in the X-5 detector array can be very valuable for winter time land use studies with spacecraft multispectral data. The FIR channel can distinguish the areas with man made buildings from the cooler undeveloped land. The FIR channel can also distinguish different urban classes. The commercial and industrial areas are warmer than the residential areas. As mentioned above, it is speculated that the urban areas are warmer than the undeveloped land because of a combination of building heat losses and high solar absorption of the asphait roofs.

A MIR channel also appears helpful in delineating the classes considered. In fact, the results indicate that for the channels available in this data set, at least one channel is needed for each of the following spectral regions - VIS, NIR, MIR, and FIR to most effectively separate land use classes considered in this study.

A major question, however, still remains concerning the visible channel (channel 4). Only one channel was available and this channel may have been degraded significantly by noise (Table 4.2). Also as indicated by the results in sections 2 and 6 channel 4 tended to be one of the noisier visible channels. Therefore these results do not indicate that channel 4 is a good visible channel. If other visible channels had been available, they may have contained more information than channel 4.

The results do indicate that the inclusion of the far-infrared channel of the type in the X-5 detector array can be a significant help in multispectral analysis for land-use mapping. There are still some problems; however, a temporal overlay of summer data with winter data may solve many of them. For example, downtown Ft. Wayne should be easily separated from the residential areas during the summer months because of the lack of vegetation in the downtown commercial area.

5. STUDY OF ATMOSPHERIC TRANSMISSION AND PATH RADIANCE USING SL/2 S191 SPECTRORADIOMETER DATA AND GROUND OBSERVATIONS

5.1 OBJECTIVES AND PROCEDURES

The purpose of this study was to determine the atmospheric transmittance and path radiance during Skylab overpasses on several different dates and to use this information to standardize S-192 multispectral scanner data. During the course of the program circumstances permitted the gathering of a complete data set (S-191, S-192, and Exotech Model 20C data) on only one date. As a result, S-192 data was not standardized because applying a single linear transformation to multispectral scanner data will not affect maximum likelihood classification accuracy. The purpose of the following is to present a discussion of the measurements and methods for obtaining the atmospheric transmittance and path radiance (0.50 to 0.74 μm) and a comparison of the thermal spectral radiance measured by the S-191 sensor and data derived from surface measurements.

The basic equation used in the spectral path radiance study was

$$L_{s,\lambda} = E_{t,\lambda}\rho'_{\lambda}T_{a,\lambda} + L_{p,\lambda} \qquad (5.1)$$

where $L_{s,\lambda}$ is the spectral radiance at the Skylab space station measured by the S-191 spectroradiometer, $E_{t,\lambda}$ is the spectral irradiance at Lake Monroe measured by the Exotech spectroradiometer, ρ_{λ}' is the bidirectional reflectance distribution function (BRDF) of the water measured by the Exotech spectroradiometer, $T_{a,\lambda}$ is the spectral atmospheric transmission measured using a pyrheliometer, and $L_{p,\lambda}$ is the spectral path radiance.

The total optical depth $\tau_t(\lambda)$ was estimated by plotting the natural log of the pyrheliometer output voltage versus the secant of the solar zenith angle, (approximately equal to atmospheric air mass for $\theta_{zenith} < 80^{\circ}$) for the different optical filters on the pyrheliometer {21}. The optical depth was taken as the negative of the slope of the linear curve fitted to the data points. The pyrheliometer measurements were taken every fifteen minutes from 14:00 to 18:15 GMT. The raw data is given in the Appendix.

Three filters were used. Their spectral transmittance is given in Fig. 5.1. Since bandpass filters for the pyrheliometer were not available, the difference of the radiometric measurements from filters OG1 and RG2 were used for optical depth from .51 to .63 μm, the difference of the radiometric measurements from filters RG2 and RG8 were used for the optical depth from .63 to .69 μm and the measurements from RG8 were used for the optical depth from .69 to .74 μm. A more accurate estimate of the optical depth could be obtained using bandpass filters. The measurements are plotted in Fig. 5.2.

The atmospheric transmission was then estimated for the three bands using equation 5.2 {21}

$$T_{a,\lambda} = e^{-m(a)\tau_t(\lambda)} \qquad (5.2)$$

where $T_{a,\lambda}$ is the spectral atmospheric transmission, m(a) is the atmospheric airmass through which the S191 spectroradiometer "looked", and $\tau_t(\lambda)$ is the total optical depth. The $T_{a,\lambda}$'s are given in Table 5.1.

The spectral irradiance from .45 to 2.4 μm (Fig. 5.3) was determined by the Exotech Model 20C spectroradiometer field system {22} operated by LARS personnel (see Fig. 5.4). The solar port of the instrument was calibrated for spectral irradiance both before and after the mission on June 10, 1973. The spectral irradiance was measured at intervals from 14:20 to 14:35 GMT. Each observation of spectral irradiance is an average of eight spectral scans of the spectrum from .45 to 2.4 μm.

The BRDF of the lake near the ramp (Fig. 2.1) was also determined by the Exotech field spectroradiometer system (Fig. 5.5). The BRDF was measured at intervals from 14:20 to 14:35 GMT. Calibration of the BRDF data was based

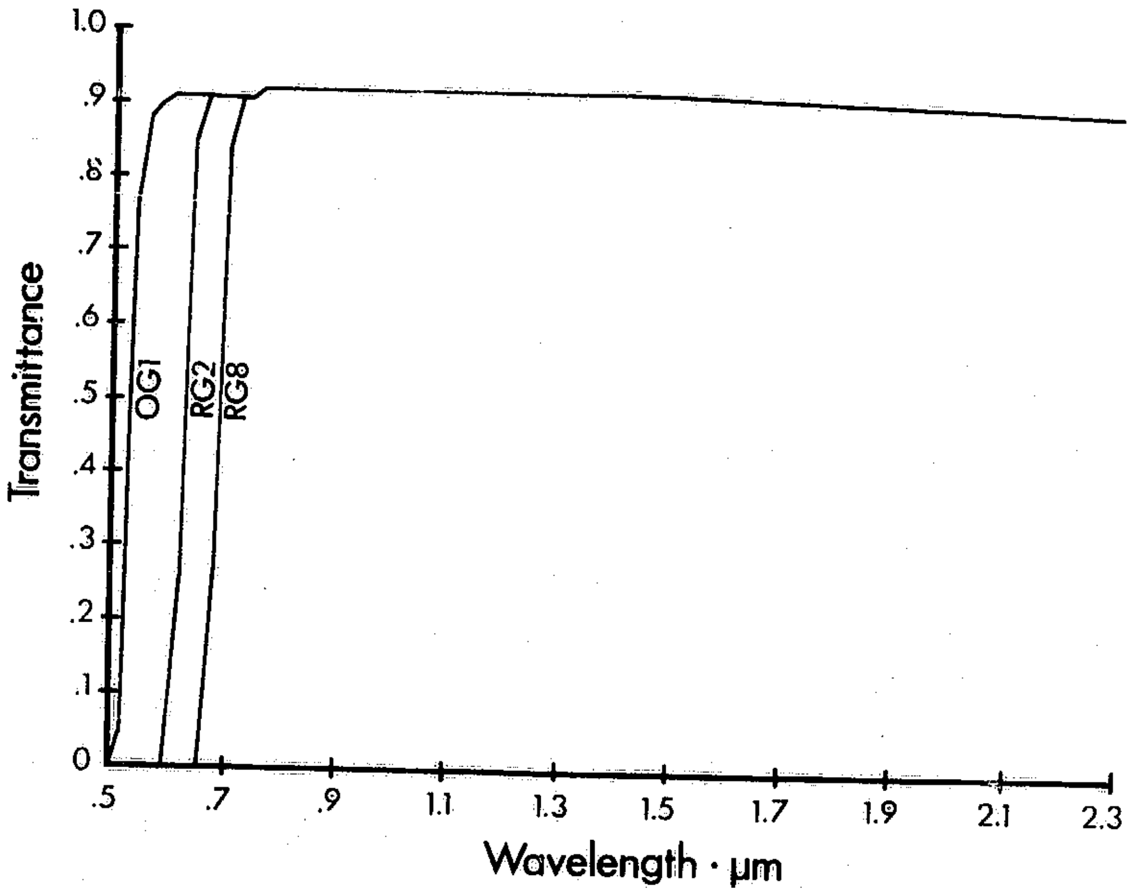


Fig. 5.1 Spectral transmittance of the filters used with the pyrheliometer.

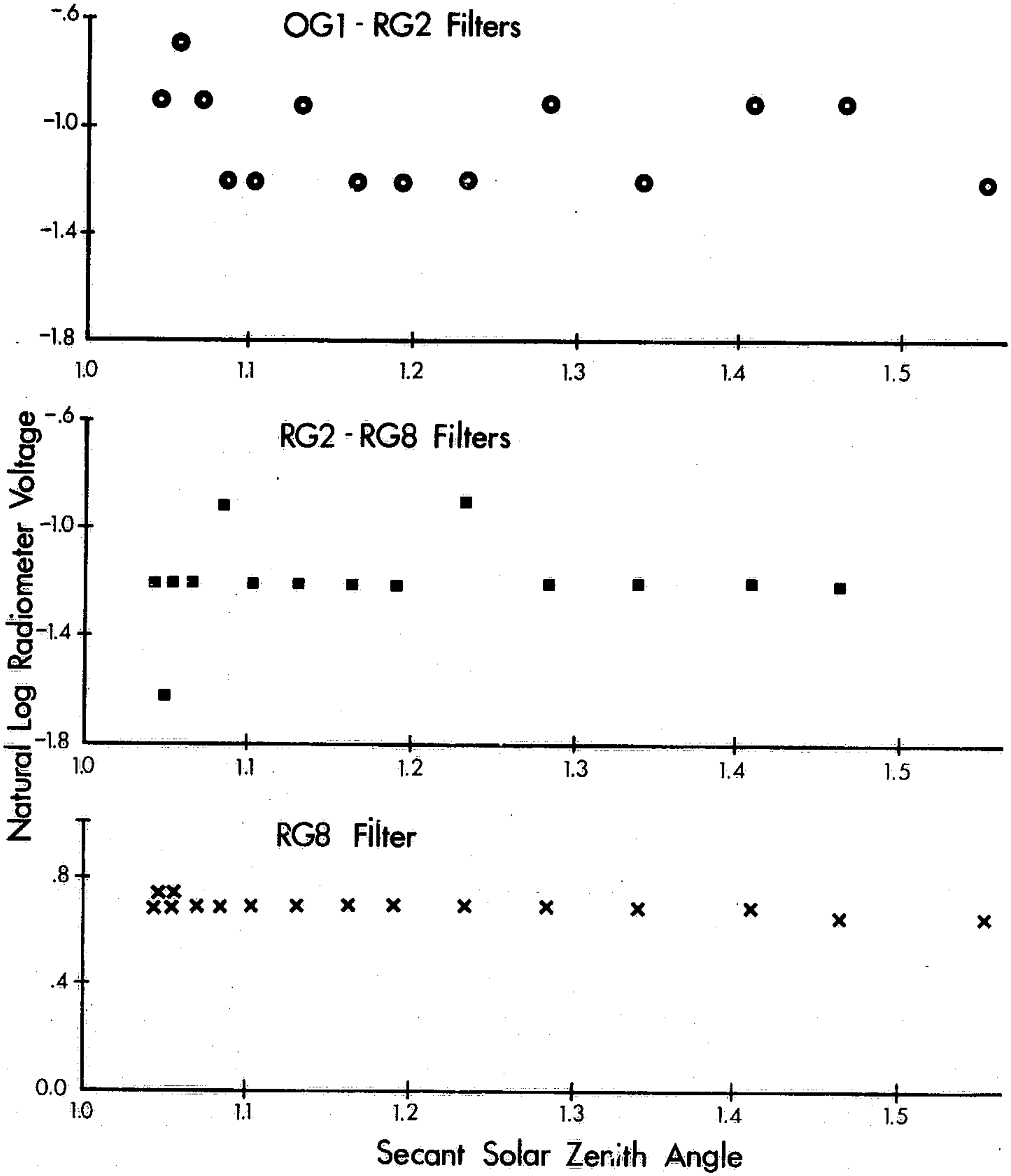


Fig. 5.2 Natural log of radiometer (pyrheliometer) voltage versus secant of solar zenith angle. Plots used to obtain optical depths.

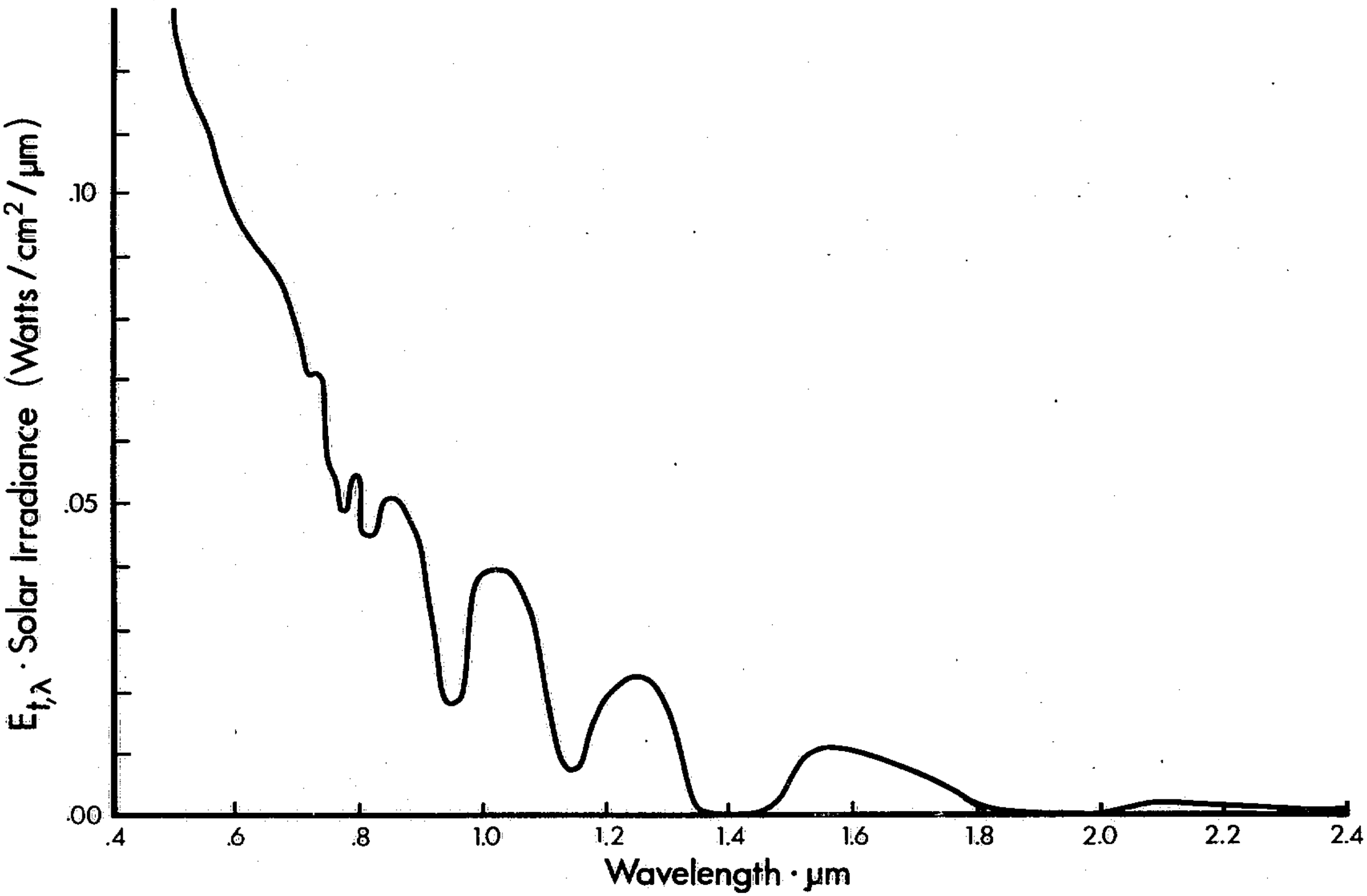


Fig. 5.3 Solar irradiance as measured by the Exotech Model 20C field spectroradiometer system at 14:25 GMT over Lake Monroe.

Table 5.1

Estimated Atmospheric Transmission

Wavelength Band (μm)	Atmospheric Transmission ($T_{A,\lambda}$)
.51-.63	.766
.63-.69	.870
.69-.74	.905

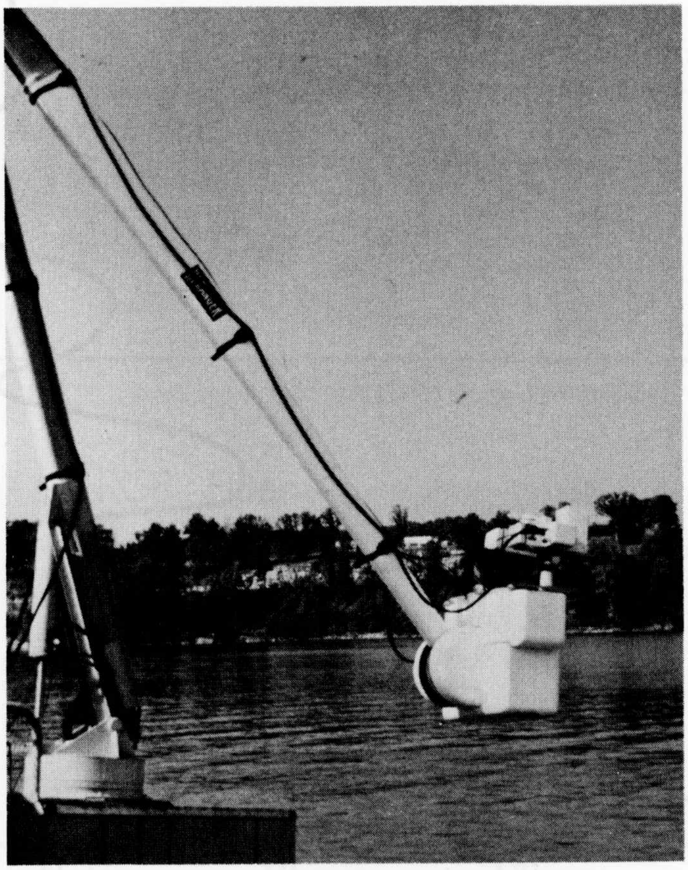


Fig. 5.4 Exotech Model 20C Field Spectroradiometer being positioned over Lake Monroe.

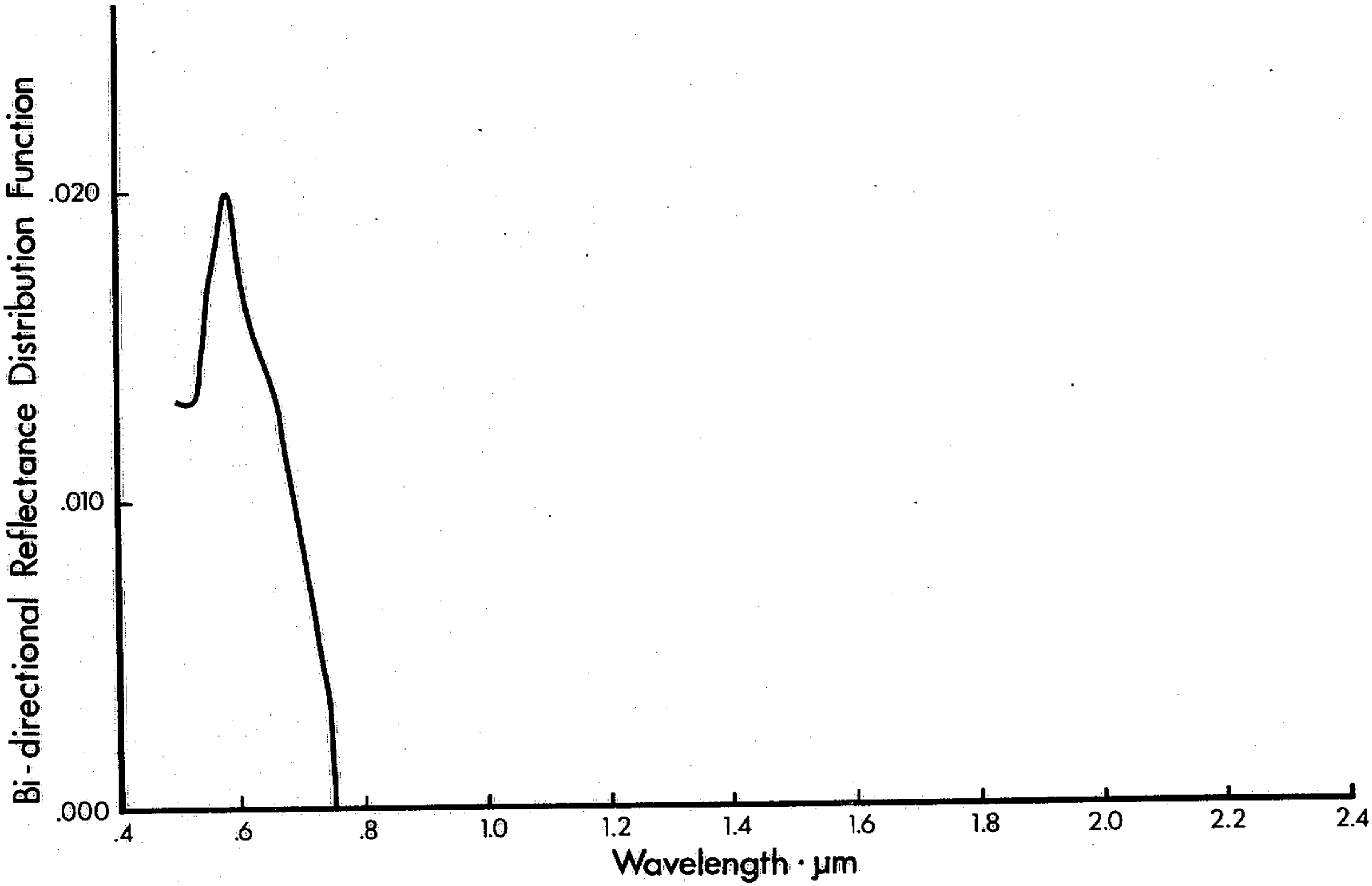


Fig. 5.5 Bi-directional reflectance distribution function of Lake Monroe as measured by the Exotech Model 20C field spectroradiometer system at 14:24 GMT.

on a comparison with a pressed barium sulfate plaque. Published values for the reflectance of barium sulfate were used for the reflectance of the plaque {23}. Each observation of the BRDF is an average of eight spectral scans.

The spectral radiance measured at the Skylab space station was taken from the S-191 tabular data (product 42-3) dated October 7, 1974. The spectral radiance given in the tabular data was corrected using Table 3.6.1-2 given in the Sensor Performance Evaluation Final Report Vol. II {24}.

It was determined using the 16mm film from the view tracking telescope data acquisition camera and the alignment error {24} that the field of view of the S-191 spectroradiometer was within Lake Monroe for the forward-aft axis (at least 200 meters from shore). No data is available for the left-right axis alignment error {24}, however, there could be a one milliradian alignment error for the left-right axis before the field of view of the spectroradiometer would include the shore of the lake.

5.2 DISCUSSION OF RESULTS

The spectral path radiance is plotted in Fig. 5.6. The path radiance drops gradually from a high at .55 μm to a low at .7 μm and then begins to increase to .74 μm. No spectral radiance from the lake was measured beyond .74 μm since the water absorbs nearly all of the incident infrared energy. The path radiance increases from .70 μm to .74 μm because of the increase in the background reflectance (with wavelength) around the lake, mainly forest. The S-191 sensor measured spectral radiance beyond .74 μm because of path radiance.

The calculated path radiance agrees fairly well with the path radiance predicted by Malila and Nalepka {25} (see Fig. 5.7), for different visibilities and background albedos. The visibility at Lake Monroe at the time of the Skylab overpass was around 24 km (15 mi.). The background albedo around the

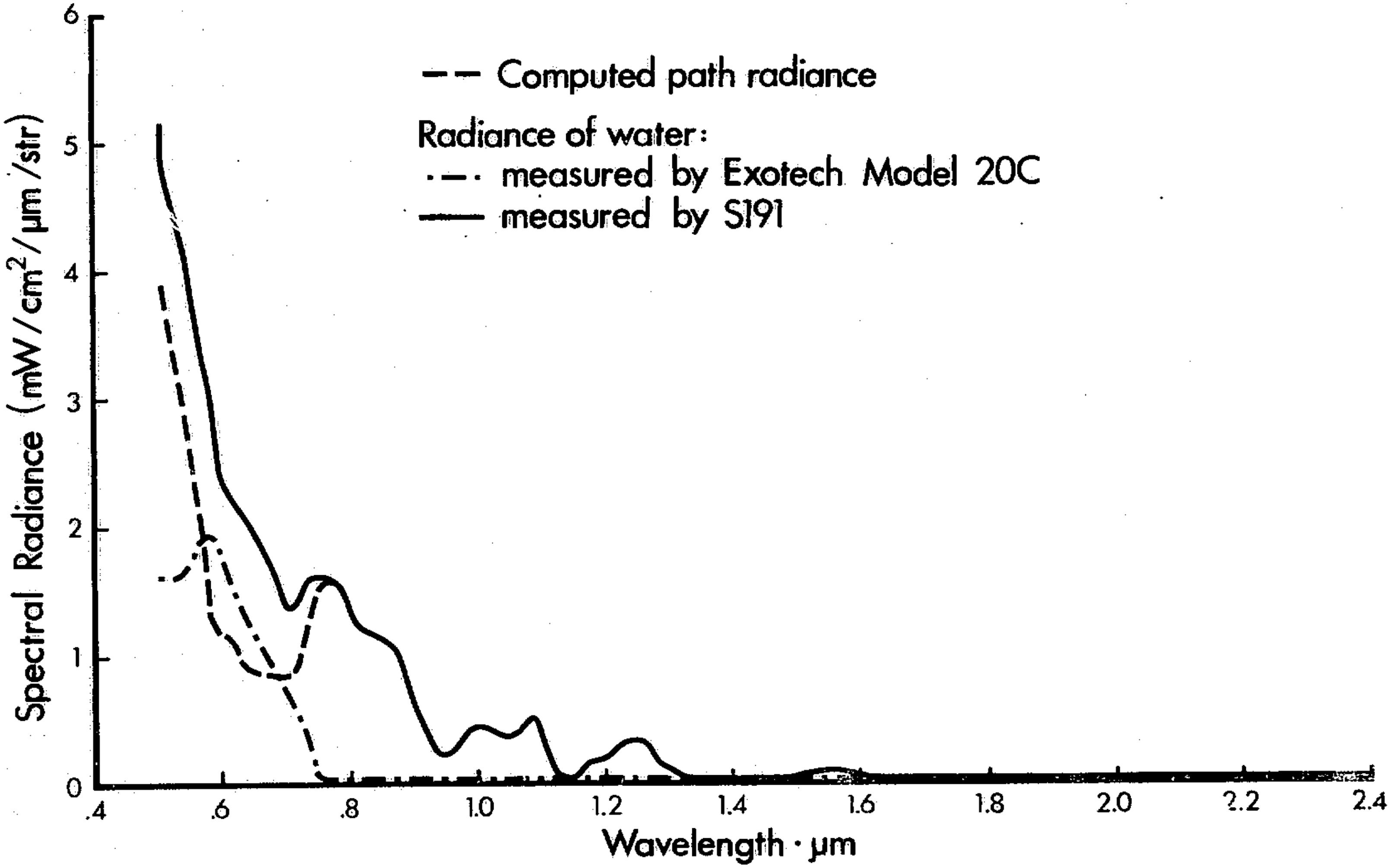


Fig. 5.6 Computed spectral path radiance, measured spectral radiance at Skylab space station and measured spectral radiance at surface over Lake Monroe.

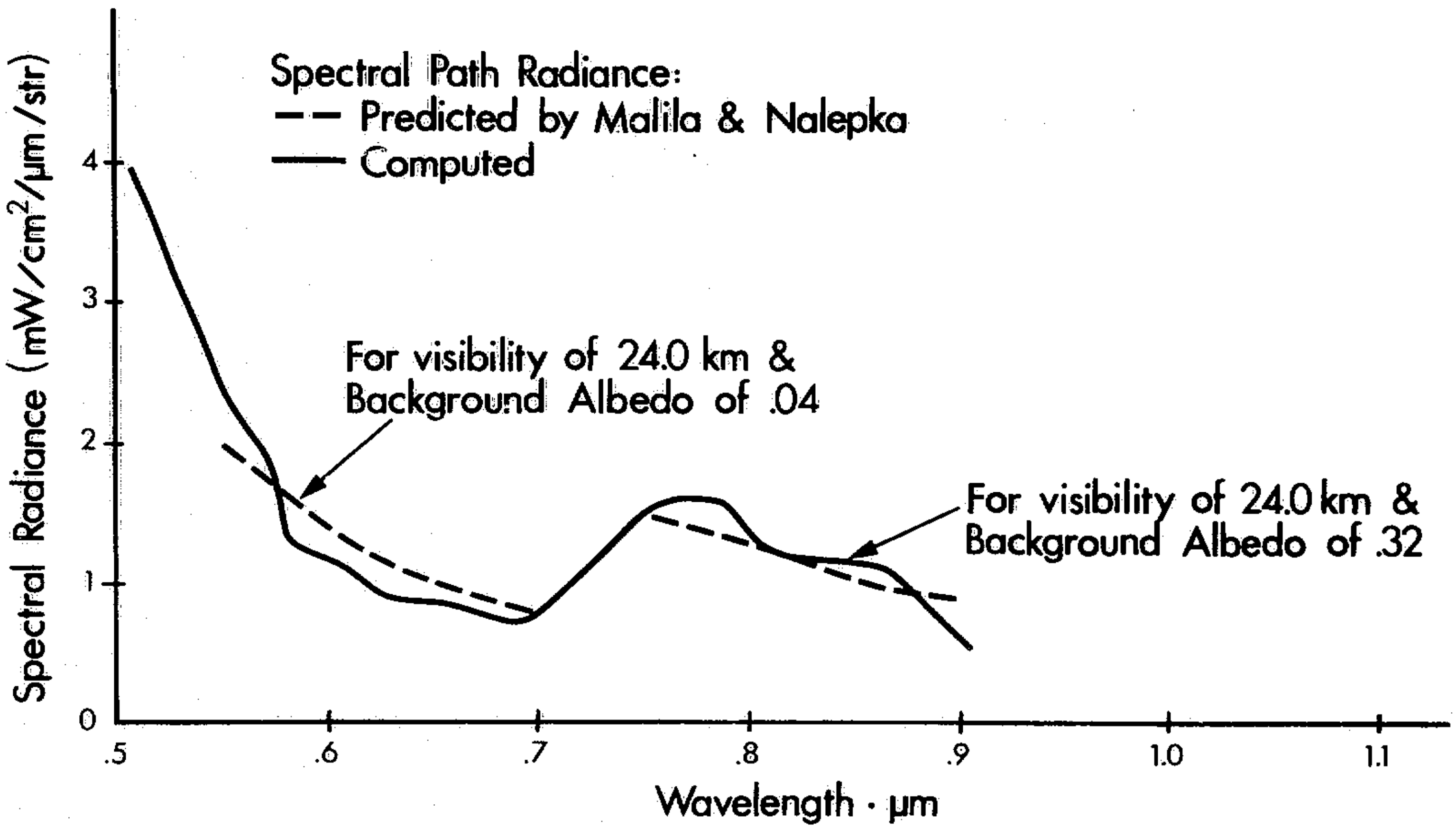


Fig. 5.7 Comparison of computed and predicted path radiance.

lake was .05-.10 (mainly forest) for the visible region and around .50 for the near infrared.

The far infrared spectral radiance measured by the S-191 spectroradiometer and the theoretical black body radiance are given in Fig. 5.8. The temperature of the water was 24.5°C. The radiances match fairly well from 10.2 to 12.5 μm and are not far different from 8.5 to 9.0 μm. This is also illustrated in Fig. 5.9 with a comparison of the lake temperature and the equivalent black body temperature.

5.3 CONCLUSIONS

The information was obtained to make a first order correction of the MSS data for the atmosphere. However, a single correction for the scene will not improve the classification accuracy using machine processing techniques since it amounts to a linear transformation of the data. If the atmosphere had varying effects across the same scene and the data is corrected using different transformations in different segments of the area, the classification could be improved. The path radiance calculation illustrates the validity of the Malila-Nalepka model in this situation. The results also indicate that high accuracy detailed spectroradiometric measurements from space platforms are possible and feasible.

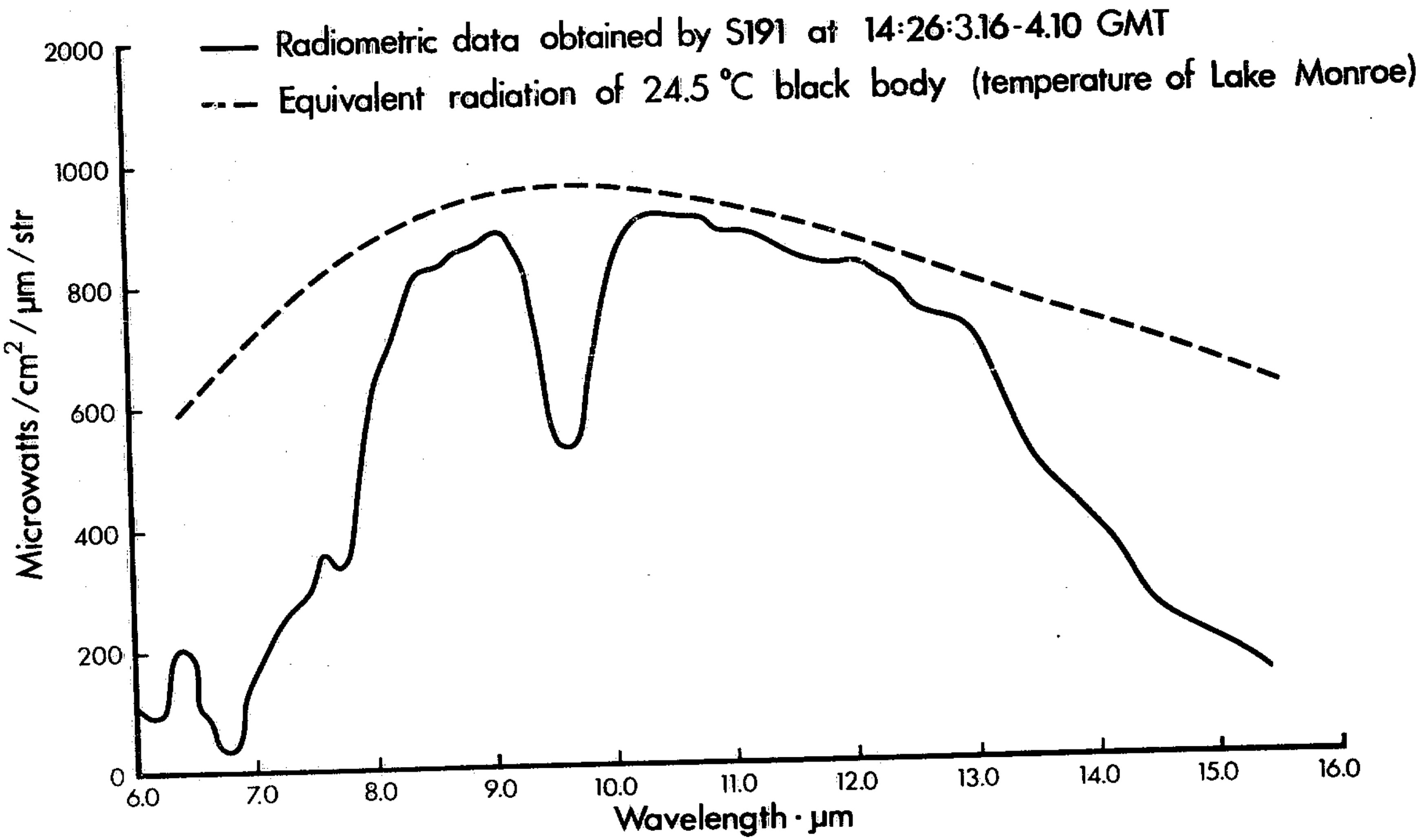


Fig. 5.8 Comparison of radiance measured by S191 over Lake Monroe, IN on 6/10/73 and equivalent radiance for 24.5°C black body (Lake Monroe).

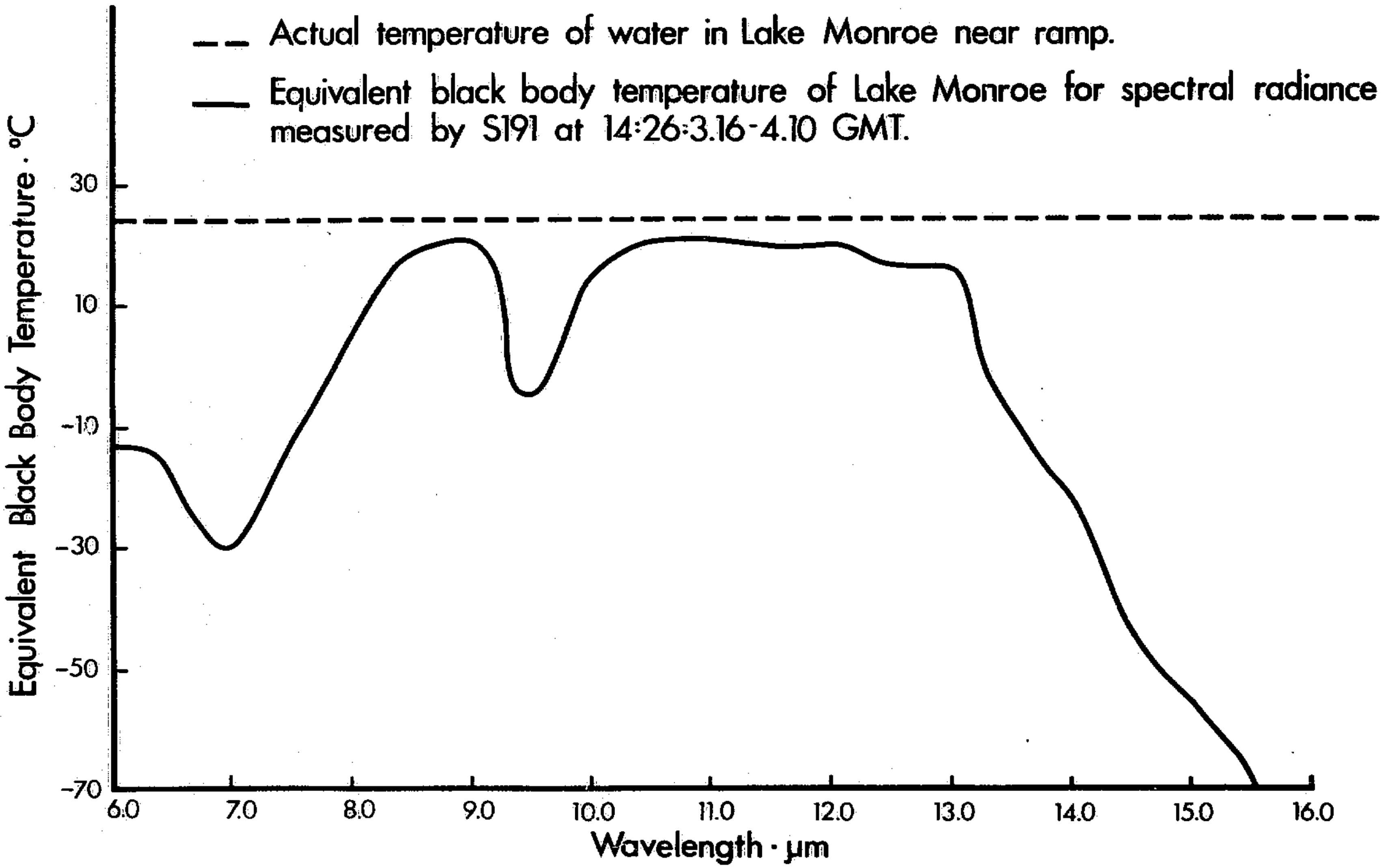


Fig. 5.9 Comparison of actual temperature of Lake Monroe and spectral radiometric temperature measured by S191.

6. EVALUATION OF SPECTRAL BAND SIGNIFICANCE

6.1 OBJECTIVE AND PROCEDURES

The purpose of this section is to present an overall evaluation of the significance of the spectral bands of the S192 MSS using the data obtained in sections 2, 3, and 4. No strong conclusions can be drawn from this analysis because of the different combinations of channels available in each data set and the different levels of noise present in each channel of the data. Also this study presents only the results for land use studies in June and January. Other types of studies - crop identification, geological studies, forest cover mapping, etc. - may require different combinations of channels. However, when this data is combined with that from other Skylab S192 studies - more definitive conclusions may be possible.

The results presented in this section are divided into two parts. The first part consists of the overall classification performance and the associated separability measures (Fig. 6.1 and 6.2) obtained in the interim and filtered SL/2 data evaluation, section 3. Also included are the training pixel performances and the associated separability measures (Fig. 6.3) obtained in the SL/4 data set analysis, section 4. The second part of the results is a study of the frequency of channel selection obtained from the separability measures generated from the analyses in sections 2, 3, and 4 (Fig. 6.4-6.6 and Tables 6.1-6.3).

The approach taken for the channel frequency selection was to select the top ten percent of all possible channel combinations of four, five, and six channels as ordered by D_T(ave) by the feature selection processor. (Refer to section 2.2.1 for a more complete discussion of the feature selection processor used in LARSYS, separability).

The results are given for the SL/2 interim data, the SL/2 filtered data and the SL/4 data. The results for the SL/2 interim data are the combination of two feature selection tables - one obtained from the analysis discussed in section 2 and one from the analysis discussed in section 3.

6.2 DISCUSSION OF RESULTS

The classification performances for different feature sets of the SL/2 interim data and the SL/4 data are similar to the relative results of the average separability measures (Fig. 6.1 and 6.3, respectively). The classification performances for different feature sets of the filtered data are also similar to the relative results of the average separability measure (Fig. 6.2) except for the combinations which include channel eight. The average transformed divergence measure indicate that the classes are more separable for those feature sets which include channel eight than some of those without channel eight. The classification performances, however, indicate the opposite. This was probably caused by the subframe dropouts in channel eight (see Fig. 3.1).

The classification performances obtained using the SL/2 data sets (both interim and filtered) indicate that the feature sets which include the visible, near infrared, middle infrared, and far infrared (VIS, NIR, MIR, FIR) regions or VIS, NIR, and MIR regions delineated the classes better than the other combinations of regions tried. The best performances for the SL/2 data sets were obtained using the VIS, NIR, and MIR regions. The FIR channel in this data set, however, was very noisy - NEΔT of $4.3^{o}C$ {13}. The particular channels included in the feature sets which produced the best results were 2,3,7,9, and 11.

The training pixel classification performances for the SL/4 data set indicate that the feature set which includes all four regions (VIR, NIR, MIR, FIR) delineated the classes better than when the FIR or MIR regions were not included.

The results given in Tables 6.1-6.3 and Figures 6.4-6.6 generally support the results from Figures 6.1-6.3. In Figures 6.4-6.6 typical responses of vegetation and soils are included for reference. The four, five and six

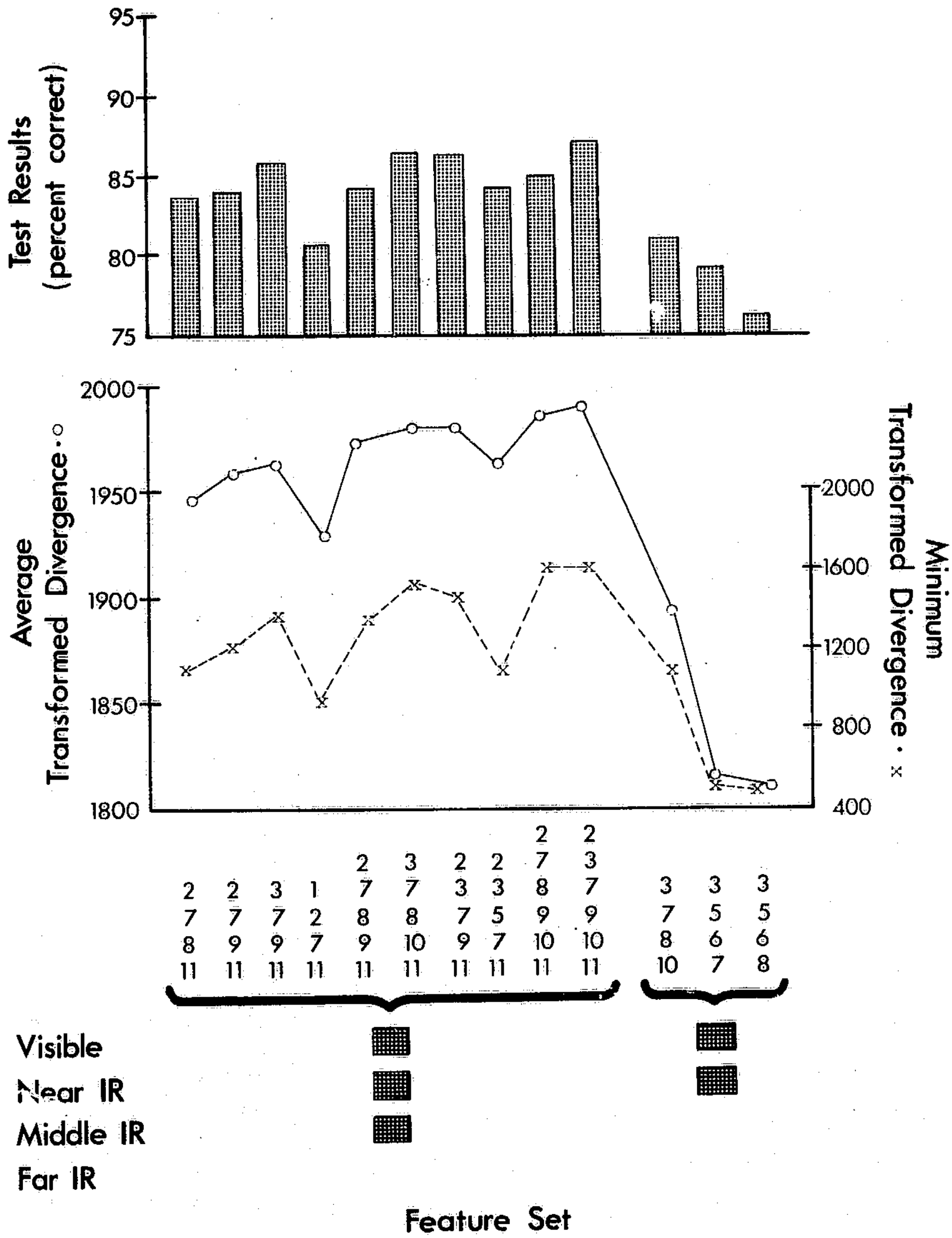


Fig. 6.1 Performance results and separability measures for feature sets from SL/2 interim data set.

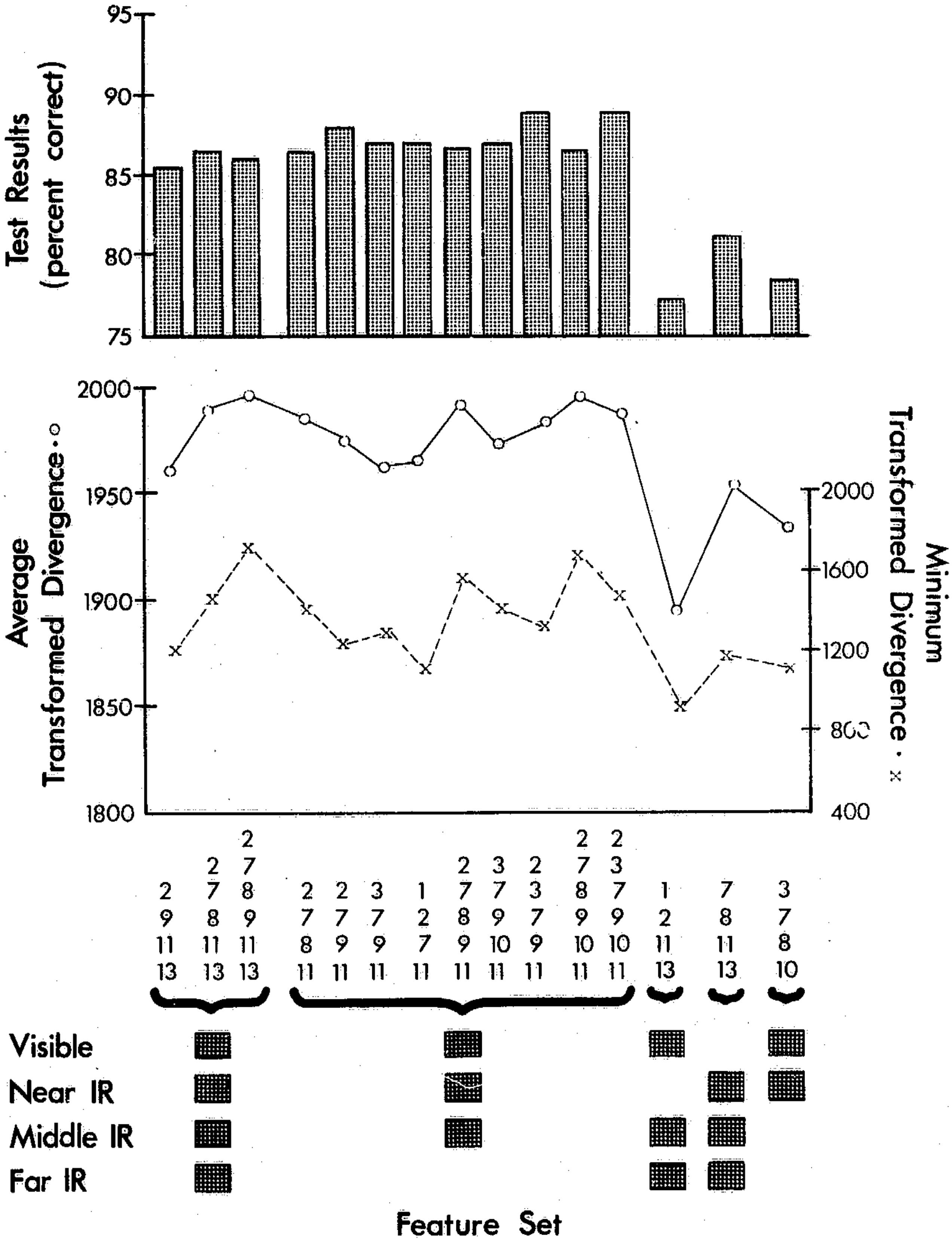


Fig. 6.2 Performance results and separability measures for feature sets from SL/2 filtered data set.

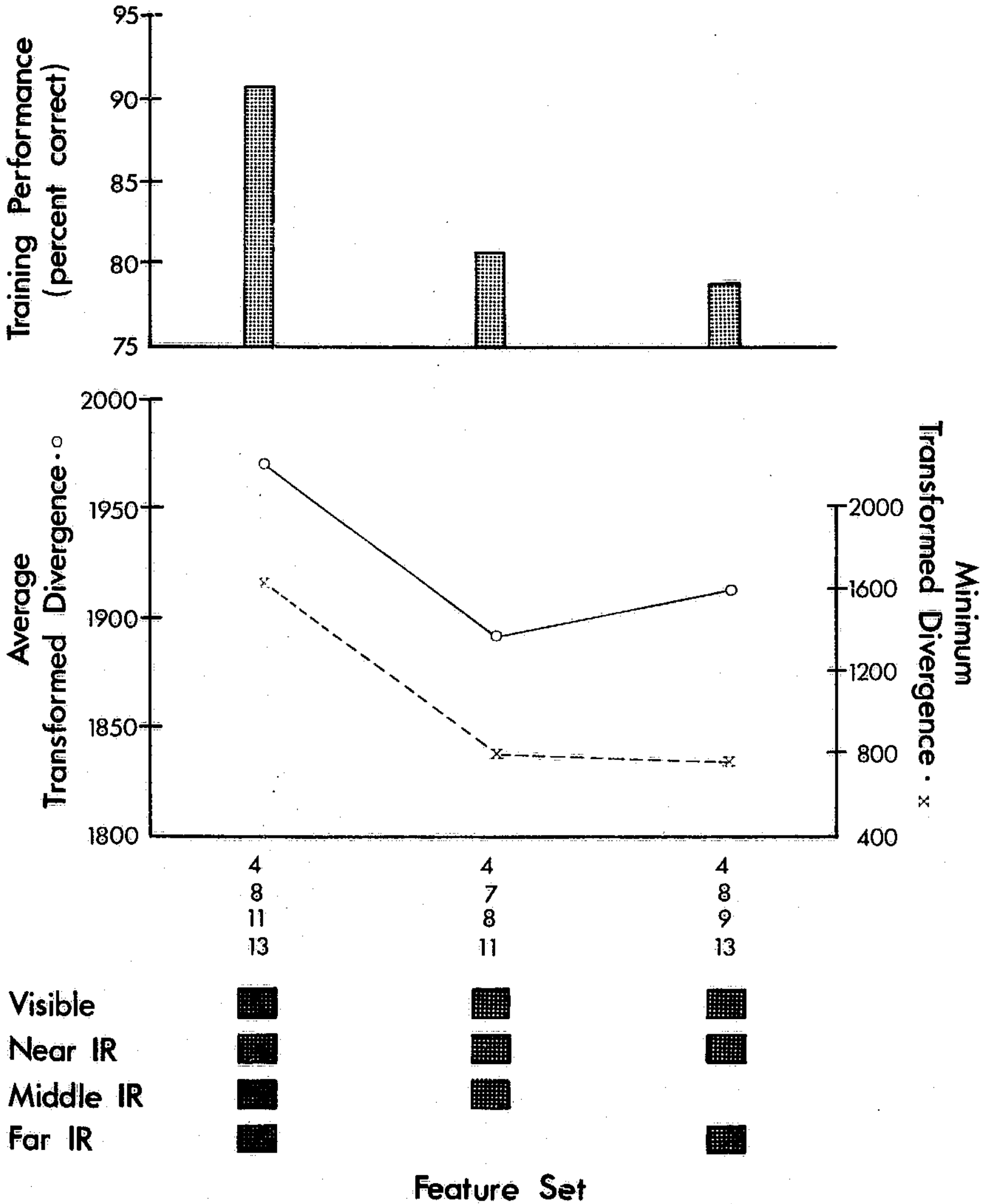


Fig. 6.3 Training pixel classification performance and separability results for feature sets of SL/4 data set.

Table 6.1

Frequency of Channel Selection for
Four Dimensional Feature Sets

SL/2 Interim, SL/2 Filtered, SL/4

S192 Channel	Number Times Possible	Number Times Selected in Top 10%	Percentage Times Selected in Top 10%
1	100,13,-	7, 3,-	7, 23, -
2	100,13,-	23, 8,-	23, 62, -
3	100,13,-	53, 3,-	53, 23, -
4	100, -,7	19, -,5	19, - ,71
5	100, -,-	24, -,-	24, - , -
6	100, -,7	11, -,3	11, - ,43
7	100,13,7	50, 8,2	50, 62,29
8	100,13,7	32, 7,3	32, 54,14
9	100,13,7	36, 7,1	36, 54,14
10	100,13,-	33, 3,-	33, 23, -
11	100,13,7	96,13,6	96,100,86
12	100, -,7	16, -,1	16, - ,14
13	- ,13,7	-, 0,7	-, 0,100

Table 6.2

Frequency of Channel Selection for
Five Dimensional Feature Sets

SL/2 Interim, SL/2 Filtered, SL/4

S192 Channel	Number Times Possible	Number Times Selected in Top 10%	Percentage Times Selected in Top 10%
1	158,13,-	25, 4, -	16, 31, -
2	158,13,-	43,10, -	27, 77, -
3	158,13,-	108, 5, -	68, 38, -
4	158, -,6	39, -, 6	25, - ,100
5	158, -,-	45, -, -	28, - , -
6	158, -,6	33, -, 1	21, - , 17
7	158,13,6	96,10, 3	61, 77, 50
8	158,13,6	68,11, 4	43, 85, 67
9	158,13,6	65,11, 4	41, 54, 33
10	158,13,-	65, 3, -	41, 23, -
11	158,13,6	158,13, 6	100,100,100
12	158, -,6	45, -,12	28, - , 33
13	- ,13,6	- , 2, 6	- , 15,100

Table 6.3

Frequency of Channel Selection for Six Dimensional Feature Sets

SL/2 Interim, SL/2 Filtered, SL/4

S192 Channel	Number Times Possible	Number of Times Selected in Top 10%	Percentage Times Selected in Top 10%
1	184,8,-	41,3,-	22, 38, -
2	184,8,-	65,8,-	35,100, -
3	184,8,-	142,3,-	77, 38, -
4	184,-,3	54,-,3	29, - ,100
5	184,-,-	66,-,-	36, - , -
6	184,-,3	50,-,1	27, - , 33
7	184,8,3	147,8,3	80,100,100
8	184,8,3	90,8,3	49,100,100
9	184,8,3	99,4,1	54, 50, 33
10	184,8,-	95,4,-	52, 50, -
11	184,8,3	184,8,3	100,100,100
12	184,-,3	71,-,1	39, - , 33
13	- ,8,3	- ,2,3	- , 25,100

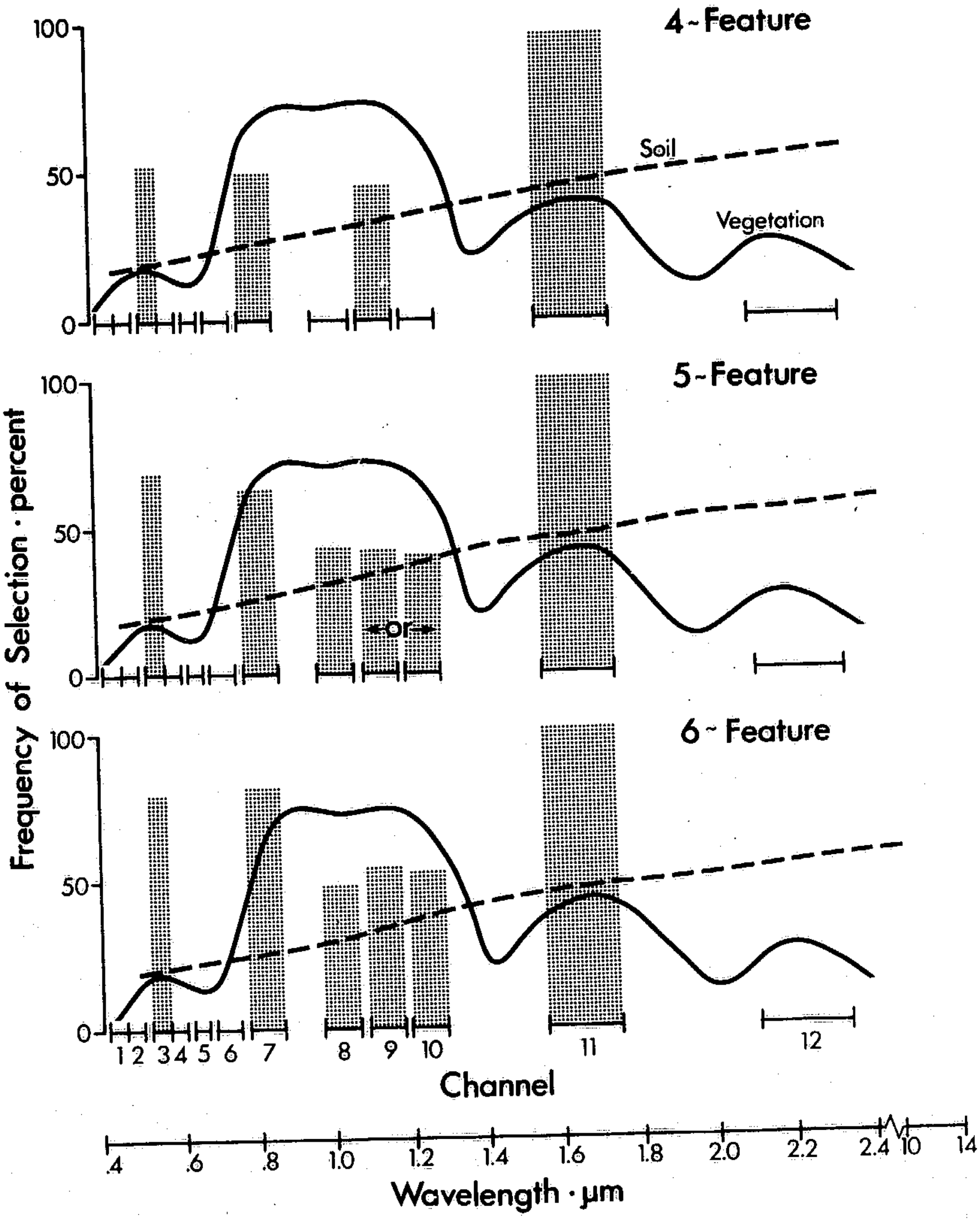


Fig. 6.4 Most frequently selected channels in the top ten percent of all possible four, five, and six feature sets from the SL/2 interim data set.

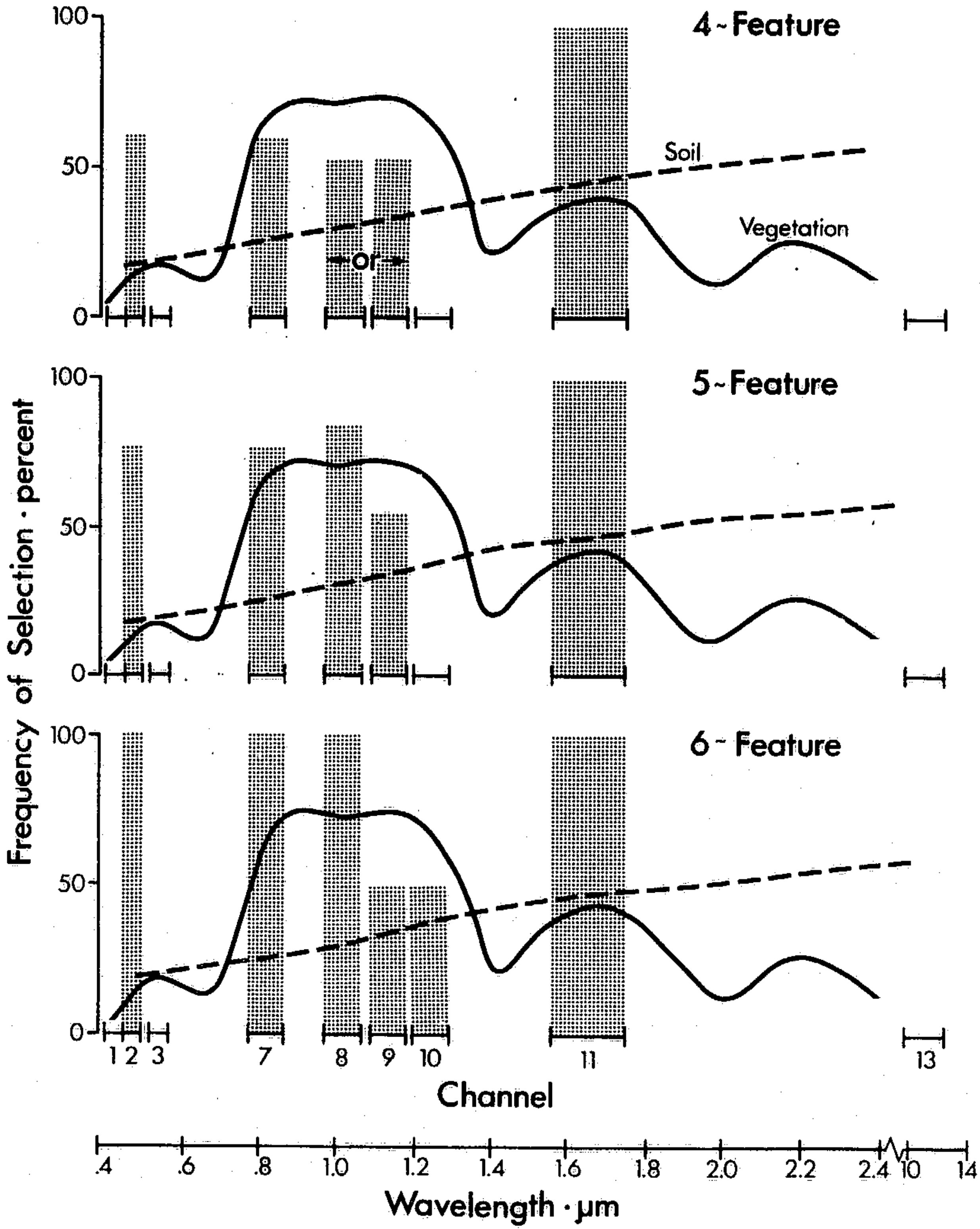


Fig. 6.5 Most frequently selected channels in the top ten percent of all possible four, five and six feature sets from the SL/2 filtered data set.

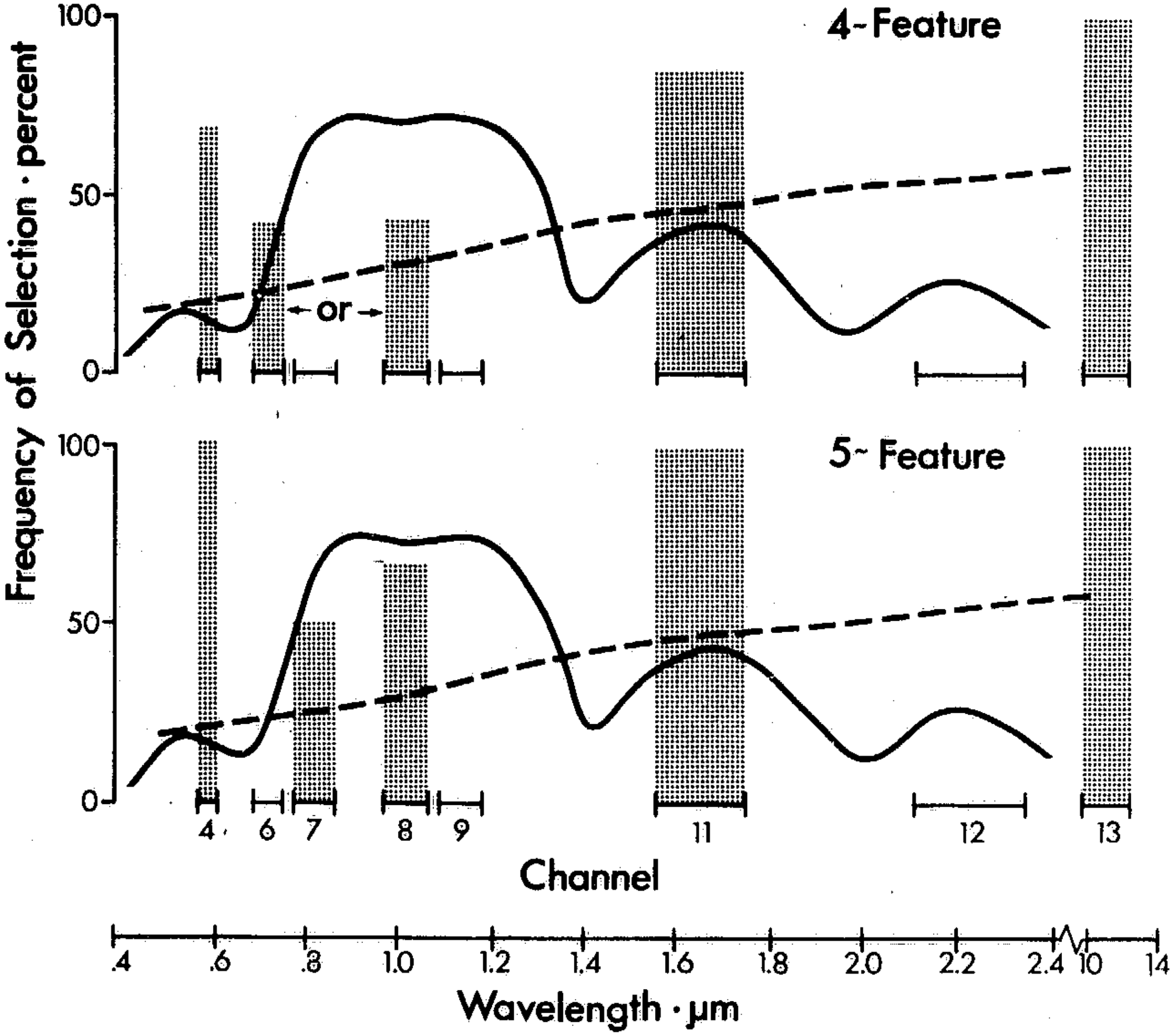


Fig. 6.6 Most frequently selected channels in the top ten percent of all possible four and five feature sets from the SL/4 data set.

channels selected most frequently from the interim data set were 3 7 9 11, 3 7 8 9-10 11, and 3 7 8 9 10 11, respectively. The four, five and six channels selected most frequently from the filtered data set were 2 7 8 11, 2 7 8 9 11, and 2 7 8 9 10 11, respectively. These sets do not agree completely with the classification results. The reason as discussed above was probably due to the dropouts in channel 8. The four and five channels selected most frequently from the SL/4 data were 4 6-8 11 13 and 4 7 8 11 13, respectively. Since there were only eight channels in the SL/4 data set, no specific combination of six channels were defined in the top three combinations - the top ten percent of all possible combinations. One should note along with these results that there wasn't a good representative set of visible channels in any of the three data sets because of either noise problems or the absence of data.

6.3 CONCLUSIONS

These two approaches do not point to an optimum set of channels (if there is such a thing). The channels which were selected most frequently across all three data sets were 7,8, and, most frequently, 11. Channel 13 was very important in the SL/4 data set and either channel 2 or 3 was important in SL/2 data sets. Overall, though, these results indicate again that to utilize spacecraft multispectral scanner data most effectively for year around information, at least one channel should be present in the scanner from each of the four major spectral regions (VIS, NIR, MIR, and FIR). Other studies {26,27,28} using aircraft MSS data have shown that at least one channel is needed from the VIS, NIR, and MIR regions and to a lesser degree one from the FIR region.

The spectral resolutions and positions of the MIR and FIR channels are fairly fixed because of the energy available and absorption bands. The visible and near infrared channels selected in these studies tended to be positioned so as to sample the entire VIS and NIR regions.

7. CONCLUSIONS OF STUDY AND RECOMMENDATIONS

The conclusions from each of the five studies described in this report are included at the end of each of the sections. Those conclusions will be summarized here and the conclusions and recommendations for the project as a whole will be given.

The study of the spacecraft multispectral data sets indicate that better land use delineation using machine processing techniques can be obtained with data from multispectral scanners than digitized S190A photographic sensor data. Better results were obtained for both a late spring scene and, to a much more significant degree, a winter scene. Spacecraft multispectral scanners can be very valuable for periodic year around data collection as long as the advantages of multispectral scanners, increased spectral range and resolution, are utilized to the fullest extent possible. This is especially true if the scanner detector array covers the visible, near infrared, middle infrared, and far infrared portions of the spectrum.

Comparable results were obtained from the Landsat 1 and Skylab S192 scanners for the late spring scene even though the S192 scanner contained channels with a broader spectral range and smaller spectral resolutions. The noise in the S192 data probably offset the expected gains, although this was not proven conclusively.

The results of the multiemulsion photographic data set were a little better than the multiband photographic data set. Moreover the multiemulsion data set is much easier and cheaper to assemble because registration of the digitized data is not necessary.

The results of the comparison of the interim and filtered S192 data indicate that the data were improved some for machine processing techniques. It is questionable, however, whether the improvement obtained was worth the time and resources spent in the filtering effort. The time delay between when the data was taken until the data was received for analysis hindered the user application efforts.

The results of the S192 X-5 detector array studies over a wintertime scene indicate that a good quality far infrared channel can be very useful. Much better delineation of land use features were obtained when the information in the far infrared channel was used than when it was not.

The results of the S191 spectroradiometer study indicate that the data from the S191 was usable and it was possible to estimate the path radiance. A drawback of the S191 is the need for a large target, such as Lake Monroe, so that the spectroradiometer has a uniform target. Most targets, such as agricultural fields, are too small in the Wabash river basin.

The results of the channel significance study indicate that channel 11, a middle infrared band, was very useful in all three data sets. The far infrared band, channel 13, was very useful for the Allen County study. Other channels frequently selected and which gave the best results were 2,3,7,8, and 9. The results however varied across data sets with the differing numbers of channels available and varying amounts of noise present in the data.

The photography was very valuable in these studies for ground reference. The type of photography used most extensively was collected from aircraft. The S190A didn't contain the detail needed for ground reference. The S190B color photography contained much more detail, however, color infrared film would have been much more useful (assuming adequate spatial resolution).

As was stated above the delay from the time the data was collected until the time the data was received discouraged the interest hoped for from the us[illegible]encies, the City of Bloomington/Monroe County Planning Department and the Allen County Plan Commission. Also these user agencies were interested in data with a finer resolution than that of the S192 scanner. They indicated however that this type of data would be very useful at a regional level (group of several counties) where detail, down to ownership boundaries, are not needed.

Based on these studies it is recommended that future space earth resource systems include multispectral scanners which contain channels in the middle infrared and the far infrared in addition to channels in the visible and near infrared. A scanner configuration which includes these four major regions will produce data which is more useful year-round and be beneficial for a wider range of activities, including those which need thermal information.

It is recommended that the resolution of future spacecraft scanners be smaller than the approximately 80 meters of the S192 system so that the data could be more useful for the land use agencies. However, based on these studies the signal to noise ratio of the data should not be sacrificed for smaller spatial resolution.

Also it is very strongly recommended that the time between the data collection and the data analysis should be as short as possible, so that the information isn't outdated before the user utilizes it.

Based on the experience in this project with the conical S192 data, it is recommended that a rectilinear line scanner be used in future systems. The problem of line straightening the data appeared to cause delays. The "bow tie" problem of the rectilinear scanner is minimal for space borne scanners. In addition rectilinear scanners may be calibrated on a line-by-line basis with relative ease.

8. ACKNOWLEDGEMENTS

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10. APPENDIX

Ground Data Take at Lake Monroe, Indiana, on June 10, 1975

Pyrheliometer

Time (GMT)	Response through filter (millivolts) OG1	RG2	RG8	Blank*
14:00	2.5	2.2	1.9	3.4
14:15	2.6	2.2	1.9	3.4
14:30	2.7	2.3	2.0	3.5
14:45	2.6	2.3	2.0	3.6
15:00	2.7	2.3	2.0	3.6
15:15	2.7	2.4	2.0	3.7
15:30	2.6	2.3	2.0	3.6
15:45	2.6	2.3	2.0	3.6
16:00	2.7	2.3	2.0	3.7
16:15	2.6	2.3	2.0	3.6
16:30	2.7	2.4	2.0	3.6
16:45	2.7	2.3	2.0	3.7
17:00	2.9	2.4	2.1	4.0
17:15+	.023	.019	.016	.016
17:30	2.8	2.4	2.1	3.8
17:45	2.7	2.3	2.0	3.6
18:00+	.023	.019	.016	.016
18:15	2.6	2.2	2.0	3.6

* No Filters + Cumulus Clouds

Water Temperature

Water Off Pier Near Ramp	Temperature (°C)	Instrument
14:25	25	PRT-5
14:30	25	PRT-5
14:30	24.5	Precision Thermometer
14:35	24.5	Precision Thermometer
14:40	24.5	Precision Thermometer

Air Temperature (Shade Near Water)

Time (GMT)	Temperature (°C)	Instrument
14:30	25.0	Precision Thermometer
14:35	25.0	Precision Thermometer
14:40	25.0	Precision Thermometer